AN ASSESSMENT OF NORTHERN IRELAND'S MARINE NATURAL CAPITAL (NI-MANACA)

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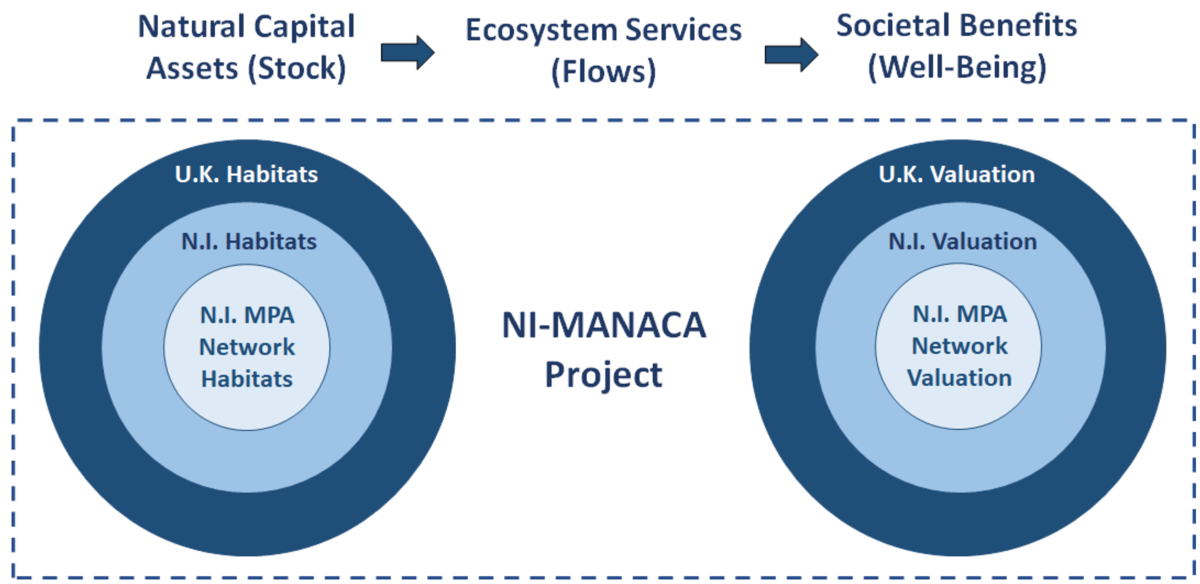
Executive Summary

1. NI-MANACA Project Aims

The Northern Ireland Marine Natural Capital (NI-MANACA) project aims to provide: a baseline assessment of the marine natural capital encompassing the entire worth of the marine environment to Northern Ireland; an evaluation of the Northern Ireland Marine Protected Area (MPA) network; and a framework to provide a Decision Support Tool for strategic management of marine spatial planning.

The marine environment can be considered in terms of stocks (natural capital assets), flows (ecosystem services) and links to well-being (societal benefits) which can be valued by society. As such, the focus of this study spans across both the natural environment, where natural capital is present and delivers flows of ecosystem services, and the human domain where societal benefits are realised. The NI-MANACA project centres around the relationship between the natural capital assets, in this case EUNIS level 3 marine habitats, and their importance in delivering benefits for society. Given that valuation data are often not available at the national or site-specific level, the project takes a hierarchical approach whereby the analysis starts at the UK level, where valuation data is more readily available, and then estimates the value of the Northern Ireland marine waters and the Northern Ireland MPA network from this.



In order to deliver the aims, the NI-MANACA project is sub-divided into three overlapping phases: (1) Natural Capital Mapping; (2) Valuation of Societal Benefits; and (3) Future Scenarios Assessments. By developing and testing a framework to automate the benefit transfer process and future scenario assessments (the Excel-based BEACH tool; **B**enefit **E**valuation through **A**ssessment of **C**omponent **H**abitats), NI-MANACA provides a future-proofed Decision Support Tool which can be used by marine planners, managers and policy-makers to support marine spatial planning both within Northern Ireland marine waters and, potentially, elsewhere. Both UK-scale valuation data and EUNIS level 3 marine habitat data are used alongside local-scale (Northern Ireland; and Northern Ireland MPA network) habitat data as inputs to the BEACH tool; these could be readily replaced with data relating to a different region, making the tool readily transportable and adaptable for applications globally.

2. Natural Capital Mapping

The first phase of the project mapped the distribution of EUNIS level 3 habitats present within UK marine waters. For this task, JNCC's EUNIS Combined map (2019) was employed as this provides a composite surface of both observed and predicted habitat maps and includes the distribution of both littoral (intertidal) and coastal (high shore) habitats for Great Britain. As the footprint of many of the conservation designations in Northern Ireland cover the littoral environment, it was necessary to ensure that the littoral habitats for the province were added to the combined map. Since no existing littoral habitat maps were available for Northern Ireland, this project estimated the distribution of EUNIS level 3 littoral habitats throughout Northern Ireland. It was apparent that several of the EUNIS level 3 habitats generated by the combination of substrate and exposure/energy were not classes routinely used at the UK-scale and therefore some data cleansing was undertaken using a set of transparent rules. A summary of the extent of EUNIS level 3 habitats within UK and Northern Ireland marine waters, and within the current Northern Irish MPA network, are presented below.

EUNIS L3	Habitats	UK Total Area (Ha)	NI Total Area (Ha)	NI MPA Area (Ha)
A1.1	High energy littoral rock	4,855	346	90
A1.2	Moderate energy littoral rock	6,839	642	330
A1.3	Low energy littoral rock	10,562	1,011	402
A2.1	Littoral coarse sediment	7,342	56	17
A2.2	Littoral sand and muddy sand	163,788	5,497	539
A2.3	Littoral mud	83,073	4,676	470
A2.4	Littoral mixed sediments	10,872	3,589	1,326
A2.5	Coastal saltmarshes and saline reedbeds	18,089	3,108	1,005
A2.6	Littoral sediments dominated by aquatic angiosperms	2,013	0	0
A2.7	Littoral biogenic reefs	4,513	0	0
A3.1	Atlantic and Mediterranean high energy infralittoral rock	162,651	1,009	740
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	101,399	2,712	1,971
A3.3	Atlantic and Mediterranean low energy infralittoral rock	49,086	1,025	898
A4.1	Atlantic and Mediterranean high energy circalittoral rock	678,527	3,312	2,002
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	662,105	19,633	14,930
A4.3	Atlantic and Mediterranean low energy circalittoral rock	158,603	5,277	4,231
A5.1	Sublittoral coarse sediment	16,004,206	199,947	65,064
A5.2	Sublittoral sand	26,428,988	127,268	62,631
A5.3	Sublittoral mud	6,534,080	237,833	81,463
A5.4	Sublittoral mixed sediments	1,977,113	62,076	37,535
A5.5	Sublittoral macrophyte-dominated sediment	19,196	1,284	909
A5.6	Sublittoral biogenic reefs	51,092	75	75
A6.1	Deep-sea rock and artificial hard substrata	681,772	0	0
A6.2	Deep-sea mixed substrata	5,322,777	0	0
A6.3	Deep-sea sand	6,463,493	0	0
A6.4	Deep-sea muddy sand	3,569,707	0	0
A6.5	Deep-sea mud	20,078,301	0	0
A6.6	Deep-sea bioherms	2,271	0	0
	Total Area (Ha)	**89,257,310**	**680,376**	**276,629**

3. Valuation of Societal Benefits

The second phase of the project identified the benefits that society receive from the marine environment, and obtained or derived valuation estimates for each societal benefit from the published literature. Fourteen societal benefits were identified and UK value estimates were obtained from the literature for eight of these with 2019 set as the baseline year for annual values. The existing UK valuation literature is important as it offers the opportunity to value Northern Ireland's marine environment by employing benefit transfer methods. The data gaps identified (six societal benefits remained without UK-scale value estimates) suggest that the values generated by the NI-MANACA project will be underestimates of the total value that the marine environment provides.

To undertake the benefit transfer process the BEACH tool disaggregates the UK-scale valuation data across the UK (EUNIS level 3) marine habitats. Both the relative abundance of different EUNIS level 3 habitats and (where possible) the importance of each habitat in delivering each societal benefit are used as weighting factors in this operation. The resultant (habitat- and benefit-specific) component values are subsequently reaggregated for 'target' waters (specifically Northern Ireland marine waters and the Northern Ireland MPA network) on the basis of their habitat composition, so generating estimates of benefit values at these new geographic scales. The range of total value estimates for the UK, Northern Ireland marine waters and the Northern Ireland MPA network are presented below:

Value Estimates	UK (£m 2019 prices)	Northern Ireland (£m 2019 prices)	Northern Ireland MPA (£m 2019 prices)
Low	6,549.28	51.07	20.81
Mid	8,891.34	68.59	27.86
High	10,862.71	83.28	33.76

These point estimates need to be interpreted with some caution as they suggest a degree of accuracy that is inconsistent with the type of analysis undertaken. However, they are indicative of the scale of benefits that might be realised.

4. Assessments of Future Scenarios

The basic value transfer functionality of the BEACH tool was augmented to account for changes in value that might be expected as the result of protection/management measures, allowing forward projections of values under defined conditions to be made. Outputs from the tool are presented as annualised estimates (in 2019 prices) and Net Present Values (NPV) over 20 years which are discounted at 3.5%.

Three assessments are presented which are used to demonstrate potential applications of the BEACH tool. **These assessments in no way reflect current policy, planning or management in Northern Ireland**.

Status Quo / Business as Usual Scenario: This scenario assumes: that unmanaged (unprotected, or non-MPA) areas of the Northern Ireland marine environment remain as they are; all of the current MPA network is managed to a 'maintain' conservation objective; and no additional MPA sites are designated. Assessment of the status quo scenario can be used to provide a baseline from which to assess the potential impacts of management options. Under this scenario the Net Present Value (over 20 years) of Northern Ireland marine waters would be in the range of £712 million - £1,166 million.

Changes in Management of the Existing MPA Network Scenario: This scenario assumes that the existing Northern Ireland MPA network is all currently managed at a maintain conservation objective, and estimates the potential additional benefits which may be delivered by increasing the proportion of the network that changed to a recover management regime. Estimates suggest that the overall value of benefits (NPV 20yr) that would accrue from the current MPA network managed at 100% maintain would be in the range £300.92 million - £488.19 million, whilst this would rise to somewhere in the range of £385.28 million - £649.26 million if the network were to be managed at 100% recover.

Values of Unit Areas of Northern Ireland Marine Waters: Randomly selected illustrative demonstration sites were generated within GIS to demonstrate the application of the approach and the functionality of the BEACH tool, and the range of values (minimum, maximum, mean, median and standard deviation) of unit areas of Northern Ireland marine waters. As might be expected, there is a large variation in the overall value of individual demonstration sites (calculated using mid-point values) across the overall sample indicating that the individual randomly selected demonstration sites tend to each perform differently. Nevertheless, this scenario indicates that a randomly selected 3,200 ha site is likely to contribute a mean value of around £4.68 million (SD = £0.43 million) to Northern Ireland (20-year) NPV across all benefit streams under a 'maintain' management regime and £6.22 million (SD = £0.88 million) under a 'recover' management regime.

5. Key Data Gaps & Recommendations

The NI-MANACA project has identified a number of data gaps and recommendations for improving our understanding of the natural capital present within Northern Ireland marine waters and the value of the benefits that it delivers for society under different management regimes. These include:

- Further work is required to improve the combined map for Northern Ireland's marine habitats including ground-truthing the modelled data for infralittoral habitats and incorporating recently modelled data for blue carbon habitats within Northern Ireland.
- There is potential to develop a GIS tool which would enable natural capital mapping data (i.e., EUNIS level 3 habitat data) to be directly incorporated into the BEACH tool.
- Data gaps were identified with respect to UK-scale valuation data for six of the 14 societal benefits that are considered; there is a need for further primary research to fill these data gaps.
- The BEACH tool is currently driven by UK-level valuation data. It is recommended that further consideration should be given to the potential inclusion of Northern Irish data where these are available.
- The importance of natural capital features in the delivery of benefits to society is central to the NI-MANACA project and these underlying relationships are currently based on previously published assessments. There is a need to review these relationships, and to fill gaps in current understanding.
- There is a need to incorporate measures of confidence into the BEACH tool so that the user is made aware of the implications of the quality of data that underpin the model. For example, information on the underlying confidence in assessments of natural capital (habitat) extent, of the relationships between natural capital and societal benefits, and of the valuation of societal benefits could all potentially be incorporated.
- At present the BEACH tool generates estimates values of benefits with no consideration of the costs involved with changes in management regime. Further work is required to investigate whether indicative management costs could also be incorporated into the BEACH tool.
- In addition to estimates of the mid-point values of benefits at the UK-scale, the BEACH tool currently accepts estimates of both lower and upper (range) limits of benefit value. However, at present, all valuation estimates undertaken by the BEACH tool are based solely on the mid-point estimates. There is scope to incorporate the ranges of valuations – where these are provided by the user – to automatically generate lower and upper (range) limits around estimates of value produced by the tool.
- The interpretive and illustrative power of the BEACH tool could be improved by developing graphical routines to sit alongside the existing tabular outputs. These might include, for example, representations of the relative abundance of different habitat types in the across the different spatial scales being considered by the tool, and the automatic generation of heat-map outputs.

6. Project Outputs

The NI-MANACA project has delivered three main outputs: a **Final Report** which contains detailed methodologies, results, discussion, data gaps and recommendations; **GIS Files** which have been developed for and applied during the NI-MANACA project; The Excel-based **BEACH tool** (Beta v1.0).

1. The Northern Ireland Marine Natural Capital (NI-MANACA) Project

The natural capital approach to policy and decision-making considers the value of the natural environment for people and the economy, providing a helpful tool to support the protection and management of the natural environment and the engagement of stakeholders within management decisions (Barnard & Atkins, 2022; Burdon et al., 2022). Following Mace et al. (2015), natural capital assets can be defined in terms of their biophysical features, the types of benefits provided and the management context. In the case of the marine environment, three types of natural capital asset can be identified: habitat assets (e.g., EUNIS level 3 habitats), species assets (e.g., commercial fish and shellfish species) and the water column (Rees et al., 2022). Natural capital assets deliver flows of ecosystem services, including provisioning services (e.g., food, genetic resources and other raw materials), supporting services (e.g., primary production, nutrient cycling), regulating services (e.g., climate regulation, water purification, flood protection) and cultural services (e.g., recreation, education and cultural heritage). These ecosystem services offer a range of benefits which are valued by society for their impact on human well-being, including human health, and the economy.

The aim of the Northern Ireland Marine Natural Capital (NI-MANACA) project is to provide: a baseline assessment of the monetary value of Northern Ireland's marine natural capital; a monetary evaluation of Northern Ireland's network of Marine Protected Area (MPA); and a Decision Support Tool for marine spatial planning based on the methodological approach adopted here. The project will provide broad scale habitat and monetary evaluations, and aims to develop an adaptable toolset to allow re-valuation of the Northern Ireland marine natural capital incorporating evidence gained through future data collection.

The ecosystem services concept, which underpins the evaluation of marine natural capital, continues to evolve. While the NI-MANACA project aims to provide a flexible framework that can be modified over time as knowledge gaps are addressed, it contributes to the wider understanding of marine natural capital and ecosystem services through its application to marine spatial planning. A schematic of the NI-MANACA project is presented in Figure 1, which shows how the project takes a hierarchical approach. The analysis starts at the UK level where the evidence base is more complete, mapping natural capital habitats based on EUNIS marine habitats, and then estimating the value of that natural capital using the available published evidence. The habitats of the Northern Ireland waters and the existing Northern Ireland MPA network are then mapped, and the value of those waters and networks estimated from the UK-scale evidence and other evidence available at the regional level.

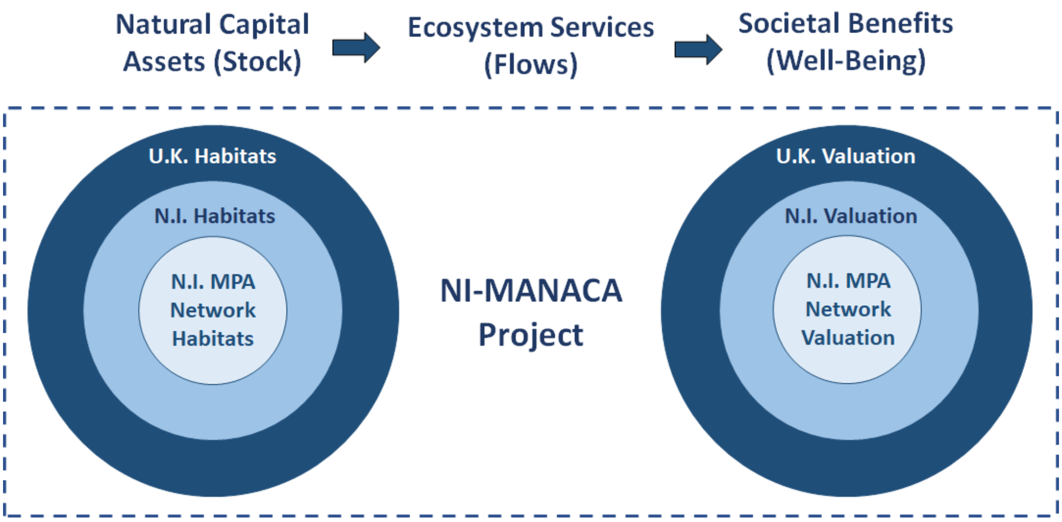


Figure 1: Schematic of the NI-MANACA project.

2. Introduction to Natural Capital, Ecosystem Services, Benefits and Valuation

The marine environment can be considered in terms of stocks of natural capital assets, which deliver flows of ecosystem services, which have links to human well-being and the economy (sometimes referred to as societal benefits) which are valued (Turner et al., 2015). Despite a growing body of literature on natural capital, ecosystem services and valuation, there are no nationally or internationally agreed definitions for many of the terms used and no consensus on the most appropriate framework or approach to employ. This inevitably causes confusion amongst stakeholders and detracts from the purpose of applying the approach to better understand the complexity of the marine environment and societies connection to it (Burdon et al., 2022). This section will therefore introduce and define these terms within the context of the NI-MANACA project and then introduce the concept of valuation including both monetary and non-monetary valuation methods.

2.1 Natural Capital (Assets)

For the purpose of the NI-MANACA project, the Natural Capital Committee (2019) definitions will be applied. As such natural capital is defined as "*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*" (Natural Capital Committee, 2019, p.3). This definition recognises that the marine ecosystem contains a range of components (e.g., habitats and species) and processes (e.g., food webs and ecological dynamics) which form natural capital assets from which ecosystem services flow (Figure 2).

There are a number of policy drivers and regulatory mechanisms which have encouraged the inclusion of natural capital concepts within the UK. For example, the UK Government's 25 Year Environment Plan (25YEP) recognises the "need to understand the full value of the marine environment and incorporate that into the decisions we take: this is key to the natural capital approach" and the HM Treasury Green Book advocates the incorporation of natural capital concepts into policy appraisal, evaluation and to support policy goals (HM Treasury, 2022). The (Draft) Northern Ireland Environment Strategy 2020 recognises the importance of protecting and enhancing natural capital for the benefit of future generations.

These policy drivers and regulatory mechanisms have encouraged the development of a number of scientific research programmes which have focussed on UK marine natural capital. Examples of these programmes include the Defra funded Marine Pioneer Project (https://zenodo.org/record/4564011#), the NERC/Defra funded Marine Ecosystem Research (MERP) programme (https://www.marine-ecosystems.org.uk/Home), the development of natural capital accounts for the UK marine environment (https://www.gov.uk/government/statistics/uk-natural-capital-accounts-marine-2021) and the NERC/ESRC funded Sustainable Management of Marine Resources (SMMR) programme (https://www.smmr.org.uk/). In addition a number of guidance documents have been produced to assist in the application of a marine natural capital approach, for example the Enabling Natural Capital Approach (ENCA) guidance (Defra, 2020) and the Environment Agency's Natural Capital Story Interactive (Environment Agency, 2020). In addition, a growing range of natural capital focussed outputs have been published from these research programmes and others which have focussed on applying the natural capital approach to decision making for the marine environment (Hooper et al., 2019), assessing the natural capital value of water quality and climate regulation (Watson et al., 2020), the development of a marine natural capital asset and risk register (Rees et al., 2022) and applying participatory mapping to link natural capital, benefits and beneficiaries (Burdon et al., 2022).

2.2 Ecosystem Services (Flows)

For the purpose of the NI-MANACA project, ecosystem services are defined as *"functions and products from nature that can be turned into benefits with varying degrees of human input"* (Natural Capital Committee, 2019, p.3). This definition recognises that ecosystem services are different to societal benefits, as ecosystem services are a naturally occurring process in the natural environment domain, whereas societal benefits are secured from ecosystem services through the input of complementary capital (built, human and social) in the societal domain. Ecosystem service flows act as the link between the natural capital assets that comprise the marine ecosystem and the goods and benefits obtained by society that are valued through their impact on human well-being and the economy (Figure 2). Figure 2 also identifies the importance of complementary capital to convert flows of ecosystem services (in the natural environment domain) to benefits for human well-being and the economy (in the societal domain).

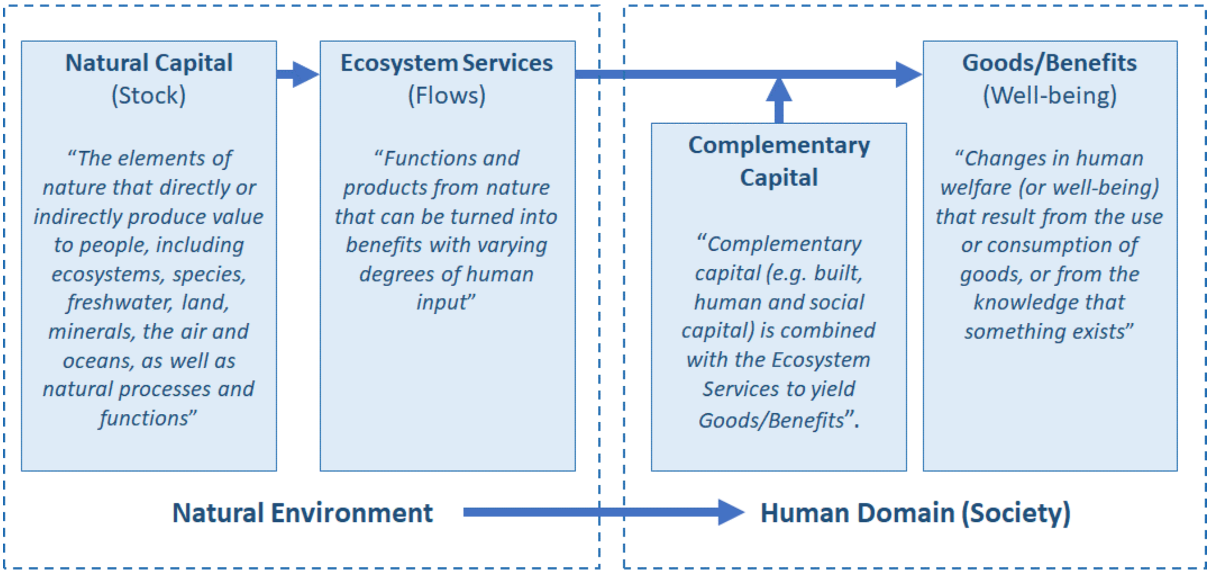


Figure 2: Conceptual framework linking natural capital, ecosystem services and societal benefits (adapted from Burdon et al., 2022).

The Millennium Ecosystem Assessment (MA, 2005) was one of the first studies to attempt to define and categorise ecosystem services. The global study identified four categories of ecosystem service: **Provisioning services** - the products obtained from the ecosystem; **Regulating services** - the benefits obtained from the regulation of ecosystem processes; **Cultural services** - the nonmaterial benefits people obtain from ecosystems, and **Supporting services** - those services that are necessary for the production of all other ecosystem services, but do not yield direct benefits to humans. A number of ecosystem services have been developed. For example, within Europe, The Economics of Ecosystems and Biodiversity (TEEB) project proposed an ecosystem services framework (de Groot et al., 2010; Kumar, 2010). This generic framework was based upon a conceptual model adapted from Haines-Young and Potschin (2010) and Maltby (2009) and, similarly to the Millennium Ecosystem Assessment, the TEEB framework was applied to a range of ecosystems (including marine/open ocean, coastal systems, wetlands, rivers/lakes, forest, deserts and urban areas). It is of note that the TEEB framework does not include supporting services, however introduces a further category, 'habitat services', which comprises the maintenance of migratory species life cycles and genetic diversity (de Groot et al., 2010). In addition, further classification systems have been cited within the literature, for example the Common International Classification of Ecosystem Services (CICES) formed part of the analytical framework for ecosystem service assessments under Action 5 of the EU Biodiversity Strategy (Maes et al., 2014) and other published work (e.g., Turkelboom et al., 2013; Culhane et al., 2018; Norton et al., 2014).

Within the UK, the National Ecosystem Assessment focused on the processes that link human society and well-being to the natural environment and developed an ecosystem services framework applicable to a wide range of terrestrial and aquatic habitats (UKNEA, 2011). Subsequently, the UK National Ecosystem Assessment Follow-On Project (UKNEAFO, 2014) developed a framework specifically for the marine environment, focussing on the relationships between marine components and processes (natural capital), flows of intermediate and final ecosystem services and societal benefits (Figure 3).

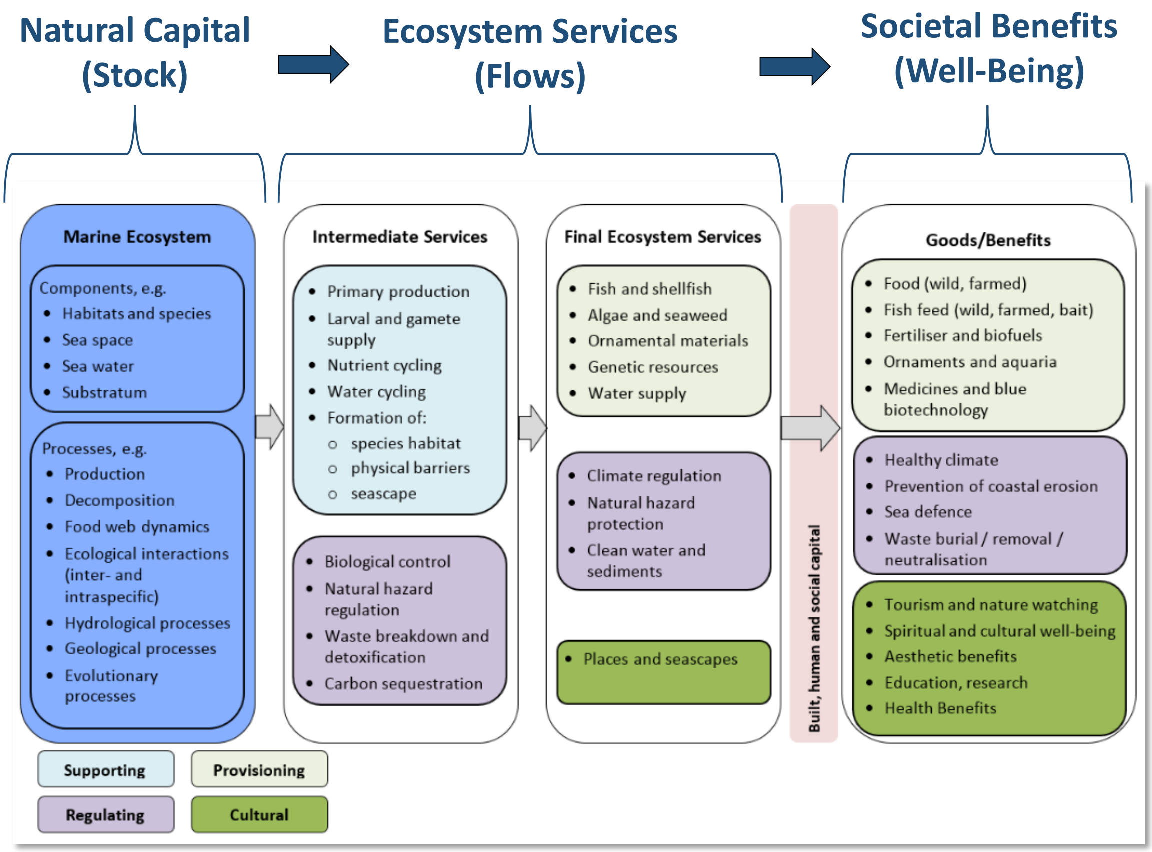


Figure 3: Natural Capital, Ecosystem Services and Societal Benefits in the UK marine environment (adapted from UKNEAFO - Turner et al., 2015).

2.3 Societal Benefits (Well-being)

For the purpose of the NI-MANACA project, we define societal benefits as *"changes in human welfare (or well-being) that result from the use or consumption of goods, or from the knowledge that something exists"* (Natural Capital Committee, 2019, p3.). The 'use or consumption of goods' can take many forms, for example food, education, mental health, recreation and sea defence, as shown in the final column of Figure 3. As suggested above, to capture these societal benefits requires the application of complementary capital, comprising built, human and social capital, for example, associated with fishing and related food processing, and recreation and tourism (Atkins et al., 2011). The pursuit of these activities often generate employment opportunities and contributes to value added within the wider economy. This recognises that societal benefits contain a human component, whereas natural capital and ecosystem services naturally occur within the marine environment without human intervention.

Building on the earlier work of the UKNEAFO, 14 benefits are identified which are generated from a range of provisioning, regulating and cultural ecosystem services (Turner et al., 2015) and capture the breadth of impacts on human well-being. For example, in a 'healthy' UK marine ecosystem, sandbanks (a natural capital stock) provide suitable habitat for sandeel populations to thrive, seabirds (e.g., puffins) then feed on sandeels (an ecosystem service flow), resulting in healthy seabird colonies which provides a valued resource for recreation achieved through nature watching and, thereby, constitutes a benefit secured by society. Of course, for society to receive the benefit an input of complementary capital is necessary, for example, a person's time, knowledge/skills and the travel means to visit a seabird colony. Given that ecosystem services are fundamental to such benefits from the marine environment, then the value of those services to human well-being can be recognised.

2.4 Valuation

The concept of value is central to the natural capital approach. Value can be defined in terms of:

- ecological value, which is the health of the system measured using ecological indicators;
- economic value, expressed and measured monetarily through market prices for benefits that are traded, especially provisioning goods, and through non-market approaches to valuation otherwise; and/or
- socio-cultural value, including shared values which we hold in common as communities, cultures and societies, and which are not easily reducible to conventional economic values e.g., relating to cultural identity and the degree to which that is related to ecosystem services (MA, 2003).

The concept of 'total social value', which comprises these three definitions, can be used to incorporate value preferences of society associated with natural capital into the decision making process in order to inform policy options and management measures (Figure 4). Whilst ecological valuation does not directly contribute to total social value, it's contribution is indirect in that it provides the basis for both assessments of economic value and socio-cultural value (Burdon et al., 2018).

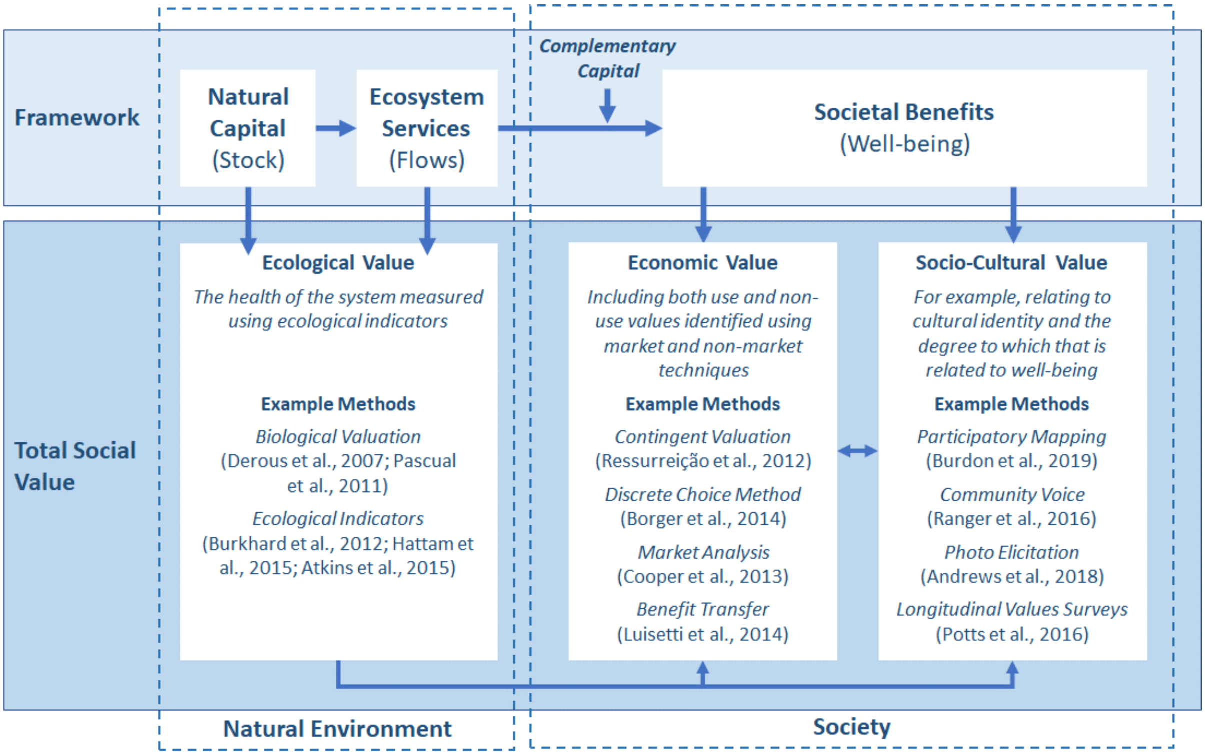


Figure 4: Conceptual framework linking natural capital, ecosystem services and societal benefits with Total Social Value and valuation methods (adapted from Burdon et al., 2022).

With regard to economic valuation, for some marine ecosystem benefits market prices may reflect their value (e.g., fish landed for human consumption), but for others a market price either does not exist (e.g., spiritual and cultural well-being) or does not reflect the social value of that benefit. It is not appropriate to value basic marine processes and intermediate services without identifying explicitly the associated final ecosystem services and societal benefits which have human welfare implications (Turner et al., 2015). Therefore valuation focusses on societal benefits only, to avoid double counting of values from natural capital and/or ecosystem services. A suite of economic valuation methods, including market and non-market approaches, are available which can be applied to value the flow and changes in the flow of ecosystem services (see Figure 4; Annex 1).

There has been an increasing attention given to ecosystem service valuation in science and this has recently been followed by an uptake and use by stakeholders. At the EU-level, an assessment of the value of ecosystem services is called for under the EU 2020 Biodiversity Strategy which emphasises the need 'to value ecosystem services and to integrate these values into accounting systems as a basis for more sustainable policies'. The EU's Water Framework Directive (WFD) and MSFD also both explicitly call for the integration of valuation into environmental management processes. In the UK, valuation studies of ecosystem services have been commissioned by Defra (e.g., Beaumont et al., 2006; Thornton et al., 2019; Börger et al., 2020), the Crown Estate (e.g., Saunders et al., 2010), the Wildlife Trusts (e.g., Fletcher et al., 2012), the Northern Ireland Marine Task Force (e.g., Barnard et al., 2014), the Environment Agency (Watson et al., 2020), Natural England (Rees et al., 2022) and the Marine Management Organisation (Burdon et al., 2022).

Primary data collection can be costly with respect to time and resources. Therefore, where valuation data are not available for a specific location/region, management decisions may need to be based upon value (or benefit) transfer methods. This approach uses primary valuation research results from one area (a study site) to make secondary predictions about values at a different area (the policy site) (Atkins et al., 2013). Within the UK, Defra has published its official guidance on value transfer and recognises it is a quicker and lower cost approach to generating economic valuation evidence when compared to commissioning a site-specific primary valuation study (eftec, 2010). This makes value transfer a practical tool for policy analysis given the time and resources constraints decision-makers regularly face. A number of limitations were also highlighted in the guidance, relating to the potential scarcity of suitable studies, the introduction of transfer errors, and the requirement for expert judgement to select and adjust the values available in the literature (eftec, 2010).

There has been a growing interest in the valuation of benefits which society gain from the natural environment since Costanza et al. (1997) attempted to value the world's ecosystem services and natural capital. This work demonstrated the importance of our marine environment (coastal and open ocean) in delivering 63% of the global value of ecosystem services. Within the UK, Beaumont et al. (2006) provide an overview of the value of goods and services provided by marine biodiversity, which formed the basis for a number of subsequent studies (e.g., Moran et al., 2008; Hussain et al., 2010). Beaumont et al. identified 13 ecosystem services provided by marine biodiversity (see Table 1 below) and reported annual monetary values for nine ecosystem services (in UK £ 2004). Norton et al. (2014) valued Ireland's marine, coastal and estuarine ecosystem services using the CICES system as a guide, and generated estimates for the quantity and value of provisioning, regulation and maintenance, and cultural ecosystem services. Whilst not focusing on ecosystem services *per se*, Stebbings et al. (2020) investigated the marine economy of the UK and in so doing values components of provisioning (e.g., marine fishing and aquaculture) and cultural (e.g., marine leisure and recreation, education and research) ecosystem services.

Natural capital concepts are also gaining prominence across the world as governments generate sets of national natural capital accounts that complement traditional national income accounts given that 'natural capital is predominantly hidden, partial or missing from a nation's economic balance sheet' (ONS, 2021a). These accounts require putting monetary values on the natural capital stock by, for example, valuing the range of flows of benefits that natural capital offers at present and into the future. The System of Environmental-Economic Accounting (SEEA), the UN guidelines for these accounts, integrates economic and environmental data to provide a multipurpose view of the interrelationships between the economy and the environment and changes in stocks of environmental assets, and contain internationally agreed standard concepts, definitions, classifications, accounting rules and tables for producing internationally comparable statistics and accounts (United Nation, 2021). Within the UK, Defra produced guidance on developing natural capital accounts (Defra, 2020). Marine natural capital accounts were developed by Thornton et al. (2019) and were first published by the Office for National Statistics in 2021 (ONS, 2021a; 2021b). The ONS recognises that valuation of marine natural capital is still very much in it's infancy, and the data generated for the marine natural capital accounts are considered experimental.

Specifically, with respect to MPAs within UK waters, a number of studies have attempted to value the impact of management interventions. These studies have been undertaken in relation to assessing the value of MPA networks in English (Moran et al., 2008; Hussain et al., 2010), Scottish (Gonzalez-Alvarez et al., 2011) and Northern Irish marine waters (Barnard et al., 2014). All of these studies used the ecosystem service framework proposed by Beaumont et al. (2006) and generated valuation data for eight out of the thirteen goods/services identified. The estimated valuation evidence obtained by these studies are summarised in Table 1. The NI-MANACA study builds on the methods developed and applied within these studies.

Table 1: Summary of previous ecosystem service framework and estimated UK values applied to MPA studies.

Code	Good/Service	Moran et al., 2008 Monetary Value (£, 2006)	González-Álvarez et al., 2011 Monetary Value (£, 2011)	Barnard et al., 2014 Monetary Value (£, 2012)
E1	Nutrient cycling	£1.3 billion	£1.8 billion	£1.85 billion
E2	Bioremediation of waste	Valuation data not available	Valuation data not available	Valuation data not available
E3	Gas and climate regulation	£8.2 billion	£7.1 billion	£7.2 billion
E4	Food provision	£884.9 million	£1.2 billion	£1.1 billion
E5	Raw materials	£116.5 million	£152.8 million	£102.3 million
E6	Biologically mediated habitat	Valuation data not available	Valuation data not available	Valuation data not available
E7	Resilience and resistance	Valuation data not available	Valuation data not available	Valuation data not available
E8	Disturbance prevention and alleviation	£0.44 billion	£0.54 billion	£0.44 billion
E9	Leisure and recreation	£1.4-3.4 billion	£1.8-4.4 billion	£1.7-4.1 billion
E10	Cultural heritage and identity	Valuation data not available	Valuation data not available	Valuation data not available
E11	Non-use values - bequest and existence	Not assessed	£0.6-3.9 billion	£1.4 billion (best estimate)
E12	Option use values	Valuation data not available	Valuation data not available	Valuation data not available
E13	Cognitive values	£453.3 million	£491.1 million	£408.7 million

3. Methodological Framework

The methodology employed for the NI-MANACA project builds on Hussain et al. (2010) which offers a framework for valuing MPA networks based on UK protected habitats, Potts et al. (2014) which provides matrices which identify the relationships between UK protected features (habitats and species) and the provision of ecosystem services and potential for societal benefits, the ecosystem services framework for UK marine waters of Turner et al. (2015), and the natural capital accounts for the UK marine environment presented in ONS (2021).

The approach adopted in NI-MANACA is hierarchical. The analysis starts at the UK level where the evidence base is more complete, mapping natural capital habitats based on EUNIS marine habitats, and then estimating the value of that natural capital using the available evidence, which is principally ONS data. The habitats of the Northern Ireland waters and the existing Northern Ireland MPA network are then mapped, and the value of those waters and networks estimated from the UK-level evidence and other evidence available at the regional level.

The Benefit Evaluation through Assessment of Component Habitats (BEACH) tool is an Excel-based tool that was developed to support the NI-MANACA project by automating the process of transferring UK-scale valuations to a range of scales within the Northern Ireland marine area. In practice this is realised through the disaggregation of UK-scale benefit valuations on the basis of underlying habitat types, with the subsequent reaggregation of habitat/benefit specific 'transfer' values for target areas at a range of scales within the Northern Ireland marine area. This basic functionality was augmented to account for changes in value that might be expected as the result of protection/management measures, allowing forward projections of values under defined conditions to be made. Further detail regarding the functionality of the BEACH tool is presented under Section 3.3 and in Annex 2.

There are three complimentary phases to the project which focus on: Natural capital mapping; Valuation of societal benefits; and Future Scenarios Assessments.

3.1 Natural Capital Mapping

There are a number of classification schemes which can be used to map marine habitats, and hence also map the extent of natural capital assets (Strong et al., 2019). For example, studies by Moran et al. (2008) and Barnard et al. (2014) used JNCC landscape types and OSPAR Threatened or Declining Habitats to map ecosystem services provided by MPAs in England and Northern Ireland, respectively. More recently, following guidance from the Office for National Statistics (ONS), Thornton et al. (2019) used the EUNIS classification (EEA, 2019) to assess the extent of UK marine and coastal assets whilst Watson et al. (2020; 2022) used the same classification to assess the natural capital value of water quality and climate regulation in temperate marine systems. A summary of the marine EUNIS habitats present in the UK, limited to levels 1-3, are shown in Table 2. It is the EUNIS marine habitat classification which is adopted for use in the NI-MANACA project.

Table 2: EUNIS level 1 – 3 marine habitats present in the UK (EEA, 2019).

EUNIS Level 1	EUNIS Level 2	EUNIS Level 3	Habitat name
A - Marine habitats	A1 - Littoral rock and other hard substrata	A1.1	High energy littoral rock
		A1.2	Moderate energy littoral rock
		A1.3	Low energy littoral rock
	A2 - Littoral sediment	A2.1	Littoral coarse sediment
		A2.2	Littoral sand and muddy sand
		A2.3	Littoral mud
		A2.4	Littoral mixed sediments
		A2.5	Coastal saltmarshes and saline reedbeds
		A2.6	Littoral sediments dominated by aquatic angiosperms
		A2.7	Littoral biogenic reefs
	A3 - Infralittoral rock and other hard substrata	A3.1	Atlantic and Mediterranean high energy infralittoral rock
		A3.2	Atlantic and Mediterranean moderate energy infralittoral rock
		A3.3	Atlantic and Mediterranean low energy infralittoral rock
	A4 - Circalittoral rock and other hard substrata	A4.1	Atlantic and Mediterranean high energy circalittoral rock
		A4.2	Atlantic and Mediterranean moderate energy circalittoral rock
		A4.3	Atlantic and Mediterranean low energy circalittoral rock
	A5 - Sublittoral sediment	A5.1	Sublittoral coarse sediment
		A5.2	Sublittoral sand
		A5.3	Sublittoral mud
		A5.4	Sublittoral mixed sediments
		A5.5	Sublittoral macrophyte-dominated sediment
		A5.6	Sublittoral biogenic reefs
	A6 - Deep-sea bed	A6.1	Deep-sea rock and artificial hard substrata
		A6.2	Deep-sea mixed substrata
		A6.3	Deep-sea sand
		A6.4	Deep-sea muddy sand
		A6.5	Deep-sea mud
		A6.6	Deep-sea bioherms

3.1.1 UK Marine Habitat Mapping

The initial collation of information sourced the current EUNIS habitat maps provided by JNCC's EUNIS Combined map (2019)[1]. The Combined map is, like EMODnet's EUSeaMap (EMODnet, 2021), a composite surface of observed and predicted habitat maps. Unlike the EMODnet products, the Combined map includes information on the distribution of littoral (intertidal) and coastal (high shore) habitats for Great Britain. As the footprint of many of the conservation designations in Northern Ireland covers the littoral environment, it was necessary that the littoral habitats for the province were added to the Combined map. Since no existing littoral habitat maps were available for Northern Ireland, this project estimated the distribution of EUNIS level 3 littoral habitats throughout Northern Ireland. As the Coastal Habitats (EUNIS B1-B3) were not included in the valuation, it was only necessary to focus on the intertidal habitats. The process to generate littoral habitats followed the following steps:

[1] Available from: https://hub.jncc.gov.uk/assets/2048c042-5d68-46c6-8021-31d177b00ac4

- A high tide level was produced using elevation data. Elevation for Northern Ireland was provided by downloading 30 m ASTER data[2]. The contour tool in ArcMap was then used to generate a single contour line at 3.5 m elevation – this value was selected based on the typical spring tide high water height for Northern Ireland. A UKHO satellite derived low tide limit (version 1[3]) was used to define the lower limit of the intertidal zone. A combination of the high and low tide levels was used to generate a polygon defining the littoral footprint in Northern Ireland.

- The EMODnet seabed substrates multiscale map, provided by EMODnet Geology[4], provides the distribution of subtidal substrates. In the absence of better information, the polygon lines defining the distribution of subtidal substrates running into shore were manually extended through the intertidal zone to the high tide limit. The same process was repeated for the EMODnet exposure (energy) polygons[5]. Finally, the surficial rock distribution, contained in the 10k BGS[6] surficial geology dataset, was extracted and used to substitute the extrapolated substrate under the footprint of the rock. The result of these steps was a single littoral substrate layer (rock and extrapolated sediments), with each substrate polygon also attributed with exposure.

It was apparent that several of the EUNIS level 3 habitats generated by the combination of substrate and exposure/energy were not classes routinely used at the UK-scale natural capital analyses (ONS, 2021a). As such the following rules were applied:

- EUNIS level 1 'A. Marine habitat' (comprising a total of 143,287 ha) was classified as unknown marine habitat and therefore was removed from the total UK area – this was in keeping with the ONS (2021a) approach;

- All combined EUNIS level 3 classes (e.g., A1.1 + A1.2) were split equally between the individual EUNIS level 3 habitats (e.g., 50% of area to A1.1 and 50% of area to A1.2);

- All EUNIS level 2 classes (A1, A2, A3, A4, A5, A6) were split proportionally between the EUNIS level 3 habitats within the same class (e.g., A1 was divided between A1.1, A1.2 and A1.3); and

- All 'Features of …' classifications (e.g., A1.4, A2.8, A3.7, A4.7, A5.7) were added to the EUNIS level 2 classes, which were then split proportionally between the EUNIS level 3 classes.

The final EUNIS habitat extent data for the UK are presented in Figure 5 and Table 3.

[2] Available from: https://asterweb.jpl.nasa.gov/gdem.asp
[3] Available from: https://data.admiralty.co.uk/portal/apps/sites/#/marine-data-portal
[4] Available from: https://www.emodnet-geology.eu/data-products/seabed-substrates/
[5] Available from: https://www.emodnet.eu/en/seabed-habitats
[6] Available from: https://www.bgs.ac.uk/datasets/bgs-geology-625k-digmapgb/

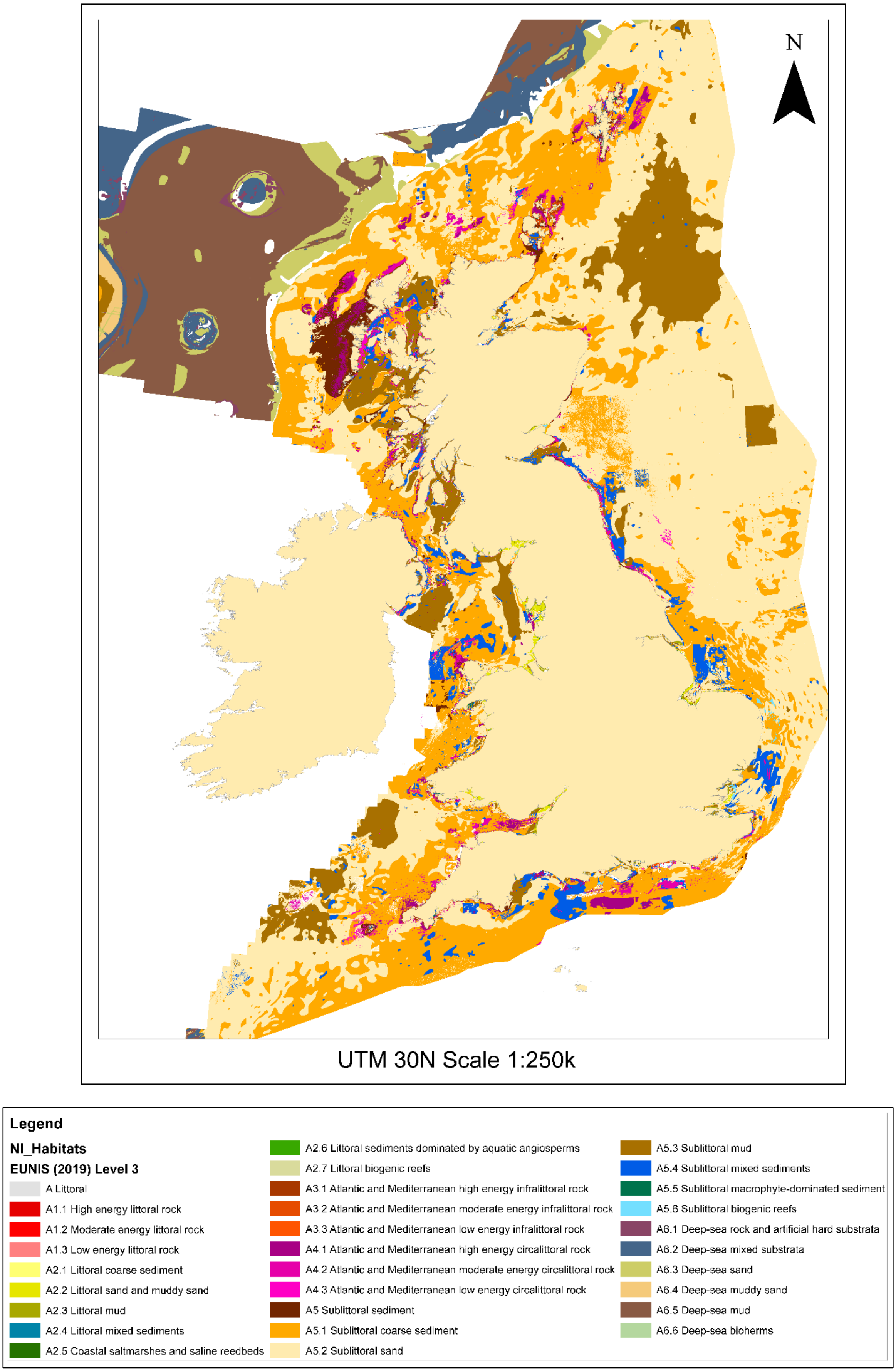


Figure 5: Map of EUNIS level 3 habitats within UK marine waters.

Table 3: Extent of level 1-3 EUNIS habitats within UK marine waters based on the Combined EUNIS map (JNCC, 2019).

EUNIS Level 2	EUNIS Level 3	Habitat	UK Total Area (Ha)
A1	A1.1	High energy littoral rock	4,855
	A1.2	Moderate energy littoral rock	6,839
	A1.3	Low energy littoral rock	10,562
A2	A2.1	Littoral coarse sediment	7,342
	A2.2	Littoral sand and muddy sand	163,788
	A2.3	Littoral mud	83,073
	A2.4	Littoral mixed sediments	10,872
	A2.5	Coastal saltmarshes and saline reedbeds	18,089
	A2.6	Littoral sediments dominated by aquatic angiosperms	2,013
	A2.7	Littoral biogenic reefs	4,513
A3	A3.1	Atlantic and Mediterranean high energy infralittoral rock	162,651
	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	101,399
	A3.3	Atlantic and Mediterranean low energy infralittoral rock	49,086
A4	A4.1	Atlantic and Mediterranean high energy circalittoral rock	678,527
	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	662,105
	A4.3	Atlantic and Mediterranean low energy circalittoral rock	158,603
A5	A5.1	Sublittoral coarse sediment	16,004,206
	A5.2	Sublittoral sand	26,428,988
	A5.3	Sublittoral mud	6,534,080
	A5.4	Sublittoral mixed sediments	1,977,113
	A5.5	Sublittoral macrophyte-dominated sediment	19,196
	A5.6	Sublittoral biogenic reefs	51,092
A6	A6.1	Deep-sea rock and artificial hard substrata	681,772
	A6.2	Deep-sea mixed substrata	5,322,777
	A6.3	Deep-sea sand	6,463,493
	A6.4	Deep-sea muddy sand	3,569,707
	A6.5	Deep-sea mud	20,078,301
	A6.6	Deep-sea bioherms	2,271
		UK Total Area (Ha)	**89,257,310**

3.1.2 Northern Ireland Marine Habitat Mapping

The UK marine habitat map (Figure 5) was clipped to extract the marine habitats present within Northern Ireland marine waters – the marine waters were defined by the 'adjacent waters limit' polyline provided by the United Kingdom Hydrographic Office[7]. The polyline was 'closed' and converted into a polygon by adding vertices across land (connecting Carlingford and Lough Foyle) – this configuration meant that high shore habitats were not clipped out of the analysis by closing the polygon with a low or high water polyline. This resulted in a map of Northern Ireland marine habitats from which the extent of each habitat can be extracted (Figure 6). The extent (in hectares) of each Northern Ireland marine habitat, compared with the UK data, are presented in Table 4. A confidence map was also produced to accompany the bespoke combined map produced for this project. The confidence values were extracted directly for the combined EUNIS map (JNCC, 2019). For the littoral habitats, a medium confidence was attached to areas supported with polygons from the EMODnet seabed substrates multiscale map (EMODnet Geology). All other predicted EUNIS level 3 littoral habitats have been given a low confidence as they mostly remain unvalidated. The resulting confidence map is also shown in Figure 6.

[7] Available here: https://datahub.admiralty.co.uk/portal/

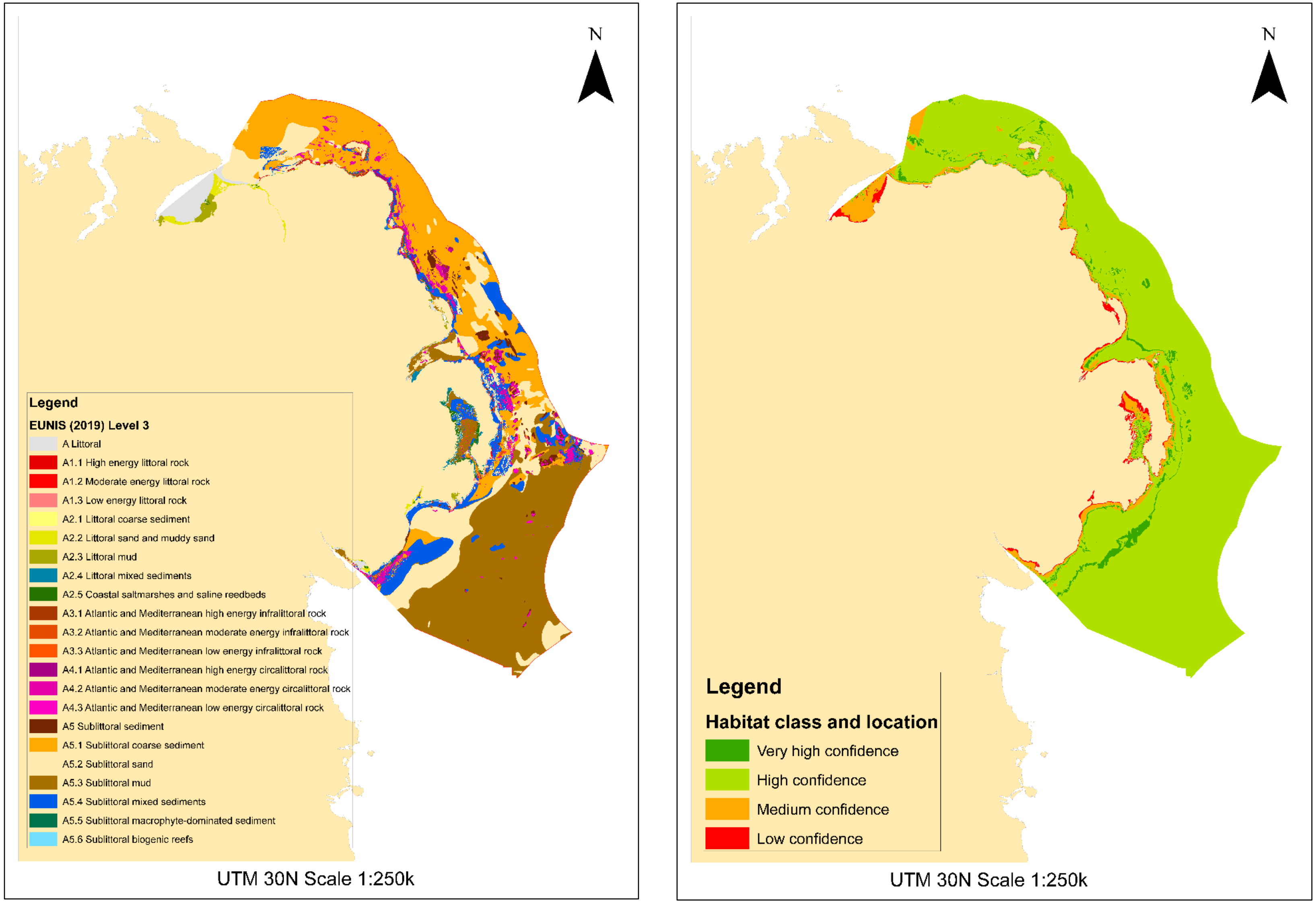


Figure 6: Map of EUNIS habitats within Northern Ireland marine waters (left) and the confidence layer associated with the bespoke habitat map (right).

Table 4: Extent of natural capital assets (EUNIS level 3 habitats) within UK and Northern Ireland marine waters.

EUNIS Level 2	EUNIS Level 3	Habitat	UK Total Area (Ha)	NI Total Area (Ha)
A1	A1.1	High energy littoral rock	4,855	346
	A1.2	Moderate energy littoral rock	6,839	642
	A1.3	Low energy littoral rock	10,562	1,011
A2	A2.1	Littoral coarse sediment	7,342	56
	A2.2	Littoral sand and muddy sand	163,788	5,497
	A2.3	Littoral mud	83,073	4,676
	A2.4	Littoral mixed sediments	10,872	3,589
	A2.5	Coastal saltmarshes and saline reedbeds	18,089	3,108
	A2.6	Littoral sediments dominated by aquatic angiosperms	2,013	0
	A2.7	Littoral biogenic reefs	4,513	0
A3	A3.1	Atlantic and Mediterranean high energy infralittoral rock	162,651	1,009
	A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	101,399	2,712
	A3.3	Atlantic and Mediterranean low energy infralittoral rock	49,086	1,025
A4	A4.1	Atlantic and Mediterranean high energy circalittoral rock	678,527	3,312
	A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	662,105	19,633
	A4.3	Atlantic and Mediterranean low energy circalittoral rock	158,603	5,277
A5	A5.1	Sublittoral coarse sediment	16,004,206	199,947
	A5.2	Sublittoral sand	26,428,988	127,268
	A5.3	Sublittoral mud	6,534,080	237,833
	A5.4	Sublittoral mixed sediments	1,977,113	62,076
	A5.5	Sublittoral macrophyte-dominated sediment	19,196	1,284
	A5.6	Sublittoral biogenic reefs	51,092	75
A6	A6.1	Deep-sea rock and artificial hard substrata	681,772	0
	A6.2	Deep-sea mixed substrata	5,322,777	0
	A6.3	Deep-sea sand	6,463,493	0
	A6.4	Deep-sea muddy sand	3,569,707	0
	A6.5	Deep-sea mud	20,078,301	0
	A6.6	Deep-sea bioherms	2,271	0
		Total Area (Ha)	**89,257,310**	**680,376**

3.1.3 Northern Ireland MPA Network Habitat Mapping

The polygon for the most up-to-date distribution of the protected marine areas within Northern Ireland was sourced from the Open Data Northern Ireland website[8]. Many of the marine designations relating to different legislation spatially overlap in Northern Ireland (e.g., Strangford Lough has overlapping designations as a Special Protection Area, Special Areas of Conservation, Marine reserves of Northern Ireland and as a Ramsar site). To avoid double counting for these individual designations, the entire protected area was merged within ArcMap (and internal boundaries 'dissolved').

[8] https://www.opendatani.gov.uk/

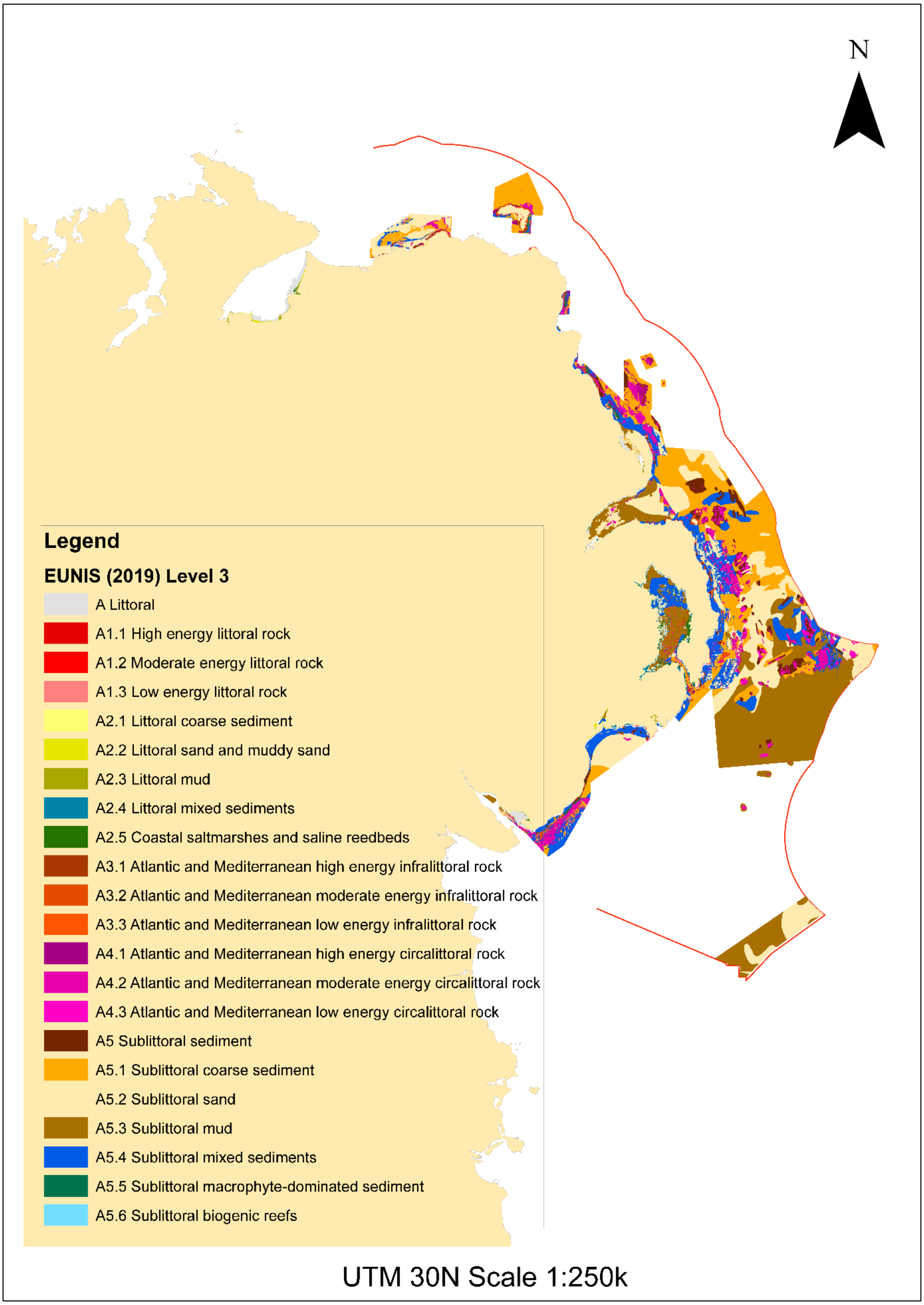


Figure 7: Extent of habitats within the existing Northern Ireland MPA network.

Table 5: Extent of EUNIS level 3 habitats within the UK, Northern Irish adjacent waters and merged Northern Ireland MPA network.

EUNIS Level 3	Habitats	UK Total Area (Ha)	NI Total Area (Ha)	NI MPA Area (Ha)
A1.1	High energy littoral rock	4,855	346	90
A1.2	Moderate energy littoral rock	6,839	642	330
A1.3	Low energy littoral rock	10,562	1,011	402
A2.1	Littoral coarse sediment	7,342	56	17
A2.2	Littoral sand and muddy sand	163,788	5,497	539
A2.3	Littoral mud	83,073	4,676	470
A2.4	Littoral mixed sediments	10,872	3,589	1,326
A2.5	Coastal saltmarshes and saline reedbeds	18,089	3,108	1,005
A2.6	Littoral sediments dominated by aquatic angiosperms	2,013	0	0
A2.7	Littoral biogenic reefs	4,513	0	0
A3.1	Atlantic and Mediterranean high energy infralittoral rock	162,651	1,009	740
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	101,399	2,712	1,971
A3.3	Atlantic and Mediterranean low energy infralittoral rock	49,086	1,025	898
A4.1	Atlantic and Mediterranean high energy circalittoral rock	678,527	3,312	2,002
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	662,105	19,633	14,930
A4.3	Atlantic and Mediterranean low energy circalittoral rock	158,603	5,277	4,231
A5.1	Sublittoral coarse sediment	16,004,206	199,947	65,064
A5.2	Sublittoral sand	26,428,988	127,268	62,631
A5.3	Sublittoral mud	6,534,080	237,833	81,463
A5.4	Sublittoral mixed sediments	1,977,113	62,076	37,535
A5.5	Sublittoral macrophyte-dominated sediment	19,196	1,284	909
A5.6	Sublittoral biogenic reefs	51,092	75	75
A6.1	Deep-sea rock and artificial hard substrata	681,772	0	0
A6.2	Deep-sea mixed substrata	5,322,777	0	0
A6.3	Deep-sea sand	6,463,493	0	0
A6.4	Deep-sea muddy sand	3,569,707	0	0
A6.5	Deep-sea mud	20,078,301	0	0
A6.6	Deep-sea bioherms	2,271	0	0
	Total Area (Ha)	**89,257,310**	**680,376**	**276,630**

3.2 Valuation of Societal Benefits

The UK marine environment provides a broad range of ecosystem services which can deliver benefits for society. For the purpose of the NI-MANACA project, the UKNEAFO ecosystem services framework (see Figure 2) is adopted here for the following reasons:

- the framework has been specifically designed for the UK marine environment and does not require further refinement (UKNEAFO, 2014);
- the framework differentiates between natural processes (natural capital and ecosystem services) and societal benefits and, therefore, avoids the potential for double counting in valuation (Turner et al., 2015);
- the framework was recently used to frame the first marine natural capital accounts for the UK (ONS, 2021a); and
- the framework links directly with the matrix approach (Potts et al., 2014) which assesses the importance of natural capital (habitats and species) in providing a range of ecosystem services and potential for societal benefits.

The UKNEAFO ecosystem services framework identifies 14 categories of benefits from the UK marine environment, resulting from provisioning, regulating and cultural ecosystem services (Turner et al., 2015). A description of each of the societal benefits is given in Table 6.

Table 6: Definitions of benefits from the UK marine environment (after Turner et al., 2015).

Societal Benefits	Definition	Example
Food (wild, farmed)	Extraction of marine biota for human consumption.	Tonnes of cod landed for human consumption
Fish feed (wild, farmed, bait)	Extraction of marine biota for non-human consumption.	Tonnes of sandeel harvested to be processed into fishmeal; volume of mackerel caught for use as bait in crab/lobster pots
Fertiliser and biofuels	Fertiliser (biocides) or energy sourced from marine biota.	Biomass of algae harvested to be processed into fertiliser
Ornaments and aquaria	Extraction of marine biota for decoration, fashion, handicraft, souvenirs etc or for display in aquaria.	Number of European lobster extracted for display in aquarium exhibits; amount of skins, shells, corals, plants, extracted from the marine environment for decoration, fashion etc
Medicines and blue biotechnology	Extraction of marine biota in order to produce medicines, pharmaceuticals, animal and plant breeding and biotechnology.	Marine-derived pharmaceuticals such as the use of sea lettuce (*Ulva lactuca*) in cosmetic and personal care items including make-up remover, shampoo and shaving lotion
Healthy climate	Improvements to human well-being as a result of a healthy climate.	Bodily harm avoided as a result of natural carbon sequestration by marine biota
Prevention of coastal erosion	Reduction in hazards resulting from the natural prevention of coastal erosion by marine biota.	Prevention of gradual damage to property and land by dunes
Sea defence	Reduction in flooding related hazards as a result of the natural protection provided by marine biota.	Saltmarsh providing a natural form of sea defence in the coastal region
Waste burial / removal / neutralisation	Contribution of marine biota to achieving pre-defined policy standard related to waste levels in water by natural waste burial, removal and neutralisation.	Natural waste breakdown by marine biota such as reedbeds – in contexts in which pre-defined regulations / standards apply

Societal Benefits	Definition	Example
Tourism and nature watching	Benefits from recreation, leisure driven by coastal seascapes and their associated marine biota.	Human welfare benefits associated with watching seabirds, marine mammals.
Spiritual and cultural well-being	Ability to enjoy preferred lifestyle, culture, heritage, folklore, religion, creative inspiration, and spirituality; sense of place (use-driven) based on ecosystem aspects.	The importance of marine environments in cultural traditions (e.g., traditional cobble fisheries on east coast) or folklore (e.g., sea shanties).
Aesthetic benefits	Enjoyment of the beauty of marine seascapes.	Higher house prices in coastal locations.
Education, research	Enjoyment of formal and informal education, research and science, knowledge systems, etc. in which marine biota play a role and are a source of information.	Amount of funding secured for research on marine biota; number of scientific research papers published which focus on marine biota.
Human health benefits	Relate to human physical and psychological health benefits associated with the direct and indirect use of the coastal and marine environment.	Psychological health benefits includes the increased psychological well-being from direct or indirect experience of the marine environment, while physical generally relates to the marine environment providing opportunities for exercise and increase physical well-being.

3.2.1 Valuation of the Societal Benefits Provided by UK Marine Waters

There is currently a paucity of valuation data for the broad range of societal benefits associated with the UK marine environment. Much of the valuation data available within the literature relates to a limited number of societal benefits, largely those which have widely recognised unit prices e.g., food provision (e.g., MMO, 2019; 2020), tourism and nature watching (e.g., Luisetti et al., 2014), and carbon sequestration resulting in a healthy climate (e.g., Luisetti et al., 2015; Watson et al., 2020). Such valuation data are often obtained at the local level through case studies with few such studies collecting time series data (which is valuable for identifying changes in benefit delivery over time) or collecting data at the scale of the UK or devolved administrations. The ensuing data gaps make valuing the marine environment challenging.

In the absence of primary data collection to support this study, valuation data were taken from published and grey literature sources. The limited availability of valuation evidence at the Northern Ireland scale is a serious constraint when considering the benefits that society and the economy obtain from the Northern Ireland's marine environment. However, the existing UK valuation literature offers the opportunity to estimate the value of Northern Ireland's marine environment by employing benefit transfer methods.

Valuation data were largely taken from the recently published marine Natural Capital Accounts (ONS, 2021a). These accounts provide UK level valuation data for a number of societal benefits. These accounts recognise that valuation of marine natural capital is still in its infancy and, therefore, the data generated for the marine natural capital accounts are considered experimental. Regarding the societal benefits of interest here, valuation of service flows were applied by the ONS by estimating physical quantity provided of each service multiplied by its price; either a market price or a price generated by a hypothetical market (ONS, 2021b). In addition, supplementary data were also examined from other recently published UK studies (e.g., Papathanasopoulou et al. 2016; Thornton et al., 2019; Stebbings et al., 2020).

A summary of the valuation data obtained from the literature is presented in its original form in Table 7. There is an inevitable time lag associated with valuation data, reflecting the time required to collect, analyse and disseminate it. All values were converted into 2019 prices which was the base-year used by the most recently published UK marine natural capital accounts (ONS, 2021a) available at the time when the NI-MANACA analysis was undertaken. Valuation data were obtained for eight of the 14 societal benefits. A full description of each societal benefit, and the source of its data, is provided in Table 7. Additional data sources are reported in Annex 3.

Table 7: Summary of the UK valuation data obtained from the literature.

Societal Benefits (SB)		Valuation (£m)	Comments	Reference(s)
SB1	Food (wild, farmed)	£284	Total net profit in 2018 (£m in 2019 prices)	**ONS (2021a):** The value of fish capture is calculated using net profit per tonne (landed) estimates, provided by Seafish, for different marine species. Net profit per tonne is calculated using economic estimates for fleet segments and Marine Management Organisation data on landings by stocks. Accounts for 85% of the fish capture tonnage - therefore likely to be an underestimate.
SB2	Fish feed (wild, farmed, bait)	No UK valuation data were available from the literature		
SB3	Fertiliser and biofuels	No UK valuation data were available from the literature		
SB4	Ornaments and aquaria	No UK valuation data were available from the literature		
SB5	Medicines and blue biotechnology	No UK valuation data were available from the literature		
SB6	Healthy climate	10.5-60.1 million tonnes CO2e sequestered £742-£4,259	A2.5 + A5.2 + A5.3 (in 2019 prices £m)	**ONS (2021a):** There is a wide spectrum of carbon sequestration rates across the three habitat types identified. We therefore provide a range of values. In 2018, we estimate a range that between 10.5 and 60.1 million tonnes of carbon dioxide equivalent were sequestrated in UK waters by these three habitats, with an estimated value of between £742 million and £4,259 million (in 2019 prices). This compares with gross carbon sequestration from terrestrial habitats of 28 million tonnes per year. Lower bounded estimates are likely to underestimate the full value of carbon sequestration services, as not all carbon sequestrating plants, organisms and habitat types are captured in this measurement. The extent estimation for UK saltmarsh is conservative when compared to other values referenced in the literature.
SB7	Prevention of coastal erosion	No UK valuation data were available from the literature		
SB8	Sea defence	£4.5 £131 £13.5 £393.5	Service value (1-in-60 year flood) Asset value (1-in-60 year flood) Service value (1-in-100 year flood) Asset value (1-in-100 year flood)	**ONS (2021a):** Our experimental approach uses geographic mapping to estimate the economic value of land in the UK protected in this way. We look at five land types: urban, suburban, neutral grassland, improved grassland, and arable and horticulture land. We aim to include other types of land and infrastructure protected by saltmarsh in future analysis.
SB9	Waste burial / removal / neutralisation	£640 £683	2016 (£ 2019 prices) 2018 (£ 2019 prices)	**ONS (2021a):** It should be noted that our estimate of the total human input of pollutants into the UK coastline is likely a significant underestimate.

Societal Benefits (SB)		Valuation (£m)	Comments	Reference(s)
SB10	Tourism and nature watching	£1,726	2018 (£m in 2019 prices)	**ONS (2021a):** In 2018, visitors' expenditure during trips to coastal margins was £1,726 million, made up of running costs (private transport cost), car parking costs, public transport costs, equipment hire, maps and guides, and admission fees.
SB11	Spiritual and cultural well-being	No UK valuation data were available from the literature		
SB12	Aesthetic benefits	£3,395 £101	2016 Total (asset) value (£m in 2019 prices) 2016 Annual service value (£m in 2019 prices)	**ONS (2021a):** In the UK, between 2009 and 2016, a sea view added an average of £8,100 (in 2019 prices) to house prices. In 2016, there were 28.49 million residential properties in the UK, with 0.49 million assumed to have a sea view. To estimate the total stock (asset) value we multiply this by the average annual effect of having a sea view (£6,885) to get £3,395 million. To estimate annual service values, we calculate a rental value of having a sea view. This is calculated using the ONS imputed annual rental estimates multiplied by the 1.73% of properties with a sea view, in turn multiplied by the annual percentage increase in property prices caused by having a sea view. Therefore, the annual value of having a view of the sea was £101 million in 2016.
SB13	Education, research	£2,272	Output (£m in 2014)	**Stebbings et al. (2020):** Marine research
		£233	Output (£m in 2014)	**Stebbings et al. (2020):** Marine consultancy
		£22	Output (£m in 2014)	**Stebbings et al. (2020):** Marine education
SB14	Human health benefits	£176,721,512 (low) £593,106,445 (mean) £745,619,531 (high)	2012 prices for England only	**Papathanasopoulou et al. (2016):** The research develops an approach which can estimate the contribution aquatic physical activities makes to quality adjusted life years (QALYs) in monetary and non-monetary terms. Using data from the Health Survey for England, the research estimates that physical activities undertaken in aquatic environments at a national level provides a total gain of 24,853 QALYs. A conservative estimate of the monetary value of a QALY gain of this magnitude is £176 million.

SB1. Food (wild, farmed)

In order to value the ecosystem service flows from fish capture, relating to the societal benefit 'food', the ONS multiplied the total live weight caught by net profit per landed-weight tonne, thereby netting out costs from the estimate of value. Physical data on marine fish live weight capture is sourced from the rectangle-level landings data published annually by the EU Commission's Joint Research Centre (JRC) Scientific, Technical and Economic Committee for Fisheries (STECF) as part of the Fisheries Dependent Information (FDI) data call (deep sea). Valuations are calculated using net profit per tonne (landed) estimates, provided by Seafish, for different marine species by marine areas. Net profit per tonne is calculated using Seafish economic estimates for fleet segments and Marine Management Organisation data on landings by stocks (landed value and landed weight) and landings by stocks and species (in cases where species are not managed by total allowable catches). Annual net profit per tonne (landed weight) is multiplied by tonnes of fish captured (live weight) for a specific species. The data are aggregated for overall annual valuations of fish provisioning from the UK EEZ (Table 8). Note that landed weight is the weight of a product at the time of landing, regardless of the state in which it has been landed. Landed fish may be whole, gutted and headed or filleted. Live weight is the weight of a product, when removed from the water.

A number of limitations for this method were recognised (ONS, 2021a):

- Marine Management Organisation data on live and landed weights of UK vessel landings into the UK indicate that aggregate landed weight is around 7% less than live weight, so combining landed weight net profits with live weight fish capture will likely overvalue the benefit.
- Net profit per tonne was not available for all fish species so not all the physical flow is valued. Based on available net profit per tonne annual data, 85% of fish provisioning (live tonnes) was valued in 2018.
- Aquaculture (farmed fish and shellfish) were removed from estimates as farmed fish are considered by the ONS as a produced asset rather than as a natural asset.

Table 8: Physical flows and annual values of UK commercial fish landings (ONS, 2021a).

	Unit	**2015**	**2016**	**2017**	**2018**	**2019**
Physical flow (1)						
Scotland	Thousand tonnes	848.0	953.9	1,009.5	1,020.6	818.1
England	Thousand tonnes	363.5	226.4	432.0	332.9	282.7
Wales	Thousand tonnes	29.2	32.5	25.0	17.1	18.1
Northern Ireland	Thousand tonnes	9.8	9.4	10.6	12.3	11.6
Total UK	**Thousand tonnes**	**1,250.5**	**1,222.2**	**1,477.2**	**1,382.9**	**1,130.5**
Percentage of tonnage valued (%)		84	92	80	86	
Annual value (2)	£ million, 2019 prices	171	341	366	284	

(1) Live weight
(2) Live weight multiplied by net profit per tonne landed weight
Sourced from Office for National Statistics, Marine Management Organisation, Seafish, Scientific, Technical and Economic Committee for Fisheries.

SB2. Fish feed (wild, farmed, bait)

No UK valuation data were available from the literature for this societal benefit.

SB3. Fertiliser and biofuels

No UK valuation data were available from the literature for this societal benefit.

SB4. Ornaments and aquaria

No UK valuation data were available from the literature for this societal benefit.

SB5. Medicines and blue biotechnology

No UK valuation data were available from the literature for this societal benefit.

SB6. Healthy climate

Living marine organisms (e.g., saltmarsh plants) as well as marine habitats (e.g., subtidal muds and sands) have the ability to sequester carbon and thereby reduce the flows of carbon, a greenhouse gas, to the atmosphere leading to a healthier climate. Valuation of this benefit requires the extent of key marine habitats (in hectares), the carbon sequestration rates of these habitats (in CO_2e) and a unit monetary value for sequestered carbon (in £).

Three important EUNIS habitats for carbon sequestration were identified (Thornton et al., 2019; ONS, 2021a): A2.5 Saltmarsh and reedbeds; A5.2 Sublittoral mud; and A5.3 Sublittoral sand and the extent of these habitats is then valued to give an estimate of this benefit. The extent of these habitats are provided in Table 5 for both the UK and Northern.

There are a wide range of carbon sequestration rates available in the literature and therefore following the approach of Thornton et al. (2019) and the ONS (2021a), low and high estimates of carbon sequestration (in tC/Ha/yr) were used (Table 7; de Haas et al. 1997; Oliver Legge, pers. comm. in Thornton et al., 2019; Luisetti et al., 2019). These low and high carbon sequestration rates were converted into carbon dioxide equivalents (tCO2e) assuming one tonne of carbon is equal to 44/12 tonnes of carbon dioxide[9]. The carbon price used is based on the projected non-traded price of carbon (£/tCO2e) as reported in Data Table 3 in the Green Book (HM Treasury, 2022), which is available for the period 2010 to 2100. Estimates for the annual value of the healthy climate benefit for the UK and Northern Ireland, are broken down by habitat, and are presented below (Table 9). Currently, for carbon sequestration the BEACH tool incorporates just the UK valuation data, though the potential for inclusion of Northern Ireland specific data is discussed in Section 4.

[9] Carbon has an atomic mass of 12 and oxygen has an atomic mass of 16. Therefore CO_2 has an atomic mass of 44 which means that one tonne of carbon will produce = 3.67 tonnes of CO_2 (i.e. 44/12).

Table 7: Annual value of carbon sequestration by key UK (blue table) and Northern Ireland (green table) marine habitats (ONS, 2021a).

UK											
Habitat	**UK area**		**Low C Sequestration rate**		**C to CO2e Conversion**		**CO2 Equivalents**		**Non-Traded Price**		**Value[1]**
	Hectares	x	tC/ha/yr	x	(44/12)	=	tCO2e/yr	x	2019 £/tCO2e	=	2019 £
Saltmarsh (EUNIS A2.5)	18,089		0.86		3.67		57,040		£68.25		£3,893,231.28
Sublittoral Sands (EUNIS A5.2)	26,428,988		0.08		3.67		7,752,503		£68.25		£529,145,810.05
Sublittoral Muds (EUNIS A5.3)	6,534,080		0.12		3.67		2,874,995		£68.25		£196,232,314.70
Total	**32,981,156**						**10,684,538**				**£729,271,356.03**
Habitat	**UK area**		**High C Sequestration rate**		**C to CO2e Conversion**		**CO2 Equivalents**		**Non-Traded Price**		**Value[2]**
	Hectares	x	tC/ha/yr	x	(44/12)	=	tCO2e/yr	x	2019 £/tCO2e	=	2019 £
Saltmarsh (EUNIS A2.5)	18,089		2.10		3.67		139,283		£68.25		£9,506,727.55
Sublittoral Sands (EUNIS A5.2)	26,428,988		0.51		3.67		49,422,207		£68.25		£3,373,304,539.04
Sublittoral Muds (EUNIS A5.3)	6,534,080		0.51		3.67		12,218,729		£68.25		£833,987,337.47
Total	**32,981,156**						**61,780,219**				**£4,216,798,604.05**

Northern Ireland											
Habitat	**NI area**		**Low C Sequestration rate**		**C to CO2e Conversion**		**CO2 Equivalents**		**Non-Traded Price**		**Value[1]**
	(Hectares)	x	(tC/ha/yr)	x	(44/12)	=	(tCO2e)	x	(2019 £/tCO2e)	=	(2019 £)
Saltmarsh (EUNIS A2.5)	3,108		0.86		3.67		9,801		£68.25		£668,977.34
Sublittoral Sands (EUNIS A5.2)	127,268		0.08		3.67		37,332		£68.25		£2,548,085.24
Sublittoral Muds (EUNIS A5.3)	237,833		0.12		3.67		104,647		£68.25		£7,142,638.46
Total	**368,209**						**151,780**				**£10,359,701.05**
Habitat	**NI area**		**High C Sequestration rate**		**C to CO2e Conversion**		**CO2 Equivalents**		**Non-Traded Price**		**Value[1]**
	(Hectares)	x	(tC/ha/yr)	x	(44/12)	=	(tCO2e)	x	(2019 £/tCO2e)	=	(2019 £)
Saltmarsh (EUNIS A2.5)	3,108		2.10		3.67		23,933		£68.25		£1,633,549.33
Sublittoral Sands (EUNIS A5.2)	127,268		0.51		3.67		237,991		£68.25		£16,244,043.41
Sublittoral Muds (EUNIS A5.3)	237,833		0.51		3.67		444,748		£68.25		£30,356,213.48
Total	**368,209**						**706,672**				**£48,233,806.21**

[1] Sourced from Office for National Statistics.

SB7. Prevention of coastal erosion

No UK valuation data were available from the literature for this societal benefit.

SB8. Sea defence

ONS (2021a,b) uses a geographic mapping approach to estimate the economic value of land in the UK protected by saltmarsh habitats. Initial focus was on five land types: urban, suburban, neutral grassland, improved grassland, and arable and horticulture land. ONS report that it is hoped that other types of land and infrastructure protected by saltmarsh will be included in future analysis.

The total hectares of land that might be affected by coastal flooding are presented in Table 10. These estimates account for topographical heights and remove areas in England and Wales where built structures are providing coastal flood protection. Built flood defence structures in Scotland and Northern Ireland are not yet excluded, so the figures reported in Table 10 are likely to overestimate the total UK saltmarsh-protected land hectarage. This approach finds 23,885 properties in UK suburban areas and 16,671 properties in UK urban areas that receive flood protection from saltmarshes.

The economic value of flood damage to agricultural land was estimated by assessing the cost of raw inputs to a field of crop or livestock and the potential loss of profit (ONS, 2021a). This method assumes that flooded agricultural land becomes unproductive for one year and recognises that livestock is mobile such that valuations for improved and neutral grassland may be overestimates. However, as land may suffer longer-term damage through saltwater inundation, this approach may underestimate the value of this societal benefit. These economic values do not capture the wider impacts of flooding, such as on mental health and ability to work.

The ONS (2021a) report provides illustrative valuations assuming a 1-in-50-year flood risk across all sites and limiting their estimate to land behind saltmarsh, which lacks topographic protection and excluding sites in England and Wales only that have built coastal flood defences. Moving to a 1-in-60-year risk across all sites provides an estimated service value of around £4.5 million (2019 prices). This can be thought of as the willing to pay to replace the sea defence services that saltmarshes provide. Moving to a 1-in-100-year risk the service value rises to approximately £13.6 million (2019 prices).

Table 10: Physical flows and annual values of sea defence benefits provided by UK saltmarsh habitats (ONS, 2021a).

	Unit	2015
Physical Flows[1]		
Area of land protected by UK saltmarshes:		
• Arable and Horticulture	Hectares	7,567
• Improved Grassland	Hectares	13,328
• Neutral Grassland	Hectares	1,001
• Suburban	Hectares	623
• Urban	Hectares	461
Total area of protected land	Hectares	22,979
Annual value[2]		
1-in-60 year flood	£ million, 2019 prices	4.5
1-in-100 year flood	£ million, 2019 prices	13.6

[1] Sourced from Ministry of Housing, Communities and Local Government, UK Centre for Hydrology and Ecology, Environment Agency, Natural Resources Wales and Ordnance Survey;
[2] Sourced from Office for National Statistics.

SB9. Waste burial / removal / neutralisation

Waste remediation (breakdown, detoxification and burial/removal/neutralisation) is an important service for the health of the marine environment and the provision of many ecosystem services (Thornton et al., 2019). There are an increasing number of studies which provide evidence of the value of UK estuarine and coastal habitats in providing this service (Watson et al., 2016; 2020).

The analysis undertaken by the ONS (2021) focussed on the flows of Nitrogen and Phosphorus that are discharged into coastal and estuarine water bodies from urban wastewater treatment plants. By observing the physical flows of Nitrogen and Phosphorous into coastal and estuarine waters, the ONS estimated the cost of removing these nutrients based on the estimated replacement costs for this marine nutrient remediation service; namely, the capital and operating costs of a wastewater treatment plant.

In 2016, the annual value of this regulating service in the UK was £640 million, and this increased to £683 million in 2019, assuming that the per kilogram unit cost of removing either Nitrogen or Phosphorous remains constant over time (Table 11). Hence, the increase in the reported annual value is due to increased flows of wastewater and the quantity of nutrients flowing from them (ONS, 2021a).

Table 11: Annual flows of Phosphorus and Nitrogen (2016 and 2018) and the annual value of the water remediation service provided by UK marine waters (2016-2019) (ONS, 2021a).

	Unit	2016	2017	2018	2019
Physical annual flows[1]					
Phosphorous (P)	Tonnes (daily)	56		60	
Nitrogen (N)	Tonnes (daily)	193		206	
Total P and N	Tonnes (daily)	249		266	
Annual value[2]	**£ million, 2019 prices**	640	644	680	683

[1] Sourced from Office for National Statistics and European Environment Agency
[2] Sourced from Office for National Statistics.

SB10. Tourism and nature watching

There is a growing body of literature which collates recreational visits to different environments within the UK. National level surveys are conducted in England (Monitor of Engagement with the Natural Environment Survey, 2009-2019), Scotland (Scottish Recreation Survey, 2003 -2012; Scotland's People and Nature Survey, 2013-2014, 2017-2018) and Wales (National Survey for Wales) to obtain such data (see Annex 3). The questions used from these surveys can be broadly summarised as:

- How many visits to the outdoors for leisure and recreation have you made in the last four weeks?
- On the last visit to the outdoors, what type of habitat did you go to?
- What was the main means of transport used on this last visit?
- How far did you travel to get to and from the main destination of this visit?
- How long was the visit, in terms of time (including travel time)?
- How much did you spend on [*spending category*]?

Combined Great Britain outputs are scaled to the UK level using population estimates for people aged 16 years and over. A detailed methodology is provided in ONS (2020b, pp.12-13).

The total number of recreational visits in the UK has increased from 3,139 million in 2010 to 5,119 million in 2018, with the number of visits to coastal margins peaking in 2017 at 467 million visits (Figure 8). Latest available data show that in 2018, 423 million trips were made to coastal margin, around 8% of all visits to nature in that year (ONS, 2021a).

Combined Great Britain outputs are scaled to the UK level using population estimates for people aged 16 years and over. A detailed methodology is provided in ONS (2020b, pp.12-13).

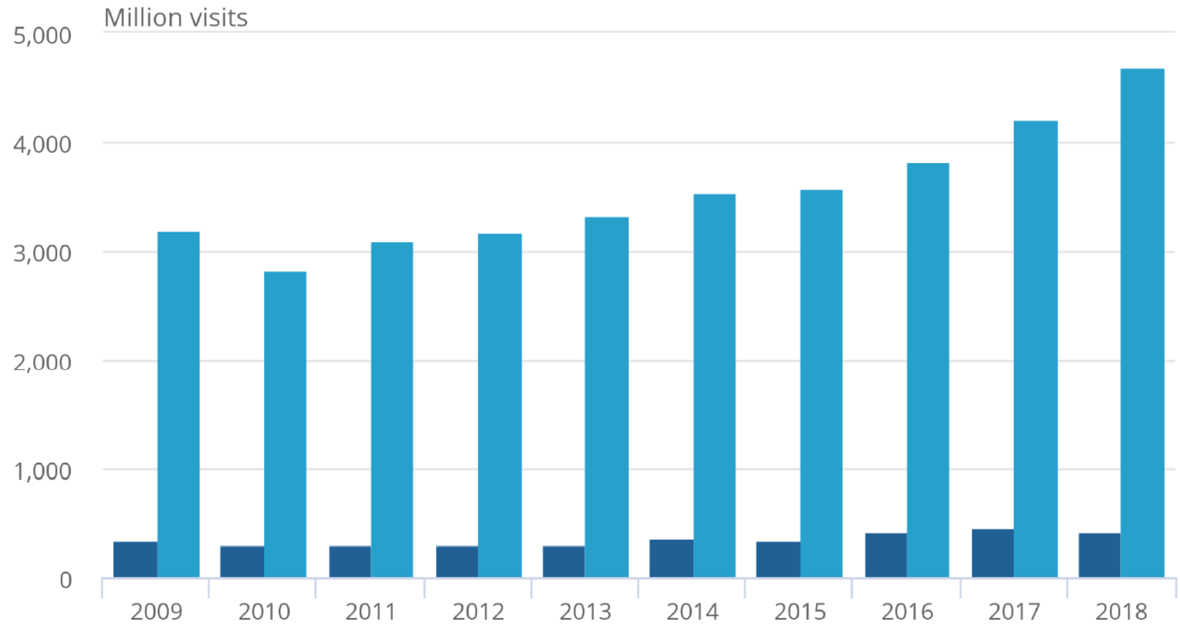


Figure 8: Visits to coastal (dark blue) and non-coastal (light blue) areas in the UK, millions, 2009-2018 (ONS, 2021a). Sourced from NatureScot, Natural England and Natural Resources Wales.

In 2018, visitors' expenditure during trips to coastal margins was £1,726 million (2019 prices), made up of private transport cost, car parking costs, public transport costs, equipment hire, maps and guides, and admission fees.

Table 12: Time spent at the coast, number of visits and annual value between 2009 and 2018 (ONS, 2021a).

	Unit	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Physical											
Coastal margins	Time spent (gross) million hours	1,016.9	957.6	923.2	966.2	934.2	1,032.0	1,017.9	1,179.7	1,394.1	1,020.3
Coastal margins	Number of visits (million)	339.7	312.1	303.6	315.1	310.2	365.5	353.7	419.4	466.6	423.1
Annual value	£ million, 2019 prices	£1,919	£1,171	£1,798	£1,693	£1,424	£1,602	£1,593	£1,606	£1,292	£1,726

Sourced from NatureScot, Natural England, Natural Resources Wales, Office for National Statistics.

SB11. Spiritual and cultural well-being

No UK valuation data were available from the literature for this societal benefit.

SB12. Aesthetic benefits

In order to estimate the aesthetic benefits associated with the UK marine environment, the ONS (2021a) analysed variables that affect house prices, including the presence of a sea view (including estuaries and channels) using a hedonic pricing approach. Other environmental variables that may affect house prices such as air pollution and noise pollution are also included. House prices were analysed between 2009 and 2016 from the property website Zoopla (with permission). Over this time period, an average of 1.73% of properties sold had a sea view. ONS applied this sample proportion to the number of UK residential properties each year to estimate the total number of UK residential properties with a sea view. In 2016, there were 28.49 million residential properties in the UK, with 0.49 million assumed to have a sea view (Table 13). To estimate annual service values, ONS (2021a) calculated a rental value of having a sea view using the ONS imputed annual rental estimates multiplied by the 1.73% proportion of properties with a sea view, in turn multiplied by the annual percentage increase in property prices caused by having a sea view. Therefore, the annual value of having a sea view in 2016 was £101 million.

Table 13: Amenity value of sea views (ONS, 2021a).

	Unit	2009	2010	2011	2012	2013	2014	2015	2016
Annual value[1]	£ million, 2019 prices	108.8	93.3	94.6	97.0	99.2	84.5	101.4	101.1
Properties in sample	Number	4,101	26,759	44,523	69,821	84,069	108,006	87,131	57,170
Properties in sample with a sea view	Number	55	451	735	1,190	1,518	2,026	1,441	920
Average property price	£, 2019 prices	£297,300	£322,803	£311,841	£308,240	£306,294	£296,054	£264,994	£260,033
Average sea view value	£, 2019 prices	£9,365	£8,763	£8,662	£8,622	£8,631	£6,986	£7,258	£6,885
Average sea view value	%	3.15	2.71	2.78	2.8	2.8	2.36	2.74	2.65

[1]Sourced from Office for National Statistics.

SB13. Education, research

The value of education and research as a societal benefit was not included in the ONS (2021a) study and, for the purposes of the NI-MANACA project, data have been taken from the published work of Stebbings et al. (2020). Stebbings et al. (2020) estimated the value of economic activity in two ways: (1) the total output of a sector, which measures the total value of goods or services demanded from final and intermediate sectors in the economy; and (2) total Gross Value Added (GVA), which estimates the sum of output less intermediate consumption. The approaches use Input-Output (IO) analysis to estimate the size and structure of the marine economy, making extensive use of evidence from the grey literature to disaggregate marine and non-marine activities. For the purposes of the NI-MANACA study, it is the total value of the output which is of interest.

Stebbings et al. (2020) estimated the value (in 2014 prices) of marine education (including marine education and training) and marine research and development (including research in the ocean and environmental consulting) separately. These categories were combined to provide the total output for the category to be £2,527 million (in 2014 prices) and were converted into 2019 prices using the GDP deflator[10] (Table 14).

Table 14: Estimated value of marine education and research (Stebbings et al., 2020).

Value of output	£m 2014 prices	£m 2019 prices*
Marine research	£2,272	£2,487
Marine consultancy	£233	£255
Marine education	£22	£24
Total	**£2,527**	**£2,766**

*Using a GDP deflator of 1.094435341.

SB14. Human health benefits

The importance to well-being of the human health benefits associated with exposure to the marine and coastal environment is a growing field of research. For example a recent evidence statement reviewed 46 peer-reviewed papers and concluded that exposure to marine and coastal environments has positive effects on human health and well-being (Shellock, 2019). The number of studies which have generated health benefit values at the UK scale is however limited and hence was not included within the marine natural capital accounts (ONS, 2021a).

In order to obtain an indicative value of health benefits at the UK scale, a study by Papathanasopoulou et al. (2016) was used. Their study presents a range of human health benefits (low, mean and high) for the English population which can be converted into 2019 prices and then used to calculate the equivalent value per adult (age 16+ years) (Table 15). Once these values were calculated, estimates of health benefits could be calculated for the UK and Northern Ireland based on populations estimates (16+ years) (Table 16). For the purposes of this project only the UK values were included within the BEACH tool.

[10] https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-june-2019-quarterly-national-accounts

Table 15: Conversion of human health benefit values from 2012 to 2019 prices and broken down into per person values (after Papathanasopoulou et al., 2016).

Human health benefits	(£m 2012 prices)	(£m 2019 prices)*	Value per adult (16+ years) in 2019**
Low	£176.7	£200.3	£4.59
Mean	£593.1	£672.1	£15.40
High	£745.6	£845.0	£19.36

* Using a GDP deflator of 1.13322678.

** Using a population of England (16+ years) of 43,640,200 as presented in Papathanasopoulou et al., 2016.

Table 16: Human health benefits provided by the UK and Northern Ireland marine environment (after Papathanasopoulou et al., 2016).

	2019 Population (All ages)	2019 Population (16+ years)	Low £m in 2019 prices	Mean £m in 2019 prices	High £m in 2019 prices
UK	66,796,807	54,098,971	£248.3	£833.2	£1,047.4
Northern Ireland	1,893,667	1,497,742	£6.9	£23.1	£29.0

Valuation of the UK Marine Environment

The final UK values for eight of the 14 societal benefits are reported below (Table 17) and it is these values which were included in the BEACH tool and used to drive the model for the future scenarios assessments (Section 3.3). It is worth noting that for some societal benefits only one value was estimated, whereas for other societal benefits the values are presented as a range of values (low, mid, high). Note, dashes in Table 17 denote valuation data not being available and do not denote a value of zero.

Table 17: Valuation of UK marine waters in 2019.

Code	Societal Benefits (SB)	Low (£m 2019 prices)	Mid (£m 2019 prices)	High (£m 2019 prices)
SB1	Food (wild, farmed)	£283.9	£283.9	£283.9
SB2	Fish feed (wild, farmed, bait)	-	-	-
SB3	Fertiliser and biofuels	-	-	-
SB4	Ornaments and aquaria	-	-	-
SB5	Medicines and blue biotechnology	-	-	-
SB6	Healthy climate	£736.8	£2,489.4	£4,242.0
SB7	Prevention of coastal erosion	-	-	-
SB8	Sea defence	£4.5	£9.0	£13.6
SB9	Waste burial / removal / neutralisation	£683.3	£683.3	£683.3
SB10	Tourism and nature watching	£1,725.7	£1,725.7	£1,725.7
SB11	Spiritual and cultural well-being	-	-	-
SB12	Aesthetic benefits	£101.1	£101.1	£101.1
SB13	Education, research	£2,765.6	£2,765.6	£2,765.6
SB14	Health benefits	£248.3	£833.2	£1,047.5
Total		**£6,549.3**	**£8,891.3**	**£10,862.7**

3.2.2 Disaggregating UK Values

The methodology used to split, or disaggregate, the total UK values of each of the 14 societal benefit types under consideration across the 28 EUNIS level 3 classes recorded in the UK is based on that presented by Moran et al. (2008) and is described below (Table 18). Moran et al. (2008) proposed four approaches for disaggregation, each based on the availability of information that might be used to define the relative importance of each habitat type to the provision of a given societal benefit.

Approach (A): This approach requires the most comprehensive set of information, and uses *a priori* judgements of the relative importance of each habitat type for the provision of a given benefit, together with information on the spatial extent (area) of each habitat present in the study area. Each habitat is weighted by the habitat's relative importance against other marine habitats, and the resultant weighting is used to apportion the total value of each benefit across the range of habitat types. This approach has been updated using the 'Matrix Approach' (Potts et al., 2014) to assess the relative importance of a given UK marine habitat in delivering a given ecosystem service or societal benefit compared to other habitats in delivering the same societal benefit. The relationship between each EUNIS level 3 habitat and each societal benefit is scored as 0 (no or negligible relationship), 1 (low relative importance), 2 (medium relative importance) or 3 (high relative importance). The confidence in each relationship is also scored as 1 (expert judgement), 2 (grey literature or non-UK peer-reviewed evidence) and 3 (UK peer-reviewed evidence). This code was used for 11 out of the 14 societal benefits in the NI-MANACA project where *a priori* assessments of importance have been made.

Approach (B): This approach can be applied in cases where it is not possible to identify underlying differences in the relative importance of different habitat types for the provision of a benefit, and disaggregates total value solely on the basis of the area of each habitat type. In effect, this approach assumes that all habitats have the same level of relative importance for the provision of a given benefit. This code was not used in the NI-MANACA project but has been coded into the BEACH tool for future use.

Approach (C): The methodological process applied here is the same as the one for Approach A (low, med, high) but differs in that the economic benefit depends on the distance from the shore. This code was not used in the NI-MANACA project but has been coded into the BEACH tool for future use.

Approach (D): This approach applies to situations with the least amount of information, requiring information on the areas of different habitat types and an estimate of the overall economic value of a given benefit. In common with Approach (B), there is no *a priori* biological basis or scientific rationale to apportion the benefit across habitat types; however, unlike Approach (B), this approach assumes that the magnitude of the benefit that is realised is independent of the absolute area of a given habitat present. In the absence of information to the contrary, this approach assumes that each of the habitat types present contributes equally to the provision of the benefit, irrespective of the relative proportion of each habitat that is present. Under this approach, the disaggregation process for a given benefit does not need an *a priori* judgement of the relative importance of each habitat. This code was used for 3 out of the 14 societal benefits in the NI-MANACA project where our current understanding and knowledge is insufficient to disaggregate value across the different habitats.

Table 18: The approaches used to disaggregate UK values across EUNIS habitats (adapted from Moran et al., 2008; Potts et al., 2014).

Key	
0	No/negligible (Code A)
1	Low relative importance (Code A)
2	Medium relative importance (Code A)
3	High relative importance (Code A)
1	Equal weighting across all habitats (Code D)

				Societal Benefits (Relative Importance)													
			Dissagregation Code	A	A	A	D	D	A	A	A	A	A	D	A	A	A
			Benefit	#01	#02	#03	#04	#05	#06	#07	#08	#09	#10	#11	#12	#13	#14
EUNIS L1	EUNIS L2	EUNIS L3	Habitat	Food (wild, farmed)	Fish feed (wild, farmed, bait)	Fertiliser and biofuels	Ornaments and aquaria	Medicines and blue biotechnology	Healthy climate	Prevention of coastal erosion	Sea defence	Waste burial / removal / neutralisation	Tourism and nature watching	Spiritual and cultural well-being	Aesthetic benefits	Education and Research	Health benefits
A	A1	**A1.1**	High energy littoral rock	2	0	0	1	1	1	3	3	0	1	1	1	1	1
		A1.2	Moderate energy littoral rock	2	0	0	1	1	1	2	2	0	1	1	1	1	1
		A1.3	Low energy littoral rock	2	0	0	1	1	1	1	1	0	1	1	1	1	1
	A2	**A2.1**	Littoral coarse sediment	1	1	0	1	1	1	2	2	1	3	1	3	1	1
		A2.2	Littoral sand and muddy sand	2	1	0	1	1	1	2	2	1	3	1	3	1	1
		A2.3	Littoral mud	2	2	0	1	1	2	1	1	2	1	1	2	1	1
		A2.4	Littoral mixed sediments	2	1	0	1	1	1	2	2	2	3	1	3	1	1
		A2.5	Coastal saltmarshes and saline reedbeds	3	0	1	1	1	3	2	2	3	3	1	3	1	1
		A2.6	Littoral sediments dominated by aquatic angiosperms	2	0	2	1	1	3	2	2	3	2	1	2	1	1
		A2.7	Littoral biogenic reefs	2	1	1	1	1	2	2	2	2	1	1	2	1	1
	A3	**A3.1**	Atlantic and Mediterranean high energy infralittoral rock	3	0	0	1	1	1	2	2	0	2	1	1	1	1
		A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	3	0	0	1	1	1	2	2	0	2	1	1	1	1
		A3.3	Atlantic and Mediterranean low energy infralittoral rock	3	0	0	1	1	1	2	2	0	2	1	1	1	1
	A4	**A4.1**	Atlantic and Mediterranean high energy circalittoral rock	3	0	0	1	1	1	1	1	0	2	1	1	1	1
		A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	3	0	0	1	1	1	1	1	0	2	1	1	1	1
		A4.3	Atlantic and Mediterranean low energy circalittoral rock	3	0	0	1	1	1	1	1	0	2	1	1	1	1
	A5	**A5.1**	Sublittoral coarse sediment	2	3	0	1	1	1	1	1	1	1	1	1	1	1
		A5.2	Sublittoral sand	2	3	0	1	1	2	1	1	1	1	1	1	1	1
		A5.3	Sublittoral mud	2	3	0	1	1	2	1	1	2	1	1	1	1	1
		A5.4	Sublittoral mixed sediments	2	3	0	1	1	1	1	1	2	1	1	1	1	1
		A5.5	Sublittoral macrophyte-dominated sediment	3	0	2	1	1	2	2	2	2	2	1	1	1	1
		A5.6	Sublittoral biogenic reefs	3	0	1	1	1	2	2	2	1	1	1	1	1	1
	A6	**A6.1**	Deep-sea rock and artificial hard substrata	2	2	0	1	1	1	0	0	0	1	1	2	1	1
		A6.2	Deep-sea mixed substrata	1	1	0	1	1	1	0	0	2	1	1	1	1	1
		A6.3	Deep-sea sand	1	1	0	1	1	1	0	0	2	1	1	0	1	1
		A6.4	Deep-sea muddy sand	1	1	0	1	1	1	0	0	2	1	1	0	1	1
		A6.5	Deep-sea mud	2	1	0	1	1	2	0	0	2	1	1	0	1	1
		A6.6	Deep-sea bioherms	2	2	0	1	1	1	0	0	1	1	1	2	1	1

3.2.3 Valuing Northern Ireland marine waters and current Northern Ireland MPA network

Using the relationships between natural capital (EUNIS level 3 habitats) and societal benefits established above (Section 3.2.2), the BEACH tool can be used to disaggregate the total value of UK marine waters to estimate the total value of Northern Ireland marine waters and also the total value of the existing Northern Ireland MPA network. Using mid-point estimates, indicative values of societal benefits gained from Northern Ireland marine waters in 2019 is in the region of £68.59 million, whilst the current Northern Ireland MPA network provides societal benefits in the region of £27.86 million (Table 19). The total value estimates can be disaggregated by the contribution of individual EUNIS level 3 classes (Table 19) and the contribution of individual societal benefits to the total values (Table 20). These value estimates are based on the mid-point UK-scale valuations. However these data can be presented as a range by using the UK low and high estimates (as presented in Table 17) as model inputs. For example, using the low and high UK-scale valuation estimates produces an indicative range for the total value at the UK-scale of £6,549.28 - £10,862.71 million, a range of £51.07 million - £83.28 million for the value at the Northern Ireland scale, and a range of £20.81 million - £33.76 million for the value at the scale of the Northern Ireland MPA network. Note, dashes in the tables denote valuation data not being available and do not denote a value of zero.

Table 19: Total values for UK and Northern Ireland (NI) marine waters and the current Northern Ireland (NI) MPA network based on the contributions of each EUNIS level 3 habitat.

Habitats	UK (£m 2019)	NI Value (£m 2019)	NI MPA Value (£m 2019)
A1.1 - High energy littoral rock	0.40	0.03	0.01
A1.2 - Moderate energy littoral rock	0.56	0.05	0.03
A1.3 - Low energy littoral rock	0.86	0.08	0.03
A2.1 - Littoral coarse sediment	0.93	0.01	0.00
A2.2 - Littoral sand and muddy sand	21.09	0.71	0.07
A2.3 - Littoral mud	9.28	0.52	0.05
A2.4 - Littoral mixed sediments	1.46	0.48	0.18
A2.5 - Coastal saltmarshes and saline reedbeds	3.18	0.55	0.18
A2.6 - Littoral sediments dominated by aquatic angiosperms	0.31	-	-
A2.7 - Littoral biogenic reefs	0.51	-	-
A3.1 - Atlantic and Mediterranean high energy infralittoral rock	16.76	0.10	0.08
A3.2 - Atlantic and Mediterranean moderate energy infralittoral rock	10.45	0.28	0.20
A3.3 - Atlantic and Mediterranean low energy infralittoral rock	5.06	0.11	0.09
A4.1 - Atlantic and Mediterranean high energy circalittoral rock	69.79	0.34	0.21
A4.2 - Atlantic and Mediterranean moderate energy circalittoral rock	68.10	2.02	1.54
A4.3 - Atlantic and Mediterranean low energy circalittoral rock	16.31	0.54	0.44
A5.1 - Sublittoral coarse sediment	1390.80	17.38	5.65
A5.2 - Sublittoral sand	2767.12	13.32	6.56
A5.3 - Sublittoral mud	718.92	26.17	8.96
A5.4 - Sublittoral mixed sediments	182.35	5.73	3.46
A5.5 - Sublittoral macrophyte-dominated sediment	2.52	0.17	0.12
A5.6 - Sublittoral biogenic reefs	5.44	0.01	0.01
A6.1 - Deep-sea rock and artificial hard substrata	56.78	-	-
A6.2 - Deep-sea mixed substrata	480.71	-	-
A6.3 - Deep-sea sand	572.91	-	-
A6.4 - Deep-sea muddy sand	316.41	-	-
A6.5 - Deep-sea mud	2172.14	-	-
A6.6 - Deep-sea bioherms	0.20	-	-
Overall totals	**8,891.34**	**68.59**	**27.86**

Table 20: Total values for UK and Northern Ireland (NI) marine waters and the current Northern Ireland (NI) MPA network based on the contributions of each societal benefit.

Societal Benefits	UK (£m 2019)	NI Value (£m 2019)	NI MPA Value (£m 2019)
Food (wild, farmed)	283.88	2.41	1.00
Fish feed (wild, farmed, bait)	-	-	-
Fertiliser and biofuels	-	-	-
Ornaments and aquaria	-	-	-
Medicines and blue biotechnology	-	-	-
Healthy climate	2,489.44	18.47	7.40
Prevention of coastal erosion	-	-	-
Sea defence	9.05	0.12	0.05
Waste burial / removal / neutralisation	683.33	5.02	1.96
Tourism and nature watching	1,725.74	13.96	5.82
Spiritual and cultural well-being	-	-	-
Aesthetic benefits	101.06	1.19	0.47
Education, research	2,765.64	21.08	8.57
Health benefits	833.20	6.35	2.58
Overall totals	**8,891.34**	**68.59**	**27.86**

3.3 Future Scenarios Assessments

3.3.1 Introduction

The effects that two alternative levels of conservation management, as applied to individual MPAs, have on the provision of societal benefits were considered in this study. The adoption of one or other of these management regimes, the specifications of which are summarised below (Table 21), give rise to two classes of MPA:

- highly restricted MPAs (HR-MPA), where the conservation objective is to 'recover'; and
- maintenance of conservation status MPAs (MCS-MPA), where the conservation objective is to 'maintain'.

It is recognised that these may not be the only levels of protection which could be given to the additional MPA components of the network, but they have been adopted here in part for consistency with earlier studies: Moran et al. (2008), Hussain et al. (2010), González-Álvarez et al. (2012) and Barnard et al. (2014).

Table 21: Specification of management regime restrictions.

Conservation Objective:	
'Recover' Management Regime	**'Maintain' Management Regime**
• General presumption against fishing of all kinds, and all constructive, destructive and disturbing activities. • Recovery measures appropriate to the local situation (enhanced restoration/aftercare measures on expiry of operating licences).	• New development activities permitted which are in the public interest (on social or economic grounds). • Existing activities to continue if these do not cause the site condition to deteriorate. • Restriction of bottom fishing gears either spatially or temporally and technical conservation measures. • Recovery measure appropriate to the local situation (enhanced restoration/aftercare measures on expiry of operating licences).

The functionality of the BEACH tool that has been developed to automate the disaggregation of UK-scale valuation and its subsequent reaggregation for discrete target areas on the basis of underlying habitat types, was augmented to account for changes in the protection/management of the target areas. This additional functionality was used to assess the implications of three scenarios / demonstrations:

- The Status Quo Situation, Business As Usual;
- Changes in the Management of the Existing MPA Network; and
- Values of Unit Areas of Northern Ireland Marine Waters.

For the purposes of these demonstrations, all value estimates are driven by the mid-point UK value data (see Table 17), however the range of value estimates (using the low and high value estimates) are also provided in the text where appropriate.

3.3.2 The effects of site management and the consideration of changes in habitat value over time

Derived (2019 equivalent) annualised values for benefit provision (Table 19; Table 20) are assumed to represent our best estimate of the current position in Northern Ireland, although it is recognised that these are likely to be underestimates given a lack of valuation evidence for a number of societal benefits. Looking forwards, the quality of habitats in unmanaged marine areas (those without specific conservation/protection measures in place) are assumed to gradually degrade over time. Consequently, there is likely to be a commensurate decline in the value of the societal benefits that such habitats produce.

Conversely, for protected sites, where management is based on a 'recover' conservation objective, it is assumed that there will be an improvement in the quality of the site's habitats, and so a potential increase in overall value of benefit provision. Similarly, for protected sites where management is based on a 'maintain' conservation objective, it is assumed that the site's habitats suffer no degradation, and therefore no decline in value of benefit provision (i.e., the results of site management are assumed to offset any degradation that would be seen if there were no protection in place).

Three example scenarios were developed to provide a more complete understanding of the potential value of the Northern Ireland marine environment, and to demonstrate the functionality of the BEACH tool.

All three of the scenario assessments undertaken (see Sections 3.3.3 – 3.3.5) consider how the current (2019 equivalent) values of benefits that are secured from specific areas of the Northern Ireland marine environment might change over a 20-year period, assuming certain management conditions. For these scenarios, valuations are based on benefits that are secured over a 20-year timeframe, although it is recognised that there will likely be benefits that accrue beyond this period.

In undertaking these assessments the magnitude of change in value compared to the current (2019 equivalent) that is expected with different management approaches, and how quickly such changes are seen, have to be modelled. Three basic profiles for changes in value are considered (Figure 9).

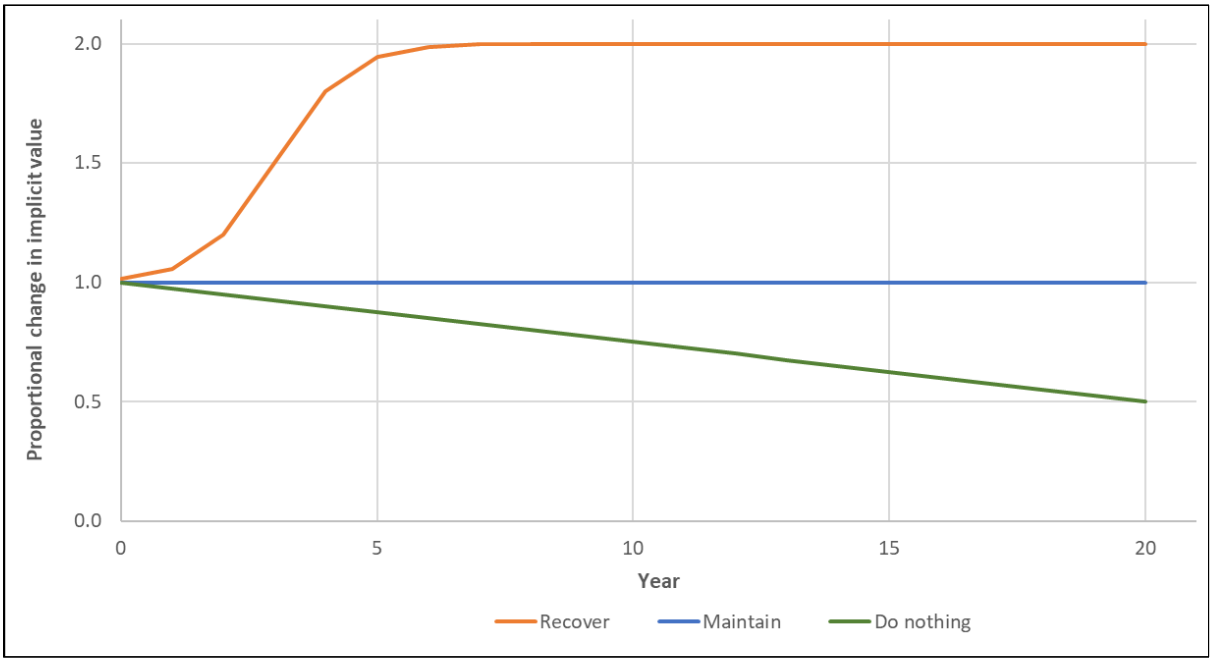


Figure 9: Schematic of change profiles associated with three options for site management (recover, maintain, do nothing).

Whereas Moran et al. (2008) modelled the basic change associated with a recover scenario with a truncated quadratic function, the BEACH tool applied here employs a modified logistic function, which produces a sigmoid (s-shaped) curve (the red line in Figure 9); see Equation 1. The use of a logistic function to model potential changes in benefit delivery over time was adopted as such (sigmoid) curves provide a useful first-order approximation to changes in biologically-mediated processes, which typically show a gradual but exponential increase in rate over an early period followed by an inflexion and a slowing rate as output reaches an (asymptotic) maximum.

$$v_t = 1 + \left(\frac{1}{1+e^{-c_1 \times (t-c_2)}}\right) \qquad \text{Equation 1}$$

where:

t = year number
v_t = estimate of nominal annual value of a given benefit at time t
c_1 and c_2 are parameters that affect the rate of change (slope) of the sigmoid curve, and the offset of the curve along the horizontal (time) axis, respectively.

The modified logistic function models an increase in the proportional change in the intrinsic value of a given benefit, as produced by a given habitat, over a 20-year period, rising from an initial nominal value of 1 at year zero (v_0 = 1), up to an asymptotic value of 2 (v_{20} = 2). This reflects an underlying assumption – adopted from Moran et al. (2008) – that a doubling in value is the absolute maximum theoretical change that might result from management under a 'recover' conservation objective.

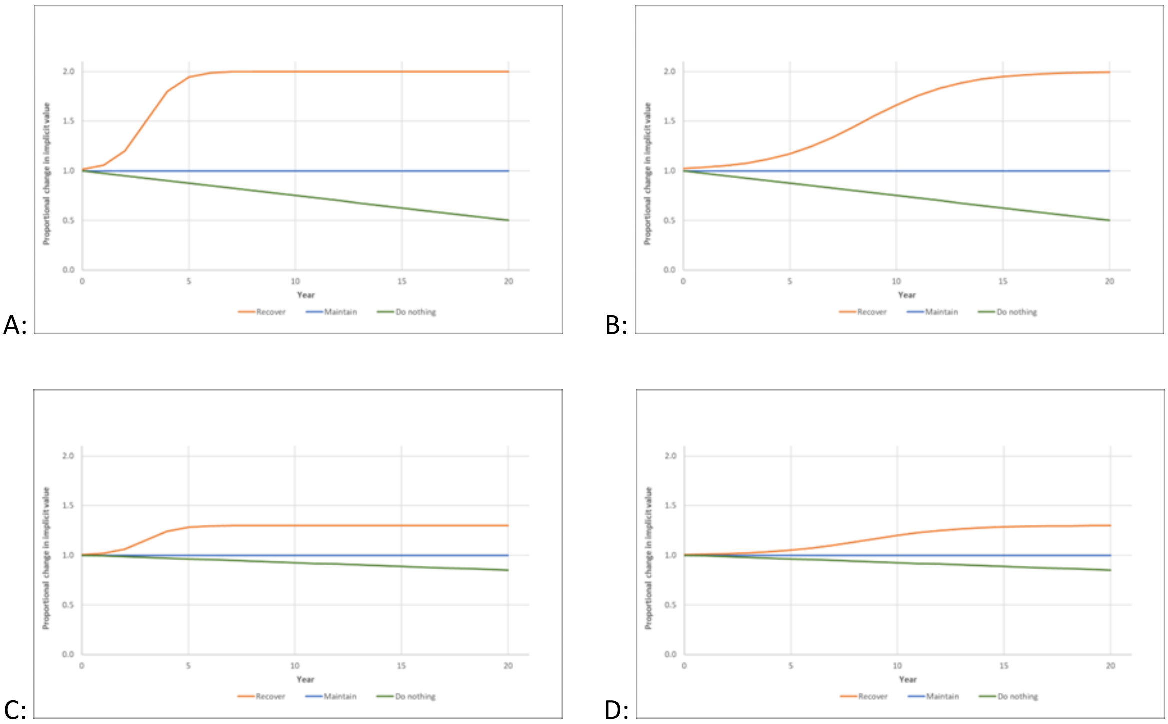
In contrast, zero active management (referred to as 'do-nothing' in Figure 9, and represented by the green line) assumes that there will be degradation in habitat quality, and hence in benefit provision and value. In the absence of other information, the decline was assumed to be linear over the 20-year period. Furthermore, and reflecting the adoption of a doubling in value as the maximum positive change associated with management, a halving in quality (and hence value) over the 20-year period was assumed to represent the worst-case underlying trend for unmanaged habitats.

Between these two extremes, the third management option considered is that associated with a 'maintain' conservation objective. The conservative view that such management results in no net change in habitat quality, and hence no change in the value of benefits is seen over time. In effect, the positive effects of site management under a maintain conservation objective are assumed to directly offset the gradual declines in habitat quality (and hence benefit value) that would otherwise be seen (under a do-nothing scenario). The consequence of this management option is represented by the blue line in Figure 9.

Whilst these three basic management options provide a series of baselines for considering how habitat quality (and hence benefit value) might change over time under different management regimes, many specific habitat/benefit combinations are likely to present a more nuanced response i.e., an overall change that is smaller in magnitude than the doubling or halving indicated for the recover and do-nothing options, respectively. Also, for the positive changes seen as a response to the recover management option, specific habitat/benefit combinations may show a faster or slower rate of response, which may also be subject to a delayed onset. Figure 10, for example, shows in graphical form how the 'baseline' changes in site value over a 20-year period (as seen under each of the three basic management options) might differ.

The information presented graphically in Figure 10 – i.e., the expected magnitude of change and, for the recover management option, how quickly this change is realised – is codified for each separate habitat/benefit combination under both the recover and the do-nothing management options. For the do-nothing management option these 'scalar codes' describe:

- the magnitude of expected change (recorded qualitatively as: very high, high, medium, low, very low, but assigned quantitative (%) scores – see Table 22);
- the period of change (how many years until the full change is realised); and
- the profile of change (usually sigmoid curve, but some instances of linear profiles).



Key to figure

A: the baseline case: change (for the recover management option) occurs over the first five years of the 20-year period; magnitude of changes seen for both recover and do nothing management options are at their theoretical maxima (i.e., doubling and halving respectively);

B: a slower response: change (for the recover management option) occurs over an extended (15-year) period; magnitude of changes remain at their theoretical maxima for both the recovery and do-nothing management options;

C: a response with reduced magnitude: change (for the recover management option) occurs over the first five years of the 20-year period; magnitude of changes are just 30% of their theoretical maxima for both the recovery and do-nothing management options;

D: a slower response with reduced magnitude: change (for the recover management option) occurs over an extended (15-year) period; magnitude of changes are just 30% of their theoretical maxima for both the recovery and do-nothing management options.

Figure 10: Modifications of the basic management response curves.

Table 22: Interpretation of the magnitude element of scalar (impact) codes used for valuation estimates.

Relative magnitude of potential change	Proportion of potential change realised (%)	
	Range	Assumed mid-point
VH (very high)	90-100	95
H (high)	50-89	70
M (medium)	10-49	30
L (low)	1-9	5
VL (very low)	<1	0.5

For example, a scalar code of H 5/20 S would infer a magnitude of change of up to 70% of the theoretical maximum, with this change occurring in the first 5 years of a 20-year period, and following a sigmoid profile. The full set of scalar codes used to model the effects of the recover management option is given below (Table 23).

Similarly, scalar codes for the do-nothing management option (which assumes a linear decline in habitat quality, and hence in benefit value) describes the magnitude of expected change (again recorded qualitatively as: very high, high, medium, low, very low). However, as it is assumed that for all habitat/benefit combinations the decline associated with a do-nothing management option is linear and takes effect over the full 20-year period, these scalar codes do not include information on the period or profile of change. The full set of scalar codes used to model the effects of the do-nothing management option is given below (Table 24).

The scalar codes shown as Table 23 (for the recover management option) and Table 24 (for the do-nothing management option) are based on codes presented by Moran et al (2008). Expert judgement by the authors was used to modify the tables (mapping the data from Moran et al. from landscape types to EUNIS level 3 habitat types, and revising the benefits framework to reflect the UKNEAFO framework) to produce the tables reported here. In addition, the scalar codes for modelling the effects of a do-nothing management option (Table 24) is based solely on data for the magnitude of expected change that was originally presented by Moran et al. (2008).

Table 23: Scalar codes for modelling the effects of a recover management option.

	RECOVER SCALAR CODES	Societal benefits													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Food provision	Fish feed	Fertiliser & biofuels	Ornaments & aquaria	Medicines & blue biotech	Healthy climate	Prevention of coastal erosion	Sea defence	Waste burial /removal/ neutralisation	Tourism & nature watching	Spiritual & cultural wellbeing	Aesthetic Benefits	Education, Research	Human Health Benefits
A1.1	High energy littoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A1.2	Moderate energy littoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A1.3	Low energy littoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A2.1	Littoral coarse sediment	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	M 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A2.2	Littoral sand and muddy sand	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	M 5/20L	VL 0/20S	VL 0/20S	M 5/20L	M 5/20L	VL 0/20S	VL 0/20S	M 5/20L	VL 0/20S
A2.3	Littoral mud	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	M 5/20E	VL 0/20S	VL 0/20S	M 5/20E	L 5/20E	VL 0/20S	VL 0/20S	M 5/20E	VL 0/20S
A2.4	Littoral mixed sediments	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	M 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A2.5	Coastal saltmarshes and saline reedbeds	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A2.6	Littoral sediments dominated by aquatic angiosperms	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A2.7	Littoral biogenic reefs	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A3.1	Atlantic and Mediterranean high energy infralittoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A3.3	Atlantic and Mediterranean low energy infralittoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A4.1	Atlantic and Mediterranean high energy circalittoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S
A4.3	Atlantic and Mediterranean low energy circalittoral rock	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S
A5.1	Sublittoral coarse sediment	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	M 5/20E	VL 0/20S	VL 0/20S	M 5/20E	L 5/20E	VL 0/20S	VL 0/20S	M 5/20E	VL 0/20S
A5.2	Sublittoral sand	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A5.3	Sublittoral mud	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A5.4	Sublittoral mixed sediments	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	L 8/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A5.5	Sublittoral macrophyte-dominated sediment	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	H 5/20E	VL 0/20S	VL 0/20S	H 5/20E	VL 0/20S
A5.6	Sublittoral biogenic reefs	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S
A6.1	Deep-sea rock and artificial hard substrata	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S
A6.2	Deep-sea mixed substrata	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S
A6.3	Deep-sea sand	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S
A6.4	Deep-sea muddy sand	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S	VL 0/20S	VL 0/20S	H 15/20E	VL 0/20S
A6.5	Deep-sea mud	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S
A6.6	Deep-sea bioherms	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	H 10/20E	VL 0/20S	VL 0/20S	H 10/20E	VL 0/20S

Table 24: Scalar codes for modelling the effects of a do-nothing management option.

DO-NOTHING SCALAR CODES		Societal benefits													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Food provision	Fish feed	Fertiliser & biofuels	Ornaments & aquaria	Medicines & blue biotech	Healthy climate	Prevention of coastal erosion	Sea defence	Waste burial /removal/ neutralisation	Tourism & nature watching	Spiritual & cultural wellbeing	Aesthetic Benefits	Education, Research	Human Health Benefits
A1.1	High energy littoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A1.2	Moderate energy littoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A1.3	Low energy littoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A2.1	Littoral coarse sediment	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A2.2	Littoral sand and muddy sand	M	VL	VL	VL	VL	M	VL	VL	M	M	VL	VL	M	VL
A2.3	Littoral mud	M	VL	VL	VL	VL	M	VL	VL	M	L	VL	VL	M	VL
A2.4	Littoral mixed sediments	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A2.5	Coastal saltmarshes and saline reedbeds	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A2.6	Littoral sediments dominated by aquatic angiosperms	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A2.7	Littoral biogenic reefs	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A3.1	Atlantic and Mediterranean high energy infralittoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A3.3	Atlantic and Mediterranean low energy infralittoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A4.1	Atlantic and Mediterranean high energy circalittoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A4.3	Atlantic and Mediterranean low energy circalittoral rock	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A5.1	Sublittoral coarse sediment	L	L	L	L	L	L	VL	VL	L	VL	VL	VL	L	VL
A5.2	Sublittoral sand	M	M	M	M	M	M	VL	VL	M	M	VL	VL	H	VL
A5.3	Sublittoral mud	H	VL	VL	VL	VL	M	VL	VL	M	VL	VL	VL	H	VL
A5.4	Sublittoral mixed sediments	M	L	L	L	L	M	VL	VL	M	VL	VL	VL	M	VL
A5.5	Sublittoral macrophyte-dominated sediment	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A5.6	Sublittoral biogenic reefs	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A6.1	Deep-sea rock and artificial hard substrata	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL
A6.2	Deep-sea mixed substrata	M	L	L	L	L	M	VL	VL	M	VL	VL	VL	H	VL
A6.3	Deep-sea sand	M	L	L	L	L	M	VL	VL	M	VL	VL	VL	H	VL
A6.4	Deep-sea muddy sand	M	L	L	L	L	M	VL	VL	M	VL	VL	VL	H	VL
A6.5	Deep-sea mud	M	L	L	L	L	M	VL	VL	M	VL	VL	VL	H	VL
A6.6	Deep-sea bioherms	M	L	L	L	L	M	VL	VL	M	M	VL	VL	M	VL

The parameters c_1 and c_2 in the modified logistic model (Equation 1) were each adjusted by trial and error until the resultant sigmoid curve provided a reasonable fit to the properties described by the 'period of change' element of each of those scalar codes that referred to a sigmoid model (Table 25).

Table 25: Parameterisation of modified logistic model.

Scalar code	c1 (rate)	c2 (offset)
5/20 S	1.40	3.00
6/20 S	1.20	3.50
8/20 S	0.85	4.50
10/20 S	0.65	5.50
15/20 S	0.45	8.50
20/20 S	0.30	10.50

These separate parameterised models were then used to calculate standardised estimates of the value of each specific habitat/benefit combination over a 20-year period, under a given management option, by following how the annualised (2019 equivalent) values - estimated from the disaggregated UK-scale valuations – would change year-on-year under the influence of a particular scalar code (specific to the management option and habitat/benefit combination). As part of this process it was assumed that benefits secured later in the 20-year period have a lower value than benefits secured in earlier periods. This 'discounting' process[11] adopts a standard discount rate for the period under consideration (in this instance 3.5%). This value is the UK Government recommended rate for discounting (HM Treasury, 2022). Summing all estimates of discounted annual benefit value across the 20-year period provides a Net Present Value (NPV) for the 20-year period.

To simplify this process, the potential change in a nominal unitary value was calculated, on a year-by-year basis, for each of the profiles represented by the range of scalar codes and for each management option. The resultant nominal annual values were each discounted (assuming a 3.5% discount rate), and pairs of discounted values from consecutive years were averaged, with all 19 resulting values being summed to generate an effective index (or scalar coefficient) for the (20-year) NPV assuming an initial nominal value of one (i.e. $v_0 = 1$); see Equation 2, over. Note that the value of $NPV_{(Scalar\ coeff)}$ is dimensionless and hence the Calculated NPV value will be in whatever units the initial nominal value (v_0) has been supplied in.

$$NPV_{(Scalar\ coeff)} = \sum_{t=0}^{t=19} \left(\left({v_t}/{(1+d)^t} \right) + \left({v_{t+1}}/{(1+d)^{t+1}} \right) \right) / 2$$

.... Equation 2

where:
t = year number
d = assumed discount rate (3.5%, or 0.035)
v_t = estimate of nominal annual value of a given benefit at time *t*
v_{t+1} = estimate of nominal annual value of a given benefit at time *t+1*

[11] Discounting is the act of determining the present value of future cash flows; because money is subject to inflation, and has the ability to earn interest, one pound today is effectively worth more than one pound tomorrow; discounting, is the act of determining how much less tomorrow's pound is worth.

Using this approach, an NPV scalar coefficient value was assigned to each scalar code for each management option (see Tables 26 and 27). Subsequently, the 20-year NPV for a given habitat/benefit combination for a marine area subjected to a given management option could be easily calculated simply as the product of the estimated current (2019 equivalent) value and the appropriate scalar coefficient.

Table 26: Scalar coefficients for calculating NPV under a recover management option.

Scalar code	Scalar co-efficient
VL 0/20S	14.533
VL 5/20L	14.522
L 5/20S	15.042
L 5/20L	15.066
L 8/20S	14.978
M 10/20S	17.315
M 15/20S	16.637
M 20/20S	16.266
M 5/20S	17.948
M 5/20L	18.089
M 6/20S	17.816
H 10/20S	21.120
H 15/20S	19.537
H 5/20S	22.596
H 8/20S	21.691
VH 10/20S	23.498
VH 15/20S	21.350
VH 20/20S	20.177
VH 5/20S	25.501
VH 8/20S	24.273

Table 27: Scalar coefficients for calculating NPV under a do-nothing management option

Scalar code	Scalar co-efficient
VL	14.445
L	14.301
M	13.501
H	12.220
VH	11.419

In addition to the recover and do-nothing options, a maintain option was also considered. This option assumed no change in habitat quality (and hence no change in benefit values) over the 20-year period, with the maintain management effectively offsetting the declines that would have otherwise occurred (as under the do-nothing option). One important consequence of this assumption is that all habitat/benefit combinations are assigned the same NPV scalar value (calculated as 14.461).

3.3.3 Scenario (i): Status Quo / Business as Usual

Background

Under this scenario the consequence of the following combination of conditions was assessed:

- Unmanaged (unprotected, or non-MPA) areas of the Northern Ireland marine environment remain as they are – a condition that further assumes:
    - A gradual (linear) degradation in habitat quality over a 20-year period;
    - An associated decrease in benefit provision; and where
    - The degree (or magnitude) of decrease is indicated by the scalar code for each specific habitat/benefit combination.
- 100% of the current MPA network is managed to a 'maintain' conservation objective – which, in turn, assumes:
    - No change in habitat quality across these sites over 20-year period (i.e., the ongoing MPA management is assumed to offset any degradation that would be seen if there were no protection in place), and consequently
    - No change in benefit provision.
- No additional MPA sites are added to the current network.

Assessment of the status quo scenario can be used to provide a baseline from which to assess the potential impacts of management options.

As noted earlier, given a lack of understanding regarding the rate (and temporal profile) of deterioration in the health of the marine environment, it was assumed that deterioration would occur in a linear fashion. For unmanaged areas a linear 50% decline in habitat quality (and hence benefit provision) over a 20-year period was assumed to represent the underlying (maximal) change, but the actual rate of decline seen for each possible habitat/benefit combination was attenuated by the magnitude element of the relevant scalar coefficient (which indicates the degree to which the potential 50% decline is effectively realised). A 20-year period was selected for determining the reduction in benefits that may be realised following the approach undertaken by Moran et al. (2008).

Codes for the majority of the 392 possible habitat/benefit combinations have a 'magnitude' element that is 'Low' (5%) or 'Very low' (0.5%) (see Table 23, above). The 'Low' magnitude coding indicates that, for those habitat/benefit combinations concerned, modelled declines are restricted to a reduction of just 2.5% below current levels (i.e., 5% of the assumed maximum reduction of 50%). In turn, the 'Very low' magnitude coding effectively limits modelled declines to a reduction of just 0.25% below current levels (i.e., 0.5% of the assumed maximum reduction of 50%). Most of the remaining codes represent a 'Medium' magnitude (30%), limiting declines to just 15% (i.e., 30% of 50%) over 20 years, whilst 7 of the 392 codes have a 'High' magnitude (70%) which has the effect of restricting the modelled decline in site quality, and hence value for these seven specific habitat/benefit combinations to a 35% fall below current levels (i.e., 70% of 50%).

Results

A summary of the results for this scenario are presented below (Table 28), taken directly from the BEACH tool. Both the current annualised (2019 equivalent) values and the Net Present Value (NPV) estimates (assuming accrual of returns over a 20-year period, with a 3.5% discounting rate) are presented. These results are estimated using mid-point values. However, using the low and high UK-scale valuations (see Table 17) as model inputs the current total value at the Northern Ireland scale is estimated to be in the range of £51.07 million - £83.28 million (as 2019 equivalent prices), whilst the (20-year) NPV is in the range £712.31 million - £1,165.76 million.

Table 28: Summary results for scenario (i) - status quo / business as usual.

HIGH LEVEL OUTPUT SUMMARY VALUES (£m)		
	2019 value	**NPV (20 yr)**
UK	8,891.34	-
NI Unmanaged	40.73	556.59
Current MPAs (100% MAINTAIN)	27.86	402.86
'New' MPA - MAINTAIN mgmnt	-	-
'New' MPA - RECOVER mgmnt	-	-
NI total	68.59	959.45

Taking the current (2019 equivalent) total value of benefits across UK waters (£8,891.34 million; from Table 28) and the total area of UK marine waters (89,257,310.4 ha; from Table 5), it is possible to generate a first approximation of the *pro-rata* benefit for Northern Ireland marine waters (which represent a total area of 680,376.0 ha; Table 5) in order to provide a sense-check for the outputs produced by the BEACH tool. For this scenario this approximation is calculated as £67.78m which obviously compares very favourably with the modelled output of £68.59m. This confirmatory approach is applicable to the wide-scale system, but is unable to account for more nuanced differences reflecting relative proportions of habitat types or their importance regarding delivery of specific services. Consequently it provides a good sense-check for the overall results but is not a panacea; it remains necessary to use a system such as that provided by the BEACH tool to provide more refined outputs.

It should be noted that each of the values presented in Table 28 are effectively totals across all habitat types and across all classes of benefit. The BEACH tool allows for this more detailed data to be retrieved and presented in tabular or graphical format. Figure 11, for example, presents the background data for the 'NI total' value for NPV (£959.45 million) – which includes all 'NI Unmanaged waters' plus current MPAs managed to a 'maintain' conservation objective – in the form of a 'heat-map', showing those habitat/benefit combinations that make the greatest contributions to overall value (shaded red), and those that contribute least (shaded green).

NPV: Status quo - current position (unmanaged NI waters *plus* current MPA network under 'maintain' management)		Societal Benefits							
		13	6	10	14	9	1	12	8
		Education, Research	Healthy climate	Tourism and nature watching	Human Health Benefits	Waste burial /removal/ neutralisatn	Food provision	Aesthetic Benefits	Sea defence
A5.3	Sublittoral mud								
A5.1	Sublittoral coarse sediment								
A5.2	Sublittoral sand								
A5.4	Sublittoral mixed sediments								
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock								
A2.2	Littoral sand and muddy sand								
A4.3	Atlantic and Mediterranean low energy circalittoral rock								
A2.5	Coastal saltmarshes and saline reedbeds								
A2.3	Littoral mud								
A2.4	Littoral mixed sediments								
A4.1	Atlantic and Mediterranean high energy circalittoral rock								
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock								
A5.5	Sublittoral macrophyte-dominated sediment								
A3.3	Atlantic and Mediterranean low energy infralittoral rock								
A3.1	Atlantic and Mediterranean high energy infralittoral rock								
A1.3	Low energy littoral rock								
A1.2	Moderate energy littoral rock								
A1.1	High energy littoral rock								
A5.6	Sublittoral biogenic reefs								
A2.1	Littoral coarse sediment								

Figure 11: Heat-map showing relative contribution of different habitat/benefit combinations to overall NPV of Northern Ireland waters under the status quo/business as usual scenario.

3.3.4 Scenario (ii): Changes in the Management of the Existing MPA Network

Background

Under this scenario the contribution made by the current MPA network to the overall value of services from the Northern Ireland marine area was considered in isolation, and the consequences of altering MPA management was assessed with respect to the following assumptions:

- no change to the extent of the Northern Ireland MPA network, and 100% of the current MPA network initially managed to a 'maintain' conservation objective;
- application of management to a 'recover' conservation objective is then assumed to be applied across an increasing % of the overall MPA network – modelled by assuming that management is applied to increasing proportions of underlying habitats across the entire network, not to discrete sites[12];
- as for the status quo scenario discussed above, the magnitude of increased service delivery through a switch to 'recover' management is indicated by the scalar code for each specific habitat/benefit combination.

Results

Table 29 presents the outputs from the BEACH tool as calculated for seven points along the continuum of protection levels considered under scenario (ii) using mid-point value estimates. The first three rows give the current (initial, 2019 equivalent) values (£m) for the Northern Ireland Unmanaged marine area, plus the area currently designated as MPAs. The lower part of the table gives the calculated NPV totals (again as £m) for the Unmanaged portion of Northern Ireland marine waters and for the current Northern Ireland MPA network assuming an increasing level of protection (0%, 10%, 25%, 50%, 75%, 90%, and 100% recover). These data could also be presented as a range (by using the low and high UK-scale value estimates as model inputs, rather than the mid-range values). For example, the overall value of benefits (as the 20-year NPV) that would accrue from the current MPA network managed at 100% maintain would be in the range £300.92 million - £488.19 million, whilst this would rise to somewhere in the range of £385.28 million - £649.26 million if the network were to be managed at 100% recover.

[12]The scope of the project, plus limitations in the available data, meant that it was not possible to undertake this assessment by adopting an MPA-by-MPA approach. In effect, it unavoidably assumes that the habitat composition is constant across all Northern Ireland MPAs. Whilst this is not an accurate reflection of the true situation (see Figure 7, for example) the results produced by the analysis for the two extremes of the protection range considered (i.e., 100% maintain/0% recover and 0% maintain/100% recover) are based on accurate figures and so provide useful 'fixed points' for this assessment, the calculated intermediate values are likely to provide useful first approximations for illustrative purposes.

Table 29: Key outputs under scenario (ii)

		'Baseline' 100% maintain	90% maintain 10 % recover	75% maintain 25% recover	50% maintain 50 % recover	25% maintain 75 % recover	10% maintain 90 % recover	100 % recover
2019 value (£m)	NI Unmanaged	40.73						
	Current MPAs	27.86						
	NI total	68.59						
NPV (20 yr) (£m)	NI Unmanaged	556.59						
	Current NI MPAs	402.86	415.14	433.55	464.24	494.93	513.34	525.62
	NI total	959.45	971.73	990.14	1,020.83	1,051.52	1,069.93	1,082.21

Increasing MPA protection … increasing overall value?

Whilst the NPV for Unmanaged waters remains constant (as they are assumed to remain unaffected by the changes in management across the MPA network) the calculated total benefit values for the current Northern Ireland MPAs show, for example, an indicative £30m increase in (20yr) NPV accruing from a change in management (from maintain to recover) across just 25% of the MPA network.

Although the figures presented in Table 29 indicate that increasing protection results in increasing value this is, however, a generalisation. There may be certain circumstances where increased protection, for example through the control of commercial activities such as fishing, might actually *decrease* the benefits accruing from a particular site (e.g., by restricting fish catch and subsequent landings - and hence reducing the overall value of wild food production that is realised). There is an argument to say that such protection may give rise to 'spill-over' effect into adjacent waters which may offset, or even over-compensate for, any site-specific losses but this cannot be predicted with certainty. The bottom line is that the results produced under this scenario can only be relied on to give an indicative view of the likely benefits associated with increased site protection.

In addition, it should be noted that, although the figures presented in Table 29 represent Net Present Value (NPV), these values are not net of costs associated with an increase in protection (from maintain to recover) across a greater proportion of the MPA network. Information on such potential management costs has not been available for this project, but their elucidation and consideration represents an area of investigation that could be usefully followed up in the future.

3.3.5 Scenario (iii): Values of Unit Areas of Northern Ireland Marine Waters

Background

The potential benefits of additional protected sites within Northern Ireland marine waters were also assessed during the operation of the BEACH tool. A randomly selected network of 64 'illustrative demonstration sites' were generated within GIS to represent hypothetical new MPAs, allowing the application of the approach and the functionality of the BEACH tool to be demonstrated. For simplicity the polygons used were circular in shape and did not overlap spatially. A site radius of 3,201 m was set, resulting in demonstration sites of approximately 3,200 ha – consequently, the total area across all 64 demonstration sites (206,184 ha) provided a first order approximation to the overall area of the existing Northern Ireland MPA network (276,629 ha).

The assessment was based on the following conditions and assumptions:

- Contribution made by an additional set of illustrative demonstration sites to the overall values of services from the Northern Ireland marine was considered in isolation.
- Assessments were based on two alternative assumptions:
    - all sites being managed to a ‘maintain’ conservation objective.
    - all sites being managed to a ‘recover’ conservation objective.

A network of 64 illustrative demonstration sites was used to demonstrate the methodology and functionality of the BEACH tool (Figure 12). This scenario assessment considers how the current (2019 equivalent) values of benefits that are secured from specific areas of the Northern Ireland marine environment might change over a 20-year period, assuming certain management conditions.

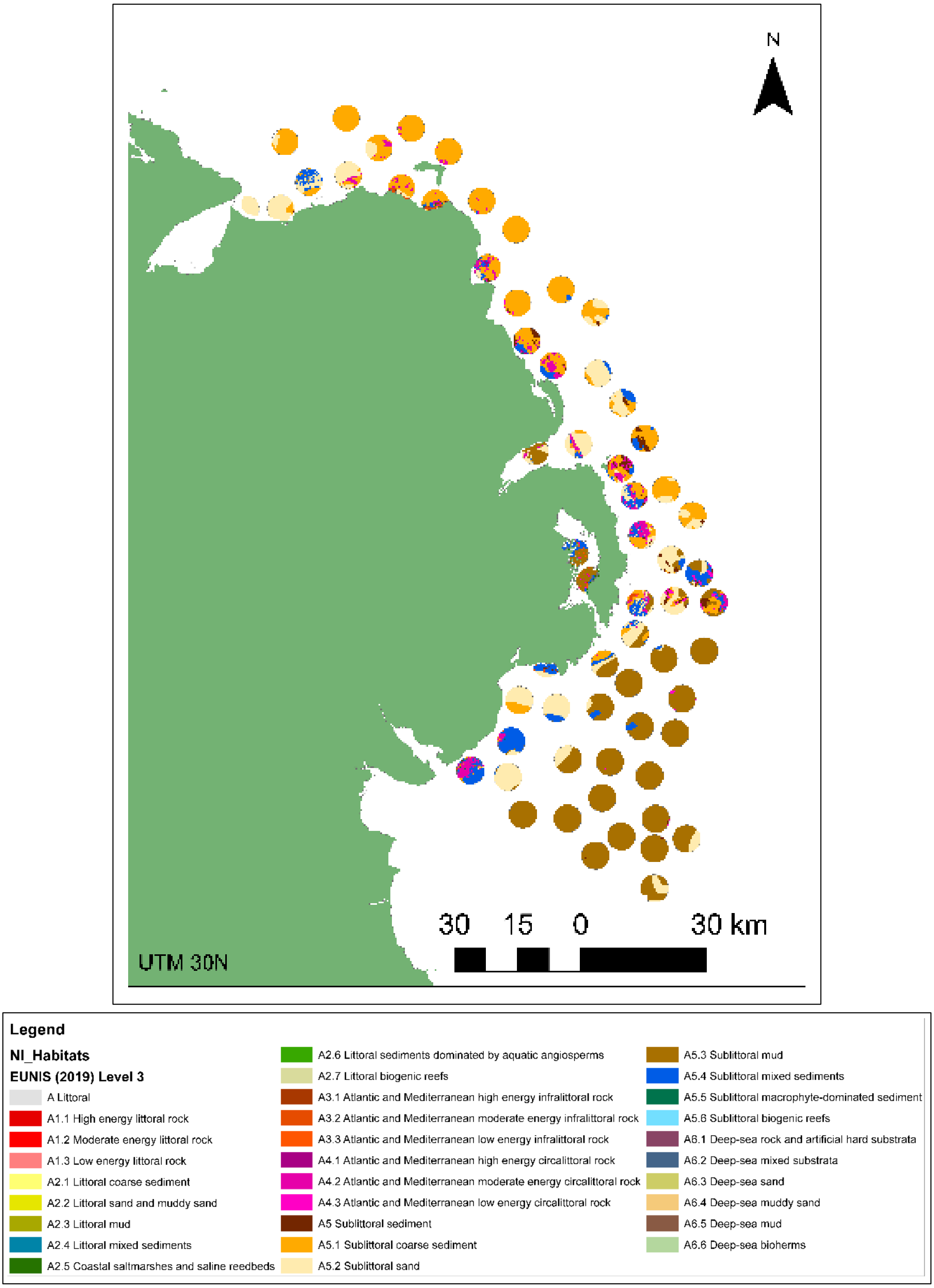


Figure 12: Location of 64 illustrative demonstration sites within Northern Ireland marine waters.

Results

As might be expected, there is a large variation in the overall value of individual demonstration sites (calculated using mid-point values) across the overall sample (Table 30) indicating that the individual randomly selected demonstration sites tend to each perform differently. Nevertheless, this scenario indicates that a randomly selected 3,200 ha site is likely to contribute a mean value of around £4.68 million (SD = £0.43 million) to the Northern Ireland (20-year) NPV across all benefit streams under a 'maintain' management.

Table 30: Value (NPV) of illustrative demonstration sites under alternative management regimes.

	Total value (NPV, £ million) across the network of 64 illustrative demonstration sites under alternative management regimes:	
Network statistic	**Maintain**	**Recover**
Minimum site value	4.02	4.66
Maximum site value	5.98	7.90
Mean site value	4.68	6.22
Median site value	4.72	6.41
Standard Deviation of site values across full network	0.43	0.88

NOTES
As some of the randomly selected illustrative demonstration sites included small areas of terrestrial habitat there was a slight variation in site area across the 64 sites that were considered. To remove any bias due to this variation, the habitat composition of all 64 sites was scaled to a consistent total area of 3,200 ha.
All values presented as £m Net Present Value over 20 years, with 3.5% annual discounting applied.

Of course, if these sites were left unmanaged (a do-nothing management option reflecting the status quo or business as usual scenario discussed earlier), then they would still contribute to the overall Northern Ireland NPV for benefits over the subsequent 20-year period. Without management however it is assumed that habitat quality, and hence the value of resulting benefit, would gradually decline over time. A more detailed comparison of outputs between individual sites shows the key role played by site-specific habitat profiles (Table 31).

Table 31: NPV (£m) by habitat type at three selected illustrative demonstration sites.

Habitat type	Site number		
	18	27	40
A1.1 – High energy littoral rock	-	-	-
A1.2 – Moderate energy littoral rock	-	-	-
A1.3 – Low energy littoral rock	-	0.02	-
A2.1 – Littoral coarse sediment	-	-	-
A2.2 – Littoral sand and muddy sand	7.15	-	-
A2.3 – Littoral mud	0.01	0.02	-
A2.4 – Littoral mixed sediments	-	0.38	-
A2.5 – Coastal saltmarshes and saline reedbeds	0.13	2.06	-
A2.6 – Littoral sediments dominated by aquatic angiosperms	-	-	-
A2.7 – Littoral biogenic reefs	-	-	-
A3.1 – Atlantic and Mediterranean high energy infralittoral rock	-	0.01	-
A3.2 – Atlantic and Mediterranean moderate energy infralittoral rock	-	0.15	-
A3.3 – Atlantic and Mediterranean low energy infralittoral rock	-	0.28	-
A4.1 – Atlantic and Mediterranean high energy circalittoral rock	-	0.01	-
A4.2 – Atlantic and Mediterranean moderate energy circalittoral rock	-	0.11	-
A4.3 – Atlantic and Mediterranean low energy circalittoral rock	-	0.15	-
A5.1 – Sublittoral coarse sediment	-	-	4.50
A5.2 – Sublittoral sand	-	0.01	-
A5.3 – Sublittoral mud	-	4.28	-
A5.4 – Sublittoral mixed sediments	-	0.39	0.20
A5.5 – Sublittoral macrophyte-dominated sediment	-	0.00	-
A5.6 – Sublittoral biogenic reefs	-	0.02	-
A6.1 – Deep-sea rock and artificial hard substrata	-	-	-
A6.2 – Deep-sea mixed substrata	-	-	-
A6.3 – Deep-sea sand	-	-	-
A6.4 – Deep-sea muddy sand	-	-	-
A6.5 – Deep-sea mud	-	-	-
A6.6 – Deep-sea bioherms	-	-	-
Total	7.30	7.90	4.70

NOTES

As some of the randomly selected demonstration sites included small areas of terrestrial habitat there was a slight variation in site area across the 64 sites that were considered. To remove any bias due to this variation, the habitat composition of all 64 sites was scaled to a consistent total area of 3,200 ha.

All three sites assumed to be managed to a recover conservation objective.

All values presented as £m Net Present Value over 20 years, with 3.5% annual discounting applied.

A comparison of the data presented for sites 27 and 40 (Table 31) provides an example of the between-site differences in habitat composition, and how this is associated with marked differences in overall site value (£7.90 million compared with only £4.7 million). Conversely, comparing sites 18 and 27, whilst there are again obvious differences in habitat composition between the two sites, the estimates of overall NPV for the sites are reasonably similar (£7.30 million and £7.90 million, respectively). Overall, the data extract presented here demonstrates that site-specific habitat composition is an important factor in overall site valuation.

It is possible to drill down into these data to assess which specific habitats might be responsible for generating the value seen at the site, or network, level. For example, it is possible to produce a heat-map for the 64 illustrative demonstration sites in order to investigate where and how value is ‘generated’– showing the relative importance of different constituent habitats and resultant societal benefits (Figure 13).

NPV (£m, over 20 years) for additional sites (under RECOVER management)		Societal benefits							
		13	6	10	9	14	1	12	8
		Education, Research	Healthy climate	Tourism and nature watching	Waste burial, removal, or neutralisation	Human Health Benefits	Food provision	Aesthetic Benefits	Sea defence
A5.3	Sublittoral mud								
A5.2	Sublittoral sand								
A5.1	Sublittoral coarse sediment								
A5.4	Sublittoral mixed sediments								
A4.2	Atlantic and Mediterranean moderate energy circalittoral rock								
A4.3	Atlantic and Mediterranean low energy circalittoral rock								
A2.5	Coastal saltmarshes and saline reedbeds								
A2.2	Littoral sand and muddy sand								
A3.2	Atlantic and Mediterranean moderate energy infralittoral rock								
A2.4	Littoral mixed sediments								
A4.1	Atlantic and Mediterranean high energy circalittoral rock								
A5.5	Sublittoral macrophyte-dominated sediment								
A3.3	Atlantic and Mediterranean low energy infralittoral rock								
A3.1	Atlantic and Mediterranean high energy infralittoral rock								
A1.1	High energy littoral rock								
A2.3	Littoral mud								
A1.2	Moderate energy littoral rock								
A1.3	Low energy littoral rock								
A5.6	Sublittoral biogenic reefs								

Low contribution ⟶ High contribution

Figure 13: Sources of value – a heat-map view of the overall value of the 64 illustrative demonstration sites, showing relative contribution made by specific habitat-benefit combinations.

Overall, this assessment of a new independent dataset of randomly located illustrative demonstration sites provides an indication of the sensitivity of the underlying model to variations in habitat composition and suggests that less reliance might be placed on outputs at the individual site scale i.e., where the underlying benefit transfer model is being applied at its limit. At the network scale, however, much of the habitat variability is probably accounted for and it is more likely that the outputs from this scenario provide a useful first approximation of the potential generic value of new MPA sites in Northern Ireland marine waters.

4. Discussion & Recommendations

While consistency with previous studies such as Moran et al. (2008) is important, the methodology applied in the NI-MANACA project has taken on board recommendations from more recent studies (e.g., Barnard et al., 2014) which recognise significant developments in our understanding of societal benefits and their valuation. Of particular importance was the shift to mapping EUNIS level 3 habitat types, the incorporation of the matrix approach (after Potts et al., 2014) in disaggregating UK-values and the adoption of the UKNEAFO framework (Turner et al., 2015) for identifying societal benefits which are consistent with the recently published UK marine natural capital accounts (ONS, 2021a). This section will discuss the results of the NI-MANACA project, identify methodological and knowledge gaps and make recommendations for further developments within this field.

4.1 Natural Capital Mapping

This project has generated EUNIS level 3 habitat classes for the littoral and high shore zones. This addition was important for correctly transferring the valuations from the scale of the UK to the Northern Irish region. The littoral habitats however are mostly unvalidated and should be treated with caution until the prediction (Combined map) is compared with actual littoral observations (this comparison should be easy to undertake but was beyond the scope of this project). It is also possible to include additional sources of information for the littoral habitats with the Combined map; for example, it would be helpful to include the modelling of Northern Irish blue carbon habitats (Strong et al., 2021) so that saltmarsh, seagrass, kelps and littoral bivalve beds can be better represented within the combined map.

The combination of the spatial footprint of human activities may also improve both the representation of habitat quality as well as the distribution of certain societal benefits. For example, Strong (2022) has recently estimated the spatial footprint of fishing, coastal infrastructure, aquaculture, high shore land-use changes, recreational activities, marine traffic and eutrophication in Northern Ireland. The same report also provides locally adjusted blue carbon tonnages for Northern Ireland that might provide additional information to support the valuation of societal benefits at a local level.

4.2 Valuation of Societal Benefits

There is currently no agreement within the scientific community regarding the best ecosystem service classification system to use. Indeed it has been argued by Fisher et al. (2009) that the classification system used to define ecosystem services should be linked to policy and management, and that different interpretations may therefore be needed depending on the context. de Groot et al. (2010) suggest that ‘perhaps we should accept that no final classification can capture the myriad of ways in which ecosystems support human life and contribute to human well-being’ and ‘that no fundamental categories or completely unambiguous definitions exist for such complex systems’. In this way different classifications can be seen to be complementary rather than competitive (Atkins et al., 2011).

For the purposes of the NI-MANACA project, 14 societal benefits were identified following the framework developed as part of the UK National Ecosystem Assessment Follow-on Project (UKNEAFO, 2014). This framework was selected as it was developed specifically for the UK marine environment and was consistent with the framework used in developing the UK marine natural capital accounts (ONS, 2021a). The UKNEAFO framework differentiates between the ecosystem services, which are delivered in the natural environment, and the societal benefits which are realised in the human domain. It would not be appropriate to value the ecosystem services in monetary terms as this may result in double counting of benefits provided for society and therefore our focus is solely on the societal benefits.

There was no resource available for primary data collection and, therefore, benefit transfer from published studies was the main option available. Estimates for the annual societal benefits delivered by the UK marine environment relied on benefit transfer methods. The limited number of UK-level studies prohibited a meta-analysis and therefore the majority of estimates were based upon a single estimate or on a range of estimates all derived using a similar methodology. Confidence in the results would be stronger if UK valuation data were more extensive.

Given the paucity of valuation data relating to the marine environment, UK valuation data was obtained from the published literature for eight out of the 14 societal benefits, with each presented in 2019 prices, using the UK GDP deflator to adjust prices to this common year where necessary. A range of valuation estimates were obtained for some societal benefits and therefore UK valuation data was presented using low, mid- and high values which represented a range of values. Following this approach, societal benefits provided by the UK marine environment were estimated to be in the region of £6.55 billion - £10.86 billion (in 2019 prices). These values are likely to be an underestimate of the total value given that there were gaps in the evidence base for a number of societal benefits. Point estimates need to be interpreted with some caution as they suggest a degree of accuracy that is inconsistent with the type of analysis undertaken. However, the estimates should be considered to be indicative of the scale of benefits that is being realised.

In order to take UK value estimates for marine societal benefits and apply them at different scales, i.e., Northern Ireland marine waters and the Northern Ireland MPA network, the NI-MANACA project followed the methodology developed by Moran et al. (2008). Valuation data is disaggregated based on our knowledge of the relationship between the importance of different marine habitats in delivering societal benefits. For the majority of societal benefits (11 out of 14), the relative importance in habitats delivering societal benefits was taken from assessments in the published literature (e.g., Potts et al., 2014). For those societal benefits where there is no scientific rationale to disaggregate across habitats then value was distributed evenly between the 28 habitat types. Once the UK value estimates are disaggregated by habitat type, the Northern Ireland natural capital mapping data can be used to estimate the value of Northern Ireland marine waters and its existing MPA network. Following this approach, societal benefits provided by the Northern Ireland marine environment were estimated to be in the region of £51.07 million - £83.28 million (in 2019 prices), whilst the Northern Ireland MPA network estimate was £20.81 million - £33.76 million (in 2019 prices). Again, it is emphasised that these value estimates are likely to be underestimates given the lack of valuation data for some societal benefits. In addition, it must be noted that all sites were treated as being 'typical', for example, in the sense that one hectare of coastal saltmarsh (A2.5) was assumed to deliver exactly the same amount of each societal benefit irrespective of its location. This assumption was necessary given the limited scientific evidence on the economic valuation of systemic MPA network effects.

Although the BEACH tool has been developed for use with UK-scale valuation data the tool does allow for the possibility of including Northern Ireland scale data where this is available. For example, Northern Ireland data on fish landings (wet weight in tonnes and price in £) for multiple years (2017-2021) is available. While this evidence is a direct indicator for the value of SB1 Food (wild, farmed) it is not entirely consistent with the approach adopted by the ONS. For the UK marine natural capital accounts, the ONS based their findings on landings evidence though removed landings costs from the data (see Section 3.2.1). In addition, Northern Ireland values were estimated for both SB6 Healthy Climate (see Table 7) and SB14 Human Health Benefits (see Table 16). Further research is required to permit Northern Ireland data to be used in the BEACH tool in a consistent way.

4.3 Future Scenarios Assessments

The future scenarios assessments presented in this report must be interpreted as hypothetical scenarios employed to demonstrate potential applications of the BEACH tool and that they in no way reflect current policy, planning or management of MPAs in Northern Irish waters.

The BEACH tool is a high-level Decision Support tool which provides indicative value estimates which can be used to support decision-making in the UK marine environment. It was not designed to be a substitute for place-based assessment which would still be required to meet legislative requirements. In its current form, it is considered inappropriate for the tool to be used for place-based or site-specific assessments given the basis of the analysis is the UK-level assessment i.e., a high level assessment, and place-based assessments are dependent on specific characteristics of that place (e.g., habitat, location, water depth, etc).

The assessments undertaken for the NI-MANACA project are for the current MPA network as a whole, and this allows little discretion in the choice of management measures at a site-specific level. In reality, management regimes would be designed for individual MPAs, taking local circumstances into consideration. Initial economic valuations were presented with the two management regimes applied across the entire network. However, looking at altering the mix of management scenarios has shown how potential benefits may change.

The NI-MANACA project assumes that higher levels of protection which are realised through more restrictive management regimes will lead to a healthier marine environment and, in turn, to greater value in terms of the societal benefits that are delivered. However, in reality, the value of some societal benefits may increase whereas others may decrease or even be reduced to zero. For example, under the recover management regime, assumes a ‘general presumption against fishing of all kinds, and all constructive, destructive and disturbing activities’. Under this management regime it is assumed that SB1 Food (wild, farmed) becomes zero and therefore there will be a reduction in the value of that societal benefit, which may in turn have an impact on the overall benefit provided by the site. However, other benefits such as SB6 Healthy climate may increase in value with undisturbed habitats providing a greater level of carbon sequestration and storage. In addition, there is increasing evidence within the literature of the impact of highly protected MPAs providing nursery areas for juvenile commercial fish populations (e.g. Stewart et al., 2020) with potential spill-over effects to the wider marine environment. At present, however, the BEACH tool does not take these any such potential off-site impacts into account.

4.4 Data Gaps and Recommendations

A number of data gaps and recommendations are provided below with respect to natural capital mapping, valuation of societal benefits and future scenarios assessments.

Natural Capital Mapping

- For the purposes of the NI-MANACA project a data gap for Northern Ireland littoral habitats was identified in the JNCC Combined map and therefore littoral habitats were modelled for Northern Ireland given their importance for delivering a range of societal benefits. It is recommended that ground truthing of Northern Ireland littoral habitats is required to validate the modelled outputs and to increase confidence in the data.
- As the marine habitats provide the primary way of scaling up the societal benefits, and the overall valuations associated with them, it is recommended that additional and on-going

resources are allocated to refining the Northern Ireland Combined map provided with this project. For example, the Combined map should be updated with recent modelling of Northern Irish blue carbon habitats (Strong et al., 2021) so that saltmarsh, seagrass, kelps and littoral bivalve beds can be better represented within the combined map.

- Whilst an assessment of confidence in the mapping data was generated (see Figure 6), this confidence was not incorporated into the BEACH tool. It is recommended that future iterations of the BEACH tool could incorporate such information so that the user is informed of the confidence in the underlying natural capital mapping data that drives the tool and underpins the valuation assessments.

- At present the GIS data is extracted from GIS software, cleaned and then pasted into the BEACH tool. It is recommended that a GIS tool could be created to enable EUNIS habitat data to be linked directly with the BEACH tool.

Valuation of Societal Benefits

- Marine valuation data is lacking at the UK-scale. For the NI-MANACA project there were still six societal benefits (i.e., fish feed; fertiliser and biofuels; ornaments and aquaria; medicines and blue biotechnology; prevention of coastal erosion; and spiritual and cultural well-being) where no UK-scale valuation data were identified. There is a need for the development of appropriate methodologies and primary research to fill the data gaps.

- UK valuation data for the NI-MANACA project was largely obtained from outputs from the UK marine natural capital accounts. Despite recognition that these accounts are experimental, the outputs are considered by the authors to be sufficiently robust for application within a UK marine context. Therefore, it is recommended that the valuation data used to drive the BEACH tool should be refined as and when updated natural capital accounts are published – the date for publication of the next marine natural capital accounts is currently unknown.

- The matrix approach is a useful tool for quick assessments of the relative importance of EUNIS habits in delivering societal benefits and therefore to provide weightings to disaggregate UK-scale values across UK habitats. The importance of natural capital features in the delivery of benefits to society is central to the NI-MANACA project and these underlying relationships are currently based on previously published assessments. There is a need to review these relationships, and to fill gaps in current understand ding.
- The Matrix approach is currently being reviewed and updated by JNCC so that an agreed approach can be made open access for use by all. This research, undertaken as part of the marine Natural Capital Ecosystem Assessment (mNCEA) Programme[13], will strengthen the links between habitats and societal benefits and ensure that a standardised approach is adopted across the UK. It is recommended that the matrix approach, which underpins the disaggregation process within the BEACH tool, is updated when the outputs from the mNCEA project are released.

- The matrix approach (after Potts et al., 2014) presents confidence scores for the relationship between natural capital features and the societal benefits they deliver. It is recommended that the potential to incorporate these confidence scores within the BEACH tool is investigated to enable the user to better understand the data which is used to drive the BEACH tool.

[13] https://marinescience.blog.gov.uk/2022/04/13/introducing-the-marine-natural-capital-and-ecosystem-assessment-programme-mncea/

- The BEACH tool is currently driven by UK-scale valuation data. However there is in-built functionality to enable it to include Northern Ireland specific data if available. It is recommended that further consideration is given to the inclusion of Northern Irish data though consideration must be given to the consistency of that data; if different methods are applied then the data will no longer be comparable to the UK valuation data.

Future Scenarios Assessments

- Given the lack of scientific evidence on the relationships between the EUNIS level 3 habitat types and the delivery of societal benefits, and on the impact of management regimes on the provision of societal benefits, a combination of literature review and expert judgement was employed, largely based on the findings of Moran et al. (2008), in order to assign appropriate weightings for the analysis. Specific relationships that result from this approach may be contested and therefore it is recommended that further research is required to review these relationships and update them where required.

- In addition to estimates of the mid-point values of benefits at the UK-scale, the BEACH tool currently accepts estimates of both lower and upper (range) limits of benefit value. However, at present, all valuation estimates undertaken by the BEACH tool are based solely on the mid-point estimates. There is scope to incorporate the ranges of valuations – where these are provided by the user – to automatically generate lower and upper (range) limits around estimates of value produced by the tool.
- At present the BEACH tool generates estimates values of benefits with no consideration of the costs involved with changes in management regime. Further work is required to investigate whether indicative management costs could also be incorporated into the BEACH tool.
- The interpretive and illustrative power of the BEACH tool could be improved by developing graphical routines to sit alongside the existing tabular outputs. These might include, for example, representations of the relative abundance of different habitat types in the across the different spatial scales being considered by the tool, and the automatic generation of heat-map outputs.

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Annex 1: Economic valuation methods

Value Domain	Method	Description	Example References
Ecological	Biological valuation	Marine biological valuation is based on a literature review of existing valuation criteria and the consensus reached by a discussion group of experts.	Derous et al., 2007; Pascual et al., 2011
	Ecological indicators	Indicators can be identified and populated to show changes in state, trajectory and behaviour of ecosystem services over time.	Burkhard et al., 2012; Hattam et al., 2015a; Atkins et al., 2015
Economic	Contingent valuation	Creates a hypothetical market by direct surveying of a sample of individuals and aggregation to encompass the relevant population.	Ressurreição et al., 2012; Atkins et al., 2007.
	Discrete choice experiment	Uses experiments to reveal factors that influence choice. Discrete choice models assume the respondent has perfect discrimination capability.	Jobstvogt et al., 2014; Borger et al., 2014a
	Market analysis	Where market prices of outputs (and inputs) are available. Could approximate with market price of close substitute. May require shadow pricing where prices do not reflect social valuations.	Cooper et al., 2013; Luisetti et al., 2011; Rees et al., 2010
	Benefit transfer	Uses primary valuation research results from one area (the study site) to make secondary predictions about values at a different area (the policy site).	Luisetti et al., 2015; Costanza et al., 2014
Socio-cultural	Participatory mapping	The gathering and mapping of spatial information to help communities learn, discuss, build consensus, and make decisions about their communities and associated natural resources.	Damastuti & de Groot, 2018; NOAA, 2015
	Citizen's Jury	Expert witnesses are invited to state their case to a group of jurors from the general public. After hearing all the witnesses' accounts, the jurors deliberate on the issue in attempt to reach a common 'verdict' or conclusion.	Hattam et al., 2014; 2015b
	Q method	Provides insights into the range of opinions that exist about some issues within a sample population, and how those opinions differ and converge. It turns qualitative deliberations with individuals into quantitative data.	Sy et al., 2018; Pike et al., 2014
	Community Voice	A participatory method which uses filmmaking to engage stakeholders to foster more inclusive, informed, and ongoing social dialogue in local communities.	Ranger et al., 2016
	Travel Cost	Cost incurred in reaching a recreation site as a proxy for the value of recreation.	Hanley et al., 2003; Chae et al., 2012
	Photo Elicitation	A qualitative interview method for eliciting comments, feelings and memories based on images such as photographs, cartoons, paintings and adverts.	Harper, 2002; Andrews et al., 2018
	Means-End & Chains Model, Laddering theory	A structured interview process for eliciting goals and personal values in relation to products / phenomena. Applied in the psychology and economics domain.	Reynolds & Gutman, 1988; Gutman, 1982
	Longitudinal values surveys	An approach that creates large scale data sets exploring and classifying public perceptions, values and priories around environmental issues.	Potts et al., 2016

Annex 2: BEACH Tool Structure

Introduction: what does the BEACH tool do?

As noted above, the BEACH tool (Benefit Evaluation through Assessment of Component Habitats) is an Excel-based tool that was developed to support the NI-MANACA project. It automates the process of transferring UK-scale (annualised) valuations to a range of scales within the Northern Ireland marine area by:

(i) disaggregating UK-scale benefit valuations – according to the relative abundance of each constituent EUNIS (level 3) habitat type, and the intrinsic value of each habitat type for each benefit stream (as outlined by the assessments within the matrix approach; Potts et al., 2014) and …
(ii) subsequently re-aggregating the derived 'transfer' values for each specific habitat/benefit combination on the basis of the extent of each constituent EUNIS (level 3) habitat type present within discrete target areas across a range of possible scales within the Northern Ireland marine area …
(iii) so producing derived annualised valuations for services/benefits at the new (target) scale.

This basic benefit transfer functionality was augmented to account for changes in value that might be expected as the result of protection/management measures, allowing forward projections of values under defined conditions to be made. This is achieved by:

(iv) applying predefined curves/profiles - describing potential changes in habitat condition (and hence in the value of associated benefit streams) under different management options (i.e., do-nothing, within unmanaged (unprotected) areas; and active management against either 'maintain' or 'recover' conservation objectives, within designated MPAs) …
(v) producing derived estimates of the nominal annualised value of each habitat/benefit stream combination, for each of the next 20 years …
(vi) and then discounting these nominal annual values (using a 3.5% annual discount rate) …
(vii) before summing the discounted values across all 20 years to generate discounted 20-year Net Present Value (NPV) estimates for each individual habitat/benefit combination at the new target scale.

The following text provides an overview of the appearance, operation and principal features of the BEACH tool, and covers the general layout of the BEACH tool, the principal inputs and controls, and the tool's main outputs.

General Layout of the BEACH tool

Figure A2.1 is an annotated screenshot of the main worksheet tab ('Controls & Inputs') of the BEACH tool. It identifies five key areas:

1 Data entry cells for recording benefit valuation data (at UK and Northern Ireland scales);
2 Data entry cells for describing the habitat breakdown (at UK, NI, and Northern Ireland MPA network scales);
3 A slider bar to allow the relative balance of management of the Northern Ireland MPA network to be adjusted between 'maintain' and 'recover';
4 Data entry cells for describing the habitat breakdown for an (optional) additional MPA site or network;
5 A brief summary output of transferred benefit (annualised valuations) and 20-year Net Present Values. summed across all services/benefits, for a range of target scales.

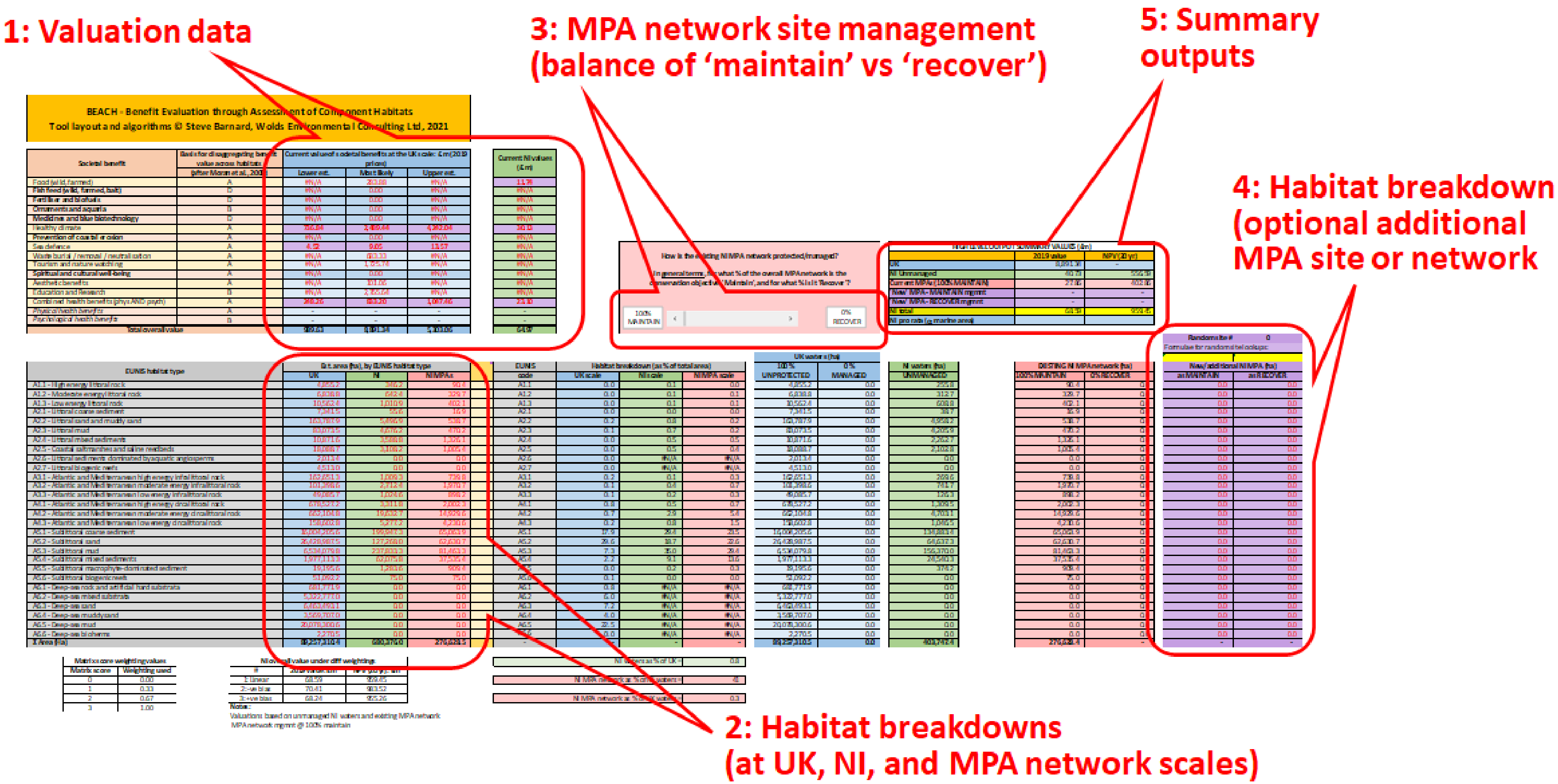


Figure A2.1: Screenshot of the main worksheet tab of the BEACH tool ('Controls & Inputs').

Operation of the BEACH tool

BEACH Inputs 1: Valuation data

These cells (see Figure A2.2, below) allow the user to enter estimates of the current value of societal benefits at the UK-scale (blue-shaded cells) and at the NI-scale (green-shaded cells). The minimum data that are required to run the tool successfully are the 'Most likely' benefit values as reported at the UK-scale. Currently, neither the lower or upper UK-scale benefit value estimates, nor the NI-scale estimates are used in the automated calculations that underlie the tool although it is planned to further develop the tool to include use of these additional data.

Note that all values are assumed to be recorded in millions of GBP (£m). Also note that, across this worksheet tab, user inputs are flagged using red text.

Societal benefit	Basis for disaggregating benefit value across habitats (after Moran et al., 2008)	Current value of societal benefits at the UK scale: £.m (2019 prices)			Current NI values (£.m)
		Lower est.	Most likely	Upper est.	
Food (wild, farmed)	A	#N/A	283.88	#N/A	**11.74**
Fish feed (wild, farmed, bait)	D	#N/A	0.00	#N/A	#N/A
Fertiliser and biofuels	D	#N/A	0.00	#N/A	#N/A
Ornaments and aquaria	B	#N/A	0.00	#N/A	#N/A
Medicines and blue biotechnology	D	#N/A	0.00	#N/A	#N/A
Healthy climate	A	**736.84**	**2,489.44**	**4,242.04**	**30.13**
Prevention of coastal erosion	A	#N/A	0.00	#N/A	#N/A
Sea defence	A	**4.52**	**9.05**	**13.57**	#N/A
Waste burial / removal / neutralisation	A	#N/A	683.33	#N/A	#N/A
Tourism and nature watching	A	#N/A	1,725.74	#N/A	#N/A
Spiritual and cultural well-being	A	#N/A	0.00	#N/A	#N/A
Aesthetic benefits	A	#N/A	101.06	#N/A	#N/A
Education and Research	B	#N/A	2,765.64	#N/A	#N/A
Combined health benefits (phys AND psych)	A	**248.26**	**833.20**	**1,047.46**	**23.10**
Physical health benefits	A	-	-	-	-
Psychological health benefits	B	-	-	-	-
Total overall value		**989.63**	**8,891.34**	**5,303.06**	**64.97**

Figure A2.2: Screenshot of data entry cells for recording benefit valuation data.

BEACH Inputs 2: Habitat breakdowns

These data input cells allow the user to input the habitat breakdown (as hectares; ha) by EUNIS (level 3) habitat classes across each of three different scales: the UK-scale (blue-shaded cells); the NI-scale (green-shaded cells); and the Northern Ireland MPA network scale (red-shaded cells) (Figure A2.3).

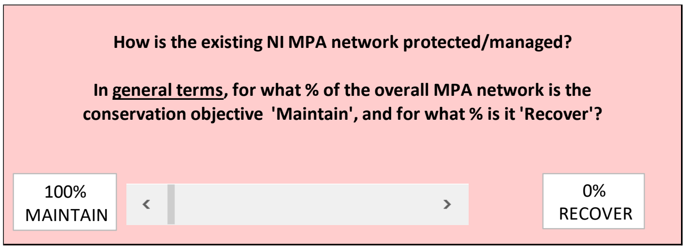
These data are typically produced as outputs from a GIS project.

EUNIS habitat type	Est. area (ha), by EUNIS habitat type		
	UK	NI	NI MPAs
A1.1 - High energy littoral rock	4,855.2	346.2	90.4
A1.2 - Moderate energy littoral rock	6,838.8	642.4	329.7
A1.3 - Low energy littoral rock	10,562.4	1,010.9	402.1
A2.1 - Littoral coarse sediment	7,341.5	55.6	16.9
A2.2 - Littoral sand and muddy sand	163,787.9	5,496.9	538.7
A2.3 - Littoral mud	83,073.5	4,676.2	470.2
A2.4 - Littoral mixed sediments	10,871.6	3,588.8	1,326.1
A2.5 - Coastal saltmarshes and saline reedbeds	18,088.7	3,108.2	1,005.4
A2.6 - Littoral sediments dominated by aquatic angiosperms	2,013.4	0.0	0.0
A2.7 - Littoral biogenic reefs	4,513.0	0.0	0.0
A3.1 - Atlantic and Mediterranean high energy infralittoral rock	162,651.3	1,009.3	739.8
A3.2 - Atlantic and Mediterranean moderate energy infralittoral rock	101,398.6	2,712.4	1,970.7
A3.3 - Atlantic and Mediterranean low energy infralittoral rock	49,085.7	1,024.6	898.2
A4.1 - Atlantic and Mediterranean high energy circalittoral rock	678,527.2	3,311.8	2,002.3
A4.2 - Atlantic and Mediterranean moderate energy circalittoral rock	662,104.8	19,632.7	14,929.6
A4.3 - Atlantic and Mediterranean low energy circalittoral rock	158,602.8	5,277.2	4,230.6
A5.1 - Sublittoral coarse sediment	16,004,205.6	199,947.3	65,063.9
A5.2 - Sublittoral sand	26,428,987.5	127,268.0	62,630.7
A5.3 - Sublittoral mud	6,534,079.8	237,833.3	81,463.3
A5.4 - Sublittoral mixed sediments	1,977,113.3	62,075.8	37,535.4
A5.5 - Sublittoral macrophyte-dominated sediment	19,195.6	1,283.6	909.4
A5.6 - Sublittoral biogenic reefs	51,092.2	75.0	75.0
A6.1 - Deep-sea rock and artificial hard substrata	681,771.9	0.0	0.0
A6.2 - Deep-sea mixed substrata	5,322,777.0	0.0	0.0
A6.3 - Deep-sea sand	6,463,493.1	0.0	0.0
A6.4 - Deep-sea muddy sand	3,569,707.0	0.0	0.0
A6.5 - Deep-sea mud	20,078,300.6	0.0	0.0
A6.6 - Deep-sea bioherms	2,270.5	0.0	0.0
Σ Area (Ha)	**89,257,310.4**	**680,376.0**	**276,628.5**

Figure A2.3: Screenshot of data entry cells for describing the habitat breakdown (at UK, Northern Ireland, and Northern Ireland MPA network scales).

BEACH Inputs 3: MPA network site management

Figure A2.4 shows the slider bar that is used to allow the user to indicate the relative balance of the current Northern Ireland MPA network in terms of the split between management to a 'maintain' and management to a 'recover' conservation objective. The adjacent, red-shaded cells provide an indication of the relative areas covered by each of these two management options across each of the 28 EUNIS (level 3) habitats. These data are produced automatically by the tool and are NOT input by the user (hence being in black, and not red, font). As the percentage balance between the two alternative management options is adjusted on the slider bar – between 100% maintain and 100% recover - the area values presented in the two red-shaded columns will be automatically updated. As discussed in the main text of this report, this percentage split is assumed to affect each habitat type within the MPA network equally and is not meant to represent a site-specific allocation between the two management options.



EXISTING NI MPA network (ha)	
100% MAINTAIN	**0% RECOVER**
90.4	0.0
329.7	0.0
402.1	0.0
16.9	0.0
538.7	0.0
470.2	0.0
1,326.1	0.0
1,005.4	0.0
0.0	0.0
0.0	0.0
739.8	0.0
1,970.7	0.0
898.2	0.0
2,002.3	0.0
14,929.6	0.0
4,230.6	0.0
65,063.9	0.0
62,630.7	0.0
81,463.3	0.0
37,535.4	0.0
909.4	0.0
75.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
276,628.4	-

Figure A2.4: Screenshot of MPA network site management controls.

BEACH Inputs 4: Habitat breakdown for (optional) additional MPA sites

The final set of data input cells allow the user to input the habitat breakdown (as hectares; ha) by EUNIS (level 3) habitat class for an optional additional MPA site or network (purple-shaded cells) (Figure A2.5). Two columns of cells are used for data inputs; the left column is for recording the area of each habitat type that is being managed to a maintain conservation objective at the MPA site or network scale, whilst the right column is for recording the area of each habitat type that is being managed to a recover conservation objective.

The cell labelled 'Random site #' (which initially holds a value of zero) acts as an index that allows for the automatic retrieval of the habitat data for each of the 64 randomly located demonstration sites that were produced as part of the assessment of scenario (iii) - (see Section 3.3.5). Entering a value between 1 and 64 into this cell will initiate the retrieval of the habitat data from the relevant demonstration site into *both* columns of this input section. This has the effect of producing parallel outputs that assume management to both a maintain and a recover conservation objective based on the same underlying habitat data, allowing a clear comparison of the relative effects of the alternative management options to be made. Returning the 'Random site #' value to zero will rest the data entry cells to zero (i.e., indicating that no additional MPA site or network should be considered).

Once the user has manually entered a value into one of the data entry cells in this section the formula that automatically retrieves the demonstration site data will be overwritten and lost. Should this happen it is possible to manually copy the contents of the two yellow cells (which, despite the text being hidden from view, hold the formulae for the random site lookups) and paste them into the two columns of cells below (i.e. into those cells shown with red text in Figure A2.5).

Random site #	0
Formulae for random site lookups:	
New/additional NI MPA (ha)	
as MAINTAIN	as RECOVER
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
0.0	0.0
-	-

Figure A2.5: Screenshot of data entry cells for describing the habitat breakdown for an optional additional MPA site or network.

BEACH Outputs

In addition to the data entry fields and controls, the main worksheet tab ('Controls & Inputs') also provides a high-level summary of the tool's outputs (Figure A2.6).

HIGH LEVEL OUTPUT SUMMARY VALUES (£m)		
	2019 value	NPV (20 yr)
UK	8,891.34	-
NI Unmanaged	40.73	556.59
Current MPAs (100% MAINTAIN)	27.86	402.86
'New' MPA - MAINTAIN mgmnt	-	-
'New' MPA - RECOVER mgmnt	-	-
NI total	68.59	959.45
NI pro rata (α marine area)	67.78	

Figure A2.6: Screenshot of high-level summary outputs.

The detailed outputs that underpin the summary figures are presented on the 'Detailed outputs' worksheet tab (Figure A2.7).

For the detailed outputs, the colour-coding that is applied to cell shading follows the conventions adopted elsewhere in the BEACH tool. Cells holding information (inputs or outputs) that relate to the UK-scale are shaded blue, whilst those that relate to the NI-scale are shaded green. Information relating to the current Northern Ireland MPA network is presented in red-shaded cells, whilst information for any additional MPA sites (or network) is given in purple shaded cells (with separate outputs for additional sites managed to a 'maintain', and to a 'recover', conservation objective). Finally, Northern Ireland total figures are shown in yellow-shaded cells.

The upper blocks of values present the outputs broken down by habitat, whilst the lower blocks are broken down by benefit type. At the same time, the left-hand blocks present outputs as annualised (2019 equivalent) values, whilst the right-hand blocks present the outputs as the 20-year Net Present Value estimates.

In all instances, values are presented as millions of GBP (£m).

BEACH Detailed outputs

Est. annualised (2019) value of societal benefits: £.m accruing - by habitat						Habitat type	Est. (20 yr discounted) Net Present Value of societal benefits: £.m				
UK	NI Unmanaged	Current MPAs	New MPAs - M	New MPAs - R	NI total		NI Unmanaged	Current MPAs	R64 # 0 M	R64 # 0 R	NI total
0.40	0.02	0.01	-	-	0.03	A1.1 - High energy littoral rock	0.29	0.11	-	-	0.39
0.56	0.03	0.03	-	-	0.05	A1.2 - Moderate energy littoral rock	0.35	0.39	-	-	0.74
0.86	0.05	0.03	-	-	0.08	A1.3 - Low energy littoral rock	0.68	0.48	-	-	1.15
0.93	0.00	0.00	-	-	0.01	A2.1 - Littoral coarse sediment	0.07	0.03	-	-	0.10
21.09	0.64	0.07	-	-	0.71	A2.2 - Littoral sand and muddy sand	8.69	1.00	-	-	9.69
9.28	0.47	0.05	-	-	0.52	A2.3 - Littoral mud	6.46	0.76	-	-	7.22
1.46	0.30	0.18	-	-	0.48	A2.4 - Littoral mixed sediments	4.13	2.57	-	-	6.70
3.18	0.37	0.18	-	-	0.55	A2.5 - Coastal saltmarshes and saline reedbeds	5.03	2.56	-	-	7.59
0.31	-	-	-	-	-	*A2.6 - Littoral sediments dominated by aquatic angiosperms*	-	-	-	-	-
0.51	-	-	-	-	-	*A2.7 - Littoral biogenic reefs*	-	-	-	-	-
16.76	0.03	0.08	-	-	0.10	A3.1 - Atlantic and Mediterranean high energy infralittoral rock	0.38	1.10	-	-	1.48
10.45	0.08	0.20	-	-	0.28	A3.2 - Atlantic and Mediterranean moderate energy infralittoral rock	1.04	2.94	-	-	3.98
5.06	0.01	0.09	-	-	0.11	A3.3 - Atlantic and Mediterranean low energy infralittoral rock	0.18	1.34	-	-	1.52
69.79	0.13	0.21	-	-	0.34	A4.1 - Atlantic and Mediterranean high energy circalittoral rock	1.83	2.98	-	-	4.81
68.10	0.48	1.54	-	-	2.02	A4.2 - Atlantic and Mediterranean moderate energy circalittoral rock	6.58	22.21	-	-	28.79
16.31	0.11	0.44	-	-	0.54	A4.3 - Atlantic and Mediterranean low energy circalittoral rock	1.46	6.29	-	-	7.76
1,390.80	11.72	5.65	-	-	17.38	A5.1 - Sublittoral coarse sediment	168.21	81.77	-	-	249.98
2,767.12	6.77	6.56	-	-	13.32	A5.2 - Sublittoral sand	89.48	94.83	-	-	184.31
718.92	17.20	8.96	-	-	26.17	A5.3 - Sublittoral mud	229.82	129.62	-	-	359.43
182.35	2.26	3.46	-	-	5.73	A5.4 - Sublittoral mixed sediments	31.25	50.06	-	-	81.31
2.52	0.05	0.12	-	-	0.17	A5.5 - Sublittoral macrophyte-dominated sediment	0.67	1.73	-	-	2.39
5.44	-	0.01	-	-	0.01	A5.6 - Sublittoral biogenic reefs	-	0.12	-	-	0.12
56.78	-	-	-	-	-	*A6.1 - Deep-sea rock and artificial hard substrata*	-	-	-	-	-
480.71	-	-	-	-	-	*A6.2 - Deep-sea mixed substrata*	-	-	-	-	-
572.91	-	-	-	-	-	*A6.3 - Deep-sea sand*	-	-	-	-	-
316.41	-	-	-	-	-	*A6.4 - Deep-sea muddy sand*	-	-	-	-	-
2,172.14	-	-	-	-	-	*A6.5 - Deep-sea mud*	-	-	-	-	-
0.20	-	-	-	-	-	*A6.6 - Deep-sea bioherms*	-	-	-	-	-
8,891.34	**40.73**	**27.86**	**-**	**-**	**68.59**	**Overall totals**	**556.59**	**402.86**	**-**	**-**	**959.45**

Est. annualised (2019) value of societal benefits: £.m accruing - by benefit						Societal benefit	Est. (20 yr discounted) Net Present Value of societal benefits: £.m				
UK	NI Unmanaged	Current MPAs	New MPAs - M	New MPAs - R	NI total		NI Unmanaged	Current MPAs	New MPAs - M	New MPAs - R	NI total
283.88	1.41	1.00	-	-	2.41	Food (wild, farmed)	18.71	14.44	-	-	33.14
-	-	-	-	-	-	*Fish feed (wild, farmed, bait)*	-	-	-	-	-
-	-	-	-	-	-	*Fertiliser and biofuels*	-	-	-	-	-
-	-	-	-	-	-	*Ornaments and aquaria*	-	-	-	-	-
-	-	-	-	-	-	*Medicines and blue biotechnology*	-	-	-	-	-
2,489.44	11.06	7.40	-	-	18.47	Healthy climate	151.23	107.08	-	-	258.31
-	-	-	-	-	-	*Prevention of coastal erosion*	-	-	-	-	-
9.05	0.07	0.05	-	-	0.12	Sea defence	1.01	0.69	-	-	1.70
683.33	3.06	1.96	-	-	5.02	Waste burial / removal / neutralisation	41.88	28.29	-	-	70.18
1,725.74	8.14	5.82	-	-	13.96	Tourism and nature watching	115.52	84.21	-	-	199.73
-	-	-	-	-	-	*Spiritual and cultural well-being*	-	-	-	-	-
101.06	0.72	0.47	-	-	1.19	Aesthetic benefits	10.33	6.85	-	-	17.18
2,765.64	12.51	8.57	-	-	21.08	Education and Research	163.47	123.95	-	-	287.42
833.20	3.77	2.58	-	-	6.35	Combined health benefits (phys AND psych)	54.44	37.34	-	-	91.78
-	-	-	-	-	-	*Physical health benefits*	-	-	-	-	-
-	-	-	-	-	-	*Psychological health benefits*	-	-	-	-	-
8,891.34	**40.73**	**27.86**	**-**	**-**	**68.59**	**Overall totals**	**556.59**	**402.86**	**-**	**-**	**959.45**

Figure A2.7: Screenshot of BEACH detailed outputs from the 'Detailed outputs' worksheet tab.

Annex 3: Links to Data Sources Used by the ONS (2021)

Benefit		Department	Publication title	Web links
Amenity value of sea views	Dwelling stock	Office for National Statistics	Dwelling stock by tenure, UK	https://www.ons.gov.uk/peoplepopulationandcommunity/housing/datasets/dwellingstockbytenureuk
	Imputed rentals	Office for National Statistics	04.2 Imputed rentals for housing CP NSA £m	https://www.ons.gov.uk/economy/nationalaccounts/satelliteaccounts/timeseries/adfu/ct
Carbon sequestration	Carbon price	Department for Business, Energy and Industrial Strategy	Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal	https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal
	Blue Carbon in Scotland (higher carbon sequestration rates: Burrows et al., 2017)	Scottish Natural Heritage	Assessment of Blue Carbon Resources in Scotland's Inshore Marine Protected Area Network	https://www.nature.scot/sites/default/files/Publication%202017%20-%20SNH%20Commissioned%20Report%20957%20-%20Assessment%20of%20Blue%20Carbon%20Resources%20in%20Scotland%27s%20Inshore%20Marine%20Protected%20Area%20Network.pdf
	UK carbon sequestration (lower rates referenced: Luisetti, et al., 2019 and de Haas et al., 1997)	Joint Nature Conservation Committee	Initial natural capital accounts for the UK marine and coastal environment	http://randd.defra.gov.uk/Document.aspx?Document=14643_JNCCCefasmNCAReportSummary.pdf
Fish capture	ICES rectangle-level fish landings	European Commission, Joint Research Centre	Fisheries landings & effort: data by c-square (2015-2019)	https://data.jrc.ec.europa.eu/dataset/79745491-f847-450a-a26d-fd4a8e4a14f4
	ICES rectangle spatial factors	Marine Management Organisation	ICES rectangle spatial factors	https://www.gov.uk/government/statistics/uk-commercial-sea-fisheries-landings-by-exclusive-economic-zone-of-capture-report-2019

Benefit		Department	Publication title	Web links
	ICES stock assessments	The International Council for the Exploration of the Sea	Stock assessment graphs	https://standardgraphs.ices.dk/stockList.aspx
Flood protection	Dwelling stock	Ministry of Housing, Communities and Local Government	Dwelling Stock Estimates: 31 March 2019, England	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/886251/Dwelling_Stock_Estimates_31_March_2019_England.pdf
	Land Use	Ministry of Housing, Communities and Local Government	Land Use in England, 2018	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/900910/Land_Use_in_England__2018_-_Statistical_Release.pdf
	Land classification	UK Centre for Hydrology and Ecology	Land Cover Map 2015	https://www.ceh.ac.uk/services/land-cover-map-2015
	Flood defences - England	Environment Agency	Flood Map for Planning (Rivers and Sea) - Spatial Flood Defences (without standardised attributes)	https://data.gov.uk/dataset/76828b72-3c9c-4700-83c7-d7c36047d322/flood-map-for-planning-rivers-and-sea-spatial-flood-defences-without-standardised-attributes
	Flood defences - Wales	Natural Resources Wales	Flood defences with standardised attributes	http://lle.gov.wales/catalogue/item/SpatialFloodDefencesWithStandardisedAttributes/?lang=en
	Housing footprints	Ordnance Survey	Zoomstack Map	https://www.ordnancesurvey.co.uk/business-government/products/open-zoomstack
Marine recreation	Recreation - Scotland	NatureScot	Scotland's people and nature survey - participation in outdoor recreation	https://www.nature.scot/scotlands-people-and-nature-survey-participation-outdoor-recreation
	Recreation - England	Natural England	Monitor of engagement with the Natural Environment (MENE)	https://www.gov.uk/government/collections/monitor-of-engagement-with-the-natural-environment-survey-purpose-and-results
	Recreation - Wales	Natural Resources Wales	National Survey for Wales	https://naturalresources.wales/evidence-and-data/research-and-reports/national-survey-for-wales/?lang=en
Wastewater	Population estimates	Office for National Statistics	United Kingdom population mid-year estimate	https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/timeseries/ukpop/pop

Benefit		Department	Publication title	Web links
	Waste water	European Environment Agency	Waterbase - UWWTD: Urban Waste Water Treatment Directive – reported data	https://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-6
Other datasets used in ONS (2021) publication				
	GDP deflators	HM Treasury	GDP deflators at market prices, and money GDP June 2019	https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-june-2019-quarterly-national-accounts
	Discount factors	HM Treasury	Green Book supplementary guidance: discounting	https://www.gov.uk/government/publications/green-book-supplementary-guidance-discounting
	Bond Yield	Bank of England	Annual average yield from British Government Securities, 10 year Nominal Par Yield	http://www.bankofengland.co.uk/boeapps/iadb/index.asp?Filter=Y&Travel=NIxIRx&levels=1&XNotes=Y&C=DUS&G0Xtop.x=51&G0Xtop.y=7&XNotes2=Y&Nodes=X41514X41515X41516X41517X55047X76909X4051X4052X4128X33880X4053X4058&SectionRequired=I&HideNums=-1&ExtraInfo=true
	Capital stocks	Office for National Statistics	Capital stocks and fixed capital consumption, UK Statistical bulletins	https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/bulletins/capitalstocksconsumptionoffixedcapital/previousReleases
	Exchange rate	Bank of England	Monthly average Spot exchange rate, US$ into Sterling	https://www.bankofengland.co.uk/boeapps/database/fromshowcolumns.asp?Travel=NIxAZxSUx&FromSeries=1&ToSeries=50&DAT=RNG&FD=1&FM=Jan&FY=1963&TD=31&TM=Dec&TY=2025&FNY=Y&CSVF=TT&html.x=66&html.y=26&SeriesCodes=XUMAUSS&UsingCodes=Y&Filter=N&title=XUMAUSS&VPD=Y
	Supply and use tables	Office for National Statistics	UK Supply and use tables	https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables
	Annual Business Survey	Office for National Statistics	SECTION D - ELECTRICITY, GAS, STEAM AND AIR CONDITIONING SUPPLY	https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/datasets/uknonfinancialbusinesseconomyannualbusinesssurveysectionsas