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Northern Ireland Marine Plan Storyline

Narrative of marine (spatial) planning scenarios explored in the MSPACE project

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Section A: The MSPACE project

MSPACE is a £1.7m, 4 year (2021-2025), highly integrated, multidisciplinary project, conceptualised to drive forward the capability of the four UK Nations in designing and implementing climate-smart marine spatial plans (MSP). The project is funded by UKRI under the UK Government's Strategic Priorities Fund. The projects team brings together natural and social scientists, planning practitioners and industry representatives from across the UK Nations, and global experts in ocean sustainability and climate change. The main ambition of the project is to support the delivery of marine planning that addresses the causes and impacts of climate change (i.e. mitigation and adaptation) in a way that is economically feasible and socially acceptable, supporting people and nature for future generations.

We first delivered an Early Warning System report, infographic and summary for policy makers, which analyses state-of-the-art climate modelling projections and identified opportunities for climate-smart spatial management of UK marine conservation, fisheries and aquaculture. These are based on the identification of areas of our marine waters with different degrees of sensitivity to ongoing climate change. We then mapped the governance structures around four case-study marine plans across the UK nations, and the preferences of its stakeholders on marine space.

We are now co-developing with our stakeholders 4 alternative possible spatial management scenarios for each case-study (Section D, East of England Inshore and Offshore, Northern Ireland, Scotland (Orkney Islands) and Wales), as follows:

1. The first scenario represents the current marine plan for a region (*Business as Usual Scenario*).
2. The second is a climate-smart scenario that uses the information made available in the MSPACE Early Warning System to prioritise changes in spatial uses to include the specific use of areas identified in the Early Warning System report as having low sensitivity to climate change (i.e. climate change refugia) to maximise environmental and economic goals for marine conservation (*Conservation Scenario*).
3. The third is the same as the second, except designed to maximise environmental and economic goals for fisheries and aquaculture (*Food Provision Scenario*).
4. A fourth scenario takes elements from the other three scenarios to maximise environmental and economic goals for the region (*Compromise Scenario*).

Project recommendations for each case-study region are based on the Compromise Scenario.

In the last year of the project (2024-2025), we convert the co-produced decision support system created by MSPACE into a web-based, artificial intelligence assisted tool, and test its application with our project partners towards the delivery of climate-ready spatial management policies across the UK nations.

Section B: Regional context

The Northern Ireland (NI) marine area consists of approximately 6,800 km^2 of sea, with more than 650 km of coastline. The Marine Plan for Northern Ireland covers both inshore and offshore regions. The inshore region extends from mean high water spring tides out to 12 nautical miles from baselines, although in places along the north and north-east coast, this is reduced due to the proximity of Scotland's marine area. The offshore region extends south-eastwardly from the 12 nautical mile territorial limit to the outer boundary of the Northern Ireland marine area, 31 nautical miles from the inshore boundary, at its farthest extent. The plan area also shares boundaries with Scotland, Wales, the Isle of Man and the Republic of Ireland.

The draft Marine Plan for Northern Ireland was published in 2018 and the second six-yearly report on progress with the Marine Plan was laid before the NI assembly in November 2021. The Department of Agriculture, Environment and Rural Affairs (DAERA) published a revised Statement of Public Participation in October 2022. This sets out how and when stakeholders can be involved in the Marine Plan process.

The draft Marine Plan for Northern Ireland supports the vision of a healthy marine area which is managed sustainably for the economic, environmental and social prosperity of present and future generations. It has 8 plan objectives, supported by 15 core policies and 10 key activity policies. These key activity policies include:

- Commercial fisheries: Public authorities must consider any potential impact from proposals on commercial fishing activities and the ecosystem services that support commercial fishing.
- Aquaculture: Supports proposals where there will be no unacceptable adverse impact on marine activities, uses and/or the marine area and any potential adverse impact is, in order of preference, avoided, minimised and/or mitigated.
- Energy: To improve the security and diversity of Northern Ireland's energy supply. Exploring the potential of all locally produced energy sources will contribute towards energy diversity and security of supply. Renewable energy, as a low carbon energy source, can reduce carbon emissions and help achieve renewable energy targets.
- Tourism: To promote a healthy, attractive and well maintained marine and coastal area, that showcases Northern Ireland's iconic landscapes and features. This is essential to recreational and tourism related activities and their future growth.

The draft Marine Plan for Northern Ireland contains a core policy for climate change adaptation and mitigation, to ensure that GHG emissions that might arise from proposals are minimised or mitigated, and to enable enhanced resilience of developments, activities and ecosystems to the effects of climate change and coastal change. Other core plan policies also mitigate and adapt to climate change. For example, the Air Quality core policy ensures that proposals consider and address potential direct or indirect air pollution, which may also contribute to greenhouse gas emissions, and the Coastal Processes core policy notes the greater risk of coastal change and flooding from climate change induced sea level rise and increased storm frequency and severity.

It is anticipated that the Marine Plan for Northern Ireland will be adopted and published in 2025. A version for adoption has been drafted to take account of consultation responses and relevant legislation, policies, strategies and plans since 2018. Crucially, in relation to climate change mitigation and adaptation, the legislation includes the Climate Change Act (Northern Ireland) 2022, containing legally binding targets to achieve net zero greenhouse gas emissions by 2050, and the policies include Northern Ireland Executive's Energy Strategy for Northern Ireland – The Path to Net Zero Energy, containing a target of 1GW of offshore wind from 2030.

Relevant to adaptation, the Climate Change Act 2008 requires the Department of Agriculture, Environment and Rural Affairs (DAERA) to coordinate and publish a Northern Ireland Climate Change Adaptation Programme (NICCAP) every five years on behalf of the Northern Ireland Executive, setting out details of the policies and proposals to be implemented by Northern Ireland Government Departments in response to the latest Climate Change Risk Assessment (CCRA).

Relevant to mitigation, adaptation, and nature-based solutions, the Climate Change Act (Northern Ireland) 2022 requires that all Northern Ireland Government Departments have a duty in working towards climate change targets and programmes in the exercise of their functions, while specified public bodies must report on climate change mitigation and adaptation relating to the exercise of their functions. Nature-based solutions must also be considered in climate action plans. Nature-based solutions, which include blue carbon habitats, were recognised in the UNFCCC Glasgow Climate Pact 2021, which highlighted the interlinkages between climate change and biodiversity, with biodiversity providing both climate change adaptation and mitigation benefits.

To determine stakeholder preferences for the use of marine space in Northern Ireland and thereby inform the development of the MSPACE climate-smart spatial management scenarios presented in this document (Sections D.4 – D.6), we used direct survey techniques during remote 1-2-1 interviews conducted from July 2022 through April 2023 (Reinhardt & Danahey Janin, 2025). We gave stakeholders a values questionnaire which asked participants which are active in either conservation, fisheries or aquaculture, to give a numerical value from 0-100 on several criteria associated with marine space. The number given was explicitly meant to represent the value, or level of importance, that the specific element of the marine space represented to them in their professional capacity. We sought this information as these sectors are seen as key stakeholders to the planning process in Northern Ireland. As each participant filled out their ratings, a member of the research team engaged them in conversation to elicit complementary information on why and how they valued these elements at the levels indicated.

The original selection of elements of the marine space to rank was based on the World Bank's "Roles Oceans and Coasts Play in Human's Lives" (p. 2) (*Biodiversity and Ecosystem Services in Marine Spatial Planning: Supporting biodiversity and healthy ecosystem services in oceans and coasts*, 2022), augmented by insights gleaned from other sources (IPBES, 2022; Newton & Elliott, 2016; Strickland-Munro et al., 2015). This list included: leisure and recreation; food provision; identity, culture, and heritage; conservation designations; tourism; governance; biodiversity; learning and research; biosecurity; water quality; economy; health; and transportation and shipping. Once interviews began, participants were given the opportunity to name additional elements they found important about the marine space. Some respondents also chose not to rate elements about which they felt they had no professional opinion/remit. If another element of the marine space was mentioned 3 or more times by respondents, it was added to the questionnaire. As a result, only a portion of respondents rated these additional fields: climate change; energy.

With respect to the Northern Ireland plan, we spoke with respondents in the sectors of aquaculture, conservation, fisheries, and regulation/government. The self-identification of these sectors among respondents is represented in Table B.1.

Table B.1 Respondents' self-identification of sectors in which they work or have a professional interest

Northern Ireland - Sectors	Freq.	Percent
Aquaculture, Conservation, Fisheries, Other	2	13.33
Aquaculture, Fisheries	1	6.67
Conservation	5	33.33
Fisheries	5	33.33
Other	2	13.33
Total	15	100

The indicative value rankings of criteria by participants speaking about the Northern Ireland are summarised in Table B.2. On average, respondents rated conservation designation, governance, biodiversity, and learning and research highest.

Table B.2 Means, Standard Errors, and Confidence Intervals for ratings of elements of the marine space, as rated by respondents

Northern Ireland	Obs	Mean	Std. Dev.	95% Conf	Interval
Biodiversity	14	85.35714	18.4124	74.72614	95.98815
Biosecurity	14	65.42857	28.77155	48.81637	82.04077
Climate change	6	81.33333	19.45936	60.91199	60.91199
Conservation designation	14	85.85714	13.1784	78.24816	93.46613
Economy	14	72.78571	22.19556	59.97038	85.60105
Energy	6	62.33333	29.31666	60.91199	93.09928
Food provision	14	77.14286	27.4138	61.31460	92.97111

Governance	14	84.28571	18.63177	73.52805	95.04338
Health	14	64.78571	25.78962	49.89523	79.67620
Identity/culture/heritage	14	70.71429	18.79619	59.86169	81.56688
Learning and research	14	86.42857	14.04232	78.32078	94.53637
Leisure/recreation	13	52.69231	30.34904	34.35257	71.03205
Tourism	13	63.46154	22.95145	49.59211	77.33096
Transport and shipping	14	55.57143	22.93038	42.33182	68.81103
Water quality	14	75.64286	24.27283	61.62814	89.65757

Section C: Projected impacts of climate change in the Marine Plan for Northern Ireland area

C.1: Glossary

Annex 1 habitats and species: Habitat types and species which occur in the UK and for which SACs and SPAs have been, or can be, designated (see below for specific definitions of SAC and SPA).

Biologically relevant artificial light (critical depth): The depth to which artificial light of an irradiance that elicits biological responses in marine organisms penetrates.

Bright spot: a site where multiple habitat conditions for a given set of species is improved in the short and mid-term, entering a new ecosystem state beyond its natural variability (*sensu* Hawkins & Sutton, 2012; Queirós et al., 2021) , but where this state is defined by trends that are inconsistent with mean expected long-term climate change trends for the surrounding region e.g. cooling where the long-term trend is warming; increased dissolved oxygen where the long term trend is deoxygenation.

Climate change hotspot: A site where a climate signal emerges. That is, a site where climate pressures drive an ecosystem into a new ecosystem state, beyond its natural variability (sensu Hawkins & Sutton, 2012; Queirós et al., 2021).

Climate change refuge: A site that remains climate-resilient within a given period of analysis.

Climate change resilience of habitats: the ability of a habitat to remain within a current or reference ecosystem state, within the boundaries of its natural variability, despite climate change pressures. In this report, focused on the detection of the emergence of climate signals within UK marine waters, their species and habitats, we define resilience as the absence of the emergence of a climate signal, when climate pressures drive an ecosystem into a new ecosystem state, beyond its natural variability (*sensu* Hawkins & Sutton, 2012; Queirós et al., 2021).

Designated feature: The habitat(s) or species for which a conservation area in the UK is designated.

Intervention: Theoretical spatial management measures simulated in each climate-smart scenario. These represent potential easy-wins that could be delivered or encouraged through marine planning, to improve climate change adaptation or mitigation potential for each of the MSPACE focal sectors.

Marine Conservation Zone - MCZ: Marine protected areas designated under legal order made by Defra under section 116(1) of the Marine and Coastal Access Act 2009 (MCAA) for Northern Ireland's offshore region, or made by DAERA under the Marine Act (Northern Ireland) 2013.

Marine Protected Area - MPA: The purpose of an MPA is to protect and recover rare, threatened and important habitats and species from damage caused by human activities. In this document, MPA is used as a catch-all term to denote any designated conservation site

in the plan area. In practice, there are a number of different MPA designations (SAC, SPA, MCZ, ASSI, Ramsar see this glossary for the different types present in the planning area), which are created under specific, and different, pieces of legislation.

Nationally determined contributions: Commitments that countries make to reduce their greenhouse gas emissions as part of climate change mitigation. These commitments include the necessary policies and measures for achieving the global targets set out in the Paris Agreement.

Priority area: An area identified within a climate change refuge for a given sector, which represents either climate resilient sectoral activity (when the priority area is already used by a sector) or an opportunity to expand into a new area (when the priority area is not currently used by the sector)

Scenario: Theoretical situation which represents possible alternative futures for the EMP area. Scenarios vary in ambition to act on climate change evidence (as presented in the MSPACE Early Warning System) and on the prioritisation of outcomes for specific sectors.

Seafloor aquaculture: For the purposes of this document, seafloor aquaculture is any cultivated production of species that occurs on the seabed (e.g. seabed production of mussels, trestle culture of oysters).

Special Area of Conservation - SAC: Marine protected areas put in place to protect habitats and species listed in Annexes I and II of Council Directive 92/43/EEC (the Habitats Regulations).

Special Protection Area - SPA: SPAs referred to in this document are all SPAs "with marine components". These sites are MPAs that protect bird species listed in the Birds Directive (2009/147/EC) as Annex I or as regularly occurring migratory species, that are dependent on the marine environment for all or part of their life-cycle, where these species are found in association with intertidal or subtidal habitats within the site.

Water column aquaculture: For the purposes of this document, water column aquaculture is any cultivated production of species that occurs in the water column (e.g. rope grown mussels or seaweed, salmon cages).

C.2: MSPACE Early Warning System: summary of results for Northern Irish waters

The development of scenarios in MSPACE begins with an assessment of climate-driven changes in the UK EEZ. Here, we summarise first the findings of an assessment carried out by the project to identify key challenges and opportunities emerging from climate change for the spatial management of UK seas. Specifically, the MSPACE Early Warning System ("EWS", Queirós et al. 2024) was co-produced with the UK Marine Climate Change Impacts Partnership, key agencies with statutory responsibility for planning across the UK nations, and key representatives of maritime sectors. In that report, climate change modelling datasets were analysed as a means to explore the potential to deliver climate-smart spatial management strategies for marine planning across the UK EEZ; that is, strategies that could promote climate change adaptation of marine sectors (including marine conservation) as well as climate change mitigation. The work focused specifically on identifying the location of areas which exhibit long-term sensitivity to climate change (climate change hotspots) and those more resilient to climate change (climate change refugia and bright spots). This was done through analyses designed specifically to estimate climate effects on marine conservation, fisheries and aquaculture, interpreted within the context of the broader UK blue economy. In the Early Warning System, we focused on identifying areas that fell into each of those three categories consistently over the 21st century, in both emissions trajectories considered (RCP4.5 and RCP8.5). RCP4.5 (the "slowly declining emissions" scenario) assumes strong curbs in global emissions toward climate change mitigation from 2050 onwards, leading to a mean global warming by the end of the century of ~2.4 °C. Contrastingly, emissions continue to rise steadily throughout the 21st century under RCP8.5 (the "growing emissions" scenario), leading to mean global warming ~4.3^{o}C. The two scenarios correspond to a mean warming of UK sea surface temperature of about 1°C and 2°C by the end of the 21st century, respectively, in the physical modelling dataset used. The EWS report is supported by a technical report that provides an assessment of the confidence that can be placed in the modelling datasets used as inputs, in terms of their ability to replicate real life observations. Those analyses are provided in Kay et al. 2024, which is Annex 1 of the EWS report. Annex 2 of the report provided evidence on the current seabed status of the UK EEZ, based on an estimate of the effects of bottom contact fisheries and aggregate extraction. In the EWS, we also explored how climate change effects relate to the distribution of those other pressures on seabed habitats, and that cumulative assessment can be found in the main report here.

What follows is a summary of the key findings outlined in the EWS report which are relevant to the Marine Plan for Northern Ireland. When considering the locations of long-term climate change hotspots and refugia with high agreement between emissions scenarios, we found that NI waters are projected be relatively sensitive to climate change, with limited areas emerging as long-term climate change refugia for the three focal sectors (capture fisheries, aquaculture and marine conservation), under the two emissions scenarios we considered.

C.2.1 Climate change impacts on marine species and habitats in NI waters

When considering the locations of long-term climate change hotspots and refugia emerging with high agreement in both emissions scenarios RCP4.5 and RCP8.5, we found that Northern Irish waters harbour some refugia that could be maximised for conservation benefits. Focussing on habitat conditions promoting carbon sequestration (Queirós et al., 2024; Supplementary Information Table S3), we found that a refuge for such "climate services" (Benyon et al., 2020; Flavell et al., 2020) is apparent across much of the planning area, including some areas already designated as protected

areas. Those areas may hold promise with regard to the siting of protected areas that could help deliver resilient climate change mitigation (Queirós et al., 2024, EWS Figure 8).

Considering Northern Ireland's marine protected area (MPA) network with a focus on biodiversity, it is likely that several conservation sites will remain resilient to climate change due to the presence of refugia for benthic habitats in the Irish Sea (Queirós et al., 2024, EWS Figure 6). This overlaps with several MCZs and SACs containing features such as horse mussel (*Modiolus modiolus*) beds, rocky reefs and their associated communities, ocean quahog (*Arctica islandica*), sea pens and burrowing megafauna (which is an OSPAR threatened and declining habitat, and has been assessed as being in poor condition) (Queirós et al., 2024; EWS Annex 2, Figure 7), and a range broad-scale sedimentary habitats used as designation features including subtidal coarse and mixed sediments, subtidal mud and subtidal sand.

C.2.2. Climate change impacts on marine fisheries and aquaculture in NI waters

Based on the EWS analyses, we find that pelagic and demersal wild capture fisheries and water column aquaculture (Queirós et al. 2024; Supplementary Information Table S4), could be particularly vulnerable to climate change, as hotspots for these sectors emerge across most of the planning area if current target species are considered. These results highlight that the abundance of key species targeted by wild capture fisheries, such as the langoustine *Nephrops norvegicus*, are expected to decrease in the future in response to climate change. However, an extensive refuge for seafloor aquaculture emerges from the analysis, stretching from the coast of County Down out into the North Channel. While much of this occurs in deep, exposed offshore waters, some of the refuge close to the coastline could be suitable for future development.

Section D: The MSPACE management scenarios for the Marine Plan for Northern Ireland area

D.1: Scenario overview

We now outline four scenarios, co-developed with stakeholders in the region (Table A1, Annex 2), representing possible alternative futures for Northern Irish waters. Scenarios vary in ambition to act on climate change evidence (as presented in the MSPACE Early Warning System) and on the prioritisation of outcomes for specific sectors. These scenarios therefore represent alternative, hypothetical ways through which the potential for climate change adaptation and mitigation of marine wildlife and sectors in the NI region could be encouraged through planning actions. They are expected to lead to different ecological, social and economic outcomes for the region, based on climate change impacts and opportunities. These scenarios build on formulations described in Annex 1, as follows:

1. **The Business-as-Usual Scenario**: represents a possible future for NI waters which does not provide marine planning policies that act on climate change evidence as presented in the EWS, and simply estimates the modelled effects of climate change on the region, considering the current distribution of human uses and conservation areas.

Additionally, three climate-smart scenarios are co-developed, which prioritise outcomes for specific sectors, and propose spatial interventions that promote climate change adaptation and mitigation, based on specific uses of identified climate change refugia for those sectors:

2. **The Conservation Scenario:** prioritises climate change adaptation for the conservation sector (i.e. marine conservation and restoration), and the protection of areas delivering the potential for resilient, nature-based climate services toward climate change mitigation. The interventions considered aim to avoid, minimise or mitigate the impacts of activities which could negatively affect the climate change adaptation potential of 1) habitats and species of high conservation value in NI where they occur in climate change refugia, and 2) areas which at present hold important carbon stocks and which are projected to have climate resilient seabed carbon sequestration potential in the future.

3. **The Food Provision Scenario:** prioritises climate change adaptation for the fishing and aquaculture sectors. The spatial interventions outlined in this scenario aim to support and safeguard climate-resilient fisheries and to facilitate the development of climate-resilient aquaculture in Northern Ireland, by prioritising the access of these sectors where their resources occur in climate change refugia.

4. **The Compromise Scenario:** aims to promote a balance of improved outcomes for the conservation and food provision sectors, with a view for what other priorities stakeholders hold for the region with regard to other sectors of economic activity (Section B). The interventions considered aim to support climate-resilient fisheries, facilitate the development of climate-resilient aquaculture and seek to avoid, minimise or mitigate the impacts of activities which could negatively affect habitats and species of conservation interest in NI waters. These aims are supported by prioritising access to areas of climate change refugia for each sector, or by prioritising conservation objectives where designated conservation areas overlap with climate change refugia. It is expected that the Compromise Scenario may meet a broader set of objectives with regard to stakeholders in Northern Ireland.

D.2. Scenario co-development methodology

D.2.1. Spatial data interrogation

The methodology for scenario co-development is summarised in the diagram below (Figure D.2.1). First, GIS datasets showing the locations of climate change refugia and hotspots relevant to each of the four spatial management scenarios, produced as part of the MSPACE Early Warning System, were overlaid with spatial distributions of designated conservation sites and human activities (e.g. locations of planned and operational offshore renewable energy structures, locations of aquaculture infrastructure, fishing effort distribution, etc.). This allowed us to estimate how current sectoral activities overlap with climate change hotspots, and thus where each focal sector may become unsustainable without additional climate change adaptation measures (e.g. an MCZ designated for benthic features located in a projected climate change hotspot for benthic habitats). The same analyses also allowed us to identify how areas used at present by a given sector overlap with identified climate change refugia (or bright spots) for that sector, leading to potentially climate-resilient sectoral activity or growth into the future (e.g. currently fished areas located within projected climate change refugia for fisheries). These areas of overlap between marine activities and correspondent refugia (or bright spots) were termed "priority areas" for each sector, within each spatial management scenario (Figure D.2.1, 1). Specific spatial management interventions for priority areas were then co-developed with stakeholders though an iterative, participatory processes (including in person workshops, online meetings, and email correspondence). The set of interventions co-developed in each climate-smart scenario are seen to represent potential easy-wins that could be delivered or encouraged through marine planning, to improve climate change adaptation or mitigation potential for that (those) sector(s) (Figure D.2.1, 2). Proposed interventions also seek to account for the values that surveyed stakeholders in the region placed on the marine environment (Reinhardt & Danahey Janin, 2025). Co-developed interventions take into account the potential for co-location of activities, where possible. All climate-smart scenarios (i.e. all but the Business-as-Usual Scenario) therefore propose a set of interventions to this end (Figure D.2.1).

Co-developed interventions in each scenario also consider possible conflicts between sectors. For example, where a climate refuge for demersal fisheries was identified in an area where demersal fisheries occur, the scenario may simulate that planning (and associated governance mechanisms) thereafter avoid, minimise or mitigate any proposed activity that limits access of demersal fishers to that site. This provides a means to help safeguard the climate-resilience of the sector in question. That may cause a knock-on effect for another sector which currently uses that identified priority area, which may lose access in the scenario if activities are not compatible (e.g. aggregate extraction and benthic fisheries). Priority areas identified within scenarios, underpinning proposed interventions, also include climate change refugia that might provide opportunities for sectoral expansion in the future into areas where there is not currently activity for that sector, against a backdrop of climate change impacts elsewhere. For instance, areas that were identified as climate refugia for seafloor aquaculture which do not harbour aquaculture facilities at present were flagged as priority areas for industry development moving forward.
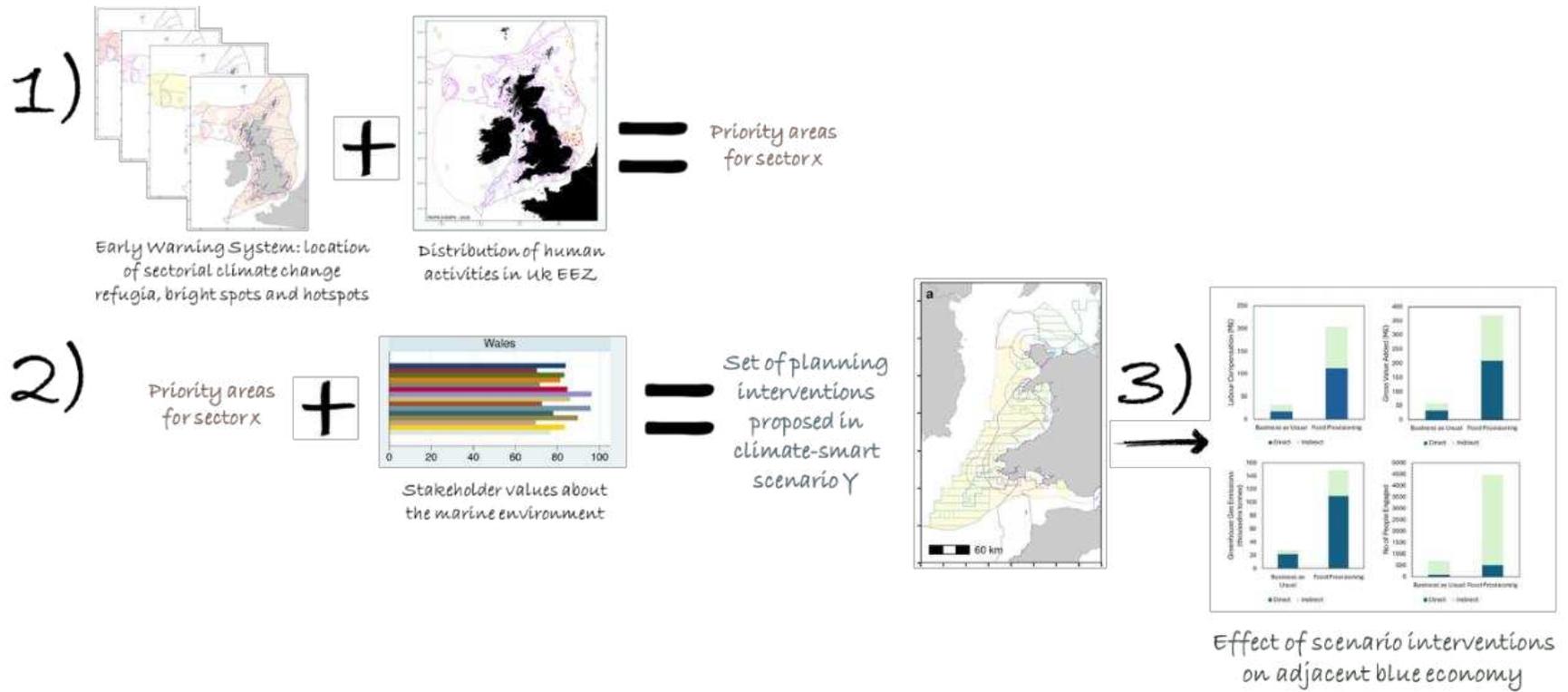
Figure D.2.1: Schematic representation of climate-smart scenario co-development. Stakeholders were consulted during all stages of co-development.

It is important to note that areas that are identified as climate refugia, and subsequently priority areas for some sectors, can be climate change hotspots for others, as all climate change sensitivity analyses were carried out per sector in the MSPACE Early Warning System (please see Section C). Once priority areas for each sector had been identified, and possible spatial management interventions co-developed, we were then able to calculate the possible effect of these interventions on other sectors within each scenario. For example, if a priority area for aquaculture were to be developed in the future, but the area is fished at present, how much area (in Km^2) could be lost to fisheries due to the development of the site? In such cases, it is possible that area lost to one sector due to the development of new activities by another would be strongly impacted by climate change effects on the first sector regardless, and these effects of climate change on cross-sector interactions are accounted for in our economic estimates (Figure D.2.1 3; Annex I). In this way, we attempt to identify possible conflicts and trade-offs between sectors, while also considering the overall climate effect on each MSPACE focal sector in the planning area. Once the spatial effect of each management scenario had been calculated (e.g. the area in Km^2 identified as priority areas or area lost for each sector), it was then possible to model the economic effect of each scenario (Figure D.2.1 3).

D.2.2. Economic analysis

The economic modelling carried out in MSPACE is aimed at translating the spatial interventions simulated in co-developed scenarios into economic metrics, to help end-users explore how climate action interventions outlined in scenarios affect the adjacent blue economy. This work aims specifically to fill a perceived data gap, and supports end-users in the development of evidence-based approaches that promote a better understanding of the economic feasibility of climate change adaptation and mitigation strategies through marine planning and associated governance mechanisms.

The economic modelling method deployed is termed Input-Output modelling and focuses on how changes to the input (or resource) used by a given sector (e.g. changes in wild capture fisheries catch) affect economic metrics for that sector, as well as other sectors within that economic structure, both directly and indirectly (Roca Florido et al., 2025). Based on data availability emerging from extensive data searches at the UK and devolved nation level and co-development with stakeholders, the economic model has 15 marine focussed sectors (Table A2, Annex 2), and 62 general sectors. The primary driver of economic effects (direct and indirect) are the changes in resource (space) available to marine conservation, fisheries and aquaculture simulated in scenarios, as these are sectors reliant on the marine environmental conditions more directly, that are explored in the Early Warning System report. The marine focussed sectors are particularly explicit on fisheries and aquaculture which represent 9 of the 15 sectors (Roca Florido et al., 2025, Table 2). Whilst the renewable sector in particular is seen as a key sector for the future in Northern Ireland, we did not estimate the economic effects of climate change on the future activity of that sector due to the fact that no seabed in the Irish Sea has yet been leased for development, and no information on the indicators used for these analyses was available at the beginning of the project. Hence, all estimates presented exclude the possible background effect of a growing renewable sector in Northern Ireland.

The economic model necessitates linear assumptions between resource availability to a sector and the particular area within the marine plan: for instance, for the *Nephrops* fisheries, the catch of the sector is scaled linearly to the area where the fishery is known to occur, whilst we recognise that, in reality, total catch will vary across the area where the fishery is active (based on analysed fisheries

statistics, MMO, 2022). Specifically, we assume that catch is equally distributed across the plan area accessible to a given fleet segment, at the resolution of ICES statistical rectangles (30nm x 30nm; 0.5°lat x 1°lon); i.e. we assume that a 95% loss of area in a statistical rectangle to a climate change hotspot equates to a 95% loss in catch for that rectangle. We make a similar assumption for aquaculture, e.g. that a 10% loss of area currently used for aquaculture equates to a 10% decrease in production. This simplification is a necessary step to enable the translation of proposed scenario interventions without adding too much complexity to analysis that would prevent the application of this approach to data poorer areas across the UK EEZ. The methodology employed is described in detail in Roca Florido et al. (2025).

For each economic scenario, we used input-output modelling to estimate the impacts on labour compensation, gross value added (GVA), greenhouse gas (GHG) emissions, and employment across all sectors of the Northern Ireland blue economy. These estimates capture both the direct and indirect effects resulting from simulated changes in the area of activity (i.e. resource use) of the fisheries, aquaculture, and/or marine conservation sectors, based on detailed marine sectoral mapping presented in Roca Florido et al. (2025). Specifically, for each sector, we estimate labour compensation as the total cost of employment to an employer, including wages, overtime, pension contributions, employers national insurance contributions and other costs associated with employment. We also estimate the Gross Value Added (GVA), that is, labour compensation plus gross operating surplus plus taxes less subsides. Furthermore, we estimate greenhouse gas emissions of carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons, sulphur hexafluoride, nitrogen trifluoride in carbon equivalent resulting linearly from changes in activity of each sector, based on those direct and indirect effects. We also estimated, per sector, the number of persons engaged in the sector as the number of people employed, whether full or part time.

D.3. Business as Usual Scenario

This scenario estimated the effects of climate change within Northern Irish waters if no additional climate-smart spatial management measures are implemented or encouraged via marine planning. Therefore, no spatial interventions are simulated as part of this scenario, and as such, it represents the status-quo.

D3.1 Ecological outcomes under Business as Usual

D.3.1a Spatial analysis of ecological outcomes for species and habitats of conservation value

Five different analyses were undertaken in the Early Warning System report in order to establish the effect of climate change on marine conservation objectives in the area of the Marine plan for Northern Ireland. Analyses focussed on those variables that describe benthic and pelagic habitats, habitats and prey of value to benthic and pelagic megafauna, and climate services (Chapter 3.1 of Queirós et al., 2024). Within NI waters, climate change hotspots (hereafter, "hotspots") for pelagic habitats and benthic and pelagic megafauna cover the whole planning area, while hotspots for benthic habitats cover the northern part of the planning area, along the coast of County Antrim and along the SW coast of County Down (Figure D.3.1, Table D.3.1). It is therefore possible that those conservation areas which fall within climate change hotspots may not continue to provide the same benefits to designated features in the future, as climate change unfolds across the NI region.

Some climate change refugia for benthic habitats and climate services were also identified in the region (Figure D.3.2, Table D.3.1). Conservation areas that fall within these refugia include South Rigg Marine Conservation Zone (MCZ), Queenie Corner MCZ, Pisces Reef Complex Special Area of Conservation (SAC), and a significant part of North Channel SAC (designated for harbour porpoise *Phocoena phocoena*), all of which overlap with both benthic habitats and climate services refugia. These areas are also located, in whole or in part, within the Irish Sea mud belt, which has been assessed as being highly impacted by demersal trawling, and with a seabed in poor condition (Queirós et al., 2024; Annex 2). Additionally, the Outer Belfast Lough MCZ falls within a refuge for benthic habitats, as does some of The Maidens SAC, while Rathlin Island MCZ sits within a refuge for climate services (Figure D.3.2). These areas, which are predominantly composed of coarser sediments, have been assessed as having either low or moderate impacts from demersal trawling, with good seabed quality (Queirós et al., 2024; Annex 2). In these areas identified as harbouring climate change refugia in both emissions trajectories analysed, the marine ecosystem is likely to continue to function in a comparable way to the present day. This would suggest that conservation areas which overlap with those refugia may continue to provide benefits into the future, regardless of the emissions trajectory, although those areas which harbour seabed in poor condition may not be as effective as those in good condition. Finally, some of the more coastal MPAs such as Outer Belfast Lough MCZ, The Maidens SAC and parts of the North Channel SAC are exposed to artificial light at night (ALAN) pollution (Queirós et al., 2024; Annex 2 Figure A.1, data from Smyth et al., 2024), which has been shown to interfere with a number of life history processes in marine organisms (Marangoni et al., 2022 and references therein). Biologically relevant light penetrates the water column to a depth of >10m in these areas, although it is likely that, given the average water depth, light will only reach the seabed in Outer Belfast Lough MCZ. It is therefore possible that ALAN pollution could add additional pressure to marine habitats and species beyond climate change and the above noted seabed impacts.
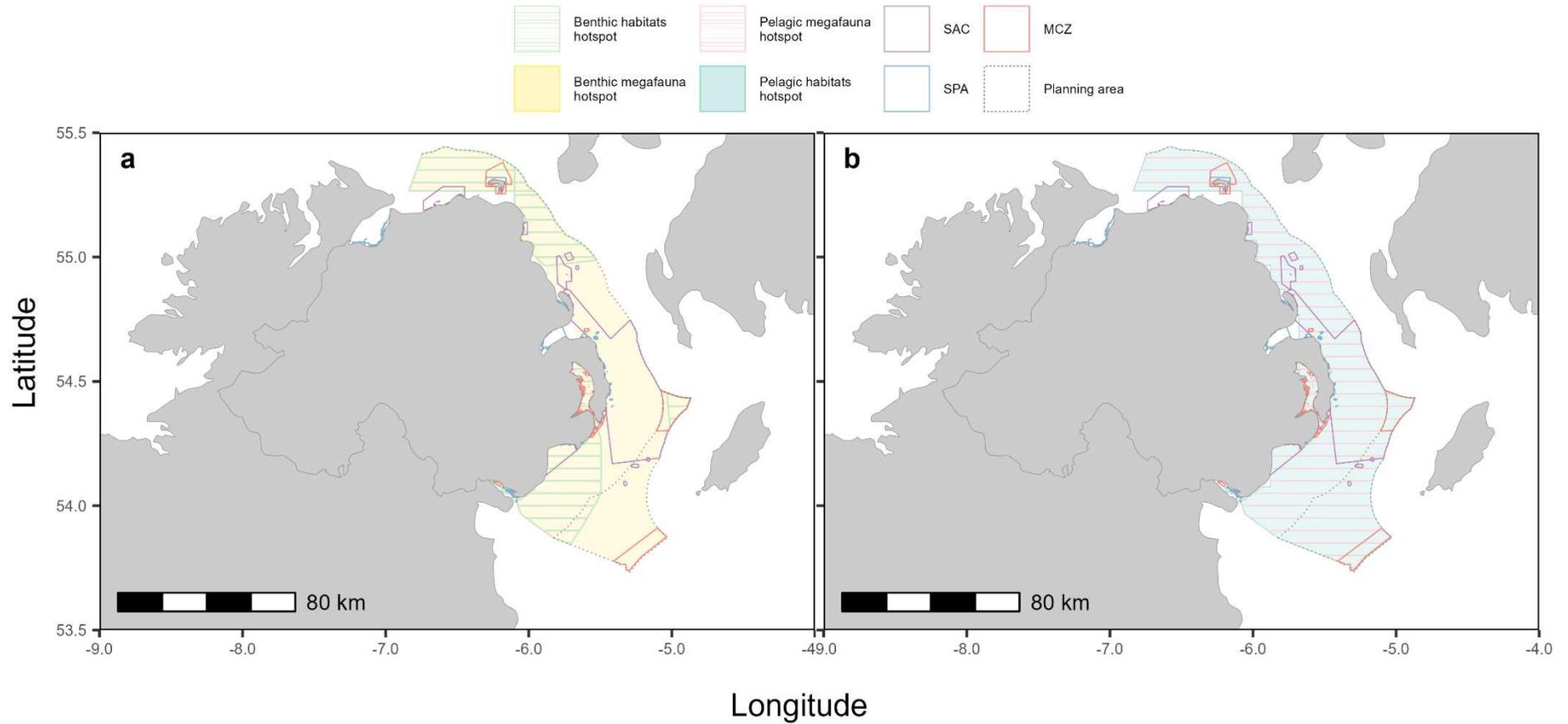
Figure D.3.1: Locations of conservation hotspots in the NI marine planning area. Benthic habitats and benthic megafauna hotspots (a), pelagic habitats and pelagic megafauna hotspots (b). Those conservation areas which fall within climate change hotspots may not continue to provide the same benefits to designated features in the future, as climate change unfolds across the region.
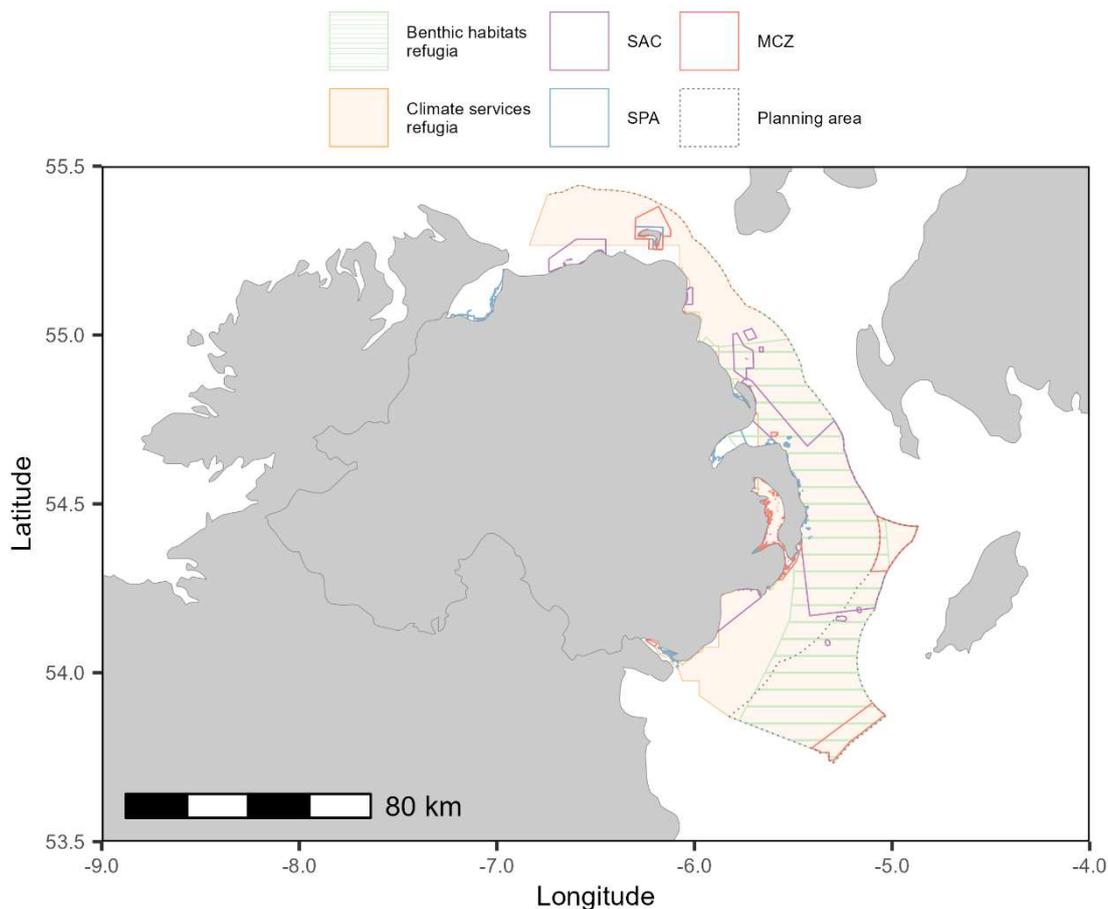
Figure D.3.2: Locations of conservation refugia in Northern Irish waters (benthic habitats and climate services refugia). Conservation areas which overlap with refugia may continue to be effective and deliver services into the future regardless of the emissions trajectory.

Table D.3.1: Summary of the expected climate change effects on Northern Irish waters in the Business-as-Usual Scenario, and their expected ecological and economic effects.

Climate change impact	Expected ecological effects	Expected economic effects
Conservation: • Widespread climate change hotspots for benthic megafauna, pelagic habitats and pelagic megafauna • Widespread climate change refugia for benthic habitats and climate services	**Conservation:** • MPAs overlapping with hotspots may not continue to provide the same benefits in the future as they do now • MPAs overlapping with refugia may continue to function as they do at present, even under climate change pressures • Climate services refugia may be useful for climate change	• Significant reductions in all variables against a baseline with no climate effects. • ~40% reduction in total labour compensation, gross value added, and greenhouse gas emissions. ~30% reduction in the number of employees. These losses are predominantly within fisheries.

	mitigation in areas where they overlap seabed with high sedimentary organic carbon levels	
Fisheries: • Widespread climate change hotspots for demersal, benthic and pelagic fisheries	**Fisheries:** • Abundances of key demersal and pelagic species estimated to decline in fisheries hotspots	
Aquaculture: • Widespread climate change hotspots for water column aquaculture • Climate change refuge for seafloor aquaculture in the North Channel	**Aquaculture:** • Potential for sectoral expansion into refugia for seafloor aquaculture	

D.3.1b Spatial analysis of ecological outcomes for species and habitats of value to fisheries and aquaculture

Four analyses were undertaken In the Early Warning System to establish the effects of climate change on demersal and pelagic capture fisheries and seabed and water column aquaculture production (collectively termed hereafter as "food provision"). For capture fisheries, analyses focussed on species distribution modelling of species representing the top landings by value landed by international and UK registered vessels in the UK (Queirós et al., 2024, Supplementary Information Table S4). For aquaculture, we considered species distribution modelling for key UK aquaculture species (sugar kelp *(Saccharina latissimi)*, blue mussel *(Mytilus edulis)* and salmon (*Salmo salar)*), and a range of modelled environmental data to represent key drivers of species distributions based on sectoral document analysis at the UK scale (Queirós et al., 2024).

Identified food provision climate change hotspots cover a large part of the NI planning area (Figure D.3.3, Table D.3.1), with demersal fisheries hotspots and water column aquaculture hotspots encompassing a majority of Northern Irish waters. Pelagic fisheries hotspots cover all but a small area to the east of the South Rigg MCZ. The analysis of the data leading to these hotspots indicates demersal and pelagic capture fisheries may see losses in the future as abundances of key commercial species such as langoustine (*Nephrops norvegicus*), haddock (*Melanogrammus aeglefinus*), herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*) decline. Currently, aquaculture facilities in NI are located in very coastal areas which are not covered by the modelling data used in our analyses. For this reason, we cannot determine how climate change will affect their production moving forward. However, there is some possibility for seafloor aquaculture to expand into unexploited areas off the coast of Co. Down, due to the presence of a climate change refugia in that area for the sector (Figure D.3.4).
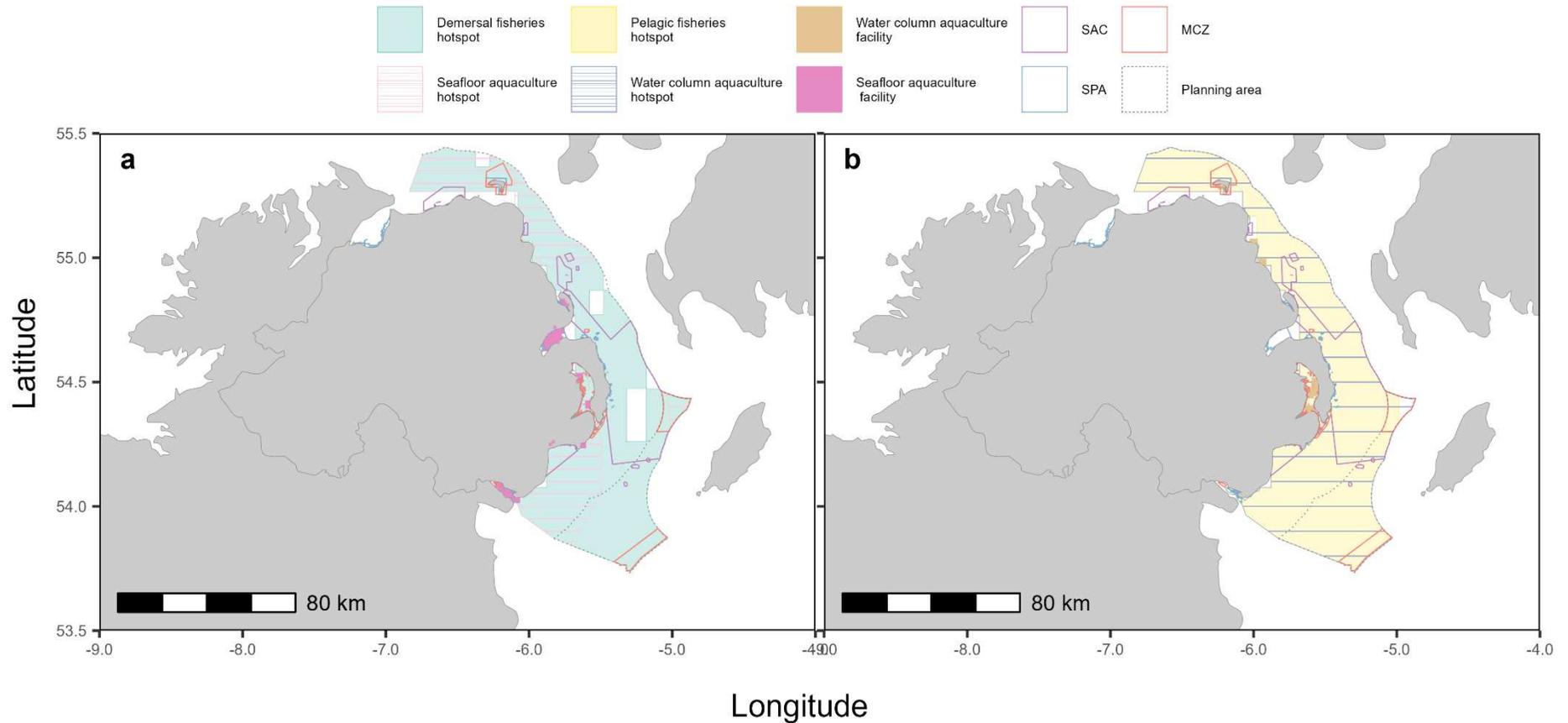
Figure D.3.3: Locations of food provision (fisheries and aquaculture) hotspots in the NI marine planning area. Demersal fisheries and seafloor aquaculture hotspots are shown in panel a, and pelagic fisheries and water column aquaculture hotspots are shown in panel b. Both demersal and pelagic fisheries may see losses in hotspot areas in the future as key commercial species abundances decline, while environmental conditions may challenge the expansion of water column aquaculture due to widespread hotspots for that sector.
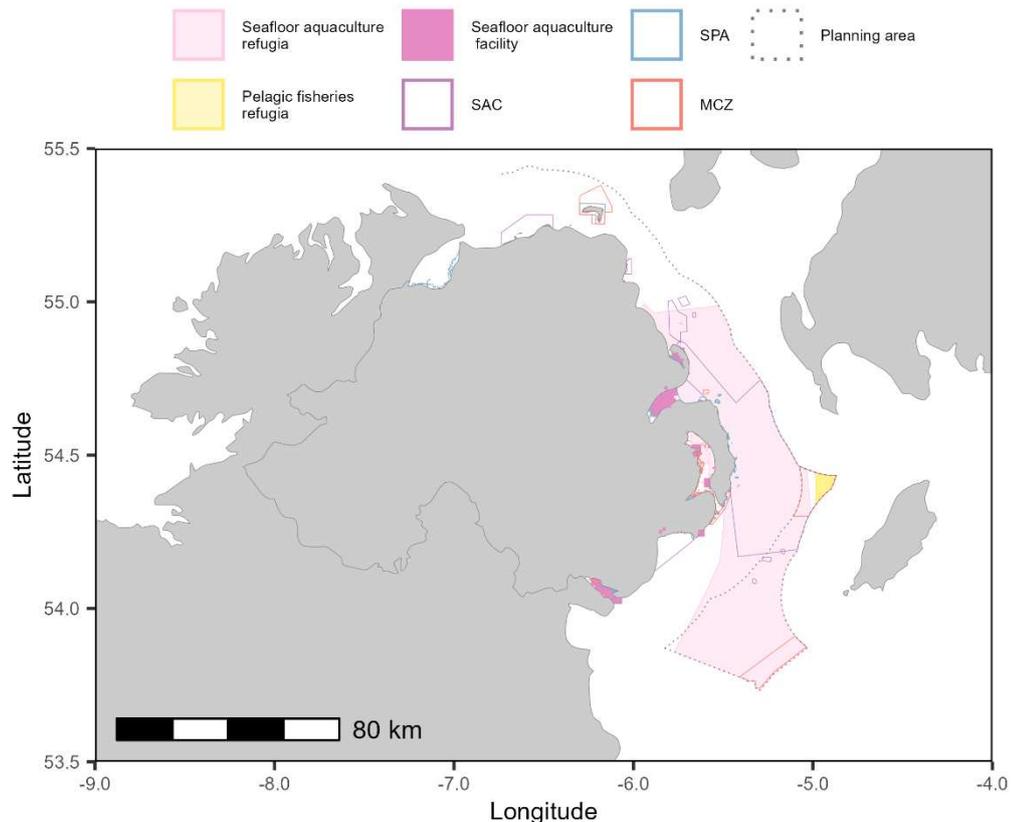
Figure D.3.4: Locations of food provision (fisheries and aquaculture) refugia in Northern Irish waters. A small refuge for pelagic fisheries appears at the eastern edge of the planning area, in the South Rigg MCZ, while there is a large refuge for seafloor aquaculture in the North Channel. Due to water depth, exposure and uses of the area by other sectors (including capture fisheries), it is unlikely that the whole of the seafloor aquaculture refuge could be developed by the sector. This is discussed in more detail in Section D.5.

D3.2 Economic outcomes for the adjacent blue economy of the Northern Ireland region

The Business as Usual Scenario represents a significant loss to the marine economy in Northern Ireland. We estimate that the hotspot areas represent approximately a loss of around 65% of area available to be fished for the pelagic, and demersal and benthic fleets within the NI waters, and~ 30% of the area available for the *Nephrops* fleet. In this and all other scenarios we assume that catch scales linearly across the plan area used by a given fleet segment (based on analysis of fishing activity data, not shown), i.e. we assume that the 65% loss in area available to pelagic, demersal and benthic fleets equates to a 65% loss in catch, and the 30% loss in area available to the *Nephrops* fleet results in a 35% loss of catch. Together, losses to the fishing fleet translate to reductions of around 40% in labour compensation, gross value added, and greenhouse gas emissions, and around a 29% reduction in number of people employed (Figure D.3.5) compared with fishing and aquaculture baseline (i.e. with no climate effects). It is worth noting that this is in part because aquaculture is a significant contributor to each of these indicators and is unaffected by climate in our model because current aquaculture facilities in Northern Ireland are located in inshore areas outside the model domains used here (Queiros et al. 2024). The biggest reductions across all impact variables estimated here result from the fishing fleet segments themselves, though warehousing and water transport wholesale sectors also see significant reductions.
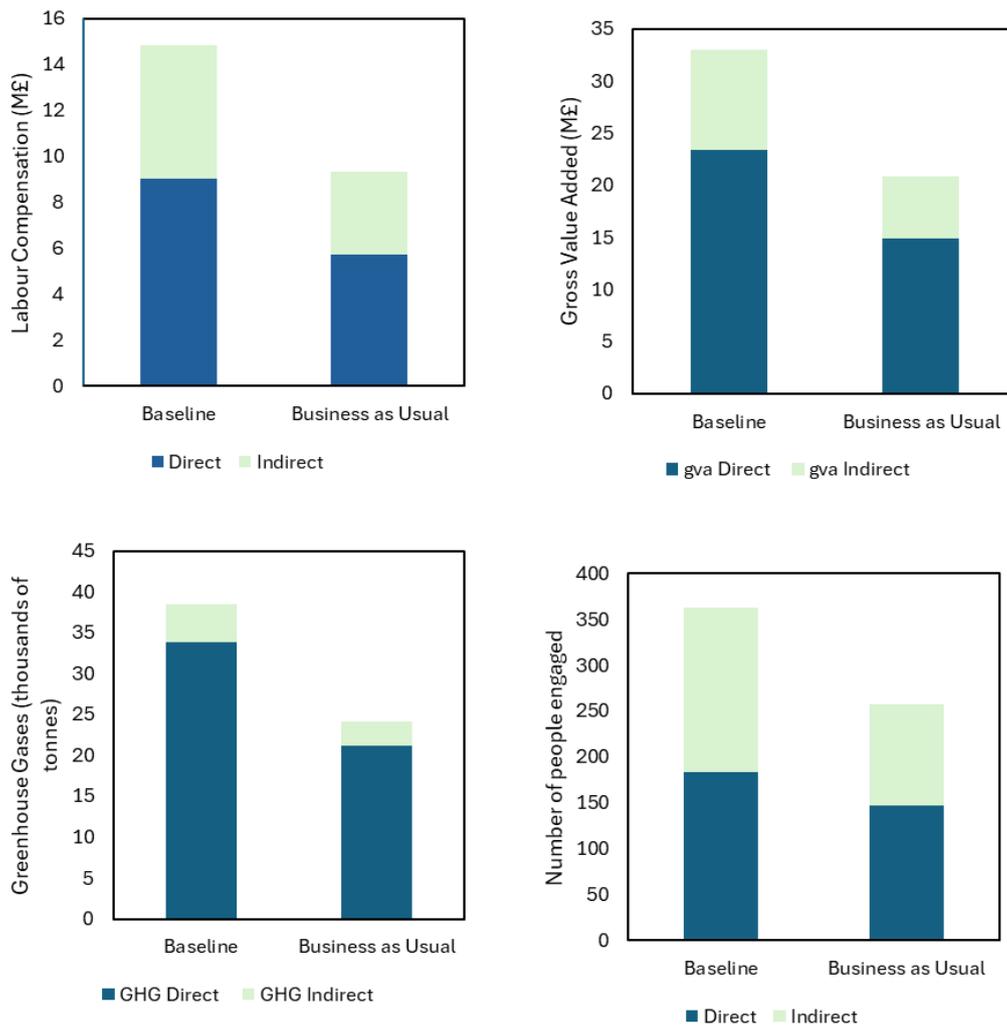
Figure D.3.5: Modelled changes in wages, GVA, GHG emissions and employment of the Northern Ireland Blue Economy due to climate change impacts in the Business as Usual Scenario.

D.4.The Conservation Scenario

D.4.1 Spatial interventions maximising ecological outcomes under the Conservation scenario

In this hypothetical scenario, we simulate spatial interventions that:

1. aim to avoid, minimise or mitigate the impacts of activities which could negatively affect the climate change resilience or adaptation potential of habitats and species of conservation interest in Northern Irish waters. Simulated interventions are located in climate change refugia for benthic habitats.

2. aim to avoid, minimise or mitigate the impacts of activities which could negatively affect the future provision of climate services providing climate change mitigation. Simulated interventions are located in climate change refugia for climate services.

The draft list of interventions considered below as a planning scenario was co-developed with key team members at AFBI and DAERA involved in advice to marine planning, and representatives of the capture fisheries industry (including representative from NIFPO and ANIFPO), in order to ensure that they were well aligned with the current needs of those reviewing and implementing the Marine Plan for Northern Ireland.

The spatial interventions C1 and C2 below have the purpose of avoiding, minimising or mitigating the impacts of activities which could negatively affect benthic habitats and species of high conservation interest and the future provision of climate services (respectively) in NI waters (Table D.4.1). In this hypothetical planning scenario, we simulate that this aim would be supported by additional legislation from DAERA, potentially prioritizing marine conservation in these areas (and thus restricting access to mobile demersal gears, as is already the case in 13 areas in Northern Ireland, including the Outer Belfast Lough MCZ, Rathlin Island MCZ and the Maidens SAC). Additional legislation or policy changes would encourage current MPAs to be managed with a whole site approach (including the protection of organic carbon stores), rather than with a focus on Nationally Important Marine Features. Furthermore, we simulate that offshore renewable energy development in priority areas for conservation is limited, and that this aim is supported by engagement of Northern Irish planning and licensing authorities with the Crown Estate to ensure that these areas are not leased in future bidding rounds, as no areas are currently leased to the sector in Northern Ireland.

Intervention C1: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for benthic habitats identified in Outer Belfast Lough and Queenie Corner MCZs, and North Channel and Pisces Reef Complex SACs. We identified four priority areas for conservation which reflect the locations of long-term (2026-2069) climate change refugia for benthic habitats, and which fall within already designated protected sites. These sites harbour a number of Nationally Important Marine Features (NIMF) such as Ocean Quahog (*Artica islandica*) and horse mussel *(Modiolus modiolus*) beds, along with OSPAR threatened and declining habitat (sea-pen and burrowing megafauna), the Annex 1 habitat "reef", and a range broad-scale sedimentary habitats including subtidal coarse and mixed sediments, subtidal mud and subtidal sand.

Intervention C2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for climate services identified in Queenie Corner and South Rigg MCZs, and North Channel SAC. We identified three priority areas (Figure D.4.1) which reflect the locations of long-term (2026-2069) climate change refugia for climate services, and which fall within already designated protected sites. Two of these sites (Queenie Corner MCZ and North Channel SAC)

also contain identified priority areas for benthic habitats. Organic carbon accumulation in these three MPAs has been estimated to be between 75 – 140 gC m^{-2} yr^{-1} (Burrows et al., 2024).

Table D.4.1: Summary of spatial interventions C1 and C2 proposed in the planning Conservation Scenario, and the expected ecological and economic effects of those interventions. Each intervention represents a possible mechanism by which **the impacts of activities which could negatively affect habitats and species of conservation interest in NI waters could be avoided, minimised or mitigated**. Full descriptions of each intervention, and the reasoning behind them, can be found in the main text.

Spatial intervention	Expected ecological effects	Expected economic effects
C1: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for benthic habitats identified in Outer Belfast Lough and Queenie Corner MCZs, and North Channel and Pisces Reef Complex SACs.	C1: Avoiding, minimising or mitigating the impacts of demersal trawls may promote climate resilience and adaptation potential of habitat features and species in priority areas. It may also indirectly improve foraging habitat for harbour porpoise (*Phocoena phocoena*), and indirectly promote biomass recovery of exploited species such as *Nephrops* as side-effects. C1: Avoiding, minimising or mitigating the impacts of offshore wind development in the identified priority areas could act to avoid direct impacts of development on designated features and mitigate the impacts of development elsewhere in NI waters (e.g. providing compensatory measures).	• Reductions in all variables against Business as Usual. • ~25% reduction in total labour compensation and gross value added • ~40% reduction greenhouse gas emissions • ~15% reduction in the number of employees
C2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for climate services identified in Queenie Corner and South Rigg MCZs, and North Channel SAC.	C2: Avoiding, minimising or mitigating negative impacts on the seabed in priority areas where sediment has a high carbon sequestration potential may limit direct carbon release and degradation (avoided emissions) from disturbed sediment.	
	C1 and C2: Avoiding, minimising or mitigating seabed disturbances in identified priority conservation areas could benefit the condition of wrecks in those areas.	

D.4.2. Potential ecological and heritage benefits of simulated spatial management interventions

Both of the simulated spatial management interventions listed above could result in the potential exclusion of vessels fishing with mobile demersal gears from identified priority areas for conservation. As noted above, 13 areas have already been closed to vessels operating mobile demersal gears. It is possible that the habitats and features present in the priority areas would benefit from both interventions. For example, in the South Rigg and Queenie Corner MCZs, the subtidal mud and burrowing megafauna communities and the subtidal coarse sediment and sand (South Rigg only) for which the sites were designated are all in unfavourable condition and considered vulnerable to demersal trawling and dredging (JNCC, 2021a, 2021b). The *Modiolus* beds inside the North Channel SAC would likely benefit from intervention C1, given that *Modiolus* aggregations are known to be vulnerable to damage from mobile demersal gears (Fariñas-Franco et al., 2018). It is also possible that intervention C1 could improve foraging habitat for harbour porpoise in the priority area identified in the North Channel SAC, as they are known to feed on benthic prey (Evans, 2010). Intervention C1 could therefore improve the condition of designated features in line with JNCC and DAERA assessments and recommendations, and help to fulfil the conservation objectives of these protected areas. Additionally, the proposed priority areas overlap with some of the spawning grounds for plaice, sandeel, sole, whiting, cod, hake, ling and mackerel. It also overlaps with nursery areas for whiting, cod, hake, mackerel, plaice, herring, anglerfish and spurdog (DAERA, 2018, NI Marine Plan, Figues 9b and 9c). Intervention C1 could therefore benefit spawning aggregations and early life stages for key commercial species.

In the case of the priority areas identified for climate services in the South Rigg and Queenie Corner MCZs, and the North Channel SAC, it is possible that intervention C2 may limit direct carbon release and degradation (avoided emissions) from disturbed sediment. Although we acknowledge that it is unproven that protecting seafloor sediments from disturbance improves carbon storage or sequestration potential, the protection of marine carbon sinks may represent a sensible precautionary policy (Epstein et al., 2022; Epstein & Roberts, 2022; Jankowska et al., 2022).

Both interventions C1 and C2 could perhaps result in future limitations on the development of offshore wind in the identified priority areas (though seabed bidding areas are not currently identified in Northern Irish waters). This may benefit benthic and blue carbon habitats within them (Burrows et al., 2024), as many of these habitats and species (e.g. *Modiolus, A. islandica* and burrowing megafauna such as *Nephrops*) are vulnerable to physical disturbance and have low recovery potential following development of offshore wind infrastructure (Henderson, 2023; Rees, 2005). Interventions specifically within the priority area inside the North Channel SAC could also favour harbour porpoise, as this species is known to be disturbed during the construction phase, and are not thought to forage close to operational wind turbines (Leemans & Fijn, 2023).

While we did not evaluate the effects of climate change on heritage assets directly, we do account for possible effects of the simulated interventions on heritage assets in the area. The identified priority areas contain 24 wrecks (Annex 2, Figure A.2), including some historic British Merchant Navy steamships which were lost during WWI, although none of them are designated under the Protection of Wrecks Act 1973, the Protection of Military Remains Act 1986 or the Historic Monuments & Archaeological Objects NI Order 1995. Nevertheless, the condition of these wrecks may benefit from the simulated interventions. Priority areas in Outer Belfast Lough MCZ, and the *Modiolus* beds towards the western inshore edge of the North Channel SAC both contain recreational scuba diving

sites (Annex 2, Figure A.2), and the increased biodiversity in the area that may be promoted by the simulated interventions may encourage divers to preferentially visit those sites (Morse et al., 2024), due to biomass recovery in the sites themselves, and overspill of species or larger individuals from the larger priority area further offshore in the North Channel SAC (Di Lorenzo et al., 2016). The interventions will not affect access to priority areas by recreational anglers fishing with pole and line, and there are no recreational moorings in the priority areas, so anchorages for yachting would be unaffected by the interventions.
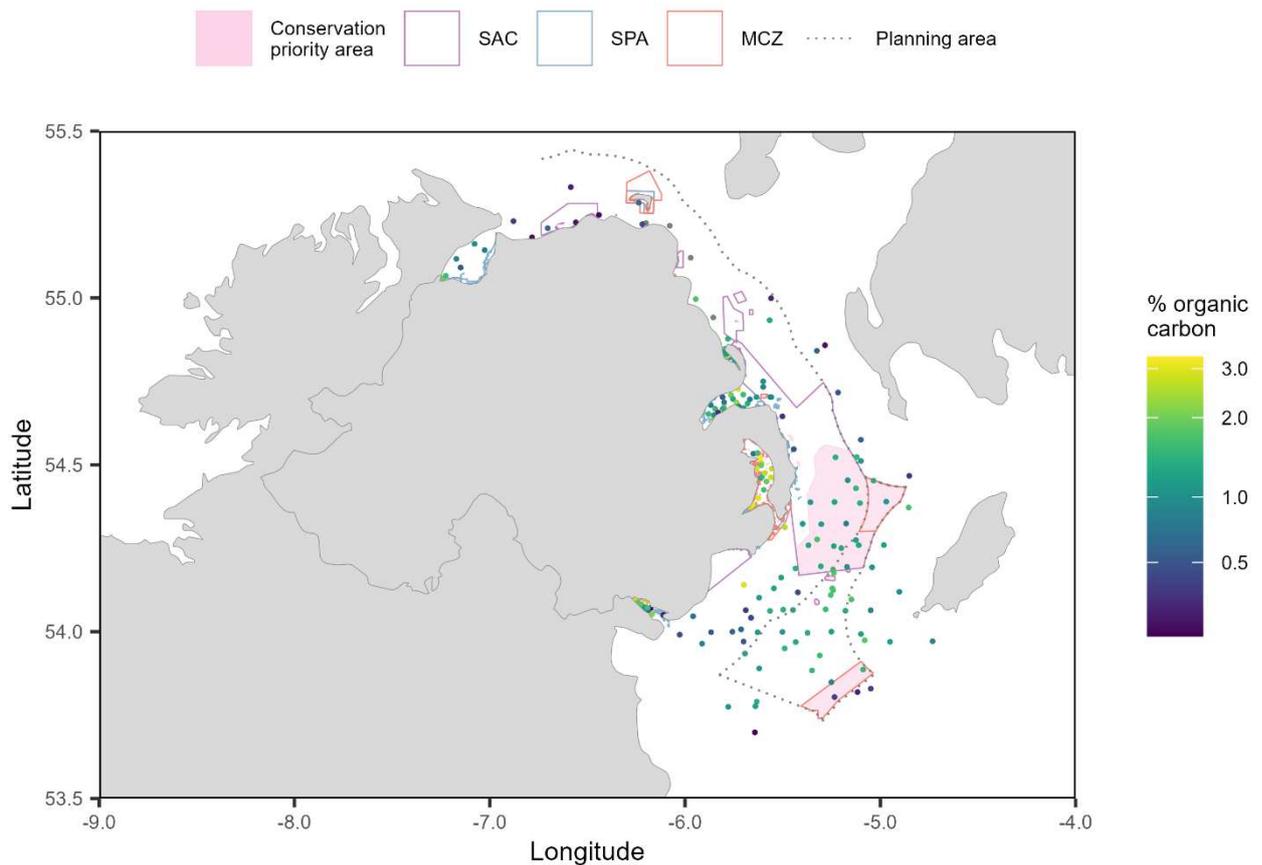

Figure D.4.1: The Conservation Scenario. Pink shading represents the identified priority areas for conservation, which contain OSPAR threatened and declining habitat (predominantly sea pen and burrowing megafauna, but also two *Modiolus modiolus* beds) or NIMF, which also sit within refugia for either benthic habitats or climate services (or both), and within already designated conservation areas (South Rigg, Queenie Corner and Outer Belfast Lough MCZs, Pisces Reef Complex SAC and the southern part of the North Channel SAC). Points represent observed organic carbon content of NI sediments (Hunter & Agri Food and Biosciences Institute, 2024).

D4.3 Economic outcomes for the adjacent blue economy of the Northern Ireland region

In the Conservation Scenario we see further reductions in all impact variables relative to the Business as Usual Scenario (Figure D.4.2). There is an approximately 25% reduction in labour compensation and gross value added, a ~35% reduction in greenhouse gas emissions and ~15% reduction in the number of persons engaged. These reductions are predominantly driven by interventions that may limit the activity of the *Nephrops* fleet segments in some areas of the seabed. In this scenario the area that is hypothetically lost to the *Nephrops* fleet increases from 30% (climate change only) to 65% (climate change plus restrictions due to the prioritisation of conservation in some areas). Closures do not impact other fleets to the same extent, and outside the *Nephrops* fleet losses in

catch stay similar to the business as usual scenario. The biggest reductions in all variables are within *Nephrops*, with associated Warehousing and Water Transport also being significantly impacted.

It is beyond the scope of the current modelling work to develop alternative scenarios that might offset the losses due to conservation-based closures to fisheries. However, we can indicatively say that an increase in demand of £20 million in either the Hotel or in the Scientific Research sector would restore labour compensation and GVA across the blue economy to Business as Usual levels, while greatly increasing the number of people engaged, reducing greenhouse gas emissions and increasing conservation outcomes.
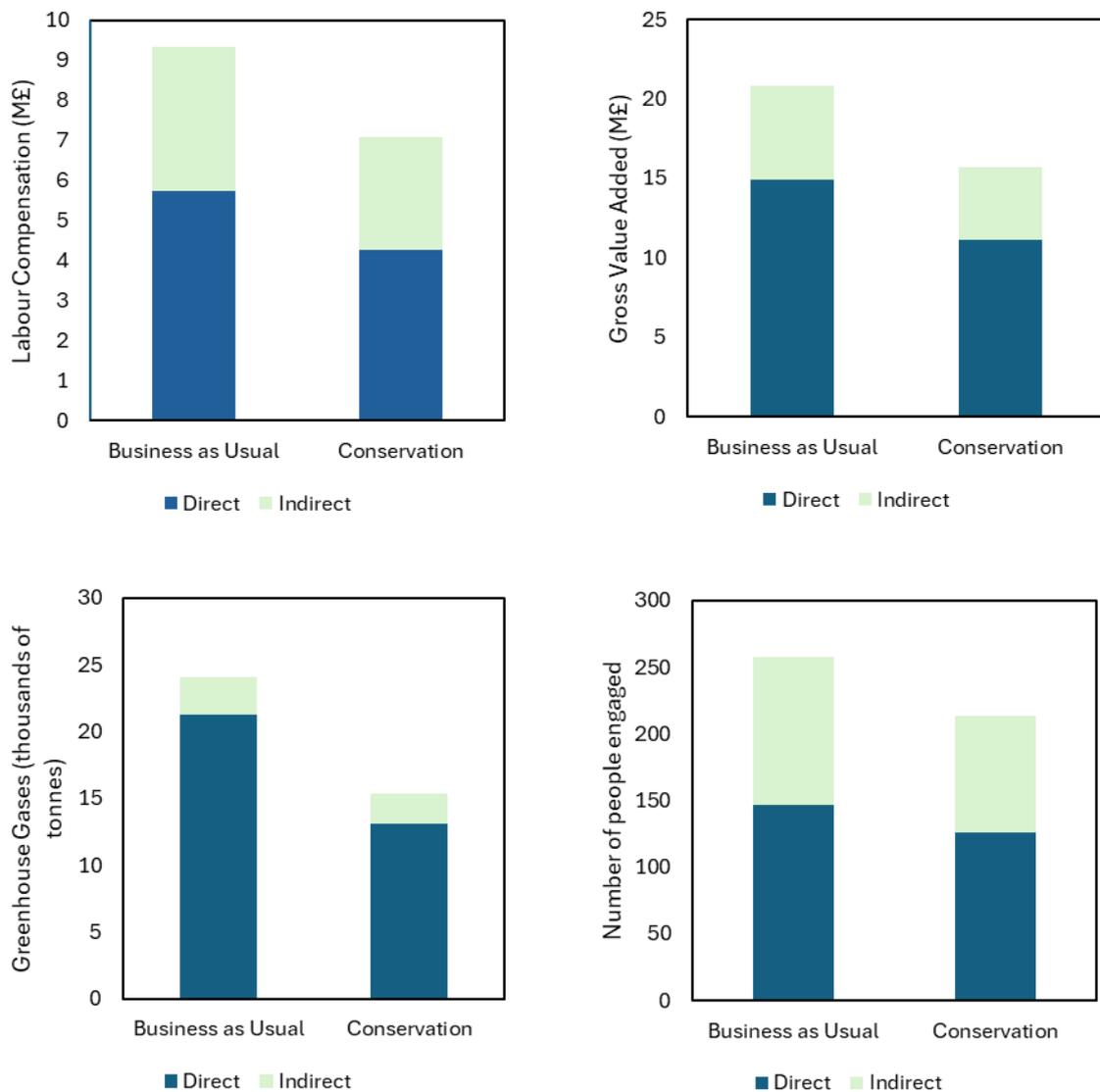

Figure D.4.2: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Conservation Scenario, as compared to the Business as Usual Scenario

D.5. The Food Provision Scenario

D5.1 Spatial interventions maximising outcomes under the food provision scenario

In this hypothetical scenario, we propose spatial interventions that:

1. aim to support and safeguard climate-resilient fisheries in the NI planning area. Simulated interventions are located in climate change refugia for demersal and pelagic fisheries.

2. aim to facilitate the development of climate-resilient aquaculture in NI waters. Simulated interventions are located in climate change refugia for seafloor aquaculture.

The draft list of interventions considered below as a hypothetical planning scenario was co-developed with key stakeholders involved in the region in order to ensure that they were well aligned with the current needs of those reviewing and implementing the Marine Plan for Northern Ireland, as well as those affected by them in the fisheries and aquaculture sectors.

The spatial interventions FP1 and FP2 below have the purpose of supporting and safeguarding climate resilient capture fisheries and facilitating the development of climate resilient aquaculture in Northern Irish waters (Table D.5.1). In this planning scenario, we simulate that these aims would be supported by planning and licensing authorities in Northern Ireland considering the locations of identified priority areas for fisheries and aquaculture when evaluating applications for development of marine space by other industries and sectors (e.g. offshore wind).

Intervention FP1: Avoid, minimise or mitigate proposals for uses that may be incompatible with access by the pelagic fleet to currently unfished areas, identified as pelagic fisheries priority areas.
We identified priority areas for capture fisheries based on the locations of climate change refugia for the sector. A small (~10km^2) refuge for pelagic fisheries was identified in the offshore area towards the eastern edge of South Rigg MCZ (Figure D.5.1), although we note that abundances of the key currently targeted species herring (*Clupea harengus*) and mackerel (*Scomber scombrus*) are both projected to decline across all of NI waters. There is the possibility that catch diversification could help with sector sustainability in the future, for example, abundances of both the European pilchard (*Sardina pilchardus*) and horse mackerel (*Trachurus trachurus*) are projected to remain stable or even increase in NI waters by mid-century, perhaps providing opportunities for the pelagic fleet even in the face of climate change. There were no climate change refugia projected for demersal fisheries in Northern Irish waters, and so we were unable to identify priority areas for the sector. At the present time, shellfish species such as langoustine (*Nephrops norvegicus*, which is of particularly high value), edible crab (*Cancer pagurus*) and king scallop (*Pecten maximus*) represent the majority of Northern Irish demersal capture fisheries landings, although species such as haddock (*Melanogrammus aegelfinus*) and anglerfish (*Lophius piscatorius*) are also targeted (MMO, 2022). While we did not have modelling data available for scallop, our analysis suggests that abundances of the other key species above are projected to decline in the future. However, we recognise that shifting species distributions are resulting in new species entering NI waters which do not currently make up a significant proportion of catches (Pinnegar et al., 2020), and these species could therefore increase in commercial value. Because the value to the sector of those potential catches of new species will depend on consumer attitudes, they are not included in these analyses.

It is also possible that the sustainability of the demersal fleet could be improved, which may improve resilience and adaptation potential in currently exploited stocks (Gaines et al., 2018; Sumaila & Tai, 2020). For example, the *Nephrops* fishery is known to have an issue with by-catch of haddock and whiting that are under the minimum conservation reference size (Cosgrove et al., 2019). Although it is mandatory for all vessels targeting *Nephrops* to work selective gears to ensure minimal by-catch of

Irish Sea cod, there is some improvement in gear selectivity that could be made to reduce unwanted catches of undersize haddock and whiting. Such gears have been (and continue to be) tested, and found to both reduce numbers of unwanted species, and improve the quality of landed *Nephrops* (Cosgrove et al., 2019; Northern Ireland Gear Trials Project, 2020). Given that investing in new gears can be costly for fishers, it is likely that additional incentives may be needed to encourage them to fish more selectively. An example of a scheme that might promote gear modifications in the *Nephrops* fishery is the "*Nephrops* scheme", which seeks to encourage this by providing an enhanced share of the national *Nephrops* quota in return for a commitment to using a selective gear to reduce unwanted catches (Cosgrove et al., 2019).

Intervention FP2: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector. A refuge for seafloor aquaculture of approximately 210km^2 was identified along the coast of Co. Down. This site is likely to be able to support aquaculture in the region in the long-term, despite broader climate change pressures, and we identify it as a priority area for the sector. Although the site is quite shallow (<50m depth), we recognise that whilst offshore pelagic aquaculture is commonplace in Europe and growing in the UK, developing seabed aquaculture facilities in exposed areas may be more challenging. There are important navigation routes along this section of the coast, including access to Belfast Lough and deployment of static sea surface infrastructure (e.g. for farming) would not be permitted if it interferes with these routes. Critically, two areas of conservation interest have been *excluded* from the priority area for seafloor aquaculture to ensure the continued health of the sites – the Outer Belfast Lough MCZ, which contains a significant population of the ocean quahog (*Arctica islandica*), and horse mussel (*Modiolus modiolus*) beds off the Outer Ards. There are also 27 wrecks located in the area identified for expansion of seafloor aquaculture, including some 19th century vessels, and British Merchant Navy ships sunk during WW1, which may be damaged by the installation of new aquaculture infrastructure. There are some recreational scuba diving sites located in the Outer Belfast Lough which falls within the seafloor aquaculture priority area, and access to these sites may be restricted following installation of infrastructure. There are no recreational moorings in either of the areas prioritised for food provision, so anchorages for yachting would be unaffected. It is likely that for all these reasons, the whole site could not be developed, although some of it may still be suitable. However, given that current seafloor aquaculture infrastructure in NI covers approximately 19km^2, development of even a fraction of the area identified could represent a significant increase in seafloor aquaculture production potential in the region.

If seafloor aquaculture production of mussels is to be increased, then it is likely that the industry may have to address the issue of mussel seed collection. At present, wild mussel seed in Northern Ireland is dredged from seed beds (under quota – seed fisheries can be closed if recruitment is judged by AFBI to be insufficient to maintain the fishery), and re-laid at aquaculture facilities to be grown on. Subsequently, there is some concern about shortages of wild seed, and the sustainability of the industry moving forward (O'Biern, 2022). Employing new ways of collecting seed (e.g. dedicated seed collectors, where ropes are suspended in the water column for wild seed to settle on (Kamermans & Capelle, 2019)) could be necessary to support the expansion of the industry, although trials will be needed to ensure that collectors are located in areas where settlement is sufficient to maintain supply to commercial facilities. As noted for the fisheries sector above, it is possible that under climate change, Northern Irish waters may become suitable for the aquaculture production of warmer water species, which may provide an opportunity for sectoral development. Again, we did not include possible "new" species in our analysis for the sector as production value is likely to depend on consumer attitudes, and so we could not say for certain which species may be targeted for culture.

Table D.5.1: Summary of spatial interventions proposed in the Food Provision Scenario, and the expected ecological and economic effects of those interventions. Each intervention represents a possible mechanism which **supports climate-resilient fisheries and facilitates the development of climate-resilient aquaculture in the Northern Ireland planning area**. Full descriptions of each intervention, and the reasoning behind them, can be found in the main text.

| Spatial intervention	Expected sectoral effects	Expected economic effects
FP1: Avoid, minimise or mitigate proposals for uses that may be incompatible with access by the pelagic fleet to currently unfished areas, identified as pelagic fisheries priority areas.	FP1: Continued/priority access to sites identified as priority areas for fisheries could contribute to the resilience of the fishing sectors and help to support the industry in the face of climate change.	• Increases in all variables against Business as Usual. • ~270% increase in total labour compensation and gross value added • ~90% increase in greenhouse gas emissions • ~460% increase in the number of employees
FP2: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector.	FP2: Development of the identified priority area for seafloor aquaculture represents a possible opportunity for sectoral expansion. FP2: Development of the identified priority area for seafloor aquaculture may affect the condition of historic wrecks in the area (although none of them are legally protected from disturbance at present), and restrict access to SCUBA dive sites in Outer Belfast Lough.	
	FP1 and FP2: Restricting the future development of offshore wind in the identified priority fisheries and aquaculture areas could act to ensure that access to climate change refugia for the sectors is maintained.	
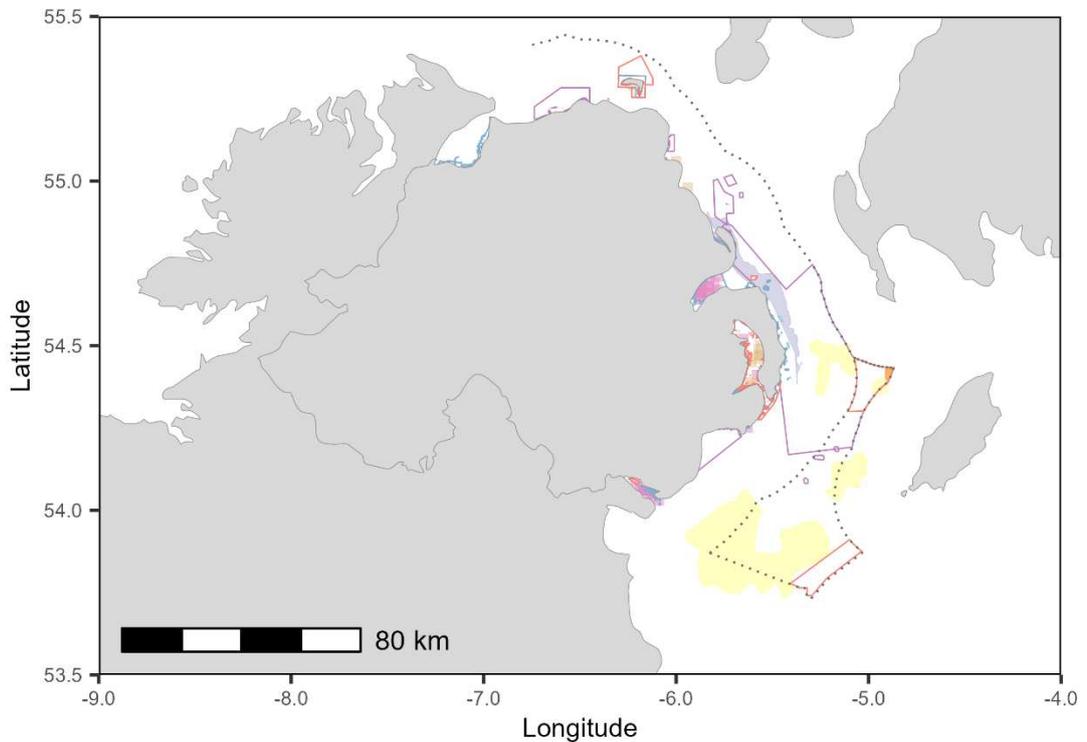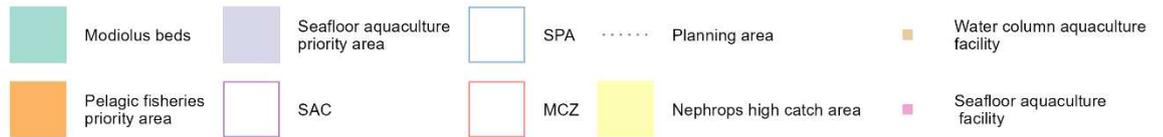
Figure D.5.1: Food Provision scenario: Two areas harbouring food provision refugia have been identified as priority areas for pelagic fisheries (in the eastern corner of the South Rigg MCZ) and seafloor aquaculture (shallow sites close to the coastline, excluding the Outer Belfast Lough MCZ and two *Modiolus modiolus* beds in the North Channel SAC).

D5.2 Economic outcomes for the adjacent blue economy of the Northern Ireland region

Relative to the Business as Usual Scenario, the Food Provision Scenario greatly increases all our indicators (Figure D.5.2). Accounting for direct and indirect effects we see increases in Labour Compensation, and Gross Value Added of around 270%, increases in Greenhouse Gas emissions of around 90% and 460% increases in the number of people employed. This is driven by the growth in aquaculture, because the simulated expansions are so large relative to existing provision. Impacts are predominantly concentrated in the aquaculture sector itself, though as in other scenarios Warehousing heavily impacted, and there are also significant supply chains impacts in financial and leasing sectors.
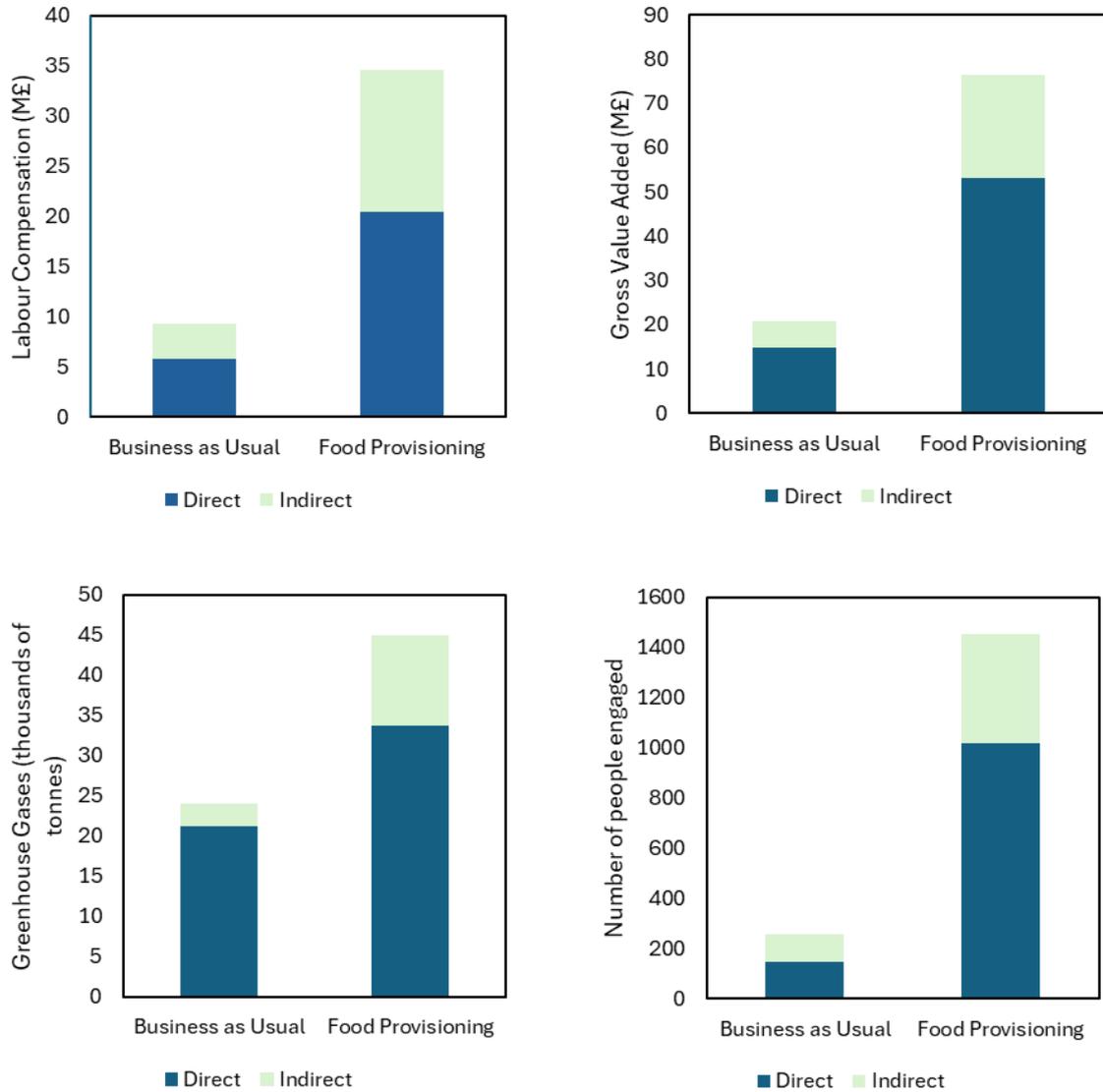
Figure D.5.2: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Food Provision Scenario, as compared to the Business as Usual Scenario

D.6. The Compromise Scenario

D6.1 Spatial interventions maximising outcomes under the compromise scenario

Measures considered in this hypothetical planning scenario have the following aims, given estimated climate change impacts and considering what other priorities stakeholders hold for the region (Reinhardt & Danahey Janin, 2025):

1. aim to support and safeguard climate-resilient fisheries in NI waters. Simulated interventions are located in climate change refugia for pelagic fisheries.
2. aim to facilitate the development of climate-resilient aquaculture in NI waters. Simulated interventions are located in climate change refugia for seafloor aquaculture.
3. aim to avoid, minimise or mitigate the impacts of activities which could negatively affect the climate change resilience or adaptation potential of wild species and habitats of conservation interest in NI waters. Simulated interventions are located in climate change refugia for benthic habitats.
4. aim to avoid, minimise or mitigate the impacts of activities which could negatively affect the future provision of climate services providing climate change mitigation. Simulated interventions are located in climate change refugia for climate services.

This scenario is expected to balance the needs of wild capture fisheries and aquaculture production with the need to ensure that the marine environment is adequately protected in order to provide a healthy, resilient and adaptable marine ecosystem. It is expected that the Compromise Scenario may meet a broader set of objectives with regard to stakeholders in Northern Ireland than the other three scenarios.

The spatial interventions CM1 and CM2 below have the purpose of avoiding, minimising or mitigating the impacts of activities which could negatively affect benthic habitats of high conservation interest and the future provision of climate services in Northern Irish waters (Table D.6.1). In this planning scenario, we simulate that this aim would be supported by additional legislation from DAERA, potentially limiting access to identified priority areas for conservation to mobile demersal gears in those areas where it is still permitted at present, and additional legislation or policy changes that might allow current MPAs to be managed more flexibly – e.g. with a whole site approach to management (including the protection of organic carbon stores), rather than for designated features specifically. The spatial interventions CM3 and CM4 have the purpose of supporting and safeguarding climate-resilient capture fisheries and facilitating the development of climate-resilient aquaculture in the NI planning area (Table D.6.1). These aims would be supported by planning and licensing authorities in NI considering the locations of identified priority areas for fisheries and aquaculture when evaluating applications for development of marine space by other industries and sectors. Finally, we simulate that offshore renewable energy development may be limited in priority areas for conservation, fisheries and aquaculture (though no areas are currently licensed in NI to this end, and so the scenario does not include economic modelling of this impact), and that this aim would be supported by engagement of planning and licensing authorities with the Crown Estate to ensure that these areas are not leased in future bidding rounds. This prioritisation is informed by the values of stakeholders in the region (Reinhardt & Danahey Janin, 2025).

Intervention CM1: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for benthic habitats identified in Outer Belfast Lough and Queenie Corner MCZs, and North Channel and Pisces Reef Complex SACs. Under this scenario, the identified priority areas for conservation in the North Channel and Pisces Reef Complex SACs (including the

Outer Ards *Modiolus* beds in the North Channel SAC) and the Belfast Lough and Queenie Corner MCZs are still present, although the area in North Channel SAC has been made smaller. This is to simulate fisheries access to areas which have historically provided high *Nephrops* catches (Figure D.6.1).

Intervention CM2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for climate services identified in Queenie Corner and South Rigg MCZs, and North Channel SAC. The priority areas for conservation in South Rigg and Queenie Corner MCZs and North Channel SAC identified in the Conservation Scenario (Section D.4) remain as such here, although as in intervention CM1, the priority areas in the North Channel SAC and South Rigg MCZ are smaller in this scenario to simulate continued access to *Nephrops* fishing grounds.

Intervention CM3: Avoid, minimise or mitigate proposals for uses that may be incompatible with access by the pelagic fleet to currently unfished areas, identified as pelagic fisheries priority areas. As in the Food Provision Scenario (Section D.5), the identified refuge for pelagic fisheries is also a priority area for the fleet in this scenario. There were no climate change refugia projected for demersal fisheries in Northern Irish waters, so we were unable to identify priority areas for the sector, however, as noted in interventions CM1 and CM2 above, the spatial extent of identified conservation priority areas has been reduced from those simulated in the Conservation Scenario in order to maintain access to fishing grounds by the *Nephrops* fleet. However, it is worth mentioning again that the Irish Sea mud belt itself is located within a climate change hotspot for demersal fisheries (Figure D.3.3), and *Nephrops* abundances in the area are projected to be significantly negatively impacted by climate change (Annex 2, Figure A.2). It is, therefore, possible that the profitability of this fleet might be reduced as a consequence, even with continued access to current fishing grounds.

Intervention CM4: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector. The priority area for seafloor aquaculture ($\sim$210km^2) that we identified (due to the location of a refuge for seafloor aquaculture that sits in water <50m depth) in the Food Provision Scenario (Section D.5) remains as a priority area for aquaculture development under this scenario (Figure D.6.1). As noted above, access to Belfast Lough for shipping must be maintained, and the Outer Belfast Lough MCZ and Outer Ards *Modiolus* beds have been ***excluded from the area*** recommended for development to ensure that the integrity of these important conservation features are maintained. Although none of the 27 wrecks that sit within the identified priority area for seafloor aquaculture are designated under the Protection of Wrecks Act 1973, the Protection of Military Remains Act 1986 or the Historic Monuments & Archaeological Objects NI Order 1995, any proposed development would likely need to conduct an environmental impact assessment to ensure that any vessels of historical significance are not disturbed.

Table D.6.1: Summary of spatial interventions proposed in the Compromise Scenario, and the expected ecological and economic effects of those interventions. Each intervention represents a possible mechanism which **supports climate-resilient fisheries, facilitates the development of climate-resilient aquaculture and seeks to avoid, minimise or mitigate the impacts of activities which could negatively affect habitats and species of conservation interest in NI waters**. Full descriptions of each intervention, and the reasoning behind them, can be found in the main text.

Spatial intervention	Expected ecological effects	Expected economic effects
CM1: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for benthic habitats identified in Outer Belfast Lough and Queenie Corner MCZs, and North Channel and Pisces Reef Complex SACs.	CM1: Avoiding, minimising or mitigating access by mobile demersal gears to habitat features could maximise the effectiveness of the identified climate change refuge in conservation priority areas, promoting the climate change resilience of these habitats.	• Increases in all variables against Business as Usual. • ~240% increase in total labour compensation and gross value added • ~50% increase in greenhouse gas emissions • ~450% increase in the number of employees
CM2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for climate services identified in Queenie Corner and South Rigg MCZs, and North Channel SAC.	CM2: Avoiding, minimising or mitigating negative impacts on the seabed in priority areas where sediment has a high carbon sequestration potential may limit direct carbon release and degradation (avoided emissions) from disturbed sediment.	
CM3: Avoid, minimise or mitigate proposals for uses that may be incompatible with access by the pelagic fleet to currently unfished areas, identified as pelagic fisheries priority areas.	CM3: Priority access to sites identified as refugia for fisheries could contribute to the resilience of the fishing sectors and help to support the industry in the face of climate change.	
CM4: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector.	CM4: Development of the identified priority area for seafloor aquaculture represents a possible opportunity for sectoral expansion. CM4: Development of the identified priority area for seafloor aquaculture may restrict access to SCUBA dive sites in Outer Belfast Lough, and affect the condition of historic wrecks in the area (although none of them are legally protected from disturbance at present).	
	CM1-CM4: Avoiding, minimising or mitigating the impacts of offshore wind development in the identified	

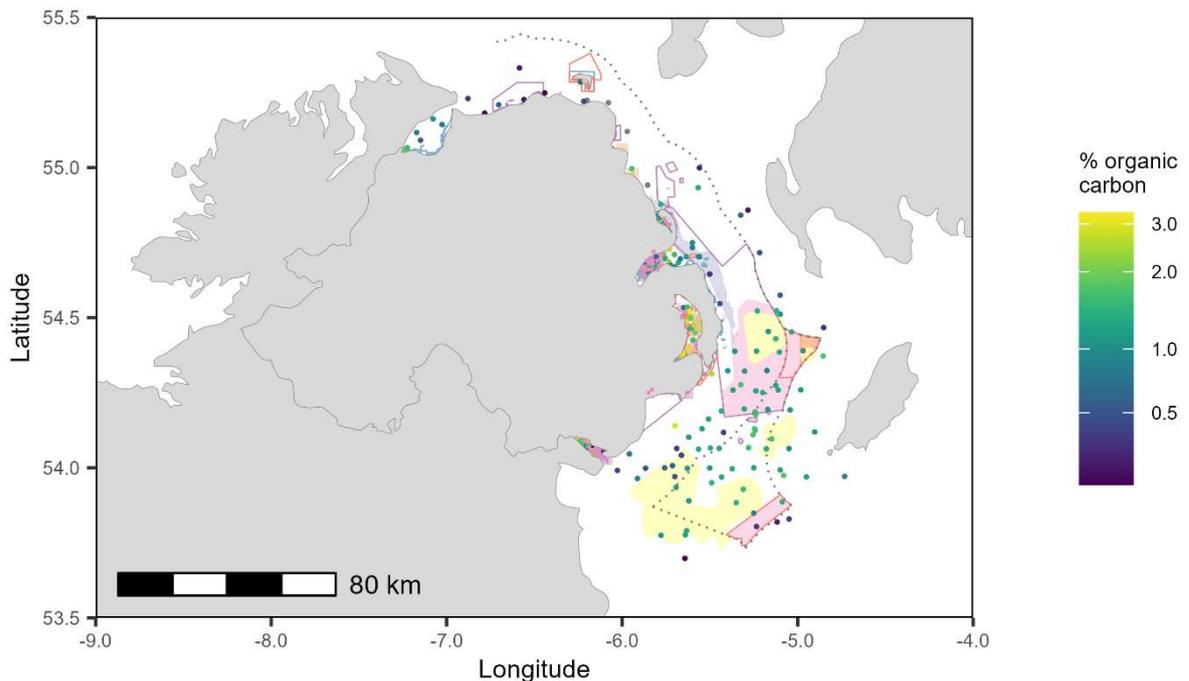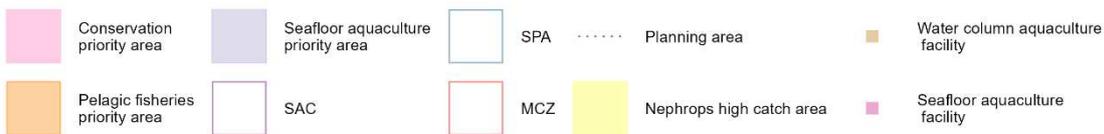|	priority areas for conservation, fisheries and seafloor aquaculture could act to avoid direct impacts of development on designated features (e.g. harbour porpoise, *Modiolus beds*), protect sedimentary organic carbon stores from disturbance and ensure that access to climate change refugia for the fisheries and aquaculture sectors is maintained.	

Figure D.6.1: Compromise Scenario: Climate change refugia for benthic habitats and climate services are identified as priority areas for conservation in this scenario, although parts of the North Channel SAC and South Rigg MCZ which harbour refugia have been excluded from the priority conservation areas to simulate fisheries access to an area of the Irish Sea mud belt which has historically provided high *Nephrops* catches. The priority areas for pelagic fisheries and seafloor aquaculture outlined in the Food Provision scenario remain as such in this scenario. Points dotted across the planning area represent measured organic carbon content of NI sediments (Hunter & Agri Food and Biosciences Institute, 2024)

D6.2. Potential ecological benefits of proposed spatial management measures

It is possible that interventions CM1 and CM2, designed to limit negative impacts on benthic habitats and provision of climate services in identified priority areas for conservation, would benefit the MPAs in which they sit more widely, and assist in achieving stated conservation objectives (e.g. the recovery of designated features to favourable condition, protection of NIMF and improved foraging habitat for harbour porpoise). It is also possible that interventions applied in the conservation

priority areas could prove beneficial to the *Nephrops* fishery in the longer-term by reducing the number of pressures on the stock within it, perhaps increasing climate resilience (Bates et al., 2019) and biomass (Vigo Fernandez et al., 2023). Furthermore, the conservation priority areas have been shown to be spawning grounds for plaice, sandeel, sole, whiting, cod, hake, ling and mackerel. They also overlap with nursery areas for whiting, cod, hake, mackerel, plaice, herring, anglerfish and spurdog (DAERA, 2018, NI Marine Plan, Figues 9b and 9c). Interventions CM1 and CM2 could therefore benefit spawning aggregations and early life stages for key commercial species. In the case of the priority areas identified for climate services in the Queenie Corner and South Rigg MCZs, and the North Channel SAC, it is possible that intervention CM2 may limit direct carbon release and degradation (avoided emissions) from disturbed sediment. Although we acknowledge that it is unproven that protecting seafloor sediments from disturbance improves carbon storage or sequestration potential, the protection of marine carbon sinks may represent a sensible precautionary policy (Epstein et al., 2022; Epstein & Roberts, 2022; Jankowska et al., 2022). The simulated interventions will not affect recreational anglers fishing with pole and line, and there are no recreational moorings in the conservation priority areas, so anchorages for yachting would be unaffected by the interventions.

Interventions CM3 and CM4 could both present opportunities to support the fishing and aquaculture sectors in the face of climate change pressures. While opportunities are more limited for the capture fisheries sector, it is possible that under intervention CM3, use of the identified priority area, along with possible catch diversification could promote a measure of climate resilience for the pelagic fleet. Intervention CM4 could allow for the expansion of seafloor aquaculture in the NI planning, utilising the identified priority area for seafloor aquaculture off the coast of Co. Down. However, as noted in the Food Provision Scenario, it is likely that the entirety of the aquaculture priority area could not be developed by the sector to ensure that navigation routes to Belfast Lough are not impeded.

D6.3 Economic outcomes for the adjacent blue economy of the NI region

Relative to the Business as Usual Scenario, the Compromise Scenario substantially increases all our indicators, though to a lesser extent than the Food Provision Scenario (Figure D.6.2). Again, results are predominantly driven by the growth in Aquaculture, because the simulated expansions are large relative to the existing sector size. The relative decline against the Food Provision Scenario is due to the simulated impacts of intervention CM1 on the *Nephrops* fishing fleet segments. Because aquaculture is carbon efficient relative to the *Nephrops* fleet, the Compromise Scenario sees a relatively small rise in greenhouse gas emissions (this effect is much larger in the Food Production scenario).
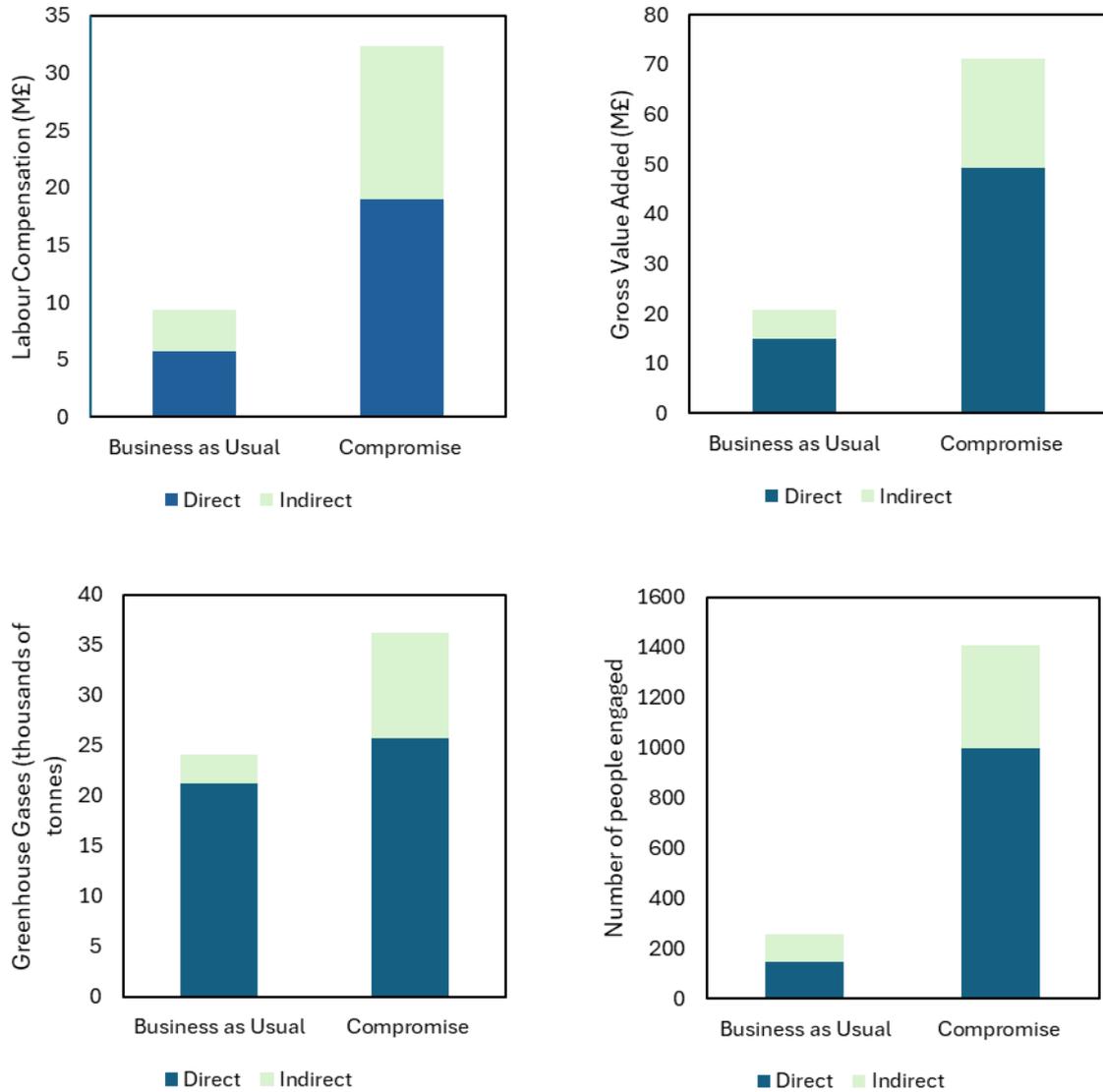
Figure D.6.2: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Compromise, as compared to the Business as Usual Scenario.

Annex 1: Scenario co-development formulae

The following are summary equations that represent the formulation of the management scenarios co-developed in MSPACE.

1. Business as Usual Scenario

Example with Revenue (R):

Total R$_{BAU}$ = R$_p$ − R$_h$

1.1. Effects on Fisheries

BAU = business as usual scenario

p = area fished at present

h = area fished at present that overlaps with fishery hotspot

1.2. Effects on Aquaculture

BAU = business as usual scenario

p = area where aquaculture infrastructure is located at present (note if pelagic or benthic)

h = area where aquaculture infrastructure is located at present that overlaps with aquaculture hotspot (note if both pelagic or benthic)

Climate-smart scenarios

2. Food Provision Scenario

2.1. Fishery (intermediate) Scenario : optimises outcomes for the fishing sector

Example with Revenue (R):

Total R$_{FS}$ = R$_p$ − R$_h$ + R$_r$

FS = fishery scenario

p = area fished at present

h = area fished at present that overlaps with fishery hotspot

r = area in fishery refuge (pelagic or demersal) that is not currently fished

2.2. Aquaculture (intermediate) Scenario (optimises outcomes for the Aquaculture sector)

Example with Revenue (R):

Total R$_{AS}$ = R$_p$ − R$_h$ + R$_r$

AS = aquaculture scenario

p = area where aquaculture infrastructure (water column or seafloor) is located at present

h = area where aquaculture infrastructure (water column or seafloor) is located at present that overlaps with aquaculture hotspot

r = area in aquaculture refuge (water column or seafloor) where there is no aquaculture infrastructure located at present

2.3. Final Estimate

Combines overall estimates from the above Fishery and Aquaculture scenarios

Total R_{FP} = $R_p - R_h + R_r$

FP = Food Provision scenario

p = area where aquaculture infrastructure is located at present (note if pelagic or benthic) + area fished at present

h = [area where aquaculture infrastructure is located at present that overlaps with aquaculture hotspot] + [area fished at present that overlaps with fishery hotspot]

r = [area in aquaculture refuge where there is no aquaculture infrastructure located at present] + [area in fishery refuge that is not currently fished]

3. Conservation scenario

3.1 For impacts on fishing

Total R_{CS} = $R_p - R_h - R_r$

CS = conservation scenario

p = area fished at present

h = area fished at present that overlaps with a fisheries hotspot

r = area identified in conservation analysis as a climate change refuge (benthic habitat, pelagic habitat, benthic megafauna, pelagic megafauna, climate services) that is proposed as a priority conservation area and in which fishing restrictions are proposed.

3.2. For impacts on tourism/recreation

Total R_{CS} = $R_p - R_h + R_r$

CS = conservation scenario

p = area protected at present (e.g. MCZ + SAC + SPA)

h = area protected at present that overlaps with hotspot

r = area identified in conservation analysis as a climate change refuge (benthic habitat, pelagic habitat, benthic megafauna, pelagic megafauna, climate services) that is proposed as a priority conservation area and in which we expect to see benefits to marine recreational activities e.g. scuba diving, wildlife watching

4. Compromise Scenario.

4.1 For impacts on fishing

Total R_{FS} = $R_p - R_h - R_r + R_f$

FS = conservation scenario

p = area fished at present

h = area fished at present that overlaps with a fisheries hotspot

r = area identified in conservation analysis as a climate change refuge (benthic habitat, pelagic habitat, benthic megafauna, pelagic megafauna, climate services) that is proposed as a priority conservation area and in which fishing restrictions are proposed.

f = area identified in fisheries analysis as a refuge for pelagic or demersal fisheries that is proposed as a fisheries priority area

4.2 For impacts on fishing

Total R_{AS} = $R_p - R_h + R_r$

AS = aquaculture scenario

p = area where aquaculture infrastructure (water column and seafloor) is located at present

h = area where aquaculture infrastructure (water column and seafloor) is located at present that overlaps with aquaculture hotspot

r = area in aquaculture refuge (water column and seafloor) where there is no aquaculture infrastructure located at present

4.3. For impacts on tourism/recreation

Total R_{TRS} = $R_p - R_h + R_r$

TRS = Tourism/recreation scenario

p = area protected at present (e.g. MCZ + SAC + SPA)

h = area protected at present that overlaps with hotspot

r = area identified in conservation analysis as a climate change refuge (benthic habitat, pelagic habitat, benthic megafauna, pelagic megafauna, climate services) that is proposed as

a priority conservation area and in which we expect to see benefits to marine recreational activities e.g. scuba diving, wildlife watching

4.4 Final Estimate

Combines overall estimates from the above Fishery, Aquaculture and Tourism/recreation scenarios

Total R$_{cs}$ $= R_p - R_h - R_f + R_r + R_c$

CS = Compromise scenario

p = area where aquaculture infrastructure (water column or seafloor) is located at present + area fished at present

h = [area where aquaculture infrastructure is located at present that overlaps with aquaculture hotspot] + [area fished at present that overlaps with fishery hotspot]

f = area identified in conservation analysis as a climate change refuge (benthic habitat, pelagic habitat, benthic megafauna, pelagic megafauna, climate services) that is proposed as a priority conservation area and in which fishing restrictions are proposed.

r = [area in aquaculture refuge where there is no aquaculture infrastructure located at present] + [area in fishery refuge that is not currently fished]

c = area identified in conservation analysis as a climate change refuge (benthic habitat, pelagic habitat, benthic megafauna, pelagic megafauna, climate services) that is proposed as a priority conservation area and in which we expect to see benefits to marine recreational activities e.g. scuba diving, wildlife watching.

Annex 2: Supplementary Information

Table A1: Stakeholders consulted during the co-development of the MSPACE management scenarios.

Name	Organisation
Hugh Edwards	DAERA NI Marine Plan Team
William Hunter	Agri Food and Biosciences Institute

Table A2: Marine focussed sectors in the economic model. For all sectors used in the model, please see Roca Florido et al. (2025)

|	Sector
1	Area VIIA Nephrops over 250kW
2	Area VIIA Nephrops under 250kW
3	Under 10m demersal trawl/seine
4	Under 10m pots and traps
5	Pots and traps over 10m
6	Scallop dredge
7	Demersal beamers and trawlers
8	Low activity vessels
9	Aquaculture
10	Processing and preserving of fish crustaceans and molluscs
11	Repair and maintenance of ships and boats
12	Wholesale of other food including fish crustaceans and molluscs
13	Retail sale of fish crustaceans and molluscs in specialised stores
14	Water transport
15	Service activities incidental to water transportation
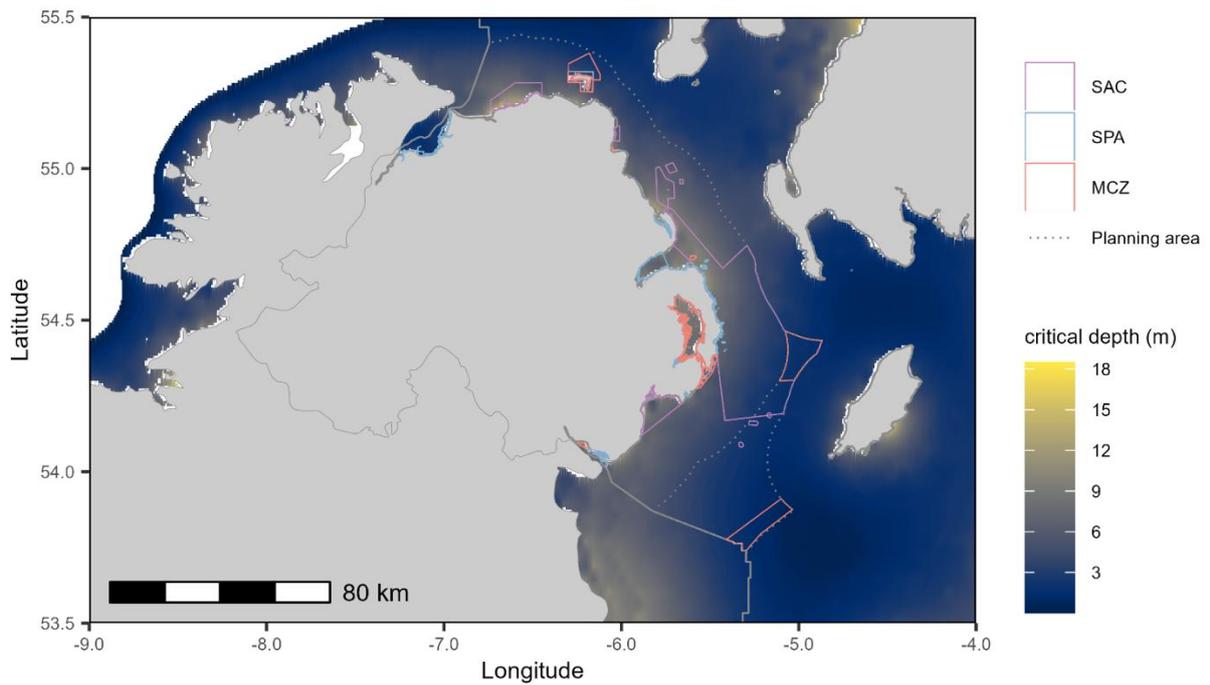
Figure A.1 Depth to which biologically relevant artificial light levels penetrate the water column (data from Smyth et al., 2024), along with the locations of designated conservation sites. Given the average water depth along the coast of NI, it is likely that biologically relevant light will only reach in the seabed in the Outer Belfast Lough MCZ, suggesting that on the whole, conservation sites in NI waters are not highly impacted by ALAN pollution.
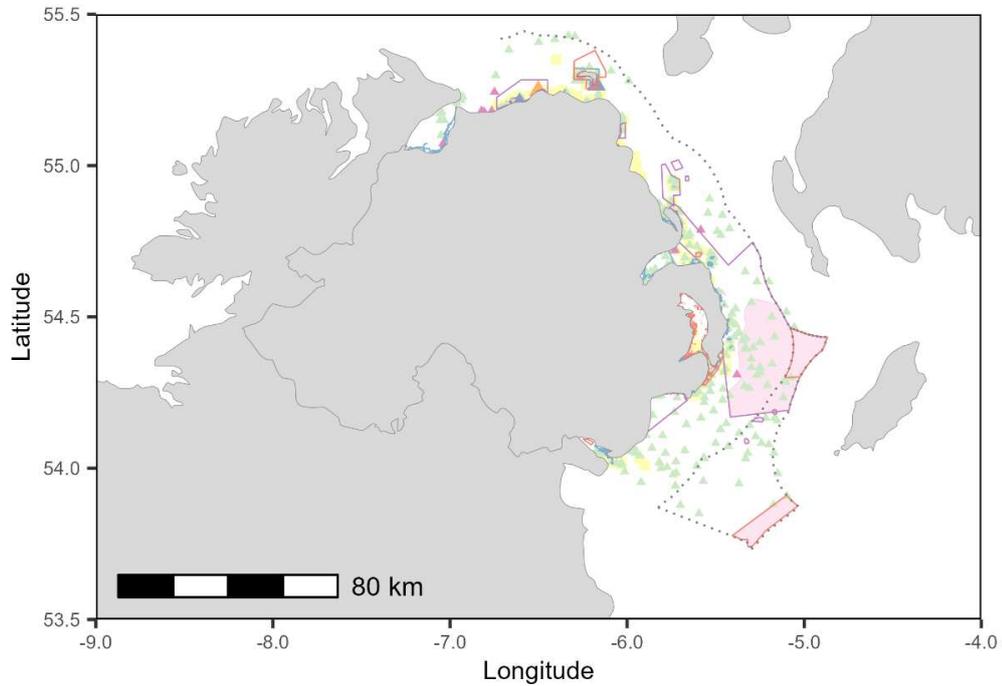
Figure A.2: Proposed conservation scenario showing the locations of dive sites and wrecks
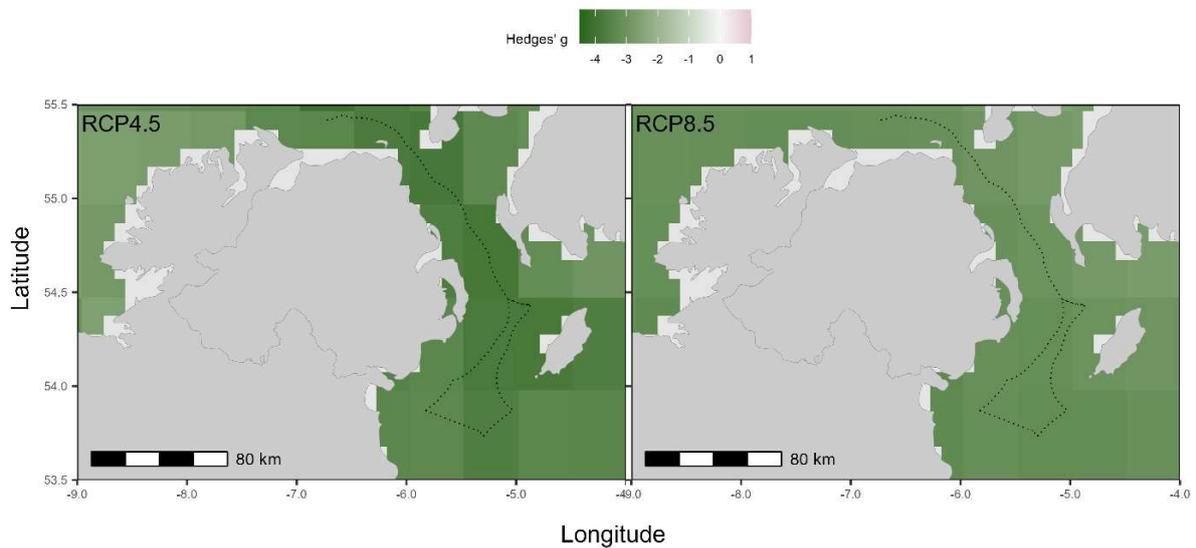

Figure A.3: Projected changes in the distribution of *Nephrops* in Northern Irish waters, in the period of 2040-2059 relative to the reference period (2006-2025), under RCP4.5 (left) and RCP8.5 (right). Colour provides the value of the estimated normalised mean different estimator (Hedge's g), with green indicating a decline and pink an increase in abundance

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