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RESEARCH ARTICLE

A marine natural capital asset and risk register—Towards securing the benefits from marine systems and linked ecosystem services

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Abstract

1. Documented biodiversity loss has galvanised a global process to develop conceptual frameworks that link the social and ecological systems. This paper focusses on the development of the first marine natural capital asset and risk register as a foundational decision support tool to understand the risk to ecosystem service delivery in relation to policy or management interventions.
2. We make use of existing marine data products to define the component parts of the asset status (extent, condition, spatial configuration) in line with a natural capital approach. We 'Pioneer' the application of this approach in North Devon, UK, an area defined by UK Government to test how marine natural capital can be effectively managed to deliver benefits to the environment, economy and people, and identify how best to share and scale up this learning.
3. We demonstrate that the majority of asset–benefit relationships are at a medium to high risk of loss under current use and management.
4. Despite policy and management measures to reduce pressures on marine systems, activities linked to fishing, farming and the water industry continue to pose a medium to high risk to the asset–benefit relationships. A lack of accurate spatial fishing effort data greatly reduces opportunities for rational and targeted approaches to improve the condition status of marine natural capital assets. Marine protected areas as a single tool are insufficient to prevent further loss of biodiversity that underpins all asset–benefit relationships.
5. *Synthesis and applications*. Through development of the first marine natural capital asset and risk register we demonstrates a novel decision support tool to understand the risk to ecosystem service availability in relation to environmental policy or management interventions. The results highlight that current marine

governance strategies to protect biodiversity are not sufficient to reduce the risk of loss of ecosystem services. Wider application of the marine natural capital approach will require increasing confidence in the metrics to define marine asset status; more directed monitoring (extent and condition) and; greater accuracy in spatial fishing effort.

KEYWORDS
ecosystem accounts, ecosystem services, marine protected areas, marine spatial planning, natural capital, risk

1 | INTRODUCTION

Documented biodiversity loss has galvanised a global process to develop conceptual frameworks that link social and ecological systems, generating the term 'ecosystem services', first defined as the 'benefits people obtain from ecosystems' (Millennium Ecosystem Assessment, 2005). Acknowledgement of the challenges facing humanity to continue to benefit from nature has led to calls for 'humanity to start accounting for and governing natural resources and actively shape development in tune with the biosphere' (Folke et al., 2011; Rockström et al., 2009). In the crossover from conceptual typologies of ecosystem services to their governance in practice, frameworks to standardise the approach have been developed. Building from the initial concept of ecosystem services, the cascade framework (Haines-Young & Potschin, 2010a) was the first to demonstrate the conceptual flow between ecological to social systems. Establishing that ecosystems (i.e. the biotic and abiotic components) link to ecological functions (e.g. primary production) to provide ecosystem services (e.g. fish) which can then be realised as a good or benefit (e.g. food). This understanding of 'cascade' enabled translation of the complexity between the biophysical and the human system. From this, an effort to standardise how ecosystem services were described was developed to ensure that future decision support tools focusing on the flow between the ecological system and the human system could be standardised (Haines-Young & Potschin, 2010b; Haines-Young & Potschin, 2018). These include the European based Common International Classification for Ecosystem Services (CICES) and the United States based national Ecosystem Services Classification System (NESCS; Haines-Young & Potschin, 2018; United States Environmental Protection Agency, 2015).

Internationally, several projects have sought to develop and test the conceptual framework for ecosystem services in practice (Maes et al., 2018; TEEB, 2010; UK NEA, 2011). In particular, they build on the cascade model, integrating the role that external pressures, governance and capital inputs have, in terms of how the benefits from ecological systems are realised (Braat & de Groot, 2012). Further development of the framework from a 'cascade' to a 'dynamic' model places ecosystem services firmly within the ecological system recognising that these services would be generated regardless of human demand or intervention. Instead, benefits from ecosystem services are derived when other capitals (e.g. manufactured, financial) enable benefits to be realised and are of value within the social system; this in turn is influenced by governance and external factors (e.g. climate change), with impacts or pressures returned on the ecological system (Costanza et al., 2017).

In March 2021, the United Nations Statistical Commission adopted a new framework, the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA-EA) as a means to 'reshape decision and policy-making towards sustainable development' (Committee of Experts on Environmental-Economic Accounting, 2021). Underpinning these tools is a requirement to integrate statistics on ecosystems (including biophysical measures of the extent and condition of natural assets) with national economic activity (King et al., 2021). First generation ecosystem accounts have been published in 24 countries (Hein et al., 2020).

In the context of the United Kingdom, the development of an experimental System of National Accounts (SNA) for ecosystems (Dutton & Engledew, 2020) has meshed with a parallel programme of policy development where the component part of the ecological system that provides ecosystem services is referred to as natural capital (Costanza & Daly, 1992). Since 2011, a systematic approach has developed in the United Kingdom to fully incorporate the role of the ecological system in supporting the delivery of ecosystem services and human well-being into decision making (UK National Ecosystem Assessment, 2014). This has included the development of the Natural Capital Approach as a foundational framework of the United Kingdom's 25 Year Plan to Improve the Environment (HM Government, 2018b).

Operationalising the Natural Capital Approach centres on four definitions (Natural Capital Committee, 2017):

Natural capital: The elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions.

Assets: A distinctive component of natural capital as determined by the functions it performs, for example, soils, freshwater and species.

Ecosystem services: Functions and products from nature that can be turned into benefits with varying degrees of human input.

Benefits: Changes in human welfare (or well-being) that result from the use or consumption of goods, or from the knowledge that something exists.

Assessment and appraisal frameworks aiming to understand the rate of change of natural capital in relation to policy or management interventions include tools such as Environmental Impact Assessments, Natural Capital Accounts, Asset and Risk Registers, Regulatory Impact Assessment and Sustainability Appraisal (Hooper et al., 2018). In a first step to operationalising the natural capital approach for the United Kingdom, a natural capital asset and risk register was developed by Mace et al. (2015). This was a preliminary high-level assessment of broad habitat types (terrestrial and marine) based at a national scale. The development of the asset register by Mace et al. (2015), common to the SEEA-EA guidance, structures ecosystems into units based on the extent, condition and ecosystem services supplied by each ecosystem type, for example, km^2 forest (UNSD, 2014). The monetary value, reflecting ecosystem types and units linked to ecosystem service supply and use values, were not included in the Mace et al. (2015) asset register, nor are values of the ecosystem assets. Instead, the authors focused on 'risk'.

The complexity of the connections between ecological and social systems requires pluralistic and precautionary approaches to assess current mechanisms for limiting or preventing the loss of ecosystem services (Costanza et al., 2017). Risk assessment for ecological systems draw heavily from decision-support tools developed within the business and industry sector. These tools have been designed to identify risks to operations based on an assessment of business assets, plausible risk, likely impacts and ownership of the driver of risk (Leonard, 1995). Risk registers are now widely used across sectors from construction (Kuchta & Ptaszyńska, 2017) to health (Mansfield et al., 2015). Quantitative and qualitative approaches to risk assessment are now commonly applied in environmental management, noting that uncertainty (in data and outcomes) is an inherent part of a multidisciplinary process (Hamel & Bryant, 2017). Indeed, risk levels do not need to be accurately numerically quantified (with statistical significance) in order to instigate management intervention; the purpose of a risk based approach can be to compile evidence and compel discourse for action (IPCC, 2014).

The Mace et al. (2015) asset and risk register revealed substantial gaps in knowledge about the marine data and data products available to describe the ecosystem units and therefore the associated risk of loss of ecosystem services (Mace et al., 2015). The purpose of this paper is to fill this knowledge gap by testing, for the first time, previously developed marine assessment tools and the resulting data products within a natural capital decision support framework. It focusses on the development of the UK's first marine natural capital asset and risk register as a foundational tool to inform routes towards the sustainable management of marine systems.

2 | MATERIALS AND METHODS

2.1 | UK case study area

The UK Government Department for Environment, Food and Rural Affairs (Defra) created four 'Pioneer' projects to inform the development and implementation of their 25 Year Environment Plan (HM Government, 2018a). The North Devon Marine Pioneer (NDMP) is intended to test, at a local scale, how marine natural capital can be effectively managed to deliver benefits to the environment, economy and people, and identify how best to share and scale up this learning (Figure 1).

2.2 | The natural capital assets

Following Mace et al. (2015), assets can be defined based on biophysical features, the types of benefits provided and the management context. In this study, three types of natural capital assets for marine systems were identified: *Habitat assets*—all European Nature Information System (EUNIS) level 3 habitats (or above where data exist); *species assets*—commercial species (fish and shellfish) with and without quota and migratory species (salmon and seatrout); and *the water column*—water bodies, bathing waters and shellfish waters.

2.3 | The relationship between assets and benefits

Ecosystem services and benefits were defined in line with the definitions in the UK National Ecosystem Assessment (2014). Asset–benefit relationships were prioritised for inclusion in the assessment based on the evidence in the literature that there is a medium to high ecosystem service potential (see Appendix S1 in Supporting Information).

2.4 | Compiling the risk register

Mace et al. (2015) recorded degradation of natural capital in the asset and risk register in relation to the degree to which it may lead to loss of ecosystem services and benefits for present and future generations. Three dimensions of asset status are identified that help resolve how much benefits are affected by deterioration in the assets. These are: i) extent, ii) condition and iii) spatial configuration.

2.5 | Input data products for habitat assets (Figure 2)

The following data products provide the input for an assessment of habitat assets (Figure 2).

2.5.1 | The asset–benefit matrix (Figure 2a)

Links between habitat and species assets and benefits for the case study area were built on previous matrices of ecosystem services provision from UK marine habitats (Fletcher et al., 2011, 2012; Potts et al., 2014; Saunders et al., 2015; see Appendix S1).

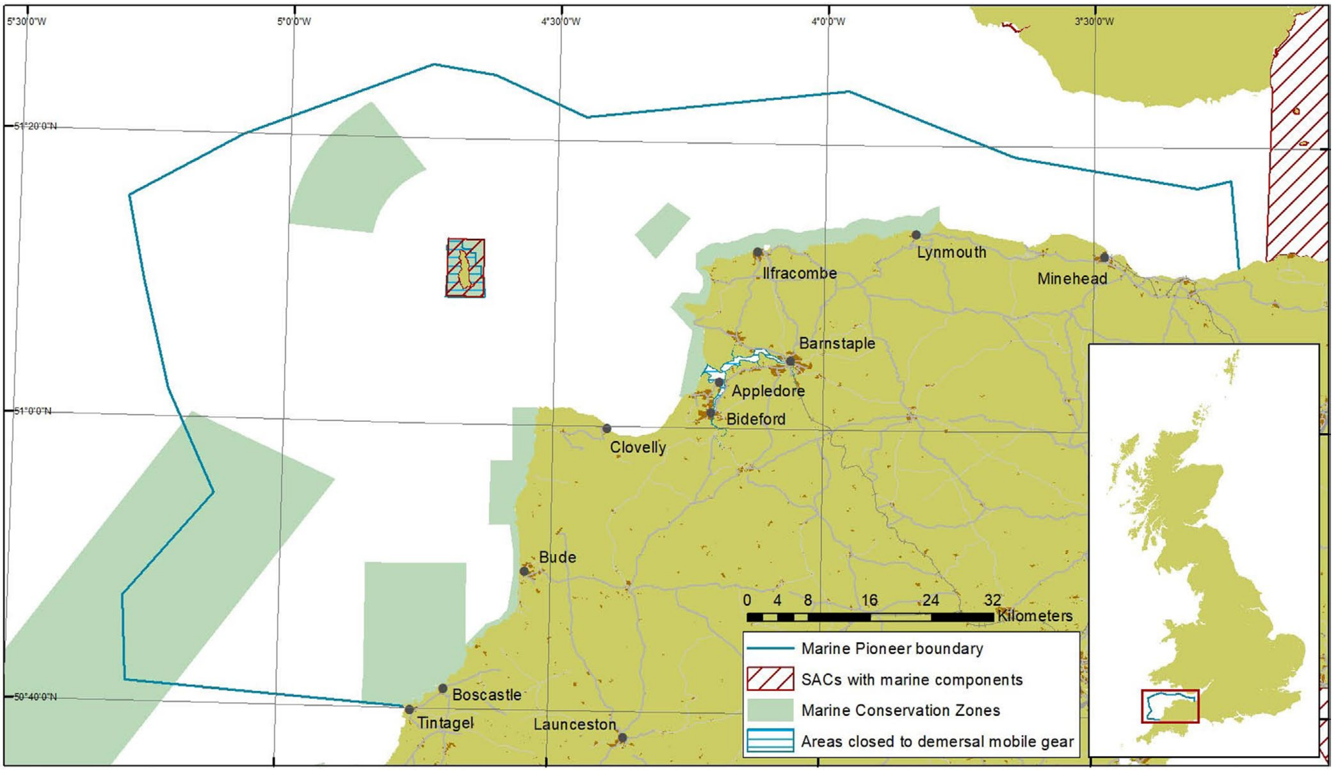

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FIGURE 1 The North Devon Marine Pioneer. Including: 1. Areas of the seabed designated for conservation as a marine protected area (MPA; special area of conservation, SAC with marine components, marine conservation zones) and; 2. Areas of the seabed where fisheries management measures prevent the use of demersal mobile gear

2.5.2 | Habitat extent (Figure 2b)

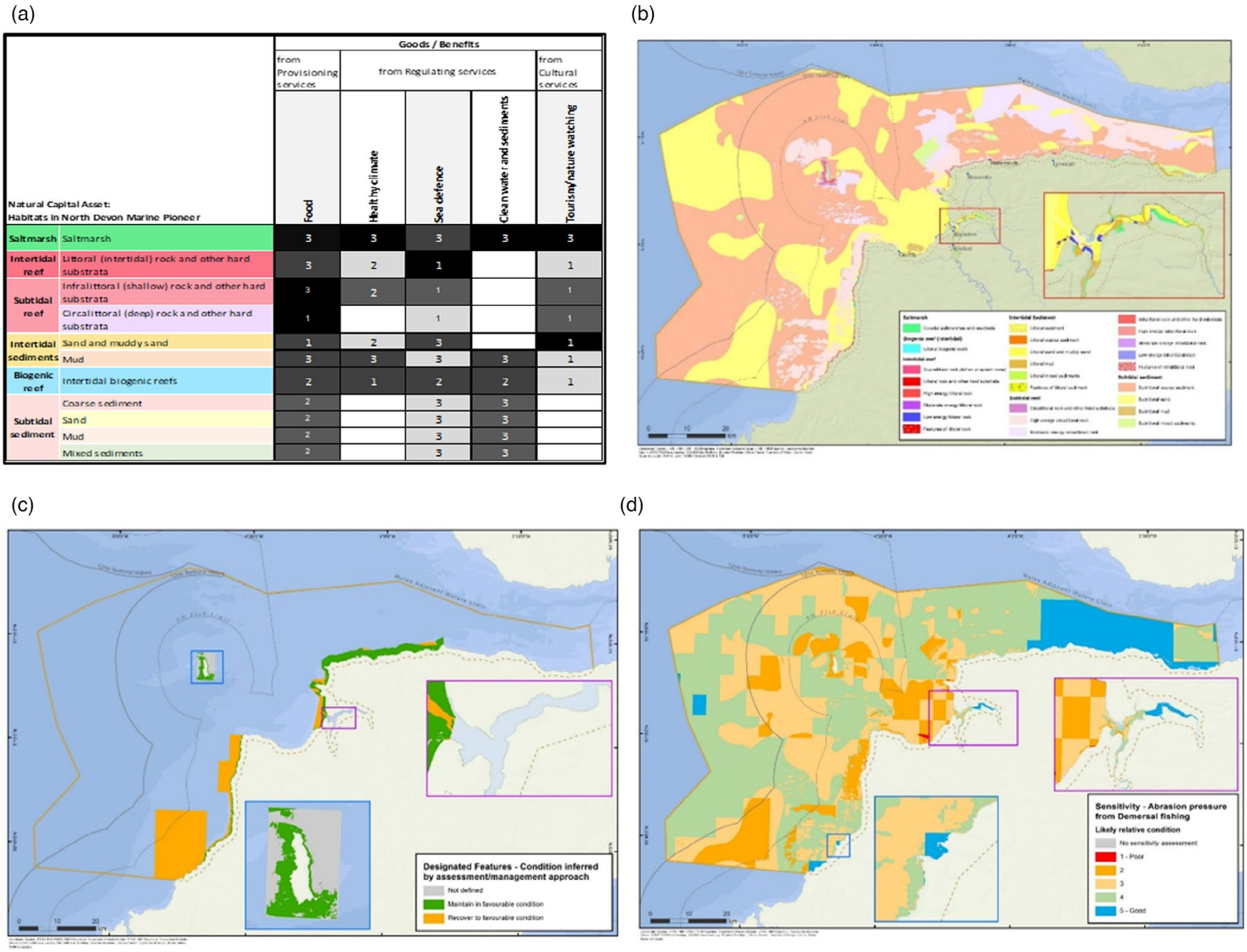
A composite map of habitats (and associated confidence metrics) below mean high water was generated that combined spatial datasets from: (a) A Natural England internal habitats dataset, compiled from best available survey maps and (b) modelled data from the European Marine Observation and Data Network (EMODnet)/EUSeaMap (EMODnet/EUSeaMap, 2019; see Appendix S1). The total extent (km^2) of each habitat occurring within the case study area was calculated from the composite habitat map using ArcGIS. The extent (km^2) of habitat within MPAs (as the primary marine management tool to protect and restore natural capital habitat assets) was also calculated along with the extent (km^2) of each habitat with an associated management measure (e.g. habitat extent with a byelaw, such as bottom towed fishing gear restrictions to prevent physical impacts to natural capital habitat assets; see Appendix S1).

2.5.3 | Habitat condition (Figure 2c)

For habitats within MPAs, condition is inferred through conservation objectives assigned to each habitat feature in Conservation Advice Packages produced for each MPA by the responsible UK statutory agency (Natural England, 2017). To compile these data, a review was undertaken of Conservation Advice Packages available for sites in the case study area (see Appendix S1).

2.5.4 | Habitat condition (Figure 2d)

For habitats outside of MPAs there are no data on habitat condition; therefore a proxy method was applied based on habitat sensitivity to fishing pressures (des Clers et al., 2008; Enever et al., 2017; Tyler-Walters et al., 2019). We make use of an available data product: the Marine Evidence based Sensitivity Assessment (MarESA; Tyler-Walters et al., 2018). Sensitivity here is defined as the likelihood of change when a pressure (which could be chemical, physical, hydrological or biological) is applied to a species or habitat. It is a function of the ability of the habitat or species to tolerate or resist change (resistance or tolerance) and the rate (or time taken) for it to recover from impact (resilience or recovery; Tillin & Tyler-Walters, 2014). This tool has been used to infer proxy condition assessments of habitats in UK MPAs and is a common approach, under development, to assess the extent of physical damage to seabed habitats and species in the Oslo–Paris Convention Region (OAP, 2021). For the current assessment, we define our proxy as a scale of 'Likely Relative Condition' (LRC) of the seabed habitat, where 1 indicates poor LRC (the habitat has been exposed to a



Natural Capital Asset: Habitats in North Devon Marine Pioneer		Food (from Provisioning services)	Healthy climate (from Regulating services)	Sea defence (from Regulating services)	Clean water and sediments (from Regulating services)	Tourism/nature watching (from Cultural services)
Saltmarsh	Saltmarsh	3	3	3	3	3
Intertidal reef	Littoral (intertidal) rock and other hard substrata	3	2	1		1
Subtidal reef	Infralittoral (shallow) rock and other hard substrata	3	2	1		1
	Circalittoral (deep) rock and other hard substrata	1		1		1
Intertidal sediments	Sand and muddy sand	1	2	3		1
	Mud	3	3	3	3	1
Biogenic reef	Intertidal biogenic reefs	2	1	2	2	1
Subtidal sediment	Coarse sediment	2		3	3	
	Sand	2		3	3	
	Mud	2		3	3	
	Mixed sediments	2		3	3	

FIGURE 2 The marine natural capital asset and risk register input data for illustrative purposes (a) matrix of ecosystem services provision from UK marine habitats; (b) a composite map of benthic habitats; (c) habitat condition assessments for marine protected areas; and (d) a habitat condition proxy method based on habitat sensitivity to fishing pressures. Full methods for the input data are available in Appendix S1

pressure to which it is sensitive) and 5 indicates a good LRC (no exposure to pressure or pressure thresholds are within the tolerances of the defined sensitivity of the habitat; Rees et al., 2018; see Appendix S1).

2.5.5 | Habitat spatial configuration

Where Conservation Advice Packages for features of conservation interest included an assessment of spatial distribution, for example, location, this was included in the risk assessment (see Appendix S1).

2.5.6 | Species assets (extent and condition)

Abundance of commercial species (population size or biomass), spawning stock biomass and recruitment were selected as indicators of species asset extent and condition. Landings of non-quota shellfish over time provided the best available data linked to asset quantity (Cefas, 2012). Quality of non-quota shellfish species assets was assessed from UK regional assessment of stocks (Cefas, 2012, 2017a, 2017b). Migratory species considered were Atlantic salmon *Salmo salar* and sea trout *Salmo trutta* and their status assessed using data collected by the Environment Agency (see Appendix S1).

2.5.7 | The water column (extent and condition)

Data are collected by government agencies in line with UK commitments under both the Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD), can be applied in the natural capital context as indicators of the condition of water body assets. Data on the status of each water body in the case study areas were accessed from online resources (see Appendix S1).

2.6 | Trend analysis

Where possible all data were assessed for the baseline year (2017 or next closest year when data are available) and the trend since 2010 (increase or decrease) was analysed using annual data for 2010–2017 where available.

2.7 | Policy targets

Within a risk register, it is necessary to define the nature and the severity of the risk to the asset–benefit relationship. Mace et al. (2015) categorised risk according to the performance of the asset–benefit relationship against relevant policy targets. Policy targets in this context are considered to be societal aspirations for the asset–benefit relationship and, as such, form a threshold target against which risk can be defined. Relevant policy targets applied within this Risk Register are drawn from policy targets within the Convention on Biological Diversity, European Union (EU) Directives and national guidance to achieve policy targets (see Appendix S2 in Supporting Information).

2.8 | Risk assessment

Following the process defined by Mace et al. (2015), each asset–benefit relationship was assessed against the complied evidence (input data products) according to the identified policy targets (Figure 3). The initial assessment was undertaken by an individual academic and verified with the wider project team and the North Devon Marine Pioneer Steering Group. Each component characteristic (extent, condition and spatial configuration) was assessed for status and trend (see Appendix S2). Dealing with multiple sources of data in an integrated assessment such as this poses an issue of how to deal with uncertainty across different disciplines. Within the risk register a confidence score based on robustness and agreement of evidence (IPCC, 2014), linked to the trend and status, enabled confidence in results to be presented (see Appendix S2). Each risk score was assessed for the strength of evidence and agreement between sources (uncertainty). In the final output asset and risk register, lighter shaded, red, amber or green cells indicates a risk rating where there is less confidence (greater uncertainty) in the risk rating, due to limited evidence and/or limited agreement between evidence sources (see Appendix S2).

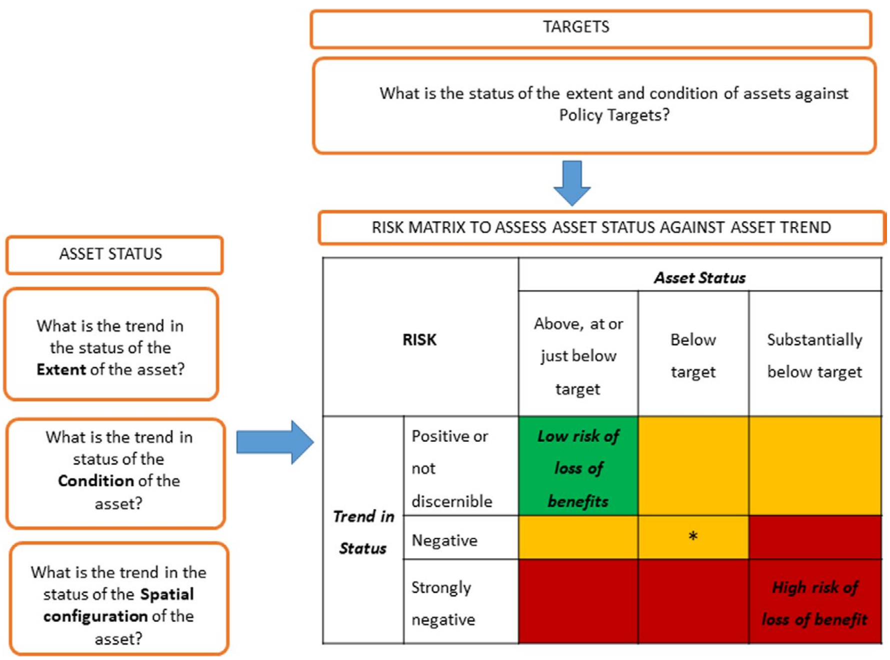


FIGURE 3 The risk assessment process. Following Mace et al. (2015) each asset–benefit relationship (e.g. saltmarsh–Recreation) was assessed against (1) the evidence compiled on the three dimensions of asset status (i) extent, (ii) condition and (iii) spatial configuration; 2) the trend in the status (where available); and (3) performance against policy targets. Red signals a high risk of loss of a benefit where the trend in status is negative and performance against policy targets is currently on target (but declining), below, and substantially below target. Green signals a positive trend in the assets status data and policy targets are being met. An amber risk rating is the middle ground where there is either a negative trend in the asset status data and performance against policy targets is below target or above, at or just below target or a positive trend in the asset status but below or substantially below a policy target. An additional precautionary approach was applied to identify risk, adapted from Mace et al. (2015). In instances where the status of benefit is below target, and the trend negative, we apply an adapted amber risk rating with an asterisk to highlight those asset–benefit relationships that are at risk of tipping over to a red risk rating

3 | RESULTS

From 285 possible asset–benefit relationships (Figure 4), 136 relationships were prioritised for assessment in the asset and risk register as providing a medium to high contribution to the ecosystem service benefit. The remaining 149 relationships were not prioritised for assessment as either the contribution to ecosystem service benefits was low, or there is no evidence to make an assessment (Figure 4).

Twenty-five asset–benefit relationships were allocated a high risk rating, 109 a medium risk rating and 2 a low risk for the assessments of the asset status (extent, condition, spatial configuration; Figure 4). The risk (of loss) of the benefit of Food (wild food fish and shellfish) is high due to the extent of sublittoral habitats without management objectives to protect the habitat assets and with impaired condition from previous fishing activity (Figure 4). Loss of the asset–benefit relationship that supports shellfish is low for lobster and medium for crab due to stock assessments that signal that these fisheries are currently sustainable (Figure 4). Confidence is low in this, however, as the stock assessment is undertaken at a larger spatial scale than the case study area. The benefit of a Healthy Climate is an amber (medium) risk of loss due to the degraded quality of the saltmarsh and rock/reef habitats. The benefit of Sea Defence provided by saltmarsh, littoral sand and mud sediments is at amber (medium) risk (of loss) due to fragmented habitats and degraded quality. The benefit of Recreation and Tourism is an overall amber (medium) risk (of loss) due to degraded habitats and incidences of poor water quality. The benefits of Clean Water and Sediments, supported by the subtidal sediments, are rated at amber (medium) risk due to impaired condition of the habitat assets from historic fishing pressure.

Across the board, confidence is low in the risk outputs due to uncertainty in the underlying data products, which, at present, represent the best available evidence for marine systems. Confidence in the risk rating is highest linked to assessments on water bodies, bathing waters and shellfish waters where the data are spatially explicit and linked to the reporting requirements of the EU Water Framework Directive.

4 | DISCUSSION

Through the application of the natural capital asset and risk register approach (Mace et al., 2015) to the marine environment, it has been possible to identify those natural capital assets and the benefits that are at greatest risk of loss under current management. This application has made use of existing methods, data products and policy targets to undertake a novel assessment of asset status in line with a natural capital perspective. This is a preliminary analysis establishing the context for applying the natural capital approach to marine systems. While there are limitations and uncertainty evident in combining multiple evidence sources (Hamel & Bryant, 2017), the strength in the risk-based approach is that it enables deliberation of the overarching issue of how ecological systems support human well-being (via the defined benefits; IPCC, 2014). Through testing the approach within the case study area, it has been possible to consider how current environmental management supports natural capital, and the resulting benefits, while also highlighting the risks. The results are relevant to environmental managers at a variety of scales, and also to the development of a SEEA-EA for marine systems.

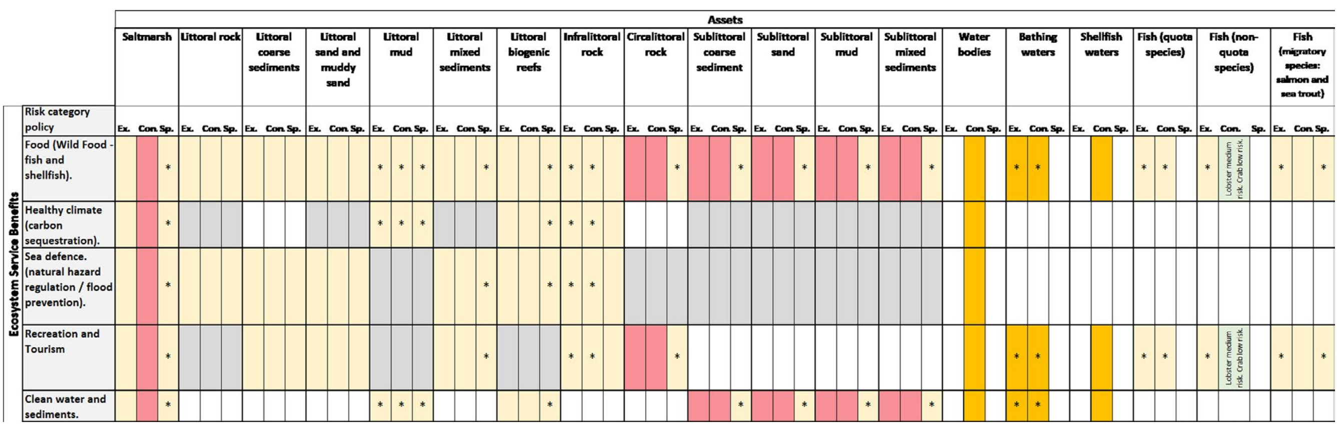


FIGURE 4 A marine natural capital asset and risk register. The assets are columns and the benefits in rows. For each ecosystem service (ES) the risk was assessed through analysis of evidence (see Appendix S1) in relation to policy targets (see Appendix S2). The colour of the cell shows the risk rating for the asset status extent (Ex), condition (Con) and spatial configuration (Sp). Red indicates it is at high risk, amber at medium risk (*amber cells with an asterisk, indicate asset status is below target and the trend in status is declining, suggesting risk rating is close to moving to the high risk category), green risk ratings are at low risk. Lighter shaded, red, amber or green cells indicates where there is less confidence (greater uncertainty) in the risk rating, due to limited evidence and/or limited agreement between evidence sources (e.g. modelled habitat data). The grey cells indicate asset–benefit relationships which were assessed to provide a low potential of benefit (and therefore not considered a priority for assessment); white cells indicate relationships where there was no evidence or too limited information to make an assessment

4.1 | The extent and condition of assets

The calculation of the extent of habitats for marine systems makes use of both modelled and survey data. While this approach represents the best available evidence, it has been recommended that units of assessment for habitats within any future accounting frameworks focus on those that are vegetated (e.g. saltmarsh), as well as biogenic reefs due to the suite of services these provide as the often coarse categorisation of modelled sediment habitats lacks the granularity necessary to understand which biological communities and functions are present (Hooper et al., 2019).

It is notable that there are benefits from natural capital linked to habitats and species assets with and without the designation of marine protected areas (MPAs) as a management tool. Condition assessments of benthic habitats are limited for the requirements of statutory Conservation Advice Packages and they apply only to the designated features of conservation interest within protected sites (so often not the whole MPA). Within the case study area, the natural capital asset and risk register demonstrates a moderate to high risk of loss of benefits linked to features of conservation interest; but the existing conservation advice is to 'maintain' the current status of the features, and so is not a driver for improvement. Only 16.8% of habitats in the case study area have a Conservation Advice recommendation to 'recover'. For the majority of features of conservation interest, there are no historic data included in the condition assessments, and therefore no understanding of the long-term trend on the condition of features. The maintenance of the status quo or recovery (to a shifted baseline) does not reduce the risk of losing benefits. The natural capital approach applied in this context highlights a need for conservation policy to shift to enable more ambitious recovery and renewal of marine habitats. This should also apply beyond the tightly delineated boundaries of features of conservation interest—that is, by adopting the whole site approach (Rees et al., 2013; Solandt et al., 2019). This has proved effective in other similar temperate MPAs (Solandt et al., 2019) and offers a more secure future horizon for natural capital assets and the associated benefits from marine systems.

The highest degree of confidence in the assessment of risk was attributed to the extent and condition of the water column. This is due to concerted efforts under EU Directives to determine the ecological status of water bodies, bathing waters and shellfish waters. However, only the composite metric is available as public data and we had to make a specific request to specialists within each agency, to 'unpack' data specific for this natural capital approach. Hein et al. (2020), through a review of the development of SEEA-EA to date, also highlight the constraint of aligning existing reporting systems to a natural capital framework. Problems exist with access, terminology and definitions. An asset and risk register could be further improved though access to these data (before it becomes a composite metric for reporting purposes) as a basis for SEEA-EA.

4.2 | The use of proxy data to infer the condition of assets

For habitats outside of MPAs, there are limited data on habitat condition. Risk to assets outside MPAs were assessed against the MSFD Descriptor 6 which states that Good Environmental Status (GES) is reached when 'sea floor integrity is at a level that ensures that the structure and function of the ecosystem are safeguarded and benthic ecosystems in particular are not adversely affected'. However, thresholds for this 'level' are yet to be defined. Within the natural capital asset and risk register, the development of the proxy habitat condition approach (Likely Relative Condition) was applied. It must be noted that the combining pressure and sensitivity data as a proxy to instigate management measures to protect marine features is not a new concept, that is, OSPAR Assessment Panel (OAP, 2021). However, exposed at this scale are the limitations on the availability of data on the level and type of fishing activity for vessels under 12 m in length and, therefore, confidence in understanding or interpreting how small-vessel fishing impacts on the condition of assets. When these data are combined into the proxy metric 'Likely Relative Condition', the major limitation is access to up-to-date information on spatial intensity of fishing activity (from Vessel Monitoring Systems), and an absence of ecologically relevant thresholds.

The novel aspect in this study is the development of a risk assessment process to understand how management impacts upon the potential for ecosystem services. This also provides an insight into how this approach could be improved at larger scales. In the context of the SEEA-EA, an emphasis is put on the need for scientific validity, which can broadly be interpreted as meeting quality standards for statistical information (Comte et al., 2020). Greater confidence in this approach would be further supported by targeted assessments of recovery of habitats and species from dominant physical pressures (dredging, static gear, anchoring etc.; Rees et al., 2020). Current policy thresholds for GES of seafloor integrity are largely precautionary as there is limited evidence or threshold for a baseline state (i.e. what to recover to). As discussed by Hopkins et al. (2018), it is not possible to determine unimpacted reference conditions indisputably, either through modelling/historic data or through marine areas where human effects are currently minimal. Additionally, if a LRC of 5 for seafloor integrity is defined as 'no human impact' for 85% -95% of a habitat extent outside an MPA within time-scale for habitat recovery, then it is possible that targets or thresholds become unobtainable, when compared with the commercial trade-off required. Understanding impact and sustainable use is a key first step. The development of metrics under GES, to measure ecosystem condition though a set of biophysical indicators linked to ecosystem function, heritage and capacity, provides further potential to infer 'safe minimum standards' for risk to marine habitats and further improve confidence in future assessments of risk (Comte et al., 2020).

4.3 | The role of MPAs

Within the case study area, the majority of asset–benefit relationships are at a medium to high risk of loss under current management. The asset and risk register demonstrates that 19.4% (1,072,7 km^2) of the case study area is within an MPA of which 2.3% (24.2 km^2) is under management measures to reduce physical impacts to the seabed (an additional 16 km^2 of byelaw area falls outside of MPAs). Considerable effort has been put into developing information on habitats and species, either for designation or international reporting. Targets and indicators for achieving better outcomes have been set, including for the extent of area under protection and habitat condition. MPAs have long been considered the main policy tool to protect biodiversity. However, it must be considered that they may not be sufficient on their own to underpin all ecosystem services and meet socio-economic priorities, depending on management and enforcement policy. While MPAs may play a significant role in achieving the benefits, the risk register demonstrates that this is a limited assumption and policy mechanisms must broaden ambition beyond MPAs to sustainable use of the wider ocean (Rees et al., 2020).

4.4 | The dominant drivers of risk to natural capital assets

Within this Pioneer context, the dominant pressures influencing risk to the asset–benefit relationship at this scale stem from the fishing, farming and water industries. These drivers of environmental state change are not new (IBPES, 2019), but this work highlights how failure to achieve policy targets across these sectors compounds the risk that society will lose the benefits offered by marine ecosystems. It is argued that translation of the biophysical environment into the ecosystem services concept enables a 'whole system awareness' (Costanza et al., 2017). The natural capital asset and risk register enables the outcomes or performance of sectoral management to be viewed through a holistic lens, where impacts to the ecosystem, stemming from different sectors, pose a risk to the flow of benefits to the human system. This asset and risk register has provided the foundational evidence base for the UK's first marine Natural Capital Plan a formal planning and management delivery document designed to integrate governance across the connected ecosystems and build in local 'place based' targets for managing and benefiting from natural capital (Ingle et al., 2020). It is the intention that any scaling up of the natural capital approach will draw from the experience of this research.

4.5 | The incorporation of value

Asset and risk registers are included within the natural capital approach methodological toolkit, but do not require the incorporation of monetary valuations. Within the asset and risk register, the whole of the natural capital is recognised as contributing towards the benefits, with levels of contribution expressed through the use of the matrix approach. It is the case that the process itself is value based, in so far as the decisions we make as individuals can imply valuation (Costanza et al., 2017). In this asset and risk register approach, the input data products provide the best available quantitative data against which the asset status could be assessed in the context of policy targets. The use of expert opinion within the methods exposes the process to unintended transfer of values from the team of researchers to the evaluation of risk within the 'evidence – agreement' approach (IPCC, 2014). We note here, however, that it is not the purpose of an asset and risk register process to be void of any subjective opinion. Indeed, it is recognised in international risk-based approaches to environmental management that, because risk can be managed or reduced in such a wide range of formal and informal approaches, it is not necessary to quantify risk accurately. What is more important is working with the best available evidence, to deliberate and work towards best outcomes for ecology, economy and society (IPCC, 2014). If nature is valued broadly for the benefits to human well-being, and a risk-based process can highlight pathways for more sustainable outcomes, then it could be argued that economic valuation is not necessary. Therefore, the purpose of a marine natural capital asset and risk register is not to invite trade-offs between value sets, but to instigate broad-scale policy change and management measures to ensure no net loss of assets and, given the current precarious status of nature, to improve the extent and condition of natural capital assets over time.

Natural capital accounting methods have been proposed as a decision support tool to inform management and incorporate economic values. Internationally, the SEEA-EA is priming the collection of both economic and environmental data to underpin the development of accounts. The linear construction of natural capital accounts explicitly linking the extent and condition of an asset to an economic outcome, however, does not take into account the interconnections between the assets (including the water column) and the dynamic profile of marine systems (Hooper et al., 2019). There is also a complex relationship between the condition of an ecosystem and the provision of ecosystem services as demonstrated by Kermagoret et al. (2019) that is challenging to link to economic outcomes. While economic valuation could improve or direct discourse on the management of risk, additional insights on values, goals and priorities based on psychological, cultural, social and ethical values could also strengthen the effectiveness of long-term processes to manage or mitigate risk (IPCC, 2014).

This natural capital asset and risk register treats nature as being inherently valuable; it also provides a potential route map to improve the governance of natural systems and underpin human well-being. Therefore, to achieve an ambition for sustainable development with nature at the heart of decision making, the development of the marine natural capital approach at greater scale in the United Kingdom, and within the SEEA-EA processes, must consider the broader value connections to natural capital alongside the balance of sustainability paradigms and linked to natural capital accounting processes (Dietz & Neumayer, 2007).

5 | CONCLUSIONS

The construction of a marine natural capital asset and risk register at the case study scale has been possible based on established data products. Highlighted in the natural capital asset and risk register is the moderate (amber) to high (red) risk of loss of the majority of asset–benefit relationships, despite proactive management towards policy targets within each sector. It is clear that a 'no-change' approach to the management of ecosystems is not a viable option if human well-being is to continue to benefit from marine ecosystems, and the same is true at increasing scale (IBPES, 2019). This study signals a need to scale up and to work across those agencies with different policy remits to co-deliver an overarching (transformative) strategy to improve the status (recovery and restoration) of natural capital. Improved confidence in the data products at both local and national scales will require more directed monitoring to demonstrate the current extent and condition of marine natural capital assets and provide a benchmark by which overall performance (towards sustainability) can be measured.

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AUTHORS' CONTRIBUTIONS

S.E.R., M.A., A.C., T.M. and T.H. conceived the ideas and methodology; A.C., S.E.R., T.M. and M.A. collected and analysed the data; S.E.R. and M.A. led the writing of the manuscript; C.I., J.O., A.L., T.H. and M.J.A. contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available via the Pearl Repository http://hdl.handle.net/10026.1/18563 (Rees et al., 2022).

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