economics for the environment

Assessing the Impact of a Closure to Bottom-towed Fishing in the Three Nautical Mile Area of Scottish Waters

Final report

Blue Marine Foundation

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Disclaimer

This report has been prepared in accordance with our Proposal dated 11 April 2023, and agreed revisions to it. We are reliant on data that is available in the public domain and that eftec and Blue Marine Foundation have collected for the purposes of this project. While we have endeavoured to provide accurate and reliable information, we are not responsible for the completeness or accuracy of any such information. This report is intended solely for the information and use of Blue Marine Foundation and is not intended to be, and should not be, used by anyone other than the specified parties. eftec, therefore, assumes no responsibility to any user of this document other than Blue Marine Foundation.

Document evolution

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Executive Summary

This report explored the ecosystem service impacts of protecting Scottish waters out to three nautical miles from the coast from bottom-trawling and dredging (referred to as bottom-towed fishing within this report). This assessment comes in the context of increasing recognition of the importance of conserving and restoring marine ecosystems, and their critical role in climate regulation, biodiversity objectives, and human well-being.

These impacts include both potential benefits such as enhanced carbon sequestration or economic and ecological gains for the static gear sector, and potential costs like the losses to the bottom-towed fishing sector. Through review of published literature and a spatial analysis, aided by advice from marine ecosystem services experts, we have assembled an evidence-based assessment of the possible impacts. The results of the study are intended to inform policy-making and conversations with marine stakeholders, including conservation advocates, fishing industry representatives and policymakers.

This report covers baseline (i.e., business as usual) evidence on the value that marine natural capital within the three nautical mile (3nm) area currently provides for the whole of Scotland. The area under fishing pressure is where bottom-towed fishing currently occurs, along with other mobile and static gears (22,153km^2 – see Table ES.1). This is the part of the 3nm area where the benthic habitat and static gear fishers will benefit by introducing a closure to bottom-towed fishing. The project assessed the size of the positive and negative ecosystem services impacts by comparing two scenarios:

- **Business as Usual (BAU):** This baseline scenario assumed the continuation of current bottom-towed fishing activities, and no major changes in other marine management, and;
- **Protection Scenario:** This scenario assumed fisheries management measures would close Scottish waters within the 3nm area to bottom-towed fishing, with no other major changes to marine management.

This determines the scope to consider ecosystem services and benefits that are material to the 3nm area, specifically the impacts attributed to protecting an additional 22,153 km^2 of habitats within this boundary (Table ES.1). In both the BAU and Protection Scenario, other factors (e.g., planned interventions or developments) and changes from other external factors (e.g., climate change) were not accounted for. This is the first study to primarily focus on impacts of bottom-towed fishing on ecosystem services within the 3nm area, rather than across the whole Exclusive Economic Zone (EEZ).

Table ES.1: Summary of baseline areas within three nautical miles from the Scottish coastline

Baseline areas within 3nm	Extent (km^2)	% of 3nm area
Total area	30,759	NA
Area fully protected from bottom-towed fishing	4,268	14%
Area unprotected (i.e., no bottom-towed fishing restrictions)	26,489	86%
Area under fishing pressure from bottom-towed fishing	**22,153**	**72%**
Area not under fishing pressure from bottom-towed fishing	4,336	14%

A variety of data was used to represent the key asset attributes, ecosystem services and benefits considered, which were reported in an extended Natural Capital Balance Sheet (NCBS)[1] form. This was to ensure that a more comprehensive picture of the natural capital asset was given by the assessment and highlighted that not all material ecosystem services could be quantified and valued for the BAU and Protection Scenario. The analysis uses the best available evidence to assess natural capital assets and quantify and monetise ecosystem service impacts. However, there are varying levels of certainty across the evidence and assumptions – which are captured throughout the assessment.

The mapping undertaken to produce the asset register is a valuable output of this assessment. It details habitat within the 3nm area at the finest resolution possible, and shows the Protection Scenario has significant impacts spread across different marine natural capital assets:

- The Scottish seabed in the 3nm area is diverse, with five benthic habitats each making up more than 10% of the total area, but no habitat makes up more than 25% of the total.
- The area fully protected from bottom-towed fishing covers 14% of the 3nm area – this is just under half of the 30% target in the Kunming-Montreal Global Biodiversity Framework (30 by 30).
- Despite their high vulnerability to benthic fishing pressures, current protections cover only a third of the area of biogenic habitats.

These data mean the protection of the 3nm area would be significant for all the main habitat types in Scottish inshore waters, and for the different ecosystem services they provide.

The assessment illustrated the impact of implementing a closure to bottom-towed fishing in the 3nm area. In comparing the BAU to the Protection Scenario (see Table ES.2), the results showed:

- The area fully protected from bottom-towed fishing would increase from 4,300 km^2 to

[1] As developed in the natural capital account for National Nature Reserves produced by Natural England (Sunderland et al., 2019), and applied to marine management by Kharadi and Bayes, 2022).

30,800 km^2. As a result, all sublittoral habitats[2] in the 3nm area would be protected from bottom-towed fishing activity.

- The estimated net carbon sequestration within the 3nm area (i.e., carbon sequestered by subtidal habitats and net of emissions from sediment disturbance)[3] doubles, reflecting the recovery of subtidal sediments. This is expected to be an underestimate, as the potential expansion of areas of vegetated habitats (e.g., kelp) was not quantified.
- There would be potential for a 52% increase in static gear fish landings from areas previously under pressure from bottom-towed fishing.
- The total net monetary benefits increased approximately five-fold in present value terms over 20 years (from -£914 million in BAU to £3.6 billion in the Protection Scenario). In overall value terms, the expected loss in value from bottom-towed fishing was offset by the recovery of marine habitats to provide other ecosystem services (e.g., carbon sequestration).

The quantified and valued material ecosystem services had moderate to low confidence, due to limitations in available evidence and applicability to the study area. The ecosystem services and benefits captured only reflect recovery of current habitat and assumes this is sustained into the future. In addition, in both the BAU and Protection Scenario, it was expected that the monetary values of unquantified benefits would be significant. Analysis of the change in coverage of different habitats protected, indicated the scale of potential recovery of marine natural capital assets and of their provision of these unquantified ecosystem services. Relative to the BAU, the Protection Scenario provided a:

- 257% increase in protection – supporting gamete dispersal of marine flora and fauna, and pest and disease control.
- 60% increase in biogenic habitat areas protected – supporting regulating services (e.g., water quality and flood protection) as well as cultural services (e.g., nature-based tourism, health and well-being).
- 94% increase in seaweed and kelp areas protected supporting wild harvesting and aquaculture, and provision of fibres and other materials.
- 103% increase in vegetated habitat areas protected – supporting additional carbon sequestration benefits.

The completed assessment highlighted the need for further research into better understanding the impacts of fisheries management policies on the level and value of ecosystem services. This included access to data on trends in marine habitat extent, condition, and the ecosystem services they provide, as well as accounting for external factors (e.g., climate change) in the assessment

[2] Defined as those habitats that are “A5 - Sublittoral sediment” in EUNIS.

[3] Emissions from sediment disturbance in the area receiving protection (i.e., 22,153 km^2 in Table ES.1) will decrease as a result of protection.

of the BAU and Protection Scenario. For example, research is required on carbon emissions to support refinement of the approaches applied (e.g., carbon emissions from sediment) and to expand the impacts assessed (e.g., carbon sequestration from other marine habitats), and on tourism and recreation to understand how activity and spending could change in response to potential recovery of habitats and species.

It was recognised that the Protection Scenario could result in significant positive and negative socio-economic impacts to the fishing sector and associated coastal communities over the assessment period. The economic transition to a scenario in which benthic habitats in the 3nm area were protected, would therefore require detailed research and planning into the support required for those affected. The significant ecosystem service values for Scotland and global society identified in this study could help justify Government action to provide such support to impacted fishers. Public funds could be used to help secure long-term benefits from and for the marine environment. This report intends to fill a knowledge gap to inform decisions towards sustainable management of Scotland's marine resources.

Table ES.2: Overview of BAU vs Protection Scenario results, Year 20

Indicator	BAU	Protection Scenario	Change from BAU
Ecosystem asset (unit)			
Area fully protected from bottom-towed fishing (km^2)	4,268	30,757	↑
Area of sublittoral zone under pressure from bottom-towed fishing (km^2)	15,810	-	↓
Asset value of benefits (PV20 £m)			
Value of fish landings from bottom-towed gears	666	-	↓
Value of fish landings from static gears	678	1,032	↑
Value of CO_2 emissions from sediment disturbance	(2,973)	-	(↓)
Value of CO_2 sequestered by subtidal sediments	662	2,357	↑
UK nature-based tourism spend on wildlife watching in 3nm area	52	52	-
Willingness to pay for increased protection of 3nm area	Not assessed	149	-
Total quantified monetary benefits (PV20 £m)	**(914)**	**3,590**	↑
Significance of unquantified monetary benefits			
Includes: harvested wild seaweed and cultivated seaweed, maintenance of nursery populations and habitats, thriving wildlife, CO_2 sequestered by other marine habitats, nature-based recreation, health & wellbeing, scientific/education, aesthetic, spiritual and/or emblematic services.	Moderate in short term Potentially high in long term		

Table notes: Values in (red) are negative and represent negative impacts (i.e., costs). (↓) denotes a reduction in a negative impact.

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Abbreviations & Acronyms

AIS	Automatic Identification System
BAU	Business as usual
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
Defra	Department for Environment, Food and Rural Affairs
EAV	Equivalent Annual Value
EEZ	Exclusive Economic Zone
EUNIS	European University Information Systems organisation
IPCC	Intergovernmental Panel on Climate Change
JNCC	Joint Nature Conservation Committee
mNCEA	Marine Natural Capital and Ecosystem Assessment
MPA	Marine Protected Area
NCBS	Natural Capital Balance Sheet
ONS	Office for National Statistics
SVO	Social Value of Offset
uASM	Universal Asset Service Matrix
VMS	Vessel Monitoring System
WTP	Willingness To Pay
3nm	Three Nautical Mile

1. Introduction

This report was commissioned by Blue Marine Foundation (Blue Marine) to explore the ecosystem service impacts of protecting the three nautical mile (3nm) area out to sea from the coastline in Scottish waters from bottom trawling and dredging (i.e., bottom-towed fishing). This assessment comes in the context of increasing recognition of the importance of conserving and restoring marine ecosystems for their critical role in climate regulation, biodiversity objectives, and human wellbeing.

1.1 Project objectives

Blue Marine commissioned this study to understand the benefits and costs of re-introducing a 3nm limit around the Scottish Coastline. The 'three nautical mile limit' was previously in place between 1886 and 1984. The management of the 3nm area is a key factor in the economic and environmental sustainability of the Scottish fishing sector and marine environment.

Blue Marine, as members of the Our Seas coalition[4], is campaigning for the re-introduction of a modern inshore limit. The results of this study will help to inform and support Our Seas coalition objectives and Blue Marine's conversations with various stakeholders, including policymakers, aimed at improving the protection of Scotland's marine environment, fisheries, and coastal communities (see Section 2.4 for further details).

This report provides evidence on the baseline value that marine natural capital in the 3nm area of Scottish waters provides for the whole of Scotland. Against this baseline, it assessed the size of the positive and negative ecosystem services impacts associated with the introduction of policy measures to conserve and restore inshore waters through a closure to bottom-towed fishing.

Note that this report covered ecosystem services analysis at a Scottish scale. It did not cover non-ecosystem service impacts (e.g., changes to management costs) nor consequential social impacts (e.g., on employment). This was to focus the work on ecosystem services. Extension to wider economic impacts (e.g., processing sector, jobs) should be possible but can be better assessed following the ecosystem services assessment.

1.2 Structure of the report

The report includes a description of the approach, methods for valuing ecosystem services, and results. In addition, there are a set of appendices with further details on the GIS analysis for habitat mapping and fish landings, typologies for habitat classification and ecosystem services, as well as assumptions and sources for valuation methods.

[4] https://www.ourseas.scot/

2. Approach

This section sets out the approach to ecosystem service valuation. It summarises the analysis framework and natural capital approach, along with explaining how key inputs to the analysis were identified.

2.1 Analysis framework

To understand the potential ecosystem services impacts of inshore marine protection in Scottish waters, a methodology based on the natural capital approach was used. This approach integrated data from various sources and employed several analysis techniques to ensure the most comprehensive understanding of the impacts possible. The analysis framework in Figure 2.1 summarises the approach used.

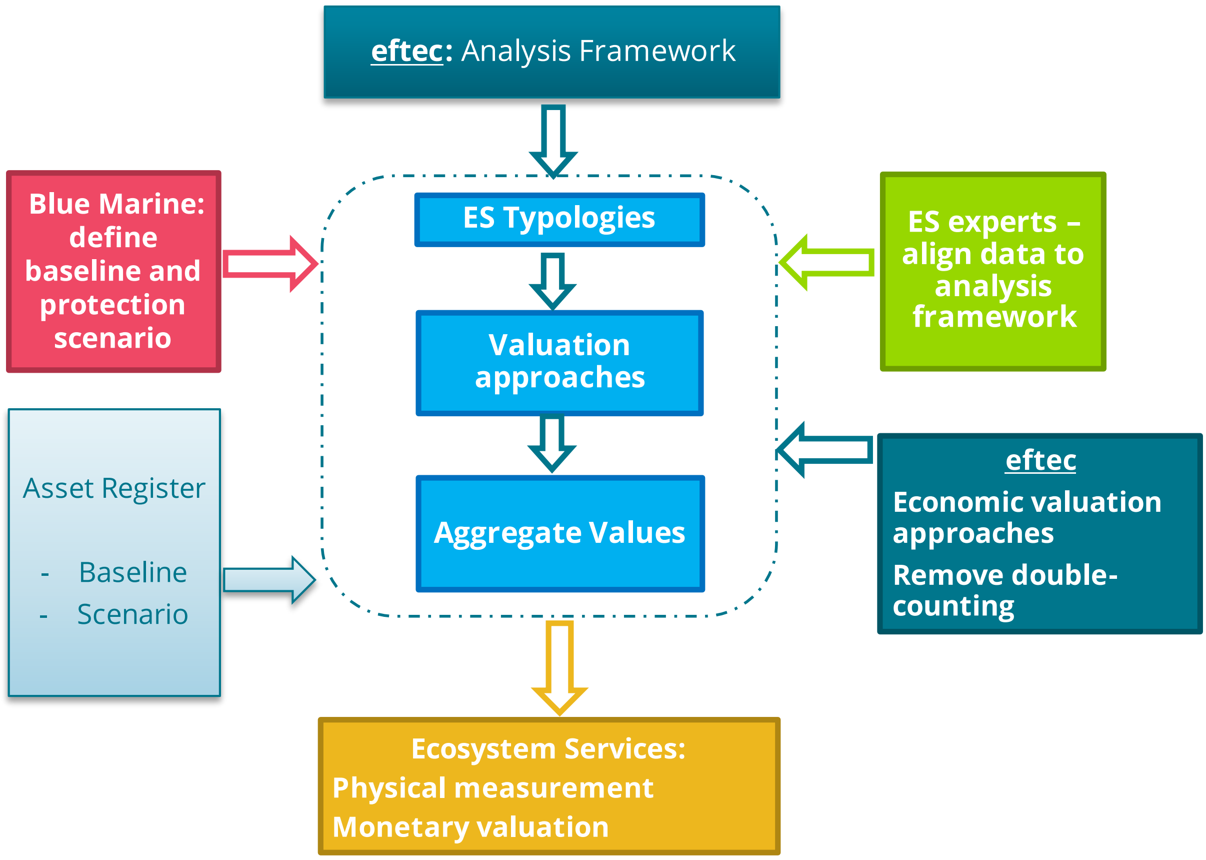

Figure 2.1: **Analysis Framework.**

2.2 Scenario descriptions

The analysis undertaken in this report considered two scenarios to assess the current state of policy against the expected changes that would result from a closure to bottom-towed fishing in the 3nm area.

- **Business as Usual (BAU):** This baseline scenario assumed the continuation of current bottom-towed fishing activities, and no other changes in marine management, and;
- **Protection Scenario:** This scenario assumed a complete cessation of bottom-towed fishing within the 3nm area, with no other changes to marine management.

The impacts of both the BAU and Protection Scenario were examined. By comparing these two scenarios, the analysis aimed to estimate the potential changes from a closure to bottom-towed fishing within the 3nm area, considering both medium (e.g., 10 years) and long-term (e.g., 60 years) effects on marine ecosystems and the services they provide. The specification of the BAU and Protection Scenario for the analysis is outlined in Table 2.1, with further detail provided in Appendix A4.1.

Table 2.1: Descriptions of Business as Usual and Protection Scenario and expected impacts

Factors	Business As Usual (BAU)	Protection Scenario
Fishing and management	• Current management and restrictions in the 3nm area remain the same (i.e., distribution between protected and unprotected areas). • All fishing continues at current levels of activity and landings, including bottom-towed fishing, other mobile and static gears.	• Bottom-towed fishing activities cease within the 3nm area. • No change to those already using other mobile and static gear types – their fishing effort continues at current levels, whilst more of the area in the 3nm area becomes suitable to static gears. • 22,153 km^2 within the 3nm area receives protection from bottom-towed fishing.
Impacts on natural capital assets and ecosystem services	• Condition of seabed and marine habitats remains at current levels, including fish and shellfish stocks. • Ecosystem service quantities and benefit values from protected areas and areas not under pressure from bottom-towed fishing remains constant over time.	Habitat condition within the newly protected area improves, which impacts ecosystem services: • Fish and shellfish population increases in both the previously trawled area and its surroundings, providing spill-over benefits. • Carbon in the sediments of the area previously subject to bottom-towed fishing stops being released by these activities. • Additional flows of material ecosystem services arise from areas receiving protection (i.e., 22,153 km^2). • Species abundance and diversity improves.
Other factors	• Planned interventions or developments in the Scottish inshore region are not accounted for in this analysis. • Other changes by external factors (e.g., climate change, economic growth, technological development) also remain unquantified in this analysis.	

2.3 Natural capital approach

Natural capital is "the stock of renewable and non-renewable natural resources (e.g., plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people" (Natural Capital Coalition, 2016). A natural capital approach can be defined as distinguishing between the natural capital stocks and the flows of benefits they provide; projecting benefits into the future; and linking the provision of benefits to the extent and condition of assets. The intention is to ensure that interventions and business decisions prioritise maintaining the assets to sustain benefits, and not to maximise one of the benefits at the expense of others or the extent and condition of the natural capital asset itself. The Green Book (HM Treasury, 2022) provides a higher-level overview of the impact pathway(s) linking changes in the natural environment to changes in value to society. This impact pathway is shown in Figure 2.2, adapted to align with the context of this study.

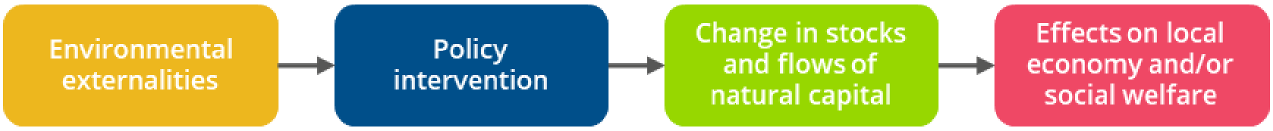

Figure 2.2: Natural capital impact pathway *Source: Adapted from HM Treasury (2022).*

The Protection Scenario (i.e., policy intervention) was assessed in terms of environmental changes. By utilising a natural capital perspective, the study took a more holistic basis for determining and measuring impacts, resulting from changes in stocks of natural assets and/or flows of benefits. The resulting approach to the assessment is illustrated in Figure 2.3. This approach allows for synergies to be clearly established and accompanying reporting outputs to capture a wider view of benefits and values. This approach was refined through discussion with Blue Marine and an expert group.

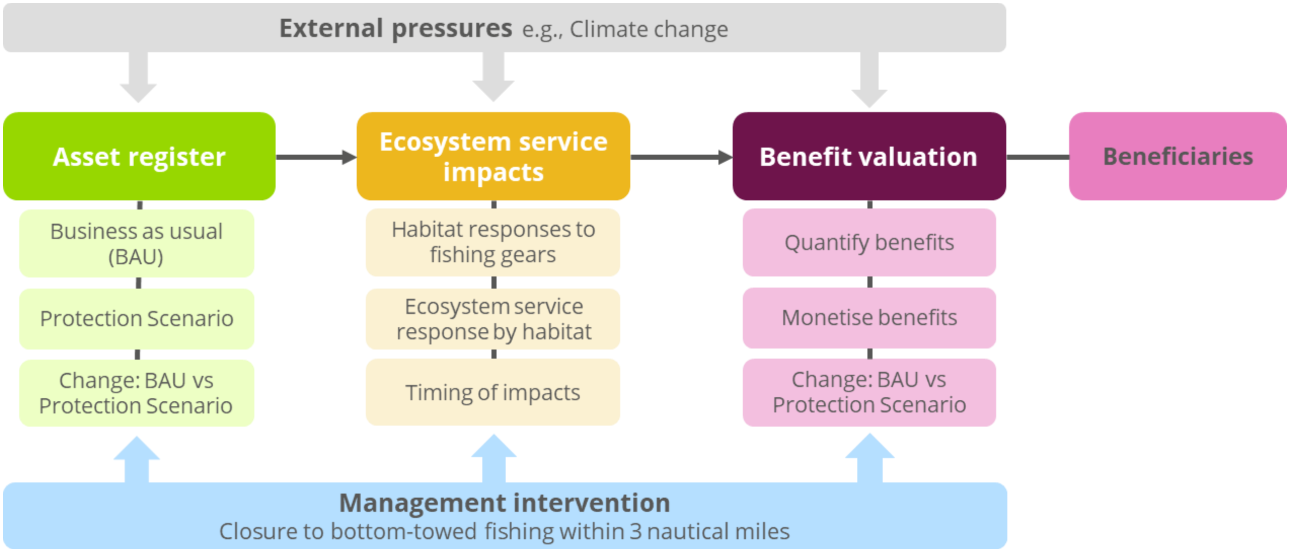

Figure 2.3: Natural capital approach to assessing bottom-towed fishing closure.

Based on assumed future trends in asset size and condition and ecosystem services and/or values, the present value of the sum of future benefits was calculated to give an asset value. The ecosystem service (annual and asset) value calculations are described in more detail in Section 3.3 and Appendix 4. In general, methods used recognised government data sources and large-scale modelling sources for quantities of benefits and unit values and followed approaches used in previous relevant assessments (e.g., Kharadi & Bayes (2022)).

The advantages of this natural capital approach are that it:

- Considers long-term value of natural capital assets, therefore encouraging the monitoring and sustainable management of natural capital;

- Identifies both private and public values provided by natural capital assets;
- Provides a framework within which changes in natural capital assets can be measured over time, relative to a 'baseline year'. It can also be the basis of scenario analysis to test future changes in the extent and condition of natural capital assets; external factors like climate change; and outcomes of decisions by the stakeholders; and
- Measures changes in the value of natural capital benefits by cause (i.e., by extent and condition of natural capital assets, beneficiaries, external factors, and effect of decisions).

There are particular challenges to assessing marine natural capital. These include:

- The three-dimensional structure and dynamic characteristics of the marine environment makes economic valuation of marine ecosystem goods and services particularly difficult relative to terrestrial environments. It can be harder to link ecosystem goods and services to specific marine habitats, many of which derive from a combination of biotic and abiotic assets together with other capital inputs (e.g., manufactured assets).
- There is often little information on how flows of goods and services vary with changes in the underlying natural capital assets, and the relationships are likely to be non-linear and complex (e.g., perhaps being discontinuous, having thresholds, and sometimes path dependency). For example, all habitat types may play a role in maintaining fish stocks that support commercial landings of fish and many external factors (e.g., temperature and acidity of water, benthic environment, pollution of water body from different sources, fishing pressure etc.) influence fish stocks, which makes isolating the impact of one particular change challenging.

The outputs of this work are reported in accordance with an extended Natural Capital Balance Sheet (NCBS)[5] which provides a full overview of key asset attributes, ecosystem services and benefits considered as part of this study. This application of the extended natural capital balance sheet follows its application in Kharadi and Bayes (2022), where an 'extended' NCBS was developed to showcase the results of scenario analysis.

2.4 Summary of management in the 3nm area

The inshore area (i.e., from coastline to 12nm) contains some of Scotland's most productive habitats, including valuable fishing grounds, and habitats that support commercial fish stocks throughout Scottish waters. Relative to all Scottish waters, the inshore area is disproportionately important for many ecosystem services, due to more diverse and productive shallow water habitats and their proximity to human populations and activities.

Scottish inshore waters within the 3nm area were protected under fisheries regulations between 1886 and 1984. Those restrictions were in response to fishermen's concerns about the emergence and impact of bottom trawling activity on the marine environment and the fisheries. For example, in the early 19th century the rise in bottom-towed fishing activity in the Firth of Clyde resulted in a decline of fish landings due to over-fishing in the inlet and use of damaging fishing practices (Thurstan and Roberts, 2010). This was partly

[5] As seen in the natural capital account for National Nature Reserves produced by Natural England (Sunderland et al., 2019).

driven by increased demand for alternative fishing grounds as many fish stocks in offshore waters reduced or collapsed. Fish landings data for the area and historical accounts indicate that the closure to bottom-towed fishing helped marine ecosystems to recover and maintain their productivity. Following continued pressure from the commercial bottom trawl industry the closure was repealed in 1984. Today bottom-trawling is allowed[6] in over 90% of Scotland's inshore waters and dredging in 95% of them. Since 1984, inshore fish stocks have plummeted along with the numbers of active fishermen around its coast (Thurstan and Roberts, 2010). Fishers are having to fish harder for less, as habitats have been reduced to a fraction of their historic extent.

The 3nm area is shown in Figure 2.4. It is partially covered by bottom-towed fishing restrictions. While some of these are full closures (i.e. permanently closed to all types of bottom-towed fishing), some offer only seasonal protection, prohibit specific features on fishing vessels, or are linked to vessel or engine size. More details are provided in the asset register results (Section 4). Table 2.2 presents a summary of current restrictions across the 3nm area, giving areas:

- Fully protected from bottom-towed fishing with restrictions in place is shown in Figure 2.5. Note that fishing by other mobile (e.g., purse seines) and static gear types (e.g., lines, creel fishing) may still occur.
- Under pressure from bottom-towed fishing, along with other mobile and static gears. These are the habitat areas that would receive protection in the Protection Scenario – the row in bold in Table 2.2.
- Not under fishing pressure from bottom-towed fishing – where the underlying data indicate fishing using these gear types does not occur, however fishing with other mobile and static gears may still occur.

Table 2.2: Summary of protection levels in the 3nm area

Baseline protection levels within the 3nm area	**Extent (km²)**	**% of total 3nm area**
Total area	30,759	100%
Area fully protected from bottom-towed fishing	4,268	14%
Area unprotected (i.e., no bottom-towed fishing restrictions)	26,489	86%
Area under pressure from bottom-towed fishing	**22,153**	**72%**
Area not under pressure from bottom-towed fishing	4,336	14%

Table note: Definitions of fishing gear types are in Appendix A1.2.

[6] Note that in this context 'allowed' indicates permission for these activities to be used but does not reflect the rate at which these activities occur as not all areas are suitable for bottom-towed fishing despite it being allowed.

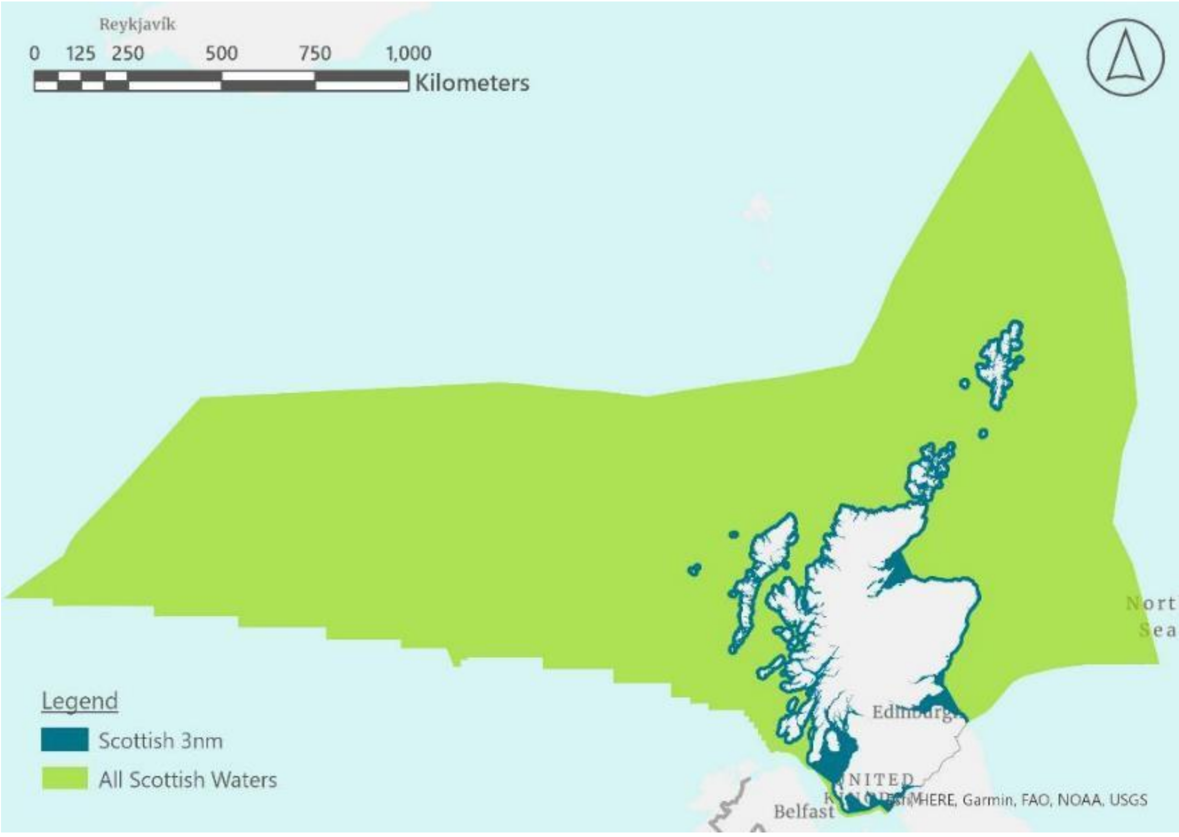

Figure 2.4: **Map of 3nm area relative to all Scottish waters.**

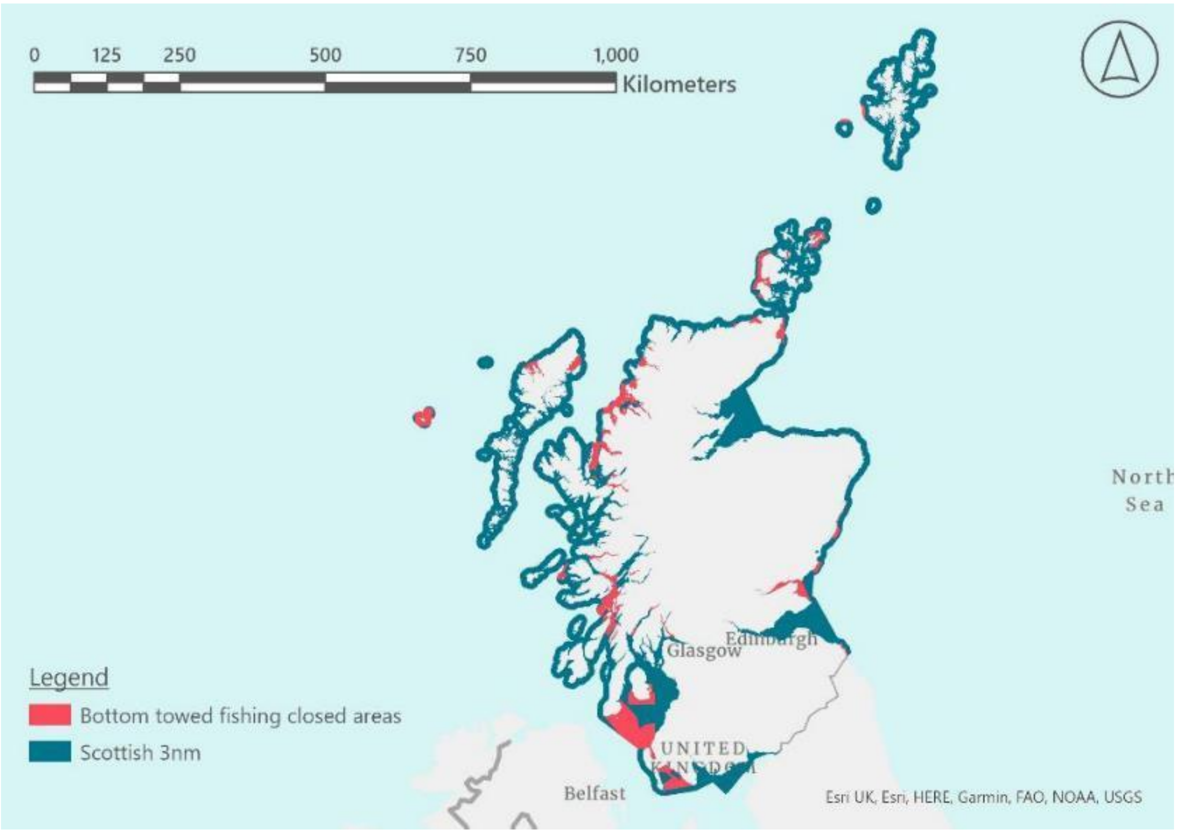

Figure 2.5: **Areas closed to bottom-towed fishing within the 3nm area.**

Landings of bottom-towed gears across all Scottish Waters is shown in Table 2.3 (as reported in Scottish Sea Fisheries Statistics from 2013–2022 (Scottish Government, 2021)). Bottom-towed fishing gears include trawls, seines, twin/multi-trawl for demersal fisheries and *Nephrops* trawls and dredging used for shellfish. Other mobile gears (e.g., purse seines) are used for pelagic fisheries and are less likely to be used within the 3nm area. Estimates of fish catch, and associated value were not publicly available for the 3nm boundary, therefore within the subsequent analysis Scottish Sea Fisheries Statistics were adjusted based on previous publications from Marine Scotland (Marine Scotland Science, 2014) – further details on this are provided in Appendix 4.

Table 2.3: Landings and value of landings by bottom-towed gears in all Scottish waters

Year	Fish landings (tonnes)	Value of landings (£m, 2023 prices)
2013	265,569	478
2014	256,904	496
2015	224,544	440
2016	225,114	518
2017	278,545	608
2018	274,552	620
2019	254,882	595
2020	221,561	409
2021	209,879	426
2022	196,433	456
10-year average	**240,798**	**505**

Table 2.4 shows that bottom-towed fishing occurs in approximately 52% of all Scottish Waters, the large majority of which (48% of total area with bottom-towed fishing) are beyond the 3nm area. Although the area within the 3nm area accounts for 4% of all Scottish waters, this accounts for 8% of the area where bottom-towed fishing activity occurs in all Scottish waters.

Table 2.4: Area of Scottish waters covered by bottom-towed fishing

<table>
<tr><th colspan="2"></th><th>All Scottish Waters[1]</th><th>Within 3nm</th><th>Outside 3nm</th></tr>
<tr><td rowspan="2">Total area</td><td>km^2</td><td>617,643</td><td>30,759</td><td>586,884</td></tr>
<tr><td>% of all Scottish waters</td><td>100%</td><td>8%</td><td>92%</td></tr>
<tr><td rowspan="2">Area with bottom-towed fishing</td><td>km^2</td><td>321,126</td><td>26,545</td><td>294,581</td></tr>
<tr><td>% of all Scottish waters</td><td>52%</td><td>4%</td><td>48%</td></tr>
</table>

Table note:
[1] All Scottish waters defined as continental shelf limits (up to 350nm from baseline) (Marine Scotland, 2023).

Current activity of static gears (landings and value, based on latest Scottish Sea Fisheries Statistics) is shown in Table 2.5. Static gears include lines and gill nets for demersal fisheries and creel fishing and hand diving for shellfish.

Table 2.5: Landings and value of landings by static gears in all Scottish Waters

Year	Fish landings (tonnes)	Value (£m, 2023 prices)
2013	23,319	80
2014	25,757	86
2015	25,472	84
2016	28,024	96
2017	21,661	77
2018	24,126	96
2019	24,676	107
2020	20,355	72
2021	20,349	87
2022	20,401	82
10-year average	**23,414**	**87**

Table 2.6 shows that static gear fishing occurs in approximately 12% of all Scottish waters, with the majority occurring beyond the 3nm area (65% of total area with static gear fishing). The area within the 3nm area accounts for 4% of all Scottish waters but represents 35% of the area where static gear fishing occurs.

Table 2.6: Area covered by static gear fishing

<table>
<tr><th colspan="2"></th><th>All Scottish Waters[1]</th><th>Within 3nm</th><th>Outside 3nm</th></tr>
<tr><td rowspan="2">Total area</td><td>km^2</td><td>617,643</td><td>30,759</td><td>586,884</td></tr>
<tr><td>% of all Scottish waters</td><td>100%</td><td>35%</td><td>65%</td></tr>
<tr><td rowspan="2">Area with static gear fishing</td><td>km^2</td><td>74,152</td><td>25,621</td><td>48,531</td></tr>
<tr><td>% of all Scottish waters</td><td>12%</td><td>4%</td><td>8%</td></tr>
</table>

Table note:

[1] All Scottish waters defined as continental shelf limits (up to 350nm from baseline) (Marine Scotland, 2023).

2.5 Data collection and review

To identify the evidence needed to meet the study objectives, a set of critical questions were formulated to guide the ecosystem services and economic data collection and review:

- What are the impacts of bottom-towed fishing on marine habitats and ecosystems?
- What are the recovery rates of marine habitats following the cessation of bottom-towed fishing?
- What are the recovery rates for other ecosystem services after bottom-towed fishing ceases?

These questions were explored through two iterative stages: by reviewing the relevant literature and by engaging with marine environment experts through an online workshop.

2.5.1 Literature review

The literature review was conducted in two phases, with different objectives:

- Prior to the Expert Workshop: The aim was to identify studies that offered research and valuable insights into methodologies, values, and findings on the benefits of prohibiting bottom-towed fishing in Scottish waters. The evidence review scope was initially limited to Scottish inshore waters and literature published post-1984 due to the repeal of the closure to bottom-towed fishing later that year. It was initially conducted using literature provided by Blue Marine and expanded upon with linked relevant sources.
- Following the Expert Workshop: This search focused on collecting the best available evidence identified from the workshop and known to the project team. The aim was to assess the broader impacts of bottom-towed fishing and dredging activities, such as changes in fish and invertebrate populations, carbon storage capacities, and recreational value, among other ecosystem services. Note that after the Expert Workshop, the review scope was expanded to include the UK and northern Europe, with no time-constraint on source publication date.

The first phase of the literature review collected data and evidence relating to the following key categories:

- **Habitats within the 3nm area of the Scottish coastline:** Physical data on areas of habitats and their current management (e.g., protected areas, areas restricted to certain fishing activities) drove the scope of the assessment. Although habitat areas (i.e., extent) are of interest and a primary input to estimating ecosystem service values, details on characteristics (e.g., wave exposure, depth) were also collected to contextualise the impacts of bottom-towed fishing on specific habitats. This was investigated and provided by the GIS lead at Blue Marine.
- **Understanding current ecosystem service provision:** Current and expected effects of bottom-towed activities on marine habitats, fish, and shellfish populations. This included quantitative physical (e.g., tonnes/ha/yr) and economic (£/tonne) data on ecosystem services, such as biodiversity, carbon storage and sequestration.
- **Understanding impacts of protection:** Provide context and potential effects of implementing a closure to bottom-towed activities. This included physical and economic data for the same categories as for the BAU, but also information on habitat recovery rates (e.g., the timing of recovery).

2.5.2 Engagement with expert group

To gather a wide range of perspectives and expertise on the study objectives, Blue Marine led engagement with a range of marine environment experts from across the UK. A key part of this process was a virtual Ecosystem Service Valuation Workshop (16 May 2023) with participants from Blue Marine Foundation, University of Glasgow, Plymouth Marine Laboratory, Sustainable Inshore Fisheries Trust, and Pollination Group. The workshop served as a platform for open discussion and idea exchange about how to assess marine ecosystem service impacts.

The workshop primarily focused on discussing the impact of closing inshore Scottish waters to bottom-towed fishing. Core discussion points included:

- **Holistic Perspectives of Marine Ecosystems:** There was a consensus on the need to take a holistic view of marine ecosystems. This view should not only consider seabed habitats, but also dependent marine species such as mammals, and issues like ghost gear. Cultural services (e.g. marine tourism and recreational angling) impacted by bottom-towed fishing were also underlined as a crucial point to consider.
- **Fish Populations and Juvenile Recruitment:** Expert judgement from workshop participants suggested that an improvement in inshore habitats could lead to changes in stock dynamics, such as an increase in juvenile fish, and an increase in bycatch (e.g. for species like cod). However, data on juvenile fish populations were limited, with the most comprehensive surveys being somewhat outdated (2018 and 2019).
- **Habitat Recovery and Limiting Factors:** The information on habitat condition and recovery was considered sparse, with only a few older studies available (Loch et al., 2004; Ramsay et al., 2001). There were discussions on the impact of different forms of bottom-towed fishing on biodiversity recovery rates[7]. Analysis should consider impacts of the Protection Scenario on species throughout the benthic habitats and water column,
- **Fishing Activities and Impacts:** The effectiveness of current MPA designations in Scotland for managing illegal fishing practices on the environment remains uncertain, with the potential for an inshore bottom-towed fishing closure to increase the intensity of offshore effort and/or in illegal fishing activities. The quality of data on fishing activity was also discussed, with both Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data sources having their limitations.
- **Ecosystem Services:** The importance of defining the beneficiaries of ecosystem services in the Protection Scenario was highlighted, with potential trade-offs with fisheries, recreational activities, and tourism identified. Possible increases in recreational fishing and seaweed cultivation due to a closure to bottom-towed fishing were discussed.
- **Blue Carbon Credits:** The potential of blue carbon credits was highlighted as a possible addition to the funding for protection of marine ecosystems. However, there is uncertainty around carbon sequestration and accumulation in benthic habitats, and the marine-atmospheric carbon cycle.

The workshop discussions and the proposed assumptions provided a valuable input to the study, underlining the complexity of marine ecosystems and the multifaceted impacts of bottom-towed fishing.

[7] See Ramsay et al. (2001)

The identified knowledge gaps and areas of uncertainty emphasize the need for further research in several areas, highlighting the importance of an evidence-based approach to policy-making in marine conservation.

Following the expert workshop, eftec continued engaging with experts on an individual basis to further solidify the knowledge base needed to complete the evidence review.

2.5.3 Data log

The literature review and engagement with experts identified evidence sources for review, which was supplemented by targeted evidence searches, completed by eftec in line with guidance on rapid evidence assessments (Collins et al., 2015). Value transfer principles (eftec, 2010) were used to assess the suitability and transferability of evidence generated from a published source to the study. A source was deemed relevant following a set of inclusion and exclusion criteria: sources were included if they provided either monetary values or physical quantities relevant to the ecosystems in scope, and excluded if they were inaccessible, did not include the ecosystems under review, or were of insufficient quality to meet value transfer principles.

2.6 Other inputs

2.6.1 Habitat classification and mapping

The study used detailed spatial analysis by Blue Marine of the extent, characteristics, and management of marine inshore habitats. This analysis brought together existing data sources in novel combinations to characterise the BAU extent and management of habitats, and the extent and characteristics of habitats that would be protected under the Protection Scenario. The latter provided a basis for assessing potential changes to ecosystem services. Further details are provided in Appendix 1.

Habitat areas were categorised by type, using both the European University Information Systems (EUNIS) and Joint Nature Conservation Committee (JNCC) classifications to facilitate linking habitat data to other data types (e.g., ecosystem service quantity and economic evidence).

Habitat extent was assessed using the finest level of EUNIS Classification available within the dataset (between level 1 and level 3) and by substrate (e.g., mixed sediment). This provided the necessary level of detail to demonstrate changes in natural capital assets, but also supported identifying which marine habitats/assets could provide a set of ecosystem services. For reporting, habitats have been grouped to a high-level natural capital asset of 10 groups (e.g., biogenic habitats are grouped together). This alignment is shown in in Appendix 2.

2.6.2 Ecosystem service classification

The ecosystem service typology used within this study reflects those ecosystem services identified as 'marine' in the European Environment Agency CICES v5.1 classification. It builds on the typology defined by Culhane et al. (2019), in line with Defra's Marine Natural Capital and Ecosystem Assessment (mNCEA)[8]

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

programme. This classification typology was used in Kharadi and Bayes (2022), which adopted both the Culhane et al. (2019) and Natural England's Natural Capital Indicators for the marine environment (Lusardi et al., 2018). Note that Lusardi et al. (2018) made use of CICES v4.3, and the list used in this study was expanded to include additional services specified in CICES v5.1.

Table 2.7 presents a simplified version of the ecosystem service classification used in Kharadi and Bayes (2022). Additions to the ecosystem classification are shown in *italics*, reflecting terminology used in Scotland's Marine Assessment 2020 (Moffat et al., 2021). Ecosystem services that have been identified as relevant but are not included in either Culhane et al. (2019) or Lusardi et al. (2018) are shown in grey – for example, thriving wildlife. The list below represents a 'long list' of ecosystem services that are relevant for the marine environment and was used to assess materiality of impacts within this analysis.

Table 2.7: Ecosystem service classification

Ecosystem service category	Ecosystem service name used in this assessment
Provisioning	Seafood from wild animals
	Seafood from wild plants
	Seafood from aquaculture
	Fibres and materials
	Ornamental materials (commercial & personal)
	Minerals
	Abiotic services (renewable energy)
Regulating	Genetic materials
	Water quality
	Mediation of smell/visual impacts
	Mass stabilisation
	Flood protection
	Gamete and seed dispersal
	Maintenance of nursery populations and habitats
	Pest & disease control
	Global climate regulation
	Local climate regulation
Cultural	Cultural services: Experiential & physical use
	Cultural services: Scientific/ educational
	Cultural services: Aesthetic; Spiritual and/or emblematic
	Thriving wildlife (previously Biodiversity)

Table note: Additions to the ecosystem classification are shown in italics, reflecting terminology used in Scotland's Marine Assessment 2020 (Moffat et al., 2021). Grey lines indicate ecosystem services relevant but not included in Culhane et al. (2019) or Lusardi et al. (2018).

2.6.3 Ecosystem service valuation evidence

Other supporting data were gathered to fill the gaps following the second stage of the literature review including:

- Latest evidence from ONS, including the UK Marine Natural Capital Account (ONS, 2021a) and tourism & leisure account (ONS, 2021b);
- Natural capital account for industrial Sandeels Fishery (Kharadi and Bayes, 2022);
- Defra's 'Enabling a Natural Capital Approach' (Defra, 2023), which provides case studies and data sources for a variety of ecosystem services (e.g., carbon sequestration rates);
- Universal asset service matrix (uASM) to identify ecosystem service provision by marine habitats (Cordingley et al., 2023); and
- UK Sea Fisheries Statistics 2021 (Marine Management Organisation, 2021).

3. Valuation of ecosystem services

This section describes the study scope and boundary and methods used to quantify and value ecosystem service impacts.

3.1 Scope and parameters

This study was unique because the primary focus was on impacts of bottom-towed fishing within the 3nm area, rather than bottom-towed fishing overall (e.g., whole Exclusive Economic Zone (EEZ)). This limited the scope to consider ecosystem services and benefits that are material to the 3nm area and was further limited to the impacts attributed to protecting an additional 22,153 km^2 of habitats in the 3nm area (i.e., area unprotected and under pressure in Table 2.2). This study was driven by the current understanding of the impacts of bottom-towed fishing on ecosystem services in the marine environment, and the potential improvement in ecosystem service provision from further protection, compared to the BAU.

The analysis scope built on findings within literature that were evidence reviewed (e.g., Marine Conservation Society (2023), New Economics Foundation (2021)). This helped establish the structure of the analysis using the following key parameters:

- Geographic boundary: The boundary for the analysis was three nautical miles from the Scottish coastline, with some smoothing of this boundary (e.g., across the mouths of Firths in line with UK Hydrographic Office norms). Further details on the mapping methodology and data sources are in Appendix 1. The area within the 3nm area unprotected and under pressure from bottom-towed fishing is approximately 22,000 km^2 (Table 2.2).
- Price year: 2023 with monetary values from earlier years inflated to 2023 prices using the latest HM Treasury (2022) GDP deflators.
- Assessment time scale: Assessed the medium and long-term impacts of protection. Therefore, both a 20-year timescale in line with Scottish Government impact assessment guidance (Levett-Therivel, 2021) and a 60-year timescale in line with Green Book guidance (HM Treasury, 2022) were used. This allowed asset values to be estimated that would capture the impacts of initial habitat recovery as well as sustained recovery into the future.
- Implementation period: permanent from 2025.
- Closure and recovery: Impact coding adapted from Moran et al. (2008) and Gonzalez-Alvarez (2012), as adopted in MCS (2023). For a given habitat type and ecosystem service combination the following assumptions were made with respect to:
    - Extent of ecosystem service provision: For this study, this assumption was not applied as changes in ecosystem service provision are linked to changes in habitat condition.

      Note this is a point of difference from previous assessments where a proportion of overall improvement in provision of ecosystem services is assumed relative to a BAU (no improvement), (e.g., 5 levels (95% – 0.50%) in MCS (2023)).
    - Timescale to recovery (i.e., timing of impacts): Informed by recovery rates from Cantrell et al. (2023), which provided habitat-specific recovery rates by gear type. Recovery rates ranged from

several weeks to 100 years, with some recovery rates remaining unknown or unquantifiable. Note that this is a point of difference with NEF (2021) and MCS (2023), where recovery rates applied were from Moran et al. (2008), where recovery time is zero, benefits were assumed to be realised immediately.

  - Trajectory of recovery: It was recognised that ecosystem service provision may improve non-linearly. Therefore, an assumption on trajectory (i.e., functional form) was included to reflect either benefits realised quickly (i.e., logarithmic change), benefits realised later into the future (i.e., exponential change) or steady change over time (i.e., linear change), over the recovery period.
  - Timescale of improvement retention: Assume once ecosystems are recovered, the estimated ecosystem service quantity and benefit values would be sustained until the end of the assessment period, remaining constant over time. This is in line with assumptions in previous work (e.g., MCS, (2023)).
- Discount rate: Followed Green Book guidance (HM Treasury, 2022), using the standard discount rate (3.5% and declining) and health discount rate (1.5% and declining) where appropriate.

Furthermore, it is assumed that the status of ecosystems and the level of ecosystem service provision is only influenced by bottom-towed fishing to a certain degree. There are other factors that play a significant role in shaping the condition of the seabed and its associated ecosystem services (e.g., climate change, coastal eutrophication, or water acidification). These factors could influence outcomes in both the BAU and Protection Scenario. Nevertheless, it was not possible to consider these effects in the analysis.

Equally, it was assumed that once the area currently under pressure was protected there would be full compliance and enforcement (i.e., analysis does not account for potential non-compliance, such as illegal fishing). Incorporating such nuances in compliance was found too challenging, given the uncertainties surrounding the scale and impact of such activities.

3.2 Identifying assets and benefits

3.2.1 Asset significance assessment

A significance assessment was completed to examine how the Protection Scenario could impact the provision of ecosystem services within the 3nm limit. Significance was assessed using habitat area distribution within the Scottish 3nm boundary reported in Section 4.1.2: the area of each habitat as a % of the area receiving protection (in Table 4.2) and as a % of the total area of that habitat within the 3nm area (in

Table 4.3).

In doing so, it was possible to distinguish where a large proportion of a given habitat's area would be protected in the Protection Scenario, even if these areas may only represent a small part of the total 3nm area.

The results indicate that generally the areas protected under the Protection Scenario are spread across a number of habitat types:

- The Scottish seabed in the 3nm area is diverse, with five benthic habitats each making up more than 10% of the total area, but no habitat makes up more than 25% of the total.
- The area fully protected from bottom-towed fishing cover 14% of the 3nm area – this is just under half of the 30% target in the Kunming-Montreal Global Biodiversity Framework (30 by 30).
- Despite their high vulnerability to benthic fishing pressures, current protections cover only a third of the area of biogenic habitats.

These data mean the protection of the 3nm area would be significant for all the main habitat types in Scottish inshore waters, and for the different ecosystem services they provide.

3.2.2 Key asset attributes

As well as the extent of the assets within the 3nm limit, it was also important to consider their condition and attributes. While a large majority of the inshore area is subject to bottom-towed fishing pressure, its condition is not always well known. The attributes of these assets could be considered using attribute categories in line with those presented in Natural England's Natural Capital Indicators (Lusardi et al., 2018), following their application in Kharadi and Bayes (2022).

Table 3.1 shows the asset attributes, the associated asset register indicator included and whether it was successfully quantified in the BAU and Protection Scenario. For hydrology, appropriate indicators were not identified, whilst for cultural attributes, indicators were identified (e.g., through Lusardi et al. (2018)) but were not quantified.

Table 3.1: Natural capital assets included in the natural capital balance sheet

Asset attribute	Asset register indicator (unit)	Quantified in the BAU	Quantified in the Protection Scenario
Extent	Area under pressure from bottom-towed fishing (km^2)	Y	Y
	Area not under fishing pressure from bottom-towed fishing (km^2)	Y	Y
	Area fully closed to bottom-towed fishing (km^2)	Y	Y
	Area of sublittoral zone under pressure from bottom-towed fishing (km^2)	Y	Y
Hydrology	*Appropriate indicators have not been identified for this study.*		
	Carbon stored in subtidal sediments (tCO_2)	Y	Y

Asset attribute	Asset register indicator (unit)	Quantified in the BAU	Quantified in the Protection Scenario
Nutrient (& chemical) status	Carbon stored in other marine habitats (tCO_2)	N	N
Species Composition	Fish stock	N	N
	Shellfish stock	N	N
Cultural: Nature	Area fully protected from bottom-towed fishing	Y	Y
	Visibility of wildlife (birds, mammals, fish)	N	N
	Presence of flagship species	N	N

3.2.3 Materiality assessment

A materiality[9] assessment is included to show which benefits are likely to be provided by the marine ecosystems in the 3nm area, and which were possible to assess in this study and which were not. The assessment was undertaken using a service-asset attribute matrix which aims to show:

- Which ecosystem services are material for each ecosystem asset group (defined by EUNIS level 1); and
- Of these material ecosystem services, which benefits could be assessed.

The uASM developed by Cordingly et al. (2023) was used to identify ecosystem service provision by the marine ecosystems present in the 3nm boundary. The materiality assessment was completed in line with the key presented in Table 3.2. A materiality assessment of ecosystem service provision and expected response to closure of the 3nm area to bottom-towed fishing is shown in Table 3.3.

Table 3.2: Materiality assessment key

Key	Description
●	Material ecosystem service provision and benefits estimated in quantitative and monetary terms
○	Material ecosystem service provision, not assessed
	No material service provision
	Ecosystem service not in scope

As shown in Table 3.3, some key ecosystem services and benefits cannot be assessed (hollow dots) – this reflects impacts that cannot be quantified, but are still expected to occur as a result of the closure of the 3nm area to bottom-towed fishing. They are explicitly listed in this way to highlight that not all impacts can be assessed with the available evidence.

These ecosystem services and benefits were not quantified due to data limitations, but some could be

[9] This is defined in the Natural Capital Protocol as "an impact or dependency on natural capital is material if considering it, as part of the set of information used for decision making, has the potential to alter that decision" (p. 43, Capitals Coalition, 2016).

linked to the quantification of other material benefits. For example, ‘nature-based recreation’ was not included because VisitBritain (2023) defines ‘recreation’ as trips lasting under 3 hours, and Scotland-wide data on this for inshore marine activities could not be identified. However, there are data for trips lasting more than 3 hours, which likely describes many marine-based activities (i.e., entering inshore waters), as opposed to coastal recreation (i.e., above low water mark). These trips are categorised as the ’nature-based tourism and leisure’ ecosystem service, and data for expenditure associated with nature-based tourism and leisure (ONS, 2021b) were captured in the account.

Further, as habitats recover there may be other opportunities for growth and/or change. Some have been assessed, for example, there may be growth in cultivated seaweed production (ABPmer and RPA, 2022). Other opportunities lack relevant evidence, for example how nature-based recreation and tourism activity could change with more protection in the 3nm area. Assessing these further remained out of scope for this study, as it relates to activities that are independent from the closure to 3nm area to bottom-towed fishing.

Table 3.3: **Materiality assessment and expected ecosystem service response to closure of 3nm area to bottom-towed fishing**

Ecosystem services	Benefit	Expected response to closure of 3nm area to bottom-towed fishing pressure	EUNIS Level 1		
			A3 - Infralittoral rock and other hard substrata	A4 - Circalittoral rock and other hard substrata	A5 - Sublittoral sediment
Seafood from wild animals	Food from wild caught fish	Increase in quantity and quality of fish and shellfish stocks, however stock changes not currently quantifiable. Along with lower competition between gear types, leads to increase in static gear landings as larger area suitable for fishing by static gears.	•	•	•
Seafood from wild plants	Food from wild plants	Increase in wild harvesting of seaweed due to less physical damage to seabed allowing seaweed to grow more abundantly. Current evidence (RPA and ABPmer, 2020) suggests there is potential for the sector to grow, however link to closure remains unknown in this study.	○	○	○
Seafood from aquaculture	Food from aquaculture	Increase in available space for cultivation and the potential for improved environmental conditions (i.e., less competition between fishing and aquaculture). Current evidence (RPA and ABPmer, 2020) suggests that there is an appetite for cultivated seaweed sector to grow, however this seems to be independent of protection. Therefore, linking closure in 3nm area to cultivated seaweed production remains unknown in this study.			○
Fibres and materials		Increase in availability and diversity of marine-derived fibres (e.g., from harvested or cultivated seaweed) has the potential to bring significant benefits to the local economy, as well as the wider region.	○		○
Ornamental materials		Increase in availability of marine derived ornamental materials such as collectible shellfish for resale and collection.			○
Minerals					
Abiotic services (renewable energy)					

Ecosystem services	Benefit	Expected response to closure of 3nm area to bottom-towed fishing pressure	EUNIS Level 1		
			A3 - Infralittoral rock and other hard substrata	A4 - Circalittoral rock and other hard substrata	A5 - Sublittoral sediment
Genetic materials		Increase in marine genetic resources used for medical use and scientific research.	○	○	○
Water quality		Improvement in water quality from reduced seabed disturbance, leading to less resuspension of sediments and potentially harmful substances into the water column. Healthier marine ecosystems can better filter and process pollutants, contributing to clearer, cleaner water. If this was to be included in the analysis there would be potential for double-counting with other benefits arising from closure of 3nm area assessed in this analysis (e.g., recreation and aquaculture).	○	○	○
Mediation of smell/ visual Impacts					
Mass stabilisation		Recovery of coral reefs and kelp forests which can act as natural barriers that attenuate wave energy, protecting shorelines from erosion and reducing the impact of storm surges across coastal areas. Evidence suggests that MPAs exhibit higher resilience to severe weather-related incidents following improvements in seabed conditions (Sheehan et al., 2021).	○	○	○
Flood protection			○	○	○
Gamete and seed dispersal		Expected to positively influence the dispersal of gametes and seeds as marine habitats recover by becoming more interconnected and facilitating the movement of gametes and seeds between areas.	○	○	○
Maintenance of nursery populations and habitats		Increase and recovery of nursery habitats (such as seagrass beds, and mobile sediments). Supports the maintenance of healthy, resilient populations of commercially and ecologically important species. The protection of these areas is vital for biodiversity, fisheries productivity, and the overall health of the marine ecosystem.	○	○	○

Ecosystem services	Benefit	Expected response to closure of 3nm area to bottom-towed fishing pressure	EUNIS Level 1		
			A3 - Infralittoral rock and other hard substrata	A4 - Circalittoral rock and other hard substrata	A5 - Sublittoral sediment
Pest and disease control		The recovery of marine habitats contributes to increased genetic diversity. Such diversity is intrinsically linked to the ecosystem's ability to control pests and diseases, and the re-establishment of natural checks and balances within the ecosystem.	○	○	○
Global climate regulation	Equable climate	Subtidal sediments and vegetated habitats previously under pressure recover, resulting in sequestration of CO_2 and supports long-term storage of carbon in the seabed.	●	●	●
Local climate regulation	Temperature regulation	uASM (Cordingley et al., 2023) indicates habitats within the 3nm area provide this service, however not expected to be materially impacted under the Protection Scenario.			
Cultural: Experiential & physical use	Nature-based recreation	Healthier marine ecosystems can attract and support more wildlife, making them more appealing for recreational activities for the local population and the wider tourism sector (e.g., through diving, snorkelling, and wildlife watching). This is supported by UK evidence on MPA designation and ecosystem service provision by (Potts et al., 2014).	○	○	
	Nature-based tourism & leisure		●	●	
	Health & wellbeing	Increase in biodiversity and habitat complexity can enhance the experiential and physical use of marine environment, enabling both physical activity and well-being benefits through engagement with marine environment.	○	○	○
Cultural: Scientific/ educational	Education	Healthier marine ecosystems can support scientific research (e.g., marine life, ecological processes, effects of conservation measures) and marine-based education activities (e.g., university degrees, training courses). This can contribute to understanding of marine ecosystems, inform future conservation efforts, and educate the public about the importance of marine protection.	○	○	○

Ecosystem services	Benefit	Expected response to closure of 3nm area to bottom-towed fishing pressure	EUNIS Level 1		
			A3 - Infralittoral rock and other hard substrata	A4 - Circalittoral rock and other hard substrata	A5 - Sublittoral sediment
Cultural: Aesthetic; Spiritual and/or emblematic	Seascape	uASM (Cordingley et al., 2023) indicates habitats within the 3nm area provide this service, however not expected to be materially impacted under the Protection Scenario.			
	Existence value of wildlife	Increase in biomass and species diversity, particularly in areas where the seabed recovers from physical disturbance. Changes in wildlife populations are expected to arise across the food chain (e.g., recovery of sandeels has been linked to recovery of seabird populations as well as cetaceans and porpoises).	●	●	●
	Spiritual and/or emblematic	Recovery of Scottish marine habitats and supporting emblematic species within Scottish waters contributes to identity of coastal communities and Scotland more broadly.	○	○	○
Thriving wildlife	Non-use values	Increased biodiversity within marine protected areas, especially in reef and rocky habitats, is expected to benefit those who value the optional and non-use value of marine habitat recovery. Note that use values are reflected in other benefits.	○	○	○

Table note: Refer to Table 3.2 for description of colour coding and symbology.

3.3 Estimating impacts

The methods used to estimate both ecosystem service quantities and monetary values for impacts were consistent with the latest government guidance and published evidence such as:

- UK natural capital marine account and tourism & leisure account (ONS, 2021b);
- Natural capital account for industrial Sandeels Fishery (Kharadi and Bayes, 2022);
- Defra's 'Enabling a Natural Capital Approach' (Defra, 2023), which provides case studies and data sources for a variety of ecosystem services (e.g., carbon sequestration rates).

Full details of these methods, including assumptions and sources, are provided in Appendix 4. To account for variation in prices and quantities, average values were estimated from existing data (e.g., average £ per unit, average fish landings). Monetary values published in earlier years were inflated to 2023 prices using the latest HM Treasury (2023) GDP deflators.

Where possible, estimates of quantity and value were produced for the BAU and Protection Scenario, driven by habitat areas in the study boundary (following approach outlined in Figure 2.3). As discussed in Section 3.2.3, not all material ecosystem services and benefits were quantified, in which case they are discussed qualitatively. Both the physical flows (or quantities) of ecosystem services ecosystem services and the monetised benefits were given a significance rating where low significance is 0 and high significance is 3, as described in Table 3.4. The corresponding estimates of quantity and value were rated with respect to the confidence in the figure presented in the balance sheet from low to high, as shown in Table 3.5.

Table 3.4: Significance rating

Level	Description of significance (based on Sunderland et al., 2019)
No rating	Not assessed
0	No provision, or a very small amount in the assessment area
1	A small amount across the assessment area
2	A substantial amount for limited area, or medium provision across the assessment area
3	Large amounts across the assessment area

Table 3.5: Confidence rating

Level	Symbol	Description of confidence
No rating	●	Not assessed
Low	L	Evidence is partial and significant assumptions are made so that the data provides only order of magnitude estimates of value to inform decisions and spending choices.
Medium	M	Science-based assumptions and published data are used but there is some uncertainty in combining them, resulting in reasonable confidence in using the data to guide decisions and spending choices.
High	H	Evidence is peer reviewed or based on published guidance so there is good confidence in using the data to support specific decisions and spending choices.

Table 3.6: **Summary of approach to estimate ecosystem service quantity**

Ecosystem service (common name)	Significance of ecosystem service	Method to estimate quantity	Quantity Indicator (unit)	Confidence in Year 0 estimate
Seafood from wild animals	3	Scottish Sea Fisheries (Scottish Government, 2021) statistics for all Scottish waters was used to estimate the average quantity of fish landings in the 3nm area for bottom-towed and static gears. An approximate tonnage of landings was inferred based on the ratio between value of landings (£) to tonnes landed in a given year from the Scottish Sea Fisheries statistics of both bottom-towed fishing and static gears (i.e., tonnes/£-value landed in 2023 prices). As Scottish Sea Fisheries statistics provide data from 2009-2022, a ten-year average tonne caught per £-landed was estimated for bottom-towed fishing and static gears. The average tonne caught per £-landed was applied to estimated average annual value of landings for bottom-towed fishing and static gears. In the Protection Scenario, change in static gear landings arise as a larger area of 3nm becomes suitable for static gear fishing due to reduced gear conflict and recovery of the 3nm area previously under pressure from bottom-towed fishing. Assumes static gear intensity and effort per area fished remains constant, however fishers have a larger area to fish in as a result of reduced gear conflict.	Volume of fish landings from bottom-towed gears (tonnes/yr)	M
			Volume of fish landings from static gears (tonnes/yr)	M
Global climate regulation	3	Emissions are quantified using estimated global average carbon fluxes from sediments from bottom-towed fishing from Sala et al. (2021). The emission rate for repeated bottom-towed fishing is used in the BAU and is assumed to remain constant over time. In the Protection Scenario, as the closure comes into place emissions from this activity ceases. Note that estimated emissions do not distinguish between emissions resuspended in the water column and those released to the atmosphere. This is difficult to measure with the available evidence, and potential results in an over- or under-estimation of CO_2 emissions to the atmosphere from bottom-towed fishing in Scottish waters. Although an adjustment cannot be made on the quantity estimate, it has been accounted for as part of estimating the monetary value of emissions.	Emissions from sediment disturbance (tCO_2e/yr)	L

Ecosystem service (common name)	Significance of ecosystem service	Method to estimate quantity	Quantity Indicator (unit)	Confidence in Year 0 estimate
	3	Average carbon sequestration rates for relevant fine mud, mixed sediment, sandy mud, and sediment are assumed to be equivalent to subtidal sediments as reported by Natural England's review of carbon sequestration and storage by habitats (Gregg et al., 2021). In the BAU, sequestration is estimated for areas either protected or not under pressure from bottom-towed fishing. In the Protection Scenario this is estimated for the full 3nm area (i.e., all protected), and with the area previously under pressure time required for habitats recover in the first 8 years following the closure. Sequestration rates applied are assumed to remain constant over time. Note, biogenic habitats (e.g., reefs and mussel beds) have not been assessed due to lack of evidence, therefore estimates of carbon sequestration in both the BAU and Protection Scenario do not cover the full scope of habitats in the 3nm area that can provide this ecosystem service.	Carbon sequestered by subtidal sediments (tCO_2e/yr)	L
Cultural: Experiential & physical use	Not assessed	No suitable method to estimate tourism visits (or number of days) associated with inshore wildlife watching.	Tourist visits (number of tourists, number of days)	●
Cultural services: Aesthetic; Spiritual and/or emblematic	Not assessed	No suitable evidence to measure the number of charismatic species in the study boundary.		●

Table 3.7: Summary of approach to estimate benefit monetary values

<table>
<tr><th>Benefit</th><th>Significance of benefit</th><th>Method to estimate value</th><th>Monetary metric (unit)</th><th>Confidence in Year 0 estimate</th></tr>
<tr><td rowspan="2">Food from wild caught fish</td><td rowspan="2">3</td><td rowspan="2">Ten-year average catch (£/year) has been estimated using latest statistics on the value of landings from Scottish Sea Fisheries and scaled to the 3nm area using previous assessments of management options for Scottish inshore fisheries (Marine Scotland Science, 2014). In both the BAU and Protection Scenario, the monetary unit value is assumed to remain constant over time, with the only change in landings resulting from closure to bottom-towed fishing activity.</td><td>Value of fish landings from bottom-towed gears (avg. value)</td><td>M</td></tr>
<tr><td>Value of fish landings from static gears (avg. value)</td><td>M</td></tr>
<tr><td rowspan="2">Equable climate</td><td>3</td><td rowspan="2">The monetary value of emissions and carbon sequestered by marine habitats is estimated following the DESNZ (2021) guidance. The estimated tonnes of emissions and/or sequestered is multiplied by the non-traded central value in that year. Future flows of CO_2e are valued using the DESNZ (2023) carbon values (£/t CO_2e) series until 2050. Following DESNZ (2023) guidance, a real annual growth rate of 1.5% is then applied starting at the most recently published value for 2050 and into the future.

The valuation of emissions from sediment disturbance has been adjusted using a correction factor based on the social value of offsets (SVO). The SVO is used to account for uncertainty in whether carbon is released to the atmosphere, re-suspended in the water column and/or re-absorbed in the sediment. To ensure that long-term benefits of the closure is considered, the SVO correction factor (33%) is applied to BAU asset value estimate for emissions from sediment disturbance.</td><td>Value of emissions from sediment disturbance (£/yr)</td><td>L</td></tr>
<tr><td>3</td><td>Value of carbon sequestered by subtidal sediments (£/yr)</td><td>L</td></tr>
<tr><td>Nature-based tourism & leisure</td><td>2</td><td>Based on the ONS (2021) tourism and outdoor leisure account, expenditure on watching wildlife, bird watching, and other nature is estimated to represent 4% of total attributed expenditure to the marine environment in Great Britain. This is applied to the five-year average asset value (100-year) for attributable spend to the marine environment, to produce an estimate of nature-based tourism spend on wildlife watching. The equivalent annual value (EAV) is estimated to calculate the 20 and 60-year asset values. This assumes that attributable tourism expenditure remains constant over time in the BAU. Changes in tourism expenditure under the Protection Scenario have not been estimated.</td><td>Equivalent annual value of UK nature-based tourism spend on wildlife watching in 3nm area</td><td>M</td></tr>
</table>

Benefit	Significance of benefit	Method to estimate value	Monetary metric (unit)	Confidence in Year 0 estimate
Protection value of wildlife	2	Uses value transfer of Noble (2023) study of willingness to pay (WTP) by Scottish households for an additional 1% of total sea area protected (see Appendix 5 for value transfer), taken as a proxy for existence value of wildlife and other non-use values. WTP figures for an additional 1% of total sea area protected ranges between £2-8m per year in 2023 prices. In this assessment, the area receiving protection in the 3nm area (i.e., area under pressure from bottom-towed fishing and the area unprotected but not under pressure) relative to Scottish sea area is used to scale up the Noble (2023) aggregate WTP estimate for increased protection.	Willingness to pay for increased protection of 3nm area (£/Scottish household)	M

3.4 Comparing benefit values

Following the NCBS structure, quantities of ecosystem services are presented alongside the benefits which were monetised. The estimated benefits were aggregated and summed to give an overall assessment of the BAU inshore area ecosystem services value in present value terms. The net impacts of the Protection Scenario were calculated as the difference between the Protection Scenario outcomes and assessed outcomes in the absence of additional protection (i.e., the BAU).

The calculations used the parameters summarised in Section 3.1 (e.g., discount rate, time scales), with ecosystem service provision having been profiled to capture: (a) timing of impacts and recovery – e.g., immediacy of benefits as well as any potential lags; and (b) forecast of trends after recovery period – e.g., constant, increasing, declining.

Asset values were calculated by summing the expected future annual values of benefits over 20 and 60 years, discounted according to Green Book guidance (HM Treasury, 2022). Where possible, future values took into account expected trends in the quantity and/or value of the benefit. Where this information was not available, benefits were assumed to be constant over time. For example, carbon emissions were assumed to remain constant, however the monetary unit value of non-traded carbon increases in line with DESNZ guidance (2021, 2023).

3.5 Sensitivity analysis

In line with Green Book and Scottish Impact Assessment guidance, sensitivity analysis was performed on key assumptions identified during the analysis based on the most significant asset types, benefits, and assumptions with greater uncertainty. This included:

- Sensitivity 1 – Areas potentially exploited with static fishing gears.
- Sensitivity 2 – Different valuation evidence on the protection value of wildlife (as a proxy for existence value and other non-use values).
- Sensitivity 3 - Carbon emissions from sediment disturbance.

4. Results

This section presents the asset register and extended natural capital balance sheet (NCBS) for the BAU and Protection Scenario.

4.1 Asset register

The asset register is a registry of all relevant natural capital assets within the boundary of the account. It forms the foundation of the account and records both the extent and condition of the assets. Note that not all the indicators in the asset register were shown in the extended NCBS, therefore key asset attributes were identified using the Lusardi et al. (2019) list of marine natural capital indicators and previous examples of extended NCBS provided by Natural England.

4.1.1 Extent

The compiled asset register by the highest level of classification (i.e., 10 groups) for the BAU and the Protection Scenario is presented in Table 4.1 and Figure 4.1. The 3nm area predominantly consists of coarse substrate (22%), sand (14%), and rock or other hard substrate (14%) and muddy sand (11%).

Table 4.1: Extent account of habitats in 3nm area

High-level natural capital asset classification	EUNIS code (level 1)	Area (km^2)	% of total 3nm area
Biogenic habitats	A5 – Sublittoral sediment	58	0.2%
Coarse substrate	A5 – Sublittoral sediment	6,746	21.9%
Fine mud	A5 – Sublittoral sediment	1,094	3.6%
Mixed sediment	A5 – Sublittoral sediment	1,271	4.1%
Muddy sand	A5 – Sublittoral sediment	3,339	10.9%
Rock or other hard substrata	A3 - Infralittoral rock and other hard substrata; A4 - Circalittoral rock and other hard substrata	4,435	14.4%
Sand	A5 – Sublittoral sediment	4,360	14.2%
Sandy mud	A5 – Sublittoral sediment	1,883	6.1%
Seabed	NA	6,360	20.7%
Sediment	A5 – Sublittoral sediment	1,212	3.9%
	Total	**30,759**	**100.0%**

Table note: Data classifies areas as 'seabed' where habitat type cannot be defined, hence treated as 'N/A' when aligned to EUNIS codes.

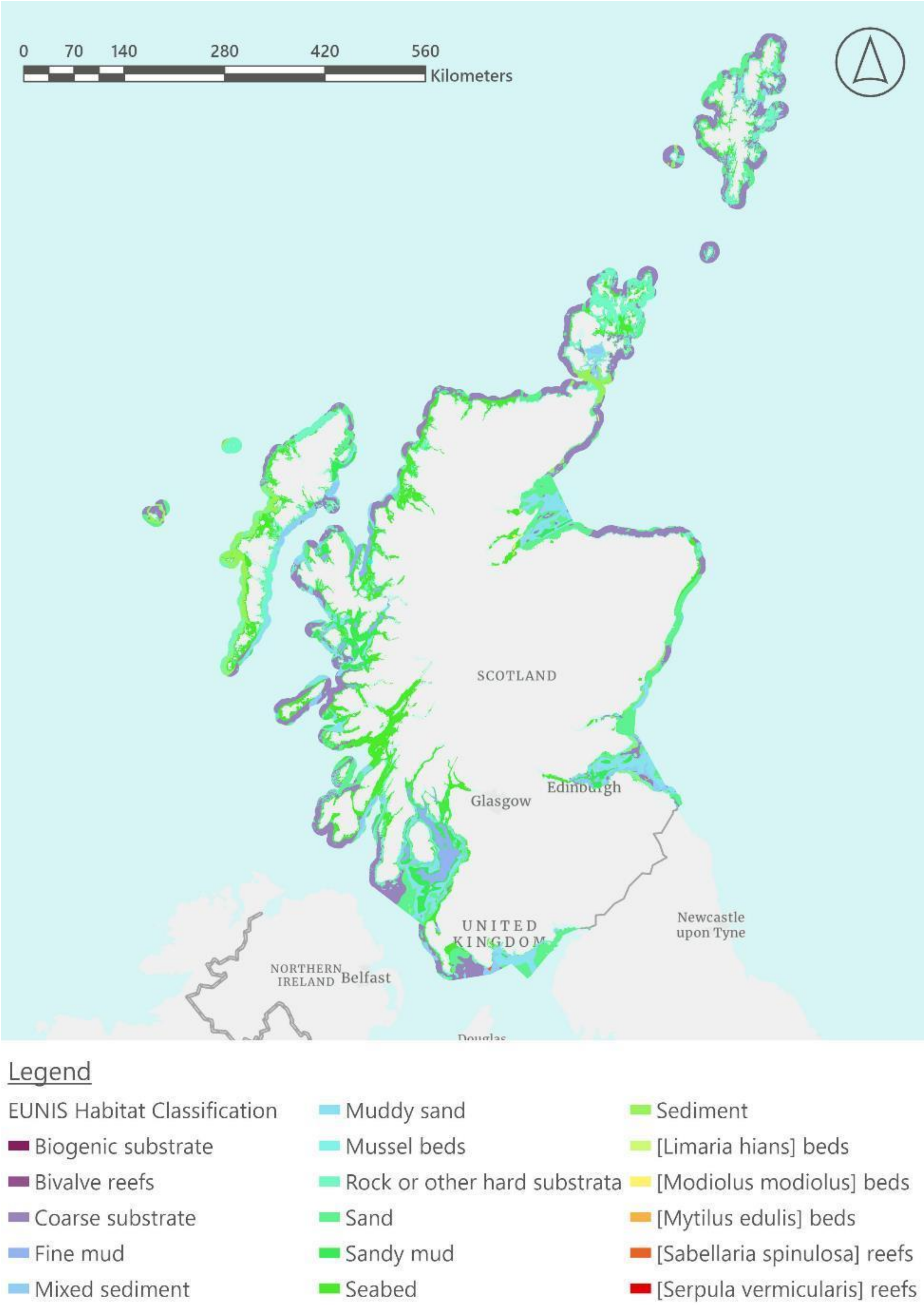

Figure 4.1: Habitat breakdown in the 3nm area.

4.1.2 Condition

The type and size of benefits provided by natural capital assets were determined by the extent (quantity) and condition (quality) of those assets (Watson et al., 2022). Therefore, the natural capital asset register also included data on condition, which could include designated areas as well as assessments of status of species (e.g., fish and shellfish stocks). The list of potential indicators for inclusion are shown in Table 3.1. Evidence to support the latter was identified through Natural England's collated evidence on carbon storage and sequestration (Gregg et al., 2021) and Smeaton et al., (2020).

The mapping of habitats was completed by management area across the 3nm area. Table 4.2 shows the area protected or not under pressure from bottom-towed fishing, and the area receiving protection in the Protection Scenario, where:

- The area under protection in the BAU is represented by areas already fully protected from, and areas not subject to fishing by bottom-towed fishing (4,268 km^2 and 4,336 km^2, respectively as shown in Table 2.2).
- The total area protected under the Protection Scenario is equal to the total 3nm area (30,759 km^2).

Table 4.2 shows the change in area protected between the Protection Scenario and the BAU. This represents the area where, relative to the BAU, the Protection Scenario protects areas previously under pressure from bottom-towed fishing (22,153 km^2). This area being protected is approximately 72% of the total 3nm area, compared to the 28% of the 3nm area protected from bottom-towed fishing in the BAU. This change in management drives the quantification and valuation of ecosystem service impacts.

The data on natural capital assets protected in the Protection Scenario is broken down in more detail (see Appendix 2). This breakdown revealed further information about the potential impact of the protections. For example, as part of the closure, approximately 15,800 km^2 of the sublittoral zone would receive protection (i.e., habitats classified as A5 in EUNIS).

Table 4.3 shows the change of area protected for each habitat as a % of the total habitat area within 3nm boundary. Following the closure of the 3nm area to bottom-towed fishing, the entirety of all habitat types within the 3nm area become protected. The relative change in the extent of protection for different habitats was used to support the assessment of significance (see Section 3.2.1).

An estimate of carbon stored in subtidal sediments was produced using evidence from Gregg et al. (2021). It was estimated that within the area protected and not under pressure from bottom-towed fishing in the BAU, subtidal sediments (e.g., fine mud, muddy sand, sandy mud) store approximately 110 million tonnes of CO_2. This was estimated to increase to 195 million tonnes of CO_2 in the Protection Scenario as the total area of subtidal sediments protected increased, representing a new steady state. There was high uncertainty associated with these estimates, therefore, they were not reported in the extended NCBS.

Table 4.2: Area of habitats under protection in BAU and Protection Scenario

	BAU		Protection Scenario		Change (Protection Scenario – BAU)	
High level natural capital asset class	**Area protected or not under pressure from bottom-towed fishing (km^2)**	**As % of 3nm area**	**Area receiving protection (km^2)**	**As % of 3nm area**	**Area where pressure from bottom-towed fishing is removed by proposed protection (km^2)**	**As % of 3nm area**
Biogenic habitats[1]	37	0.1%	58	0.2%	22	0.1%
Coarse substrate[1]	1,244	4%	6,746	22%	5,501	18%
Fine mud[1]	105	0.3%	1,094	4%	989	3%
Mixed sediment[1]	140	0.5%	1,271	4%	1,130	4%
Muddy sand[1]	483	2%	3,339	11%	2,856	9%
Rock or other hard substrata	1,563	5%	4,435	14%	2,871	9%
Sand[1]	1,160	4%	4,360	14%	3,200	10%
Sandy mud[1]	162	1%	1,883	6%	1,722	6%
Seabed[1]	2,889	9%	6,360	21%	3,471	11%
Sediment[1]	821	3%	1,212	4%	391	1%
Total	**8,604**	**28%**	**30,759**	**100%**	**22,153**	**72%**

Table notes:

[1] EUNIS code level 1: A5 – Sublittoral sediment

[2] EUNIS code level 1: A3 - Infralittoral rock and other hard substrata; A4 - Circalittoral rock and other hard substrata

Table 4.3: Habitat area protected as % of total habitat area in the BAU and Protection Scenario.

		BAU	Protection Scenario	Change	
High level natural capital asset class	**Habitat area within 3nm area(km²)**	**Habitat area protected as % of total habitat area within 3nm area**	**Habitat area protected as % of total habitat area within 3nm area**	**Difference in percentage protected between BAU and Protection Scenario**	**Percentage increase in area protected from BAU area[3]**
Biogenic habitats[1]	58	62%	100%	38%	60%
Coarse substrate[1]	6,746	18%	100%	82%	442%
Fine mud[1]	1,094	10%	100%	90%	938%
Mixed sediment[1]	1,271	11%	100%	89%	806%
Muddy sand[1]	3,339	14%	100%	86%	591%
Rock or other hard substrata	4,435	35%	100%	65%	184%
Sand[1]	4,360	27%	100%	73%	276%
Sandy mud[1]	1,883	9%	100%	91%	1,066%
Seabed[1]	6,360	45%	100%	55%	120%
Sediment[1]	1,212	68%	100%	32%	48%

Table notes:

[1] EUNIS code level 1: A5 – Sublittoral sediment

[2] EUNIS code level 1: A3 – Infralittoral rock and other hard substrata; A4 – Circalittoral rock and other hard substrata

[3] Estimated as additional area of the habitat protected within the 3nm area (%) divided by the habitat area protected in the BAU as % of total area of that habitat within the 3nm area.

Table 4.4 links material ecosystem services (as identified in Table 3.3) to changes in areas receiving protection due to closure of the 3nm area to bottom-towed fishing. Evidence from Table 4.2 and 4.3 was used to give an indication of the scale of response that increased protection of relevant seabed natural capital assets in the 3nm area could have on ecosystem service provision.

Table 4.4: **Linking protected habitats to ecosystem service and benefit provision**

Material ecosystem services – *benefits (where specified)*	**Habitats in the 3nm area supporting the service**	**Scale of response in Protection Scenario**
Gamete dispersal; Pest and disease control	All habitats.	• 22,153 km^2 of area receiving proposed protection, which is 72% of the total 3nm area. • Represents a 257% increase in the 3nm area receiving protection relative to the BAU (8,604 km^2 protected).
Water quality; Mass stabilisation; Flood protection	Biogenic habitats through attenuation of wave energy and retention of sediments.	• 22 km^2 of biogenic habitats receiving proposed protection, which is 0.1% of the 3nm area receiving protection and 38% of the total area of these habitats. • Represents 60% increase in habitat areas receiving protection relative to the BAU (37 km^2 protected).
Seafood from wild animals - *Food from wild caught fish;* Cultural: Experiential & physical use – *Nature-based recreation; Nature-based tourism & leisure; Health & wellbeing;* Cultural: Scientific/educational – *Education;* Ornamental materials; Genetic materials; Maintenance of nursery populations and habitats	Productivity and increased diversity in all habitats, particularly biogenic habitats. Potential switch from bottom-towed fishing to static gear in area receiving protection.	• 22,153 km^2 of area receiving proposed protection, which is 72% of the total 3nm area. • 22 km^2 of biogenic habitats receiving proposed protection, which is 0.1% of the 3nm area receiving protection and 38% of the total area of these habitats. • Biogenic habitats represent 60% increase in habitat areas receiving protection relative to the BAU.
Cultural: Aesthetic; Spiritual and/or emblematic – *Existence value of wildlife; Cultural – spiritual and/or emblematic;* Thriving wildlife - *Non-use values (use values are reflected in other benefits)*	General health of 3nm area, and specific benefits to distinctive species in biogenic habitats (e.g., oyster beds).	
Seafood from wild plants – *Food from wild plants;* Fibres and materials	Harvesting of seaweed and kelp on coarse substrate and rocks.	Relevant EUNIS level 2 code would be A3.11 (kelp with cushion fauna and/or foliose red seaweeds) and A3.12 (sediment-affected or disturbed kelp and seaweed communities), however, cannot be assessed beyond EUNIS level 1 A3.1 (Atlantic and Mediterranean high energy infralittoral rock) areas in asset register data:

Material ecosystem services – *benefits (where specified)*	**Habitats in the 3nm area supporting the service**	**Scale of response in Protection Scenario**
		• 374 km² of infralittoral rock receiving proposed protection, which is 2% of the 3nm area receiving protection, and 48% of the total area of this habitat in the 3nm area. • Represents 94% increase in habitat area receiving protection relative to the BAU (398 km²)
Global climate regulation – *Equable climate*	Undisturbed subtidal sediments and vegetated areas (e.g., seaweed and kelp)	For subtidal sediments: • 4,231 km² of subtidal sediments receive protection, which is 19% of the 3nm area receiving proposed protection (22,153km²) and 14% of total 3nm area (30,757 km²). • Represents 344% increase in habitat areas receiving protection relative to the BAU (1,229 km²) For vegetated areas, relevant EUNIS level 2 codes include A3.11, A3.12 and A3.2, however, cannot assess beyond level 1 EUNIS (A3.1 and A3.2): • 576 km² of area receiving protection, which is 3% of the 3nm area receiving proposed protection (22,153km²) and 2% of total 3nm area (30,757 km²) • Represents 103% increase in habitat areas receiving protection relative to the BAU (557 km²)
Seafood from aquaculture – *Food from aquaculture*	Not related to specific benthic habitats, but supported by bioremediation functions that regulate water quality.	N/A

4.2 Extended natural capital balance sheets

The extended NCBSs for the BAU and Protection Scenario present the ecosystem assets, quantified ecosystem services and valued benefits for Year 0 and Year 20, and present values over 20 years. The figures reflect the identified asset attributes (Section 3.2.2), and the material ecosystem services (Section 3.2.3) that have been quantified and valued (Section 3.3). The extended NCBS is designed to show not only quantified changes, but also material unquantified assets, ecosystem services and benefits. This is to ensure that a more comprehensive view of the natural capital asset was given by the assessment, and highlights that the monetary values reflected only part of the BAU and Protection Scenario.

Overall, in both the BAU and Protection Scenarios, there was medium confidence in the monetised benefit values for fisheries impacts, nature-based tourism and protection value of wildlife based on data from government sources (e.g., Scottish Sea Fisheries Statistics) or peer-reviewed evidence that was adjusted to reflect the study area. However, estimates of carbon sequestration by marine habitats and emissions because of sediment disturbance from bottom-towed fishing had low confidence – driven by the uncertainty in the applicability of available evidence on emission or sequestration rates to the study site (e.g., emission rates are a global average and may reflect different fishing effort relative to Scottish waters).

The **BAU NCBS** (Table 4.5) shows that quantified benefits are £134 million in Year 0 rising to £148 million in Year 20. The change in annual benefits is driven by the estimated value of fish and shellfish landings (68% of annual benefits in Year 0), followed by the value of carbon sequestered by subtidal sediments (29% of annual benefits in Year 0 rising to 36% in Year 20). Factoring in negative impacts of bottom-towed fishing which are £178 million in Year 0, rising to £240 million in Year 20, with the net quantified values estimated to be -£43 million in Year 0 and -£91 million in Year 20. The difference in value over time is solely due to the increasing unit value for non-traded carbon (DESNZ, 2023) as physical ecosystem service flows are assumed to remain constant over time. The present value of net quantified impacts is approximately -£914 million over 20 years.

The **Protection Scenario NCBS** (Table 4.6) shows that in Year 0 quantified benefits are estimated to be £99 million and increase to £327 million in Year 20. The annual benefit values are predominantly driven by the value of carbon sequestered by subtidal sediments, approximately 40% of total benefit value in Year 0 and increasing to 73% in Year 20. The increase in annual flows between Years 0 and 20 reflect assumptions on recovery of subtidal sediments and their ability to sequester carbon over time, as well as increasing unit value for non-traded carbon (DESNZ, 2023). The potential 3nm area suitable for static gear fisheries was assumed to increase as areas previously under pressure from bottom-towed fishing recover and static gears become more widely used within the 3nm area due to a reduced risk of gear conflict. Therefore, static gear landings would increase by approximately 65% between Year 0 and Year 20 (from approximately 12,600 tonnes to 26,700 tonnes landed). The present value of quantified benefits is approximately £3.6 billion over 20 years.

In comparing results for quantified ecosystem assets, ecosystem services and valued benefits between the BAU and Protection Scenario (Table 4.7) the extended NCBS shows the following:

- The area fully protected from bottom-towed fishing increased from 4,300 km^2 to 30,800 km^2 – reflecting the Protection Scenario described in Section 2.2. As a result of protection, all sublittoral habitats[10] in the 3nm area would be protected from bottom-towed fishing activity.

- As the closure is implemented, all bottom-towed fishing activity would cease. The increase in asset value of static gear fish landings (52%) reflects the increase in potential area where these gears can be used.
- However, this increase in static gear fishing does not offset the loss in bottom-towed fishing resulting in the total asset value of fish and shellfish landings over 20 years decreasing by 23% between the BAU (£1.3 billion) and Protection Scenario (£1 billion).
- The net carbon sequestration (i.e., net of emissions) reflects the recovery of subtidal sediments within the 3nm area. This is expected to be an underestimate of sequestration potential as only subtidal sediments were accounted for, with other potential vegetated habitat (e.g., kelp) remaining unquantified as well as accretion by habitats outside of the 3nm area.
- Change in nature-based tourism attributable to increased protection were not assessed due to gaps in the existing evidence on how MPAs and well-managed inshore waters (i.e., 0-12nm) impact tourism benefits in the Scottish context. However, it was assumed that the BAU estimate of wildlife watching expenditure was the best benefit estimate available. Furthermore, given the scope of this study, it was expected that differences in recreation and tourism would arise in local communities (e.g., difference between East and West coast of Scotland) which would not necessarily appear as a ”change” in benefit at the Scottish economy scale.

As a result, by implementing a closure to bottom-towed fishing in the 3nm area, total net quantified monetary benefits would increase five-fold in present value terms over 20 years (increasing from -£914 million in BAU to £3.6 billion in the Protection Scenario). The expected loss in value from bottom-towed fishing would be offset by the recovery of marine habitats to provide other ecosystem services (e.g., carbon sequestration). When looking at the distribution of benefits to beneficiary populations, those arising to global society through net carbon sequestration would double in present value terms over 20 years (from -£2.3 billion to £2.4 billion). Whilst the sum of benefits from fish capture, nature-based tourism, value of protecting wildlife to beneficiaries in Scotland showed a slight decrease over 20 years (from £1.4 billion to £1.2 billion). This result was expected given uncertainty in estimates (e.g., no change in nature-based expenditure) and benefits that remain unassessed (e.g., seaweed harvest). Equally, impacts of the Protection Scenario are likely to vary by location across Scotland’s coastal communities. These results could be an underestimate of impacts from increasing protection in the 3nm area with further research required to refine assumptions used in this study.

In addition to quantified and valued benefits, there are multiple ecosystem services that would arise from protection that remain unquantified. In both the BAU and Protection Scenario, it was expected that the monetary value of unquantified benefits would be ‘moderate’, which would include values such as biodiversity and the contribution of other marine habitats to equable climate (i.e., carbon sequestration). Table 4.8 combines the material unquantified ecosystem services (identified from Table 3.3) and habitats providing ecosystem services (from Table 4.4). Key unquantified benefits not captured in the results include:

- The effect of closures on fish stocks could not be assessed in this study. Thurstan and Roberts (2010)

[10] Defined as those habitats that are “A5 - Sublittoral sediment” in EUNIS.

provide evidence from similar closures (e.g., US, Canada, Iceland) have shown that closures to bottom-towed fishing have a positive impact on bottom-towed fisheries as stocks can recover (Thurstan and Roberts, 2010). For example, protection of the Firth of Clyde indicated that one of the benefits of fish stock protection was the sustained landings of bottom-towed fish into the 1980s (Thurstan and Roberts, 2010).

- The effect of no-take zones on scallop populations results in increased scallop size (mm) and scallop density relative to a defined baseline (Howarth, 2012). In economic terms, no-take zones can increase the productivity of the fishery and the effects of this can extend beyond the boundary where hand diving is permitted. For further evidence on the effect of closures on other shellfish stocks see Renn et al. (2024) and Stevens et al. (2014).
- The quantified and valued ecosystem services where a direct link to a habitat was made (e.g., carbon sequestration) reflected subtidal sediments only. For carbon sequestrations, benefits arising from vegetated habitats (e.g., kelp and seaweed) were not assessed. However, the analysis suggested that the Protection Scenario would result in a 103% increase in habitat areas receiving protection relative to the BAU despite this.
- The ecosystem services and benefits captured so far only reflect recovery of current habitat and assumes this is sustained into the future. The results did not account for the potential for re-establishment of habitats (e.g., establishment of seaweed and kelp on rock substrate) and the potential ecosystem service impacts that stem from them (e.g., carbon sequestration potential of kelp). However, the potential for such impacts can be assessed from the extent of suitable habitats protected from fishing pressure. For example, although the recovery profile of biogenic habitats is uncertain, they are a key resource that support tourism and recreation. The asset register data indicated that the Protection Scenario would result in a 60% increase in these habitats receiving protection relative to the BAU (see Table 4.8). In addition, a high-level assessment of potential habitat recovery and provision of ecosystem services is shown in Section 5.2. This shows that approximately 4,000 km^2 of the total area of rock or other substrata protected can potentially support ecosystem services in the future.
- With respect to seaweed harvesting and aquaculture, analysis of potential growth completed by ABPmer and RPA (2022) reflected that the current seaweed industry is predominantly wild harvesting. Their consultation suggested that there is growing interest in farmed seaweed, but the analysis assumptions were dependent on sector growth more broadly. The Protection Scenario may increase availability of wild seaweed for harvesting, and/or space for cultivated seaweed, but exactly how these would be impacted by fisheries management measures was unknown.
- The wider literature does reflect that increases in biomass and species within marine protected areas are primarily attributed to reef and rocky habitats, with less known on whether the effect holds for other habitat types such as soft sediments (Lester et al., 2009).

Table 4.5: BAU extended natural capital balance sheet

Ecosystem asset

		Value	
Asset Attribute	**Indicator**	**Year 0**	**Year 20**
Extent	Area under fishing pressure from bottom-towed fishing (km^2)	22,153	22,153
	Area not under fishing pressure from bottom-towed fishing (km^2)	4,336	4,336
	Area fully closed to bottom-towed fishing (km^2)	4,268	4,268
	Total 3nm area (km^2)	***30,757***	***30,757***
	Area of sublittoral zone under pressure from bottom-towed fishing (km^2)	15,810	15,810
Hydrology	Appropriate indicators have not been identified for this study.	Not quantified	
Nutrient (& chemical) status	Carbon stock in subtidal sediments (tCO_2)	Not quantified	
	Carbon stock in other marine habitats (tCO_2)	Not quantified	
	Total carbon stock in marine habitats (tCO_2)	Not quantified	
Species Composition	Fish stock	Not quantified	
	Shellfish stock	Not quantified	
Cultural: Nature	Visibility of wildlife (birds, mammals, fish)	Not quantified	
	Presence of flagship species	Not quantified	

Ecosystem services

Ecosystem service (common name)	**Indicator**	**Quantity**	
		Year 0	**Year 20**
Seafood from wild animals	Volume of fish landings from bottom-towed gears (tonnes)	21,640	21,640
	Volume of fish landings from static gears (tonnes)	12,550	12,550
	Total fish & shellfish landings (tonnes)	***34,190***	***34,190***
Seafood from wild plants	Volume of harvested wild seaweed (tonnes)	Not quantified	
Seafood from aquaculture	Volume of harvested cultivated seaweed (tonnes)	Not quantified	
Maintenance of nursery populations and habitats		Not quantified	
Thriving wildlife		Not quantified	
Global climate regulation	CO_2 emissions from sediment disturbance (tCO_2)	(1,871,440)	(1,871,440)
	CO_2 sequestered by subtidal sediments (tCO_2)	137,604	137,604
	CO_2 sequestered by other marine habitats (tCO_2)	Not quantified	
	Net CO_2 sequestered (tCO_2)	***(1,733,836)***	***(1,733,836)***
Cultural: Experiential & physical use	UK nature-based tourism visits	Unknown	Unknown
Cultural: Scientific/ educational	Appropriate indicators have not been identified for this study.		
Cultural: Aesthetic, Spiritual and/or emblematic	Appropriate indicators have not been identified for this study.		

Table notes:
Values in (red) are negative and represent negative impacts (i.e., costs).Grey rows indicate material ecosystem assets (Section 3.2.2) and ecosystem services (3.2.3) that remain unquantified.

Table 4.5 (cont).

Benefits and values						
Benefit	**Significance** (1 small to 3 large)	**Indicator**	**Annual benefit (£m)**		**Asset value (£m)**	**Confidence in the values**
			Year 0	**Year 20**	**PV 20**	
Food from wild caught fish	3	Value of fish landings from bottom-towed gears	45	45	666	M
	3	Value of fish landings from static gears	46	46	678	M
	3	***Total value of fish & shellfish landings***	***91***	***91***	***1,345***	M
Food from aquaculture	3	Value of harvested wild seaweed	Not assessed	Not assessed	Not assessed	
	3	Value of harvested cultivated seaweed	Not assessed	Not assessed	Not assessed	
Biodiversity			Not assessed	Not assessed	Not assessed	
Equable climate	3	Value of CO_2 emissions from sediment disturbance	(178)	(240)	(2,973)	L
	3	Value of CO_2 sequestered by subtidal sediments	40	53	662	L
		Value of CO_2 sequestered by other marine habitats	Not assessed	Not assessed	Not assessed	
	3	***Value of net CO_2 sequestered***	***(138)***	***(186)***	***(2,311)***	L
Nature-based recreation			Not assessed	Not assessed	Not assessed	
Nature-based tourism & leisure	2	UK nature-based tourism spend on wildlife watching in 3nm area	4	4	52	M
Health & wellbeing			Not assessed	Not assessed	Not assessed	
Education			Not assessed	Not assessed	Not assessed	
Protection of wildlife	2	Willingness to pay for increased protection of 3nm area	Not assessed	Not assessed	Not assessed	M
Total quantified monetary benefits			**(43)**	**(91)**	**(914)**	M
Significance of unquantified monetary benefits			**Moderate**			

Table notes:
Values in (red) are negative and represent negative impacts (i.e., costs).
Grey rows indicate material ecosystem assets (Section 3.2.2) and ecosystem services (3.2.3) that remain unquantified.

Table 4.6: **Protection Scenario extended natural capital balance sheet**

Ecosystem asset

		Value	
Asset Attribute	**Indicator**	**Year 0**	**Year 20**
Extent	Area under fishing pressure from bottom-towed fishing (km^2)	-	-
	Area not under fishing pressure from bottom-towed fishing (km^2)	4,336	4,336
	Area fully closed to bottom-towed fishing (km^2)	30,757	30,757
	Total 3nm area (km^2)	***30,757***	***30,757***
	Area of sublittoral zone under pressure from bottom-towed fishing (km^2)	-	-
Hydrology	*Appropriate indicators have not been identified for this study.*	Not quantified	
Nutrient (& chemical) status	Carbon stock in subtidal sediments (tCO_2)	Not quantified	
	Carbon stock in other marine habitats (tCO_2)	Not quantified	
	Total carbon stock in marine habitats (tCO_2)	Not quantified	
Species Composition	Fish stock	Not quantified	
	Shellfish stock	Not quantified	
Cultural: Nature	Visibility of wildlife (birds, mammals, fish)	Not quantified	
	Presence of flagship species	Not quantified	

Ecosystem services

Ecosystem service (common name)	**Indicator**	Quantity	
		Year 0	**Year 20**
Seafood from wild animals	Volume of fish landings from bottom-towed gears (tonnes)	-	-
	Volume of fish landings from static gears (tonnes)	12,550	20,678
	Total fish & shellfish landings (tonnes)	***12,550***	***20,678***
Seafood from wild plants	Volume of harvested wild seaweed (tonnes)	See Table 4.8	
Seafood from aquaculture	Volume of harvested cultivated seaweed (tonnes)	See Table 4.8	
Maintenance of nursery populations and habitats		See Table 4.8	
Thriving wildlife		See Table 4.8	
Global climate regulation	CO_2 emissions from sediment disturbance (tCO_2)	-	-
	CO_2 sequestered by subtidal sediments (tCO_2)	137,604	611,526
	CO_2 sequestered by other marine habitats (tCO_2)	See Table 4.8	
	Net CO_2 sequestered (tCO_2)	***137,604***	***611,526***
Cultural: Experiential & physical use	UK nature-based tourism visits	Unknown	Unknown
Cultural: Scientific/ educational		See Table 4.8	
Cultural: Aesthetic, Spiritual and/or emblematic		Not quantified	Not quantified

Table notes:
Values in (red) are negative and represent negative impacts (i.e., costs).
Grey rows indicate material ecosystem assets (Section 3.2.2) and ecosystem services (3.2.3) that remain unquantified.

Table 4.6 (cont.)

Benefits and values						
Benefit	**Significance** (1 small to 3 large)	**Indicator**	**Annual benefit (£m)**		**Asset value (£m)**	**Confidence in the values**
			Year 0	**Year 20**	**PV 20**	
Food from wild caught fish	3	Value of fish landings from bottom-towed gears	-	-	-	M
	3	Value of fish landings from static gears	46	76	1,032	M
	3	***Total value of fish & shellfish landings***	***46***	***76***	***1,032***	M
Food from aquaculture	3	Value of harvested wild seaweed	Not assessed	Not assessed	Not assessed	
	3	Value of harvested cultivated seaweed	Not assessed	Not assessed	Not assessed	
Biodiversity			Not assessed	Not assessed	Not assessed	
Equable climate	3	Value of CO_2 emissions from sediment disturbance	-	-	-	L
	3	Value of CO_2 sequestered by subtidal sediments	40	237	2,357	L
		Value of CO_2 sequestered by other marine habitats	Not assessed	Not assessed	Not assessed	
	3	***Value of net CO_2 sequestered***	***40***	***237***	***2,357***	L
Nature-based recreation			Not assessed	Not assessed	Not assessed	
Nature-based tourism & leisure	2	UK nature-based tourism spend on wildlife watching in 3nm area	4	4	52	M
Health & wellbeing			Not assessed	Not assessed	Not assessed	
Education			Not assessed	Not assessed	Not assessed	
Protection value of wildlife	2	Willingness to pay for increased protection of 3nm area	10	10	149	M
Total quantified monetary benefits			**99**	**327**	**3,590**	M
Significance of unquantified monetary benefits			**Moderate**			

Table notes:
Values in (red) are negative and represent negative impacts (i.e., costs).
Grey rows indicate material ecosystem assets (Section 3.2.2) and ecosystem services (3.2.3) that remain unquantified.

Table 4.7: BAU vs Protection Scenario results, Year 20

Ecosystem asset

Asset Attribute	Indicator	BAU	Protection Scenario	% change from BAU
Extent	Area under pressure from bottom-towed fishing (km^2)	22,153	-	-100%
	Area not under pressure from bottom-towed fishing (km^2)	4,336	4,336	-
	Area fully closed to bottom-towed fishing (km^2)	4,268	30,757	621%
	Total 3nm area (km^2)	***30,757***	***30,757***	**-**
	Area of sublittoral zone under pressure from bottom-towed fishing (km^2)	15,810	**-**	-100%
Hydrology				
Nutrient (& chemical) status	Carbon stock in subtidal sediments (tCO_2)			
	Carbon stock in other marine habitats (tCO_2)			
	Total carbon stock in marine habitats (tCO_2)			
Species composition	Fish stock			
	Shellfish stock			
Cultural: Nature	Visibility of wildlife (birds, mammals, fish)			
	Presence of flagship species			

Ecosystem services

Ecosystem service (common name)	Indicator	BAU	Protection Scenario	% change from BAU
Seafood from wild animals	Volume of fish landings from bottom-towed gears (tonnes)	21,640	-	-100%
	Volume of fish landings from static gears (tonnes)	12,550	20,678	65%
	Total fish & shellfish landings (tonnes)	***34,190***	***20,678***	-40%
Seafood from wild plants	Volume of harvested wild seaweed (tonnes)	Not quantified	See Table 4.8	
Seafood from aquaculture	Volume of harvested cultivated seaweed (tonnes)	Not quantified	See Table 4.8	
Maintenance of nursery populations and habitats		Not quantified	See Table 4.8	
Thriving wildlife		Not quantified	See Table 4.8	
Global climate regulation	CO_2 emissions from sediment disturbance (tCO_2)	(1,871,440)	-	100%
	CO_2 sequestered by subtidal sediments (tCO_2)	137,604	611,526	344%
	CO_2 sequestered by other marine habitats (tCO_2)	Not quantified	See Table 4.8	
	Net CO_2 sequestered (tCO_2)	***(1,733,836)***	***611,526***	135%
Cultural: Experiential & physical use	UK nature-based tourism visits	Unknown	Unknown	-
Cultural: Scientific/ educational		Not quantified	See Table 4.8	
Cultural: Aesthetic, Spiritual and/or emblematic		Not quantified	See Table 4.8	

Table notes: Values in (red) are negative and represent negative impacts (i.e., costs); Grey rows indicate material ecosystem assets (Section 3.2.2) and ecosystem services (3.2.3) that remain unquantified.

Table 4.7 (cont.)

Benefits and values				
Benefit	**Indicator**	**BAU asset value (£m)**	**Protection Scenario asset value (£m)**	**% change from BAU**
Food from wild caught fish	Value of fish landings from bottom-towed gears	666	-	-100%
	Value of fish landings from static gears	678	1,032	52%
	Total value of fish & shellfish landings	***1,345***	***1,032***	***-23%***
Food from aquaculture	Value of harvested wild seaweed	Not assessed	Not assessed	
	Value of harvested cultivated seaweed	Not assessed	Not assessed	
Biodiversity		Not assessed	Not assessed	
Equable climate	Value of CO_2 emissions from sediment disturbance	(2,973)	-	100%
	Value of CO_2 sequestered by subtidal sediments	662	2,357	256%
	Value of net CO_2 sequestered	***(2,311)***	***2,357***	***202%***
Nature-based recreation		Not assessed	Not assessed	
Nature-based tourism & leisure	UK nature-based tourism spend on wildlife watching in 3nm area	52	52	-
Health & wellbeing		Not assessed	Not assessed	
Education		Not assessed	Not assessed	
Protection value of wildlife	Willingness to pay for increased protection of 3nm area	Not assessed	149	-
Total quantified monetary benefits		**(914)**	**3,590**	**493%**
Significance of unquantified monetary benefits		**Moderate**		

Table notes:
Values in (red) are negative and represent negative impacts (i.e., costs).; Grey rows indicate material ecosystem assets (Section 3.2.2) and ecosystem services (3.2.3) that remain unquantified.

Table 4.8: Summary of expected response and scale of response for material unquantified benefits

Seabed areas protected	Ecosystem services	Expected response to protection
All habitats in 3nm area - overall area receiving protection increases by 257% relative to BAU (8,604 km^2 protected).	Gamete and seed dispersal	Marine habitats recover and become more interconnected, facilitating the movement of gametes and seeds between areas.
	Pest and disease control	Recovery of marine habitats contributes to genetic diversity.
Seaweed and kelp habitats protected have 94% increase relative to BAU (398 km^2 protected).	Seafood from wild plants, Fibres and materials	Increase in availability and diversity of seaweed, allowing more wild harvesting
Sea surface areas	Seafood from aquaculture	Increase in available space for cultivation and the potential locations with improved environmental conditions
Vegetated areas protected increase by 103% relative to BAU (557 km^2)	Global climate regulation	Recovery of vegetated habitats results in sequestration of CO_2 and long-term storage of carbon
Biogenic habitat areas protected increase by 60% relative to BAU (37 km^2 protected).	Water quality	Reduced seabed disturbance leads to less resuspension of sediments and potentially harmful substances, improving water quality
	Mass stabilisation, Flood protection	Recovered coral reefs and kelp forests attenuate wave energy, protecting shorelines from erosion, and reducing the impact of storm surges
	Ornamental materials	Increase in availability (e.g. collectible shellfish for resale)
	Maintenance of nursery populations and habitats	Increase and recovery of nursery habitats (such as seagrass beds, and mobile sediments)
	Genetic materials	Increase in marine genetic resources for medical use and scientific research
	Nature-based recreation, Health & well-being	Healthier marine ecosystems more appealing for recreational activities, enhancing both physical activity and well-being benefits.
	Education, Spiritual and/or emblematic, Thriving wildlife	Healthier ecosystems support more research and marine-based education, conserve emblematic that contribute to identity of coastal communities and Scotland and increases non-use value of marine protected areas.

4.3 Sensitivity analysis

This section presents the results of the sensitivity analysis described in Section 3.5.

4.3.1 Sensitivity 1 – Minimum and maximum potential area for static gear fishing

The results of the Protection Scenario (Table 4.6) assumed that fishing by static gears would occur in the area previously under pressure from bottom-towed activity (i.e., the area receiving protection). However, it was assumed that only areas with low or moderate wave energy exposure were suitable for static gear use – approximately 75% (16,592 km^2) of the area previously under pressure from bottom-towed fishing (22,153 km^2) and 54% of the total 3nm area (30,759 km^2). Wave energy exposure is used as a proxy for how variation in conditions can affect areas as usable fishing grounds, based on eftec's experience in previous consultations for Marine Scotland MPA designation. For example, areas with high wave energy are potentially in accessible in winter seasons, where wave energy is a factor in access to fishing grounds and therefore a proxy for conditions. This resulting estimated value represents a 'best' estimate of potential for static gear fishing following a closure to bottom-towed gears – see Section 3.3 and Appendix A4.2 for further details on methodology. Value of fish landings accounted for 18% of the total asset value in the Protection Scenario main results and was driven primarily by the assumption of how much of the area previously under pressure from bottom-towed activity was suitable for static gear types.

To test this, a minimum and maximum potential area for static gear fishing following the proposed closure was estimated. The minimum assumed that the potential area for static gear fishing remains the same as in the BAU and represents a 'worst-case' scenario, whilst the maximum potential assumed that the total area previously under pressure from bottom-towed fishing (22,153 km^2) was suitable for static gear types (i.e., no adjustment for wave energy exposure). The results of the analysis are shown in Table 4.9.

Based on assumptions of potential area suitable for static gears, the benefit asset values ranged between £678 million and £1.3 billion over 20 years, with the maximum potential showing an increase in static gear landings of 81% relative to the BAU. Therefore, the total asset value (i.e., sum of all benefit flows discounted over time) ranges between -£914 million (in BAU) to £3.8 billion (in Maximum potential) over 20 years. The sensitivity results show that the assessment was sensitive to assumptions on static gear fishing activity following a closure to bottom-towed gears. Further refinement of the assessment would require more research to determine the behavioural change of bottom-towed fishers (e.g., how many would switch to static gears), and the potential effects of price changes for catch from different gear types.

Table 4.9: Minimum and maximum potential for static gear fish landings values sensitivity results

Indicator	Scenario	Minimum potential (PV20, £m)	Main results (PV20, £m)	Maximum potential (PV20, £m)
Benefit asset value	BAU	678	678	678
	Protection	678	1,032	1,255
Benefit asset value % change from BAU	**BAU vs Protection**	-	**52%**	**81%**
Total asset value	BAU	(914)	(914)	(914)
	Protection	3,236	3,590	3,783
Total asset value % change from BAU	**BAU vs Protection**	**454%**	**493%**	**514%**

4.3.2 Sensitivity 2 – Alternative approach to valuing protection value of wildlife

As identified through the completed value transfer in Appendix 5, results from Noble (2023) were considered the most relevant to estimate the WTP for increased protection (%) of the Scottish inshore area, which is taken as a proxy for existence values and other non-use values. The WTP estimates were deemed transferrable as the focus of the research was on Scottish inshore waters and the size of the areas for proposed restrictions were consistent with the area assessed in the Protection Scenario.

An alternative approach was identified using evidence from Börger et al. (2014), where a discrete choice experiment was used to elicit the WTP for conservation benefits of increasing the area of protection of the UK part of Dogger Bank in the North Sea. The study produced annual household WTP values for three attributes (increase in species diversity, increase protection of porpoises, seals and seabirds and wide spread of invasive species) for a set of scenarios (10% and 25% increase). For application to this assessment, it was proposed that the WTP values for increase in species diversity be applied, instead of WTP estimates from Noble (2023).

Börger et al. (2014) estimated that WTP for increases in species diversity of 10% and 25%, resulting in WTP estimates of £5.3 – £9.8 per household per year in 2023 prices. Note that these results exhibited diminishing marginal returns to scale, meaning that extrapolating the results linearly to the whole 3nm area would have a high level of uncertainty. However, increased species diversity was an expected outcome from protecting the 3nm area, but the impact would not be immediate, and therefore a lag in benefit realisation was accounted for in the analysis. It was assumed that the lower end (i.e., 10% increase in species diversity) would arise in the short-term (Year 2–10), with the higher end (i.e., 25% increase) representing long-term benefits of protection (from Year 11 onwards).

The results of this analysis are shown in Table 4.10. The change in approach only impacted estimates produced in the Protection Scenario as the original study assessed a change in protection area, and thus a value transfer for the BAU was not possible (this is the same when using Noble (2023)). In comparison to figures shown in Table 4.6, using Börger et al. (2014) resulted in a higher estimated benefit asset value and total asset value in the Protection Scenario. However, although suitable for transfer there was higher uncertainty in the results based on weaker alignment of value transfer criteria of the study site to the policy site (see Appendix 5).

Table 4.10: Alternative approach to estimating protection of wildlife value sensitivity results

Indicator (PV20, £m)	BAU	Protection Scenario	% change from BAU
Noble (2023) – Benefit asset value	Not assessed	149	N/A
Noble (2023) – Total asset value	**(914)**	**3,590**	**493%**
Börger et al. (2014) – Benefit asset value[1]	Not assessed	234	N/A
Börger et al. (2014) – Total asset value	**(914)**	**3,675**	**502%**

Table note:
[1] WTP estimates per household from Börger et al. (2014) have been multiplied by latest estimate of number of households in Scotland of approximately 2.6 million in 2022 (National Records of Scotland, 2023). Household numbers are assumed constant, with WTP unit values remaining constant from Year 11.

5. Discussion

This section discusses the results of the analysis, including comparison of findings to similar assessments as well as its limitations.

5.1 Comparison to previous studies

To put the results in Section 4 into context, similar assessments of closures to bottom-towed fishing have been reviewed (e.g., MCS, 2023; NEF, 2021). Previous studies methodology used multiple methods and data sources to capture the complex dynamics of the marine environment and the various potential impacts of a closure to bottom-towed fishing in inshore Scottish waters.

Key points of difference are from data inputs and study scope such as:

- **Following a natural capital approach:** Where possible results reflect changes in natural capital assets, changes in quantity of ecosystem service provision and ultimately changes in benefit value. The intention with this study was to show change in ecosystem service provision (i.e., quantity) and have this link to benefit values. This was a key difference to previous studies (e.g., MCS (2023) and NEF (2021)) where benefit values are linked directly to area of closure, rather than change in quantity of ecosystem service provision.
- **Geographic boundary:** Limited to the 3nm area, rather than bottom-towed fishing overall (i.e., whole EEZ). As such, the scope of material ecosystem services and benefits were driven by those habitats that were present within the 3nm area – which had implications for habitats present (i.e., some were exclusive to the 3nm area, and others could be more widespread with a small proportion in the 3nm area relative to all Scottish waters). This differs from previous assessments such as NEF (2021) which looked at the impact of banning bottom-contact fishing in EU MPAs, as well as MCS (2023) which looked at impacts within the UK's offshore benthic MPA network.
- **Detailed asset register data:** A key input to this assessment was the asset register derived by Blue Marine spatial analysis (see A1.1 for more details). It identified habitats within the 3nm area by current management (i.e., protected or unprotected areas) and fishing pressure (i.e., bottom-towed fishing). It supported the significance assessment (Section 3.2.1) and identification of material impacts (Section 3.2.3). The habitat areas were presented to the finest detail that the data permitted (i.e., EUNIS level 3), allowing for nuances across substrates to be identified and linked to specific ecosystem services.
- **Choice of evidence to support quantification and valuation:** The literature reviewed in this assessment prioritised Scottish and/or UK evidence where available. Where previous work makes use of monetary unit values reported in larger databases such as ESVD, this assessment used evidence from Scottish government statistics, UK Natural Capital Accounts and WTP studies focused on Scottish waters. In selecting evidence to be used, value transfer principles were followed (eftec, 2009).

This assessment provided outputs using approaches consistent with UK and Scottish government guidance, reflecting information on natural capital assets and their provision of ecosystem services.

5.2 Potential habitat recovery and provision of ecosystem services

The asset register data provided and shown in Section 4.1.1, can be further broken down to identify habitat areas that fall into different biological zones[11] to provide an indication of light exposure and energy levels to indicate wave exposure. These areas imply the scale of potential benthic habitat recovery under the Protection Scenario. In many cases, the recovery of benthic habitats and therefore the ecosystem services they would provide are uncertain. Therefore, the area of benthic biological zones suitable for that habitat was used as an indicator of the potential spatial scale and value of their recovery.

For example, Table 5.1 shows the total area of rocky and similar substrata benthic habitats that would be protected, indicating the potential extent of recovery of seaweed communities, and the ecosystem services and functions they support, such as carbon sequestration and fisheries productivity. Table 5.2 shows the areas of mixed sediment that would be protected, subdivided by their level of wave exposure. These areas are potentially suitable for fishing with static gears, but this is less likely where locations are subject to high wave energy.

Table 5.1: Area of rock or other substrata protected under the Protection Scenario by biological zone, km^2

Biological zone	Deep circalittoral	Infralittoral	Shallow circalittoral	Total
Total area protected	505	1,275	2,204	**3,984**

Table 5.2: Area of mixed sediment protected under the Protection Scenario by biological zone and wave exposure, km^2

Biological zone	Deep circalittoral	Infralittoral	Shallow circalittoral	Total
High energy	33	30	71	134
Moderate energy	208	43	163	641
Low energy	406	49	146	415
No energy information	-	4	1	5
Total area protected	**687**	**126**	**381**	**1,194**

In addition, Table 5.3 shows habitat types by EUNIS code that would be viable for creeling. The total of these gave an estimate of the area of the 3nm area that could become available for creeling having previously been under pressure from bottom-towed fishing. The EUNIS codes reported reflect the finest resolution that the underlying habitat mapping could identify (i.e. level 2). This level of breakdown supports assessing the potential for ecosystem service provision (i.e., fish landings) following recovery of the below habitats within the 3nm area.

[11] https://www.marlin.ac.uk/glossarydefinition/verticalbiologicalzones

Table 5.3: Habitats areas suitable for creeling previously under pressure from bottom-towed fishing

Substrate	EUNIS code	Area (km^2)
Sand	A5.23 or A5.24: Infralittoral fine sand or Infralittoral muddy sand	345
Sand	A5.25 or A5.26: Circalittoral fine sand or Circalittoral muddy sand	1,610
Sand	A5.27 Deep circalittoral sand	1,245
Fine mud	A5.34: Infralittoral fine mud	5
Fine mud	A5.36: Circalittoral fine mud	31
Fine mud	A5.37: Deep circalittoral mud	952
Muddy sand	A5.33: Infralittoral sandy mud	83
Muddy sand	A5.35: Circalittoral sandy mud	1,077
Muddy sand	A5.37: Deep circalittoral mud	1,696
Sandy mud	A5.33: Infralittoral sandy mud	24
Sandy mud	A5.35: Circalittoral sandy mud	438
Sandy mud	A5.37: Deep circalittoral mud	1,259
Total potential area for creeling		**8,765**

5.3 Limitations

The assessment provides useful results on habitat areas in the 3nm area that are subject to recovery and corresponding ecosystem service impacts using best available evidence. Improvements in confidence ratings (see Section 3.3) may refine the estimated ecosystem service and benefit impacts in Section 4.2, however the overall interpretation of results would be expected to remain the same. Implementing a closure to bottom-towed fishing in the 3nm area could lead to significant benefits to both Scotland and global society.

The results presented here are conservative, contingent on the structure of the economic analysis, in particular the framing of the BAU and Protection Scenario, and the boundaries of the benefits assessed. For example, the estimated BAU does not account for continued degradation in the condition of seabed and marine habitats if bottom-towed fishing continues but there is uncertainty in forecasting this risk. There are methodological limitations as values have been estimated by applying several assumptions to fill in gaps in understanding (e.g., changes to static gear fishing) using available data (e.g., evidence within the asset register) or expert judgment. This is reflected in the confidence ratings applied to the quantified ecosystem services and benefit values in Section 3.3.

A key challenge of this work was assessing change in condition (i.e., quality) as a driver for changes in ecosystem service provision – rather than change in extent (i.e., quantity). Understanding these linkages is generally lacking in the existing evidence on natural capital – and is not unique to the marine environment. In a review of UK marine natural capital approaches and evidence (Makowska et al., 2022), it has been highlighted that there is scope for further research in this area moving forward. However, even with known pressures on the marine environment (e.g., impacts of bottom-towed fishing on marine sediments) there is minimal quantitative evidence that can be applied in studies like this. The current assessment used the available quantitative information where possible and relevant (e.g., carbon emissions from bottom-towed fishing, insights from asset register data) but this was not always possible across the quantified benefits (e.g., nature-based tourism).

To improve the evidence base, a focus on recovery of natural capital assets (i.e., marine habitats) is recommended alongside studies of specific ecosystem services. This would help to assess the overall capacity for recovery by the marine environment to provide a range of ecosystem services. It would also help to understand the resilience of the marine environment services to future changes, which is expected to be correlated with the health of the underlying habitat assets.

6. Conclusions and recommendations

This section of the report summarises the key observations and challenges identified in the study and recommendations for future work.

6.1 Conclusions

The results presented in Section 4 made use of approaches consistent with UK and Scottish government guidance, reflecting information on natural capital assets and their provision of ecosystem services. The assessment used an extended NCBS to present results for the BAU and Protection Scenario, and to compare results between the two. This comparison showed the impacts on natural capital assets, the ecosystem services they provide in physical terms and, where possible, the monetary value of benefits from a closure to bottom-towed fishing within the 3nm area. As a result, by implementing a closure to bottom-towed fishing in the 3nm area, total net quantified monetary benefits would increase five-fold in present value terms over 20 years (increasing from -£914 million in BAU to £3.6 billion in the Protection Scenario).

A valuable output from the assessment was the asset register, detailing habitat areas within the 3nm area at the finest resolution possible with available evidence. This was a key data input to identifying the significance of closing the 3nm area to bottom-towed fishing and identifying material ecosystem services and benefits for inclusion in the assessment.

This assessment reflects the current understanding of ecosystem service impacts of bottom-towed fishing on the marine environment, and the potential improvement in ecosystem service provision from further protection, compared to the BAU. Therefore, the quantification of ecosystem services in physical terms and associated benefit values was limited by the available evidence to support the analysis. However, the asset register itself supports identification of the potential future supply of ecosystem services (e.g., from vegetated areas or shallower waters) including:

- 257% increase in habitats in the 3nm area receiving protection relative to the BAU – supporting gamete dispersal and pest and disease control.
- 60% increase in biogenic habitat areas receiving protection relative to the BAU – supporting regulating services (e.g., water quality and flood protection) as well as cultural services (e.g., nature-based tourism, health and well-being).
- 94% increase in seaweed and kelp areas receiving protection relative to the BAU – supporting wild harvesting and aquaculture as well as fibres and other materials.
- 103% increase in vegetated habitat areas receiving protection that can support additional carbon sequestration benefits.

Meanwhile, the potential of this increased capacity (e.g., through re-establishment of habitats in the 3nm area) was beyond the scope of this work, as the potential recovery of natural capital (i.e., re-establishment of vegetated habitats in the 3nm area) is still subject to high uncertainty.

The results indicate that, the expected loss in value from bottom-towed fishing would be offset by the recovery of marine habitats to provide other ecosystem services benefitting Scotland (e.g., nature-based tourism) and global society (e.g., carbon sequestration). However, the timing of this offset is uncertain within this analysis, and likely better assessed at site or fisheries level to capture not only the closure to bottom-towed fishing, but also recovery of specific habitats and the fisheries themselves, and the socio-economic effects of transition to new management approaches. The results show a net benefit to society from closing the 3nm area to bottom-towed fishing. However further analysis of costs (e.g., implementation and enforcement of the Protection Scenario) would also be useful to understand the extent to which benefits outweigh costs.

6.2 Recommendations to better understand inshore ecosystem services

This assessment raises questions and highlights the need for further work to better understand the impacts of fisheries management policies and integrating them into this type of analysis. Priorities for further work include:

- Understanding marine habitat extent and condition: Assessments of this nature would benefit from more detailed monitoring and trend data on habitat extent and condition. This study made use of the finest spatial resolution (i.e., EUNIS level 2) where feasible, however a finer resolution would be required to link natural capital assets to ecosystem service provision (e.g., identifying seaweed and kelp). It is expected that some of this information is already collected, but not publicly available. Having access to historical records of marine habitat and condition data would support better definition of the BAU (i.e., record of degradation of habitats over time), as well as allow recovery of habitats following changes in policy and/or management to be verified and used in future analysis.
- Monitoring ecosystem services in Scottish waters: With the exception of commercial fishing (both landings and value) there is little available evidence on ecosystem service quantities and benefit values for Scottish waters. The available information stems from UK Marine Natural Capital Account (ONS, 2021a), with disaggregation to Scotland possible, but further distinction to the 3nm area vs inshore vs other areas require additional assumptions. This information would also support analysis of timings of costs and benefits and interpretation of these results (e.g., how many years does it take for loss in value of bottom-towed fishing to be offset by additional benefits provided).
- Accounting for external factors: The assessment was not able to quantify changes by external pressures on the marine environment (e.g., from climate change). Integrating these types of pressures into the analysis, in particular within the BAU (e.g., degradation of marine habitats), could lead to identification of different benefits as priorities for marine management and restoration. A potential starting point would be the marine pressures list within NatureScot's Feature Activity Sensitivity Tool (NatureScot, 2020) which builds on the evidence collated by JNCC (2021).

The assessment made use of the best available Scottish evidence to support the quantification of ecosystem services and monetary valuation of benefits. Further evidence and research are required to refine the approaches used and/or expand the impacts captured, this includes:

- The assessment of fish and shellfish stock changes, and consequences for commercial fishing. These effects are not straightforward to assess, and involve a mix of different commercial species, which will have different changes to populations and levels of catches in fisheries. The impact of the

Protection Scenario for fisheries is complex, involving a mix of factors such as:

- Decrease in catches using bottom-towed gears;
- Increases in catches using static gears in areas that become newly available, having previously been under pressure from bottom-towed fishing;
- Anticipated recovery of marine habitats and ecosystems, including commercially exploited species inside the 3nm area;
- Levels of by-catch within fishing effort, including juveniles of the species targeted;
- Anticipated spillovers effects from within the 3nm area, resulting in increased abundance of commercial species beyond the 3nm area, and
- How catch limits and quotas affect fishing effort (e.g., is effort limited because quota is fully exploited), and how they adjust in response to changes in populations of commercial species due to the factors outline above.

- Carbon emissions from sediment disturbance: it is not known how the sediments and carbon content in Scottish inshore habitats compare to the global average, and therefore whether impacts of a closure in the 3nm area would be greater or smaller than those calculated.
- Carbon sequestration in other marine habitats: Requires additional habitat mapping to identify vegetated habitats (e.g., kelp and seaweed) at a finer level of detail. A finer spatial resolution of data is required to identify these areas as defined by EUNIS and link to available evidence from within Gregg et al. (2021).
- Changes to nature-based tourism and recreation: A review of information on changes in tourism activities and associated expenditure in relation to changes in biodiversity[12]. Existing evidence tends to cover either the presence/absence of species (e.g., visitor spending attracted by the presence of birds of prey such as Ospreys or White-tailed Eagles), or the overall activity supported by wildlife tourism in general. Both of these are measured relative to an implicit 'no wildlife' baseline. Research is needed into the potential impact of increasing the presence of marine wildlife on tourism and recreation activity against the current (or expected future) baseline.

The overall outcome for society also involves other factors, such as:

- Changes in carbon emissions due to changes in fishing methods and catch transportation.
- Aquaculture, which is another major food production activity in coastal waters.

However, while important, these activities are not direct benefits from the ecosystem services from benthic habitats that would be impacted by the closure in the 3nm area. Therefore, they are outside the scope of this study.

In addition, it is recognised that the Protection Scenario could result in significant socio-economic impacts to the fishing sector, and associated communities. A fair economic transition to a scenario in which inshore benthic habitats are protected, would therefore require detailed research and planning into the support required for those affected. The benefit values assessed in this study include significant public goods, which are unlikely to be realised without Government funding or policy interventions. Therefore, the values

[12] Note this is an existing evidence gap that was also identified in Kharadi and Bayes (2022) as well.

identified in this study could justify Government action to provide such support, using public funds to help secure long-term benefits from the marine environment to both Scotland and global society.

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Appendix 1 – GIS analysis

A1.1 Mapping approach

Shoreline data

To complete the necessary spatial analysis, a 3nm polygon was created based on UKHO boundaries, using additional data such as ‘closing lines’ between promontories to better define the area. A 3nm buffer was added to the UKHO shoreline shapefile. This newly created polygon was then used to clip fishing activity, habitat, and fishing restriction spatial data.

Fishing restriction data

Fishing restriction data (see Appendix Table 1) was assessed for the level of protection from bottom-towed fishing:

- Full Closure – permanent prohibition of bottom-towed fishing activities.
- Temporary Mobile Gear Closure – seasonal restriction allowing bottom-towed fishing activities only during specific times of the year.
- Other – includes areas where bottom-towed fishing is licensed under specific conditions, such as the mandatory use of tickler chains.

After identifying the level of restriction, a new polygon was created including only areas with full closures.

Fishing activity data

Spatial data on bottom-towed fishing activity were downloaded from two sources: covering vessels under and over 12m. These data were merged into one spatial dataset (shapefile).

Habitat data

The total area of each habitat was calculated for:

- Within the 3nm area
- Within the 3nm area and covered by bottom-towed fishing full closures
- Within the 3nm area and under bottom-towed fishing pressure

For each of these, the area values were exported in square kilometres into Microsoft Excel. Pivot tables were then applied to provide a comprehensive summary of the total area of each habitat type under each of the different scenarios. Appendix Table 1 provides a summary of the data layers and their sources used in the analysis.

Appendix Table 1 : GIS data sources used

Data	Source	Link	Comment
Territorial Boundaries	UKHO	https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/items/bf77b2ac1b654efc95dc3665c0501e23	
Habitat data	eMODnet	https://emodnet.ec.europa.eu/en/seabed-habitats	
Fisheries data	ICES OSPAR Dataset	https://ices-library.figshare.com/articles/dataset/Data_for_OSPAR_request_on_the_production_of_spatial_data_layers_of_fishing_intensity_pressure/18601508	2009-2020. Bottom-towed fishing only
	Scottish PMF Under 12m vessels	https://spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/Marine_Scotland_FishDAC_12436	2017-2020 - bottom-towed fishing only
MPA Boundaries	JNCC/Marine Scotland	https://hub.jncc.gov.uk/assets/598a60db-9323-4781-b5a8-dcf0ca3b29f9 https://hub.jncc.gov.uk/assets/07078ed3-496d-432b-974e-1754b47536c7 https://marine.gov.scot/maps/844	Clipped to 3nm
Bottom-towed fishing restrictions	Kingfisher Fishing Restrictions	https://kingfisherrestrictions.org/fishing-restriction-map	Only dredges and trawls selected. Byelaw wording for each feature analysed to ascertain whether permanent and closed to all forms of bottom towed fishing.

A1.2 Value of fish landings methodology

Calculations of the landings of fishing vessels from within the 3nm area could not be completed with the data used to assess spatial coverage of fishing. This was due to the changes made to landings data by the government to ensure anonymity for both datasets. As a result, Scottish Sea Fisheries statistics were instead downloaded, and landings calculated as described below.

For each year of interest, tables were compiled of the value of landings split by gear type – split into categories and colour coded (final column) in Appendix Table 2 .

Appendix Table 2 : Scottish Sea Fisheries Statistics gear type alignment

Gear Category	Gear type	Gear landings values used in this assessment
Demersal Gears	Demersal trawl	Bottom-towed
	Demersal seine	Bottom-towed
	Demersal twin/multi trawl	Bottom-towed
	Lines	Static gear
	Gill nets	Static gear
	Beam trawl	Bottom-towed
	Other methods	None
Pelagic Gears	Purse seine	None
	Pelagic trawl	None
	Other methods	None
Shellfish Gears	Creel fishing	Static gear
	Nephrop trawl	Bottom-towed
	Dredging	Bottom-towed
	Hand Shellfishing	Static gear
	Other methods	None

The yearly average value was calculated for:

- Bottom-towed fishing (overall)
- Static gear fishing (overall)
- Static gear fishing (broken down by gear type).

The values from Table 8.6.6 from the 'Management of The Scottish Inshore Fisheries' report (Riddington et al., 2014) were compared to the Scottish Sea fisheries Statistics in 2012 to determine how much of the total landings in 2012 were likely to have been from within the 3nm area by assuming that the gear types were equivalent as shown in Appendix Table 3 .

Appendix Table 3 : Alignment of fishing gear types for each source

Scottish sea fisheries stats gear category	Scottish sea fisheries stats gear type	Riddington et al. (2014) report gear types
Demersal Gears	Demersal trawl	Demersal Trawl
	Demersal seine	Not reported
	Demersal twin/multi trawl	Not reported
	Lines	Pelagic Lines
	Gill nets	Not reported
	Beam trawl	Not reported
	Other methods	Not reported
Pelagic Gears	Purse seine	Not reported
	Pelagic trawl	Pelagic Trawl
	Other methods	Not reported
Shellfish Gears	Creel fishing	Pots
	Nephrop trawl	Nephrops Trawl
	Dredging	Dredge
	Hand Shellfishing	Hand dive
	Other methods	Not reported
NA	Not reported	Other Trawl

Table note: NA means there was no direct correlation between gear types that could be inferred from the two sources.

When comparing 0–3nm from the 2015 report against all Scottish waters data from Sea Fisheries Statistics, gear types didn't match exactly. The same colour scheme as in Appendix Table 3 was applied to the 2012 value of landings by gear type from Riddington et al (2014), as shown in Appendix Table 4 . How this has been translated to the 3nm area and used in the analysis, is reflected in A4.3.

Appendix Table 4 : 2012 landings by gear type, 2012 prices (Riddington et al., 2014)

Gear type	2012 Landings by gear type (£k)						Summed landings value (£k)	
	Demersal	Pelagic	Nephrops	Scallops	Other shellfish	Total	Bottom-towed	Static
Demersal Trawl	£4,168	£3.4	£670	-	£211	£5,053	£5,053	-
Nephrops Trawl	£166	£552	£18,216	£31	£15	£18,429	£18,429	-
Pelagic Trawl	-	£9,934	-	-	-	£9,934	-	-
Pelagic Lines	-	£431	-	-	-	£431	-	£431
Other Trawl	£8	£106	£14	-	£917	£1,046	£940	-
Dredge	£2	£0.5	-	£7,961	£4.6	£7,968	£7,968	-
Pots	£1	-	£14,049	£0.5	£19,509	£33,560	-	£33,560
Hand dive	-	-	-	£2,819	£219	£3,038	-	£3,038
Total	**£4,347**	**£10,475**	**£32,950**	**£10,812**	**£20,876**	**£79,459**	**£32,390**	**£37,029**

Table note: Colour-coding reflects assumes gear type (bottom-towed fishing in orange, static gear in green or neither in grey) as defined by Appendix Table 2

Appendix Table 5 provides a summary of the data layers used in the analysis.

Appendix Table 5 : Data sources for value of fish landings

Description	Link	Use
Sea fisheries stats (2009–2021)	https://www.gov.scot/collections/sea-fisheries-statistics/	Tonnage and value landed in all Scottish waters
Management of The Scottish Inshore Fisheries; Assessing The Options for Change Report	https://www.gov.scot/binaries/content/documents/govscot/publications/research-and-analysis/2015/01/management-scottish-inshore-fisheries-assessing-options-change/documents/00467217-pdf/00467217-pdf/govscot%3Adocument/00467217.pdf	Table 8.6.2 used to calculate ratio of landings between all Scottish waters and landings from fish caught within the 3nm area

Appendix 2 – Habitat classification

Appendix Table 6 shows the definitions of habitats (i.e., marine ecosystems) used throughout the reporting and analysis and how it aligns to known classification systems (e.g., EUNIS, JNCC).

Appendix Table 6 : Habitat classification alignment

High-level natural capital asset classification	Substrata (from datasets in Appendix 1)	Definition	EUNIS	Connor et al. (2004)	JNCC classification
Biogenic habitats	[Limaria hians] beds	Made of and/or by organisms such as mussel beds or coral reefs	Biogenic habitat	Biogenic reef	NA
	[Modiolus modiolus] beds				
	[Mytilus edulis] beds				
	[Sabellaria spinulosa] reefs				
	[Serpula vermicularis] reefs				
	Biogenic substrate				
	Bivalve reefs				
	Mussel beds				
Coarse substrate	Coarse substrate	Boulders, cobbles, pebbles, or sand and gravel (If sand:mud < 9:1 then %gravel = 80%; If sand:mud > 9:1 then %gravel = 5%)	Coarse sediment	Coarse sediments	Coarse sediments
Fine mud	Fine mud	Mostly slit/clay or cohesive sandy mud (Sand:mud < 1:9 and %gravel < 5 %)	Mud	Mud	Mud
Mixed sediment	Mixed sediment	Well mixed various sediments: biogenic, muddy, rocky (Sand:mud < 9:1, 5%< %gravel < 80%)	Mixed sediment	Mixed sediment	Mixed sediment
Muddy sand	Muddy sand	Muddy sand	NA	NA	NA
Rock or other hard substrata	Rock or other hard substrata	Can be rock, boulders or cobbles	Rock	Rock	Rock

High-level natural capital asset classification	Substrata (from datasets in Appendix 1)	Definition	EUNIS	Connor et al. (2004)	JNCC classification
Sand	Sand	Clean fine sand. (Sand:mud > 9:1 and %gravel < 5%)	Sand	Sand	Sand
Sandy mud	Sandy mud	Mostly slit/clay or cohesive sandy mud (1:9 < sand:mud < 9:1 and %gravel < 5%)	Mud	NA	Sandy mud
Seabed	Seabed	NA	NA	NA	NA
Sediment	Sediment	NA	NA	NA	NA

Appendix 3 – Ecosystem service typology

Appendix Table 7 : Alignment of Culhane et al. (2019) ecosystem service classification

Annex VII of Culhane et al. (2019)		Ecosystem service name used in this assessment
Marine Ecosystem Service Working Name based on CICES version 5.1	**Marine Ecosystem Service Working Name based on CICES version 4.3**	
Seafood and other nutritional outputs from in-situ aquaculture of plants and algae	Plant and algal seafood from in situ aquaculture	Seafood from aquaculture
Raw materials from in-situ aquaculture of plants and algae	Raw materials; Materials for agriculture and aquaculture	
Biofuels from in-situ aquaculture of plants and algae	Plant and algal-based biofuels	
Seafood and other nutritional outputs from in-situ aquaculture of animals	Animal seafood from in situ aquaculture	
Raw materials from in-situ aquaculture of animals	Raw materials; Materials for agriculture and aquaculture	
Biofuels from in-situ aquaculture of animals	Animal-based biofuels	
Seafood and other nutritional outputs from wild plants and algae	Seafood from wild plants and algae	Seafood from wild plants
Raw materials from wild plants and algae	Raw materials; Materials for agriculture and aquaculture	
Biofuels from wild plants and algae	Plant and algal-based biofuels	
Seafood and other nutritional outputs from wild animals	Seafood from wild animals	Seafood from wild animals
Raw Materials from Wild Animals	Raw materials; Materials for agriculture and aquaculture	
Biofuels from wild animals	Animal-based biofuels	
Genetic materials from plants and algae: seeds and spores	Genetic materials	Genetic materials

Annex VII of Culhane et al. (2019)		Ecosystem service name used in this assessment
Marine Ecosystem Service Working Name based on CICES version 5.1	**Marine Ecosystem Service Working Name based on CICES version 4.3**	
Genetic materials from plants and algae: whole organisms	Genetic materials	
Genetic materials from plants and algae: genes	Genetic materials	
Genetic materials from animals: spat and gametes	Genetic materials	
Genetic materials from animals and micro-organisms: whole organisms	Genetic materials	
Genetic materials from animals and micro-organisms: genes	Genetic materials	
Anthropogenic Waste and Toxicant Treatment via Biota	Waste and toxicant treatment via biota	Water quality
Anthropogenic Waste and Toxicant Removal and Storage	Waste and toxicant removal and storage	
Sediment Nutrient Cycling	Sediment nutrient cycling	
Chemical Condition of Seawater	Chemical condition of seawater	
Oxygen Production	Oxygen Production	
Smell Reduction	Mediation of smell/visual Impacts	Mediation of smell/visual Impacts
Reduction of Visual Impacts		
Erosion Prevention and Sediment Retention	Erosion prevention and sediment retention	Mass stabilisation
Flood Protection	Flood protection	Flood protection
Seed and Gamete Dispersal	Seed and gamete dispersal	Gamete & seed dispersal
Maintaining Nursery Populations and Habitats	Maintaining nursery populations and habitats	Maintenance of nursery populations and habitats
Gene Pool Protection	Gene pool protection	
Pest Control	Pest control	Pest & disease control

Annex VII of Culhane et al. (2019)		Ecosystem service name used in this assessment
Marine Ecosystem Service Working Name based on CICES version 5.1	**Marine Ecosystem Service Working Name based on CICES version 4.3**	
Disease Control	Disease Control	
Global Climate Regulation	Global climate regulation	Global climate regulation
Recreation and Leisure	Recreation and leisure	Cultural: Experiential & physical use
Scientific	Scientific	Cultural: Scientific/educational
Educational	Educational	
Heritage	Heritage	Cultural services: Aesthetic; Spiritual and/or emblematic
Aesthetic	Aesthetic	
Symbolic	Symbolic	
Sacred and/or religious	Sacred and/or religious	
Entertainment	Entertainment	
Existence	Existence	
Bequest	Bequest	
Ecosystem services that have been identified as relevant but are not included in either Culhane et al. (2019) or Lusardi et al. (2018).		Abiotic services (renewable energy)
		Thriving wildlife (formerly biodiversity)

Appendix 4 – Valuation methodologies

This section details the valuation methodologies of ecosystem service quantities and monetary valuation of benefits which are summarised in Section 3.3. Overall, the methodologies applied are the same across the BAU and Protection Scenario. Where this is not the case, the differences are made clear along with any assumptions and additional references used.

A4.1 Scenario descriptions

Business as Usual (BAU)

The BAU assumes no change to the current level of bottom-towed fishing activity within the 3nm area, across the assessment period (i.e., no closure is implemented) and current levels of bottom-towed fishing activity and landings within the 3nm area are assumed to remain constant. Note all other fishing activity and gear types are also assumed to remain constant at current levels (applies to other mobile and static gears). The subsequent analysis assumes no further deterioration of seabed condition from the continued use of these gear types, and hence, unchanged annual provision of ecosystem services. Furthermore, current designations (i.e., areas closed to bottom-towed fishing) and areas not under fishing pressure are also assumed to remain unchanged – any ecosystem services (e.g., carbon sequestration) arising from these areas are also assumed constant (in physical terms). These assumptions provide a baseline against which to assess the impacts of a closure within the 3nm area, but real-world ecosystem dynamics mean that some changes to these factors could be expected to occur, introducing uncertainty into the analysis.

This assumption of no change over time is made due to the uncertainty around potential interactions between changes in habitat status over time and ecosystem service provision. It is important to recognise that this assumption may not fully capture the complete spectrum of impacts of bottom-towed fishing on marine ecosystem services over time. Current literature highlights that existing levels of bottom-towed fishing are considered damaging to the ecosystem (Cantrell et al., 2023; Moffat et al., 2021). Therefore, it may be overly simplistic to assume that current conditions will persist unchanged into the future. For instance, a reduction in fish stocks could have cascading effects on fishing efforts and related recreational activities, such as angling and diving. While the BAU assumes a constant level of bottom-towed fishing, it does not account for the potential knock-on effects that might arise from ongoing environmental degradation. Therefore, while the choice of no change over time in the BAU is a necessary simplification, it is essential to acknowledge the inherent complexities and potential variables that might affect an ecosystem.

Protection Scenario

The Protection Scenario assumes that all bottom-towed fishing practices will immediately cease within the 3nm area following a complete bottom-towed fishing closure at the start of the assessment period (i.e., Year 0). By this date, all bottom-towed fishing activities would stop, leading those who rely on this specific fishing technique to either shift to alternative fishing practices (e.g., static gears), transition to other business activities, or fish further out (i.e., beyond 3nm).

The effects of protection can be expected to manifest differently over time, across habitats and the ecosystem services provided. While some impacts, such as recovery of some seabed habitats, may be observable in the medium term (e.g., 10 years), others will require a longer assessment timescale (e.g., 60 years) to be completely realised.

The changes in ecosystem service provision in the Protection Scenario are assessed using a range of habitat-specific recovery rates (Cantrell et al., 2023). The habitat recovery rates indicate the anticipated change in the current habitat condition following a closure to bottom-towed fishing. This affects the change in ecosystem services that a given habitat can provide under the Protection Scenario. These changes are then applied to the areas of habitats that are unprotected and under pressure from bottom-towed fishing activity in the BAU, but become protected under the Protection Scenario, to estimate the overall change in ecosystem services.

A4.2 Ecosystem service quantification

Seafood from wild animals

The quantity of landings within the 3nm area could not be calculated using the vessel data used to assess the spatial coverage of fishing (approach described in Appendix 1). This was due to changes made to the landings data by government to ensure anonymity for both datasets. As a result, Scottish Sea Fisheries (Scottish Government, 2021) statistics for all Scottish waters were used to estimate the average quantity of fish landings in the 3nm area for bottom-towed and static gears.

An approximate tonnage of landings was inferred based on the ratio between value of landings (£) to tonnes landed in a given year from the Scottish Sea Fisheries statistics of both bottom-towed and static gear landings (i.e., tonnes/£-value landed in 2023 prices). As Scottish Sea Fisheries statistics provide data from 2009-2022, a ten-year average tonne caught per £-landed was estimated for bottom-towed fishing and static gears.

In the BAU and Protection Scenario, the estimated average tonnes/£-value landed for bottom-towed fishing and static gears is applied to the estimated value of fish landings from within the 3nm area. This average ratio is assumed to remain constant over time. With any changes in the tonnes of fish landings driven by assumed changes in the value of landings (e.g., increase in static gear fishing potential in the Protection Scenario). The approach to estimating value of fish landings is explained in Section A4.3.

Global climate regulation

Marine habitats offer significant potential for CO_2 sequestration, primarily through the organisms and plants that inhabit them. The exact amount of CO_2 stored in the sediment layers of these habitats remains uncertain. However, it's well-established that bottom-towed fishing can disrupt the carbon sequestration process, leading to the release of some of the carbon stored in the seabed.

Carbon release from bottom-towed fishing

Bottom-towed fishing activity causes sediment disturbance, resulting in carbon dioxide emissions. This occurs each time an area is trawled or dredged. Sala et al. (2021) estimate the aqueous CO_2 emissions[13]

[13] Includes CO_2e that is re-suspended in the water column, therefore not limited to emissions released to the atmosphere.

resulting from the first year of bottom-towed fishing and emissions from continuous trawling[14] assuming intensity and footprint of trawling remains constant. These estimates reflect bottom-towed fishing activity globally between 2016 and 2019, across an area of 4,900,000 km^2 where bottom-towed fishing occurs each year. The continuous release of CO_2 into the water column and atmosphere is expected to continue annually for up to 400 years when bottom-towed gears are used. In response to peer-review critique Hiddink et al. (2023), the Sala et al. (2021) estimates were refined by Atwood et al. (2023) but these refined estimates had higher modelling uncertainty[15]. Atwood et al. (2023) had been scoped during the Expert Workshop. The experts presented the paper as the latest best-available evidence of carbon release from bottom trawling fishing, following Sala et al., (2021) which was the first study to provide estimated emissions.

To support monetary valuation, a key consideration is quantifying CO_2 emitted to the atmosphere – which requires making the distinction between CO_2 resuspended in the water column and CO_2 released to the atmosphere. This split is difficult to measure, potentially resulting in an over- or under- estimation of CO_2 emissions to the atmosphere from bottom-towed fishing in Scottish waters. Although an adjustment cannot be made on the quantitative estimate it has been accounted for as part of estimating the monetary value of emissions.

Appendix Table 8 shows the emission rates ($tCO_2e/km^2/yr$) considered for use in this assessment. For the purpose of this report, the Sala et al. (2021) average emission rate for repeated bottom-towed fishing activity is used.

Appendix Table 8 : Global average carbon emission rates from bottom-towed fishing

Source	First year bottom-towed (tCO_2e/km^2)	Continuously bottom-towed ($tCO_2e/km^2/yr$)
Sala et al. (2021)	300	118
Atwood et al. (2023)	No estimate	9 - 71

Table note: Emission rates have been estimated by dividing estimated global average annual emissions (2016-2019) by the global area that is bottom-towed per year (4,900,000 km^2).

An estimate of carbon emissions from bottom-towed fishing within the 3nm area is produced for the BAU only – to capture emissions from material habitats within the area under pressure from bottom-towed fishing (15,810 km^2)[16]. This area is multiplied by the emission rate for areas that are continuously trawled (118 $tCO_2/km^2/yr$). This gives an estimate that bottom-towed fishing in the Scottish 3nm zone releases 1.9 million tonnes of CO_2 per year due to subtidal sediment disturbance.

As in Sala et al. (2021), the rate of emissions is assumed to remain constant, reflecting the underlying

[14] Emissions are assumed to stabilise at approximately 40% of first year emissions, after nine years of continuous trawling (Sala et al., 2021).

[15] Atwood et al. (2023) presents lower CO2 release rates than Sala et al., (2021) due to different assumptions about organic carbon mineralization in sediments. It emphasizes the importance of organic carbon composition and suggests a lower reactivity value for more accurate estimations.

[16] Seabed and rocky and other hard substrata habitats (6,342 km^2) are assumed not to provide carbon release due to no sediments being disturbed, hence excluded from this analysis. This is consistent with Sala et al. (2021) where modelling includes oxic sediments, to ensure that estimates reflect carbon that is labile (i.e., more prone to remineralisation after a disturbance). Sediment type is used as a proxy for labile carbon and includes coarse, sandy, fines (e.g., silt, clay) and biogenic sediments.

assumption that bottom-towed fishing activity (intensity and effort) are assumed constant throughout the analysis. It is assumed that the same amount of CO_2 is released per square kilometre per year for each habitat affected by bottom-towed fishing, therefore the analysis does not capture habitat-specific impacts of bottom-towed fishing on carbon emissions. This assumption is grounded in the available data, which indicates that the majority of carbon released is from sandy mud habitats. This is a logical conclusion as sandy mud represents the largest extent of habitat affected by bottom-towed fishing activities. Furthermore, coastal, and intertidal habitats are not considered material in this analysis as it is assumed that bottom-towed fishing does not typically occur in coastal and intertidal zones. This assumption may overlook potential impacts in fringe areas where some form of bottom-towed fishing might occur, albeit significantly less frequently.

In the Protection Scenario, the emissions of carbon from bottom-towed fishing falls to 0 from the implementation of the proposed closure in Year 0.

The data in both Sala et al. (2021) and Atwood et al. (2023) represent a global average for areas disturbed by bottom-towed fishing. The intensity of bottom-towed fishing activity in Scottish 3nm Waters is expected to be higher than the global average. Therefore, the level of carbon emissions could be higher than the global average. However, this requires further review, taking into account other factors such as the depth of water in the areas studied.

Carbon sequestration by marine habitats

Gregg et al. (2021) provides rates of carbon sequestration (tCO_2/ha/yr) by marine habitats (e.g., intertidal sediments, kelp, and subtidal sediments). To apply the collated sequestration rates from Gregg et al. (2021) to this assessment, the habitat types have been aligned to the EUNIS classification used within this assessment. Appendix Table 9 shows this alignment and the sequestration rates. It has been assumed that the rate for subtidal sediments (specifically mud) in Gregg et al. (2021) is applicable to fine mud, mixed sediment, sandy mud, and sediment in this assessment.

Appendix Table 9 : Carbon sequestration rates from Gregg et al. (2021) used in the analysis

Habitat (Greggs et al., 2021)	Habitat Type (EUNIS)	$tCO_2e/km^2/yr$
Biogenic reefs	Biogenic habitats	No evidence identified
Subtidal sediment	Fine mud	112
Subtidal sediment	Mixed sediment	112
Subtidal sediment	Sandy mud	112
Subtidal sediment	Sediment	112

The values were multiplied by the habitat area for each high-level natural capital asset (e.g., fine mud) from the asset register. In the BAU, the sequestration rates were multiplied by the area of subtidal sediments already closed to bottom-towed fishing (450 km^2) and the area not under pressure from bottom-towed fishing (778 km^2) – providing an estimate of carbon sequestration arising in areas where bottom-towed fishing does not occur. The analysis assumes, that where pressure from this fishing activity exists it is unlikely that these habitats are sequestering (given estimated release of tCO_2 from sediment disturbance). This assumption underscores the impact of trawling on the natural carbon cycle of these habitats, emphasizing that the repeated physical disturbance from bottom-towed fishing negates any natural carbon sequestration that might have occurred in undisturbed conditions.

In the Protection Scenario, the area multiplied by the sequestration rates was extended to include the area receiving protection (i.e., fine mud, mixed sediment, sandy mud, and sediment areas previously under pressure from bottom-towed fishing, approximately 4,231 km^2). This reflects the additional CO_2 sequestered as a result of closing the 3nm area to bottom-towed fishing. Appendix Table 10 presents the estimated physical quantity of the ecosystem services provided.

Appendix Table 10 : Tonnes of CO_2 sequestered by habitat in the BAU and Protection Scenario

Habitat Type	BAU: Areas protected or not under pressure	Protection Scenario: Areas receiving protection
Biogenic habitats	No evidence identified	
Fine mud	11,811	110,731
Mixed sediment	15,707	126,608
Sandy mud	18,093	192,820
Sediment	991,993	43,763
Total CO2 sequestered	**137,604**	**473,922**
Area (km^2)	**1,229**	**4,231**

In the BAU, it is assumed that carbon sequestration rates remain constant over time. For the Protection Scenario, the analysis assumes that relevant habitats within the areas receiving protection will require up to 8 years to recover following the closure to bottom-towed fishing (based on Cantrell et al., 2023) and the capacity to provide the carbon sequestration services increases linearly (i.e., full capacity in Year 8). Therefore, the total carbon sequestration in a given year under the Protection Scenario reflects both the BAU estimates (i.e., areas that are assumed to be sequestering already) and the additional areas with capacity to sequester as a result of the closure.

Carbon stored in sediments

Gregg et al. (2021) also provides carbon storage rates by marine habitats (e.g., intertidal sediments, and subtidal sediments). The same alignment of habitat types included in Gregg et al. (2021) to the EUNIS classification used in this assessment applies. It has been assumed that the carbon storage rate for subtidal sediments (specifically mud, 20,185/km^2)[17] in Gregg et al. (2021) is applicable to fine mud, mixed sediment, sandy mud, and sediment in this assessment.

The subtidal carbon storage rate is multiplied by the relevant area of habitat in the BAU and Protection Scenario. The estimated carbon storage by subtidal sediments in Year 8 for both the BAU and Protection Scenario are shown in Appendix Table 11 . In the BAU, this reflects carbon storage in subtidal sediments in areas already closed and not under pressure from bottom-towed fishing (i.e., 1,229 km^2) and areas under pressure from bottom-towed fishing (4,231 km^2). Carbon stocks in areas already protected or not under

[17] Gregg et al. (2021) carbon storage rates have been converted from tC/ha to tCO_2/km^2 by applying an area conversion factor (ha to km^2) followed by a conversion factor of 3.67 to convert carbon to carbon dioxide (IPCC, 2018).

pressure are assumed to remain constant over time. Although there is carbon stored in areas under pressure from bottom-towed fishing this could not be estimated with confidence – in part because the area has been continuously trawled (historically), and carbon stored is expected to be decreasing over time as a result of continued sediment disturbance. Therefore, any change in carbon storage between the BAU and Protection Scenario reflects the additional area receiving protection.

Similarly, in the Protection Scenario estimates of carbon stock in areas already protected or not under pressure remain the same as in the BAU. However, the area of subtidal sediments previously under pressure from bottom-towed fishing receiving protection (i.e., approximately 4,231 km^2) are multiplied by the carbon storage rate. The analysis assumes that relevant habitats within the area receiving protection will require up to 8 years to recover following the closure to bottom-towed fishing (based on Cantrell et al. (2023)) and the capacity to store CO_2 increases linearly over this period (i.e., full capacity in Year 8). Therefore, the total carbon storage potential in a given year under the Protection Scenario reflects both the BAU estimates (i.e., areas where carbon is already stored) and the additional areas with capacity to store carbon as a result of the closure.

The estimated tonnes of CO_2 stored in Appendix Table 11 are not reported in the NCBS due to high levels of uncertainty.

Appendix Table 11 : Tonnes of CO_2 stored by habitat in the BAU and Protection Scenario in Year 8

Habitat Type	BAU: Areas protected or not under pressure	Protection Scenario: Areas receiving protection
Biogenic habitats	No evidence identified	
Fine mud	2,126,740	19,938,228
Mixed sediment	2,828,189	22,796,907
Sandy mud	3,257,820	34,719,124
Sediment	16,564,160	7,879,857
Total	**24,799,910**	**85,334,115**

Cultural: Experiential & physical use

Across Great Britain in 2019, 93 million tourism and outdoor leisure (T&OL) trips were recorded as undertaking 'watching wildlife, bird watching, other nature' activities (ONS, 2021). This represents total T&OL trips for the specific activity by UK residents. The number of outdoor activities to the marine environment across Great Britain is estimated as 129 million in 2019 (ONS, 2021). The proportion of outdoor activities attributed to the marine environment that represents watching wildlife cannot be ascertained from the published data.

The link between visits and presence or sighting of charismatic species (e.g., whales, seals, and seabirds) within the 3nm area is unknown for the BAU. In addition, it is uncertain how protection may result in a change in the number of species sited and the subsequent change on number of visits. This is an existing evidence gap and consistent with findings from other reports (e.g., Kharadi and Bayes (2022)).

A4.3 Benefit valuation

Food from wild caught fish

Landings values within the 3nm area could not be calculated using the vessel data used to assess the spatial coverage of fishing (approach described in Appendix 1). This was due to changes made to the landings data to ensure anonymity for both datasets. As a result, Scottish Sea Fisheries (Scottish Government, 2021) statistics for all Scottish waters was used to estimate the average quantity of fish landings in the 3nm area for bottom-towed and static gears.

A proportional approach was taken to scale down the value of fish landings from all Scottish waters to the 3nm area. This was done by estimating the ratio between fish landings by relevant gear types in 2012 (as shown in Appendix Table 4) to Scottish Sea Fisheries in 2012 for bottom-towed and static gears. The ratio was then applied to the estimated ten-year average value of fish landings from all Scottish waters for bottom-towed and static gears to get an approximate average value of fish landings from the 3nm area. Note the ratio applied is only a snapshot from 2012 and is likely to have varied over subsequent years, however there is insufficient publicly available data to determine what this variation has looked like.

The resulting valuations for bottom-towed and static gear landings in the 3nm boundary are used in this assessment. In both the BAU and Protection Scenario it is assumed that average value for each type remains constant, reflecting that the level of fishing intensity and effort is unchanged. In the BAU, total value of fish landings is the sum of bottom-towed and static gear landings. For the Protection Scenario, bottom-towed gear fish landings are assumed to fall to zero as a result of the proposed closure.

In the Protection Scenario, the static gear landings made in the BAU are expected to continue in the 3nm area at least at the same level as in the BAU and remains constant over time. In addition, static gear fish landings are expected to increase as a result of the closure, as areas previously under pressure from bottom-towed fishing recover and a larger area of the 3nm area becomes suitable for static gear fishing due to reduced gear conflict. It is assumed that fishing by static gears will occur in the area previously under pressure from bottom-towed activity (i.e., the area receiving protection) with low or moderate wave energy exposure. Wave energy exposure is used as a proxy for how variation in conditions can affect areas as usable fishing grounds, based on eftec's experience in previous consultations for Marine Scotland MPA designation. For example, areas with high wave energy are potentially in accessible in winter seasons, where wave energy is a factor in access to fishing grounds and therefore a proxy for conditions. These low and moderate exposure areas make up approximately 75% of the area previously under pressure from bottom-towed fishing (22,153 km^2) and 54% of the total 3nm area (30,759 km^2). This resulting estimated value represents a 'best' estimate of potential for static gear fishing following a closure to bottom-towed gears.

Benefits from the potential for increased static gear fishing in the proposed closed area are assumed to increase linearly across the first five years of the closure. This reflects the expected time required for marine habitats to recover, while also reflecting that static gear fishers can expect some benefits sooner.

This increase in static gear use (e.g., potentially by previous bottom-towed fishers) is calculated by applying an estimated average value of landings per km^2 by static gears within the 3nm area. This is based on the BAU estimated value by static gears within the 3nm area (approx. £46 million in BAU), and the size of the area within 3nm where static gear fishing occurs (approx. 25,600 km^2)[18]. This estimated static gear landings per km^2 is multiplied by the additional area available for static gear fishing (75% of 22,153 km^2). Therefore, the landings per area fished with static gear is held constant and the change in benefit reflects the larger proportion of the 3nm area that could be used by static gear in the Protection Scenario.

Equable climate

Carbon emissions from sediment disturbance and carbon sequestered by marine habitats are valued according to the latest DESNZ (2023) guidance and applies the non-traded central carbon value series (£/tCO_2e/yr). For each year in the series (i.e., up to 2050), the central value is multiplied by the estimate of tonnes of CO_2 emitted by bottom-towed fishing or sequestered by marine habitats. The approach is the same for both the BAU and Protection Scenario. Future flows of carbon are valued using the DESNZ (2023) carbon values series until 2050. Following DESNZ (2021) advice, a real annual growth rate (1.50%) is then applied starting at the most recently published value for 2050 and into the future.

As explained as part of quantifying carbon released from bottom-towed fishing, the monetary valuation of either carbon emissions or carbon sequestration reflects an exchange with the atmosphere (i.e., non-aqueous). This is consistent with the DESNZ (2023) non-traded carbon values. However, current evidence to support quantifying carbon emissions from bottom-towed fishing do not distinguish between carbon re-suspended in the water column vs re-released to the atmosphere. Therefore, an adjustment in physical terms was not possible.

An adjustment in monetary terms is possible, using a correction factor based on the social value of offsets (SVO). The SVO, typically, is an indicator measuring the compensation between carbon offsets to one tonne of CO_2 emissions (Groom and Venmans, 2023). Groom and Venmans (2023) have applied the approach primarily with terrestrial restoration projects (e.g., reforestation) in mind. However, the same principles would apply to conservation within the marine environment. In the context of this study, the uncertainty is not whether the carbon sequestered remains stored in the Protection Scenario, but whether it would have been emitted under the BAU (i.e., uncertainty in additionality). This uncertainty is reflected in risks of failure of the proposed intervention (i.e., the closure) – it is assumed that without the closure of the 3nm area to bottom-towed fishing, degradation would continue. Equally it is assumed in Section 2.2 that the closure is successfully enforced (i.e., low risk of failure), making the estimated benefits additional.

Groom and Venmans (2023) have provided a matrix to determine the appropriate SVO correction factor to apply to estimated present values of carbon benefits. Typically, it would be applied to the social cost of carbon which reflects the welfare effects of emissions' damages (Groom and Venmans, 2023). However, in this study the SVO correction factor is applied to DESNZ (2023) non-traded carbon values (i.e., marginal abatement costs) in line with UK government guidance (DESNZ, 2021). The appropriate SVO correction factor to use is determined by: (1) the most relevant Intergovernmental Panel on Climate Change (IPCC) representative concentration pathway (RCP) scenario; (2) risk of additionality at start; (3) risk of additionality at the end; and (4) maximum duration of the scheme in question. In this study, the appropriate RCP scenario is unknown and there is low risk of failure (0.5) at the start and end (0.005) of the scheme (i.e., proposed ban). To ensure that long-term benefits of the closure are considered, the SVO correction factor for 50 years is used (33%). The SVO correction factor is applied to the BAU estimates for carbon release

[18] Estimated with support from Blue Marine GIS team.

from sediment disturbance as seen in Appendix Table 10 .

Nature-based tourism & leisure

The marine environment draws both domestic tourism and outdoor leisure trips within the UK, encompassing day visits and overnight stays, as well as attracting international visitors. Tourism surveys gather data on the number of trips, expenditure during these visits, and the activities pursued during these trips. Research conducted by eftec et al. (2019), and ONS (2021) have provided estimates of visit numbers and the related spending for trips linked to the natural environment in general, and further broken down by UK broad habitats and across the devolved nations.

For this account, the emphasis is on activities such as 'watching wildlife, bird watching, and other nature'. These activities had a combined five-year average spending of approximately £552 billion across GB, adjusted to 2023 prices. Appendix Table 12 shows the five-year average (2015-2019) total and expenditure attributable to the marine environment as estimated by ONS (2021), presented both as an annual figure and a 100-year asset value.

Appendix Table 12 : Great Britain five-year average tourism and outdoor leisure expenditure – annual and asset values, 2023 prices

Expenditure type	5-year annual average (£m)	5-year average asset value (100 years, £m)
Expenditure on watching wildlife, bird watching and other nature activities	497	Not estimated
Total expenditure tourism and outdoor leisure activities	12,795	551,857
Expenditure on tourism and leisure activities attributed to the marine environment	1,420	64,096

Table note: (ONS, 2021) values have been inflated from 2019 prices to 2023 prices using latest UK GDP deflators (HM Treasury, 2022).

Based on the figures above, total expenditure on watching wildlife activities in GB accounts for approximately 4% of all expenditure in the marine environment. The average GB marine asset value is adjusted to reflect expenditure on watching wildlife (i.e., 4% of £65 billion) equating to an asset value of £2.6 billion over 100-years. This is divided by the cumulative discount factor (HM Treasury, 2022) over 100 years to produce the estimated equivalent annual value of watching wildlife in the marine environment across GB (£86.4 million).

Further adjustment is necessary to produce figures that relate to the area of Scottish waters within the 3nm area relative to GB waters (i.e., GB EEZ). The 3nm area represents 4% of the total area of the GB EEZ, which is multiplied by the aforementioned equivalent annual value (EAV) of watching wildlife in the marine environment. Thus, the EAV of watching wildlife in the 3nm area is approximately £3.6 million per year. This is assumed to remain constant over time.

Changes in wildlife watching activity and expenditure due to increased Protection Scenario have not been assessed. Therefore, the BAU EAV is assumed to be representative of the Protection Scenario. This reflects that nature-based tourism in the Protection Scenario is at least equal to the BAU. This estimate in BAU nature-based tourism value has been compared to results from the eftec et al. (2019) assessment. Appendix Table 13 presents the estimates of attributable expenditure from watching wildlife by GB domestic tourists overall (i.e., ecosystem attributable spend) and marine attributed expenditure for GB, England, and Scotland.

Appendix Table 13 : eftec et al. (2019) estimated expenditure on watching wildlife, 2017 prices

Watching wildlife, bird watching, other nature (£m)	Great Britain	England	Scotland
Total expenditure	3,419	2,239	534
Activity expenditure	1,040	668	150
Ecosystem attribution %	100%	100%	100%
Ecosystem attributable spend	1,040	668	150
Marine attributed expenditure	358	104	26
% of marine attributed spend	34%	16%	17%

Protection value of wildlife

Existence and non-use values of wildlife were quantified based on Noble (2023) which estimate the WTP of Scottish households for five characteristics of marine and coastal areas in Scotland[19]. The area of Scottish waters considered in the study reflects Scotland's EEZ limit (up to 200nm from coastline)[20] which is approximately 462,315 km^2. In addition to WTP estimates for the five assessed attributes, Noble (2023) produce an estimated WTP for every additional 1% of total sea area changed by management policies, shown in Appendix Table 14 . These figures represent management policy changes occurring within the 2.5% and 10% range of total sea area changed – beyond this, the author, recommends results should be interpreted with extreme caution. The protection value of wildlife (i.e., % increase) of the Scottish inshore area, which is taken as a proxy for existence values and other non-use values. For further details on suitability of Noble (2023) for value transfer see Appendix 5.

Noble (2023) was deemed most suitable for value transfer as: (i) the study site location (all Scottish waters) is most similar to the policy site (i.e., Scottish 3nm), and (ii) the total additional area protected in the policy site (i.e., 26,500 km^2) is within the range of areas covered by Noble (2023) (2.5% to 10% of Scottish sea area is between 11,600-46,200 km^2). Therefore, there is a lower risk of uncertainty and inaccuracy as a result of increasing or decreasing returns to scale. Although Noble (2023) provide a range of values for marine and coastal areas that could be relevant to the assessment area, the WTP figures for an additional 1% change in sea area have been taken forward in this analysis.

[19] The five characteristics include: size of area where management change occurs, distance to the coast, type of restrictions on human activities in Scottish waters, increase in wildlife and habitats, updates, or installation of educational boards. WTP estimates are produced for those estimates that were statistically significant.

[20] Concluded based on reference image provided to respondents (Figure 6 in Noble (2023)) and latest evidence from Marine Scotland (2023).

Appendix Table 14 : Willingness to pay estimates for 1% additional protection of total sea area in Scotland, 2023 prices

Estimate (unit)	Average (mean)	Lower confidence interval	Upper confidence interval
Unit value (£/household /year)	£1.98	£0.70	£3.25
Aggregate value[2] (£m/year)	£5.00	£1.77	£8.23

Table note:

[1] From Noble (2023) results are for changes within the 2.5% and 10% range of total sea area tested in this choice experiment – beyond this range, application of results should be treated with extreme caution

[2] Household WTP estimates have been multiplied by total number of households in Scotland (2.53 million) to produce aggregate WTP.

In order to assess the aggregate WTP in the Protection Scenario, the lower end of the Noble (2023) WTP value range is used (£1.8 million per year). This reflects aggregate WTP across all Scottish waters for an additional 1% of protection. In this assessment, the additional area receiving protection in the 3nm area (i.e., area under pressure from bottom-towed fishing and the area unprotected but not under pressure) is approximately 6% of Scottish waters. This percentage is used to scale-up the Noble (2023) aggregate WTP figure, producing an estimate of WTP by Scottish households for increased protection of the 3nm area.

Appendix 5 – Value transfer for protection of wildlife value

Appendix Table 15 presents the value transfer criteria and comparison between the policy site (i.e., area under pressure from bottom-towed fishing receiving protection) and the study sites in Börger et al. (2014), McVittie & Moran (2010), Kenter et al. (2013) and Noble (2023). Based on this framework, it is concluded that it is appropriate to apply Scottish households willingness to pay (WTP) for every additional 1% of total Scottish sea area changed by management policies in Scottish inshore waters from Noble (2023). This is used to calculate an estimate of WTP by Scottish households for increased protection of the Scottish inshore area in the Protection Scenario defined in this assessment (approach is described in Appendix 4). Overall, Noble (2023) is deemed most suitable for value transfer as; (i) the study site location (all Scottish waters) is most similar to the policy site (i.e., Scottish inshore waters), and (ii) the additional area protected in the policy site (i.e., approx. 26,000 km^2) is within the range of areas covered by Noble (2023) (2.5% to 10% of Scottish sea area is between 11,600-46,200 km^2)– so there is a lower risk of inaccuracy from increases or decreasing returns to scale.

McVittie & Moran (2010) assessment of non-market benefits to UK residents associated with conservation efforts resulting from the proposed Marine Conservation Zones (MCZs) under the UK Marine and Coastal Access Bill (Moran et al., 2008) was also considered for use in this project. This study produced implicit prices for a wider range of environmental outcomes such as halting loss/increase of biodiversity and environmental benefits, alongside preferences for level of restrictions (moderate or high) – so gives a broad comparator to the valuations from Noble (2023). One of the main proposed measures is the designation of a network of MCZs —the terminology applied in the proposed legislation for marine protected areas in English territorial and UK offshore waters. The main policy objective is to enable the designation of MCZ's in both territorial (up to 12 nautical miles) and UK offshore waters (the UK continental shelf) for marine flora or fauna, habitats, geomorphological features, or other natural features. Sites could be designated for features that are rare, threatened, or representative of the biological diversity of the UK marine area. Within zones provisions are made for controls on unlicensed activities (and enforcement) for protection of MCZ's.

Appendix Table 15 : Value transfer approach for protection of wildlife values

Note: Grey Cells indicate where information is not provided for the policy site - it's not relevant (N/R) because it relates to information about the published studies.

Selection criteria	The policy site	Börger et al. (2014)	McVittie & Moran (2010)	Kenter et al. (2013)	Noble (2023)
The good itself	Inshore marine environment, particularly seabed habitats	General environmental assets include birds, fish endangered species and salt water. Which are associated with ecological functions, extractive use and passive use as goods and services. These factors are measured through species diversity; protection of porpoises, seals, and seabirds; and impact of wind farms on invasive species spread	Marine biodiversity and ecosystem goods and services, noting these as the primary benefits from MCZs. These benefits include both non-use values and a broader range of services that involve direct and indirect uses.	Cultural ecosystem services of UK sea anglers, divers, and snorkelers for candidate marine protected areas in England and Scotland and existing marine SACs in Wales	Scottish households willingness to pay for marine management policies that affect characteristics of Scotland's marine and coastal areas.
The change	Cessation of bottom towed fishing within 3nm limit of Scottish waters	Conservation of an offshore ecosystem through a reduction or removal of trawling some parts of the Dogger Bank: • 10% or 25% increase in species diversity; baseline has no change in marine species diversity • Protection of porpoises, seals, and seabirds in 25% or	• Conservation of ecosystem goods and services resulting from the implementation of proposed Marine Conservation Zones: • The study looks at three levels of provision: • Current, or status quo • Decreased level	Change (increase, decreased or status quo) in provision of: • Marine landscape type • Underwater objects • Sea life • Access • Other restrictions • Vulnerable Species protected	Change in: • **Size of area where change occurs** (2.5% of total sea area, 5% of total sea area, 7.5% of total sea area, 10% of total sea area) • Distance to coast: o Inshore – from the coast out to 12 nautical miles o Offshore - from 12

Selection criteria	The policy site	Börger et al. (2014)	McVittie & Moran (2010)	Kenter et al. (2013)	Noble (2023)
		50% of the Dogger Bank area, as compared to no protection • Restricted spread of INNS (status quo) to widespread as a result of offshore wind developments in the area	• Increased level • The three levels are linked to the following attributes: • Biodiversity (and loss of) • Environmental benefits (and loss of) Restrictions to the MCZ (moderate vs highly restricted)	• Size of area • Travel distance	nautical miles out from the coast to 200 nautical miles out from the coast • **Wildlife and habitats** (Very small increase, Small increase, **Medium increase, Large increase**) • Type of restrictions (None, **Low, Moderate**, High) • Educational public display boards (**Yes**/No) However, WTP estimates are only produced for those attributes and levels that were statistically significance (shown in bold).
The monetary valuation	N/R	Increase in annual tax over the following five years from £0 to £5, £10, £20, £30, £40 or £60 to cover costs of monitoring and enforcement	Price (additional annual tax paid by household) £5 £10 £20 £50 £75 £100	One off donation £0 £2 £4 £6 £10 £20 £30 £40 More than £40	Annual household water charge - Increase: £10 £20 £30 £50 £70 £100
The location	Scottish 3nm waters: • Total area = 30,759 km^2	Offshore sand bank in the UK part of Dogger Bank • Area of Dogger Bank	UK Marine and Coastal Access Bill, specifically focusing on proposed Marine	UK candidates for Marine Protected areas, of which 23 are in Scotland.	Marine and coastal areas in Scotland, where marine and coastal areas defined as part

Selection criteria	The policy site	Börger et al. (2014)	McVittie & Moran (2010)	Kenter et al. (2013)	Noble (2023)
	• Area under pressure from bottom-towed fishing receiving protection = 22,153 km^2 • 3nm area is 4% of UK EEZ	in the UK: 17,600 km^2 • Dogger Bank is 2% of UK EEZ[21].	Conservation Zones in UK Territorial and UK offshore waters.		of the seas and coastline including beaches, coastal cliffs, towns, and settlements. From Marine Scotland (2023), the total sea area in Scotland is 462,315 km^2, indicates that proposed areas for protection (i.e., % of total sea area) equates to: • 2.5% = 11,500 km^2 • 5= 23,100 km^2 • 7.5= 34,700 km^2 • 10= 46,200 km^2
The affected populations	Scottish population (Scottish policy)	UK population (those living close to and far from the North Sea)	UK residents, reflecting the broader UK population's values, including non-use values.	UK anglers, divers, and snorkelers	Scottish population
The number and quantity of substitutes	Offshore waters (>3nm area)	No data (according to EVRI), although there would be some similar habitat within the North Sea	No data	Alternative choice on the questionnaire is: Stay home	No data within Noble (2023).
The market constructs	The policy context is focusing on the impacts of cessation to bottom towed fishing	Public good, funded through general taxation and	Public good, funded through general taxation and	Public good, supported by local donations to support local management to	Public good, funded through water taxation and delivered by Government regulation.

[21] Area of UK EEZ is approximately 730,102 km^2 (Marine Scotland, 2023).

Selection criteria	The policy site	Börger et al. (2014)	McVittie & Moran (2010)	Kenter et al. (2013)	Noble (2023)
	practices. Assumes a closure, delivered by Government regulation.	delivered by Government regulation.	delivered by Government regulation.	increase the provision of ecosystem services	
Study quality	N/R	Study was conducted in 2013.	Study conducted in 2010	Study conducted in 2013.	Survey carried out between December 2022 and January 2023. Author undertook construct and content validity testing.
Suitability for value transfer	N/R	The study covers wider environmental change (e.g., INNS and fish restrictions) but is for a smaller geographical area than the policy site (Dogger Bank vs all of 3nm area receiving protection in the Protection Scenario). Values can be adjusted for spatial area, however as estimated WTP per HH do exhibit diminishing marginal returns to scale (i.e., non-linear) this has not been deemed an appropriate adjustment. Improvements in species composition as a result of management measures in the policy site are difficult to	The choice experiment approach provides a top-down estimate of policy benefits, suggesting welfare improvements from the Marine Bill outweigh projected regulatory costs. The study suggested that survey respondents were indifferent to the levels of restrictions on activities needed to achieve halting the loss of or increasing marine biodiversity, and the provision of other environmental services relative to current trajectories of decline. Implicit prices (WTP per household per annum) are	The study could be suitable for use and non-use values for marine recreation. However, these values only represent the WTP of a small section of the UK population (i.e., divers), hence do not provide a comprehensive valuation approach. It has also been noted that, possibly due to the lack of substitutability between sites, the vales are considered higher than expected. WTP values for bans on bottom trawling are available, although in an aggregate form. National values are also available, with Scottish sites representing the lower values. (15-27	Overall, results from the choice experiment section of the survey suggest that people in Scotland are supportive of management policies in marine and coastal areas over doing nothing. Results indicate that people in Scotland hold significant values for management policies that result in larger areas changed, larger increases in the number and variety of wildlife and habitats, 'low' and 'moderate' levels of restrictions, and additional educational content. People who have visited a marine and coastal area in the last 12 months, do regular recreational activities, are younger or

Selection criteria	The policy site	Börger et al. (2014)	McVittie & Moran (2010)	Kenter et al. (2013)	Noble (2023)
		assess with available data, and therefore is not used in the value transfer.	available for all UK nations, including Scotland Values can be considered transferable, however the area and restrictions in place differ to that of the policy site (closure to bottom-towed fishing in Scottish 3nm limit vs Marine Conservation Zones in Scotland). WTP values on moderate restrictions (closure to bottom-towed fishing gear) are available and might be more indicative (£3.49/HH/yr).	million, sum of all Travel Cost). However, population differs (i.e., active users have higher values than overall population).	have a marine industrial connection tend to have stronger preferences for alternative management options over the status quo. Values for increase in habitat and fauna size could be used for biodiversity valuation. The population and area affected are in scope with the project and values can be easily transferred. The study only focuses on Scottish population, and hence excludes recreational visits from individuals and households from the wider UK.
Unit values	N/R	Study finds that respondents were willing to pay (WTP) for: • Species diversity: £4.19 per year on average for a 10% increase in species diversity on the Dogger Bank and £7.76 for a 25% increase. • Protection of	Implicit prices (WTP per household per annum) values for Scotland: • Halt loss of biodiversity: £20.92 • Increase biodiversity: £20.24 • Halt loss of environmental benefits: £16.16	On average anglers were willing to donate £10.28, divers slightly but not significantly more at £11.13. For anglers, the most important CE attributes were specimen fish (willingness-to-pay (WTP) £23.58) and rocky seafloor with tide swept channels (£25.14).	Study finds that Scottish households were WTP: • £90m-£132m per year for large wildlife increases, £40m-£80m per year for medium increases. • Low to moderate activity restriction policies: WTP £28m-£76m and £40m-

Selection criteria	The policy site	Börger et al. (2014)	McVittie & Moran (2010)	Kenter et al. (2013)	Noble (2023)
		porpoises, seals, and seabirds: £24.02 and £30.32 on average per year to protect these species on 25% or 50% of the UK Dogger Bank area, respectively. • Wind farm development: Wide spread of invasive species yielded a negative WTP of -£25.39.	• Increase environmental benefits: £19.45 • Moderate restrictions: £3.49 • Highly restricted: £4.57	Anglers were willing to pay £0.30 for each additional protected species in the area. Shipwrecks were of intermediate importance (£8.87). For divers, rocky habitats were most important, along with wrecks (£18.98). Large fish (£7.64), bird colonies (£7.02), octopus (£13.42) and most of all seals (£15.97) were also important. The presence of protected species, even whilst the chance of encountering them was very low, was also valued (WTP £0.44 per species)	£86m per year, respectively. • WTP for educational boards on marine/ coastal wildlife: £20m-£49m per year. • 1% sea area management increase: WTP £2m-£8m yearly. WTP per household values • Wildlife and habitats: Large increase £35-£52 per HH; Medium increase is £16-32 per HH • Restriction: Low restriction WTP £11-30 per HH; Moderate restriction WTP £16-34 per HH • WTP to update existing and install additional education boards about wildlife and habitats around marine and coastal areas in Scotland of

Selection criteria	The policy site	Börger et al. (2014)	McVittie & Moran (2010)	Kenter et al. (2013)	Noble (2023)
					£8-19 per HH • For every additional 1% of total sea area changed by management policies, WTP £1-3 per HH

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