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Orkney Islands Regional Marine Plan Storyline
Narrative of marine (spatial) planning scenarios explored in
the MSPACE project

Elizabeth Talbot, Simon Mair, Alberto Roca Florido, Océane Marcone, Gina Yannitell
Reinhardt, Patricia Danahey Janin, and Ana M Queirós

Executive Summary

Climate breakdown is causing unprecedented changes in coastal and ocean ecosystems¹. Such changes present significant challenges to the delivery of policy aiming to protect the health and biodiversity of marine systems, and the communities that depend on marine resources². Consequently, the development of climate-adaptive management strategies for these ecosystems, and for the economic sectors dependent on them, is testing marine policy frameworks across the UK Nations. Beyond this, pressure on marine space continues to increase as we transition to greener energy³ and pursue economic growth, both of which must be carefully balanced against the pressing need to preserve our marine species and habitats, and their ability to adapt to climate change^{4,5,6,7}.

Marine planning is a public process to document, consult and set priorities about how we manage and share our marine space⁸. At present marine plans across the UK set out key policies with the ambition to deliver climate change adaptation^{9,10,11}. As a devolved process, operating at national and regional level, marine planning can bring together our broader marine policy mechanisms to help tackle the impacts of climate change across our waters. Furthermore, because planning requires extensive consultation, it offers the opportunity to those that are affected by marine plans to help develop them.

Climate smart marine plans i.e. plans that are truly adaptive to the effects of climate change, are necessary if we are to harness opportunities for effective marine conservation and economic growth that emerge from spatial variation in the sensitivity of our marine ecosystems to climate change. However, key capability gaps have thus far hindered the ability of UK Nations to deliver such marine plans. The [MSPACE Early Warning System Report](#) began to close those gaps, by delivering a climate change assessment for the entire UK EEZ that, for the first time, demonstrated the spatial variation in sensitivity of our marine ecosystems to climate change. In this document, we use the findings from that report to explore possible climate smart management scenarios in the Orkney region, and compare those to a “business as usual” scenario, in which climate change is not considered, and the management of the region is based on the current marine plan.

¹ IPCC (2021) Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

² IPCC (2022) Climate change 2022: impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

³ HM Government (2023). Offshore Wind Net Zero Investment Roadmap. Department for Energy Security and Net Zero, London, UK.

⁴ HM Government (2018). The National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting. Department for Environment Food Rural Affairs London, UK.

⁵ Scottish Government (2023). Climate Ready Scotland: Scotland’s Climate Change Adaptation Programme 2019 to 2024. Edinburgh, UK.

⁶ Natural Resources Wales (2021). Marine Area Statement. Cardiff, UK.

⁷ Department of Agriculture, Environment and Rural Affairs (2019). Northern Ireland's second Climate Change Adaptation Programme. Belfast, UK.

⁸ HM Government (2011) UK Marine Policy Statement. London, UK.

⁹ Scottish Government (2015). Scotland's National Marine Plan. Edinburgh, UK.

¹⁰ Welsh Government (2019). Welsh National Marine Plan. Cardiff, UK.

¹¹ Department of Agriculture, Environment and Rural Affairs. Draft Marine Plan for Northern Ireland (2022). Belfast, UK.

The key findings from this document are:

- 1) In the business as usual scenario, the fishing and aquaculture sectors will be broadly impacted by climate change, with wages and employment projected to decrease by 75% when both sectors are considered together. Meeting conservation targets could also be challenging, with the majority of climate resilient areas found outside the current MPA network
- 2) Increasing protections for climate resilient areas with the aim of preserving biodiversity and providing climate mitigation services results in minimal (<5%) further economic losses when compared to the business as usual scenario
- 3) There are opportunities to significantly increase water column aquaculture production in Orkney waters, although the offshore location of climate resilient areas for this sector and the current status of technological development within the industry means it may take time before developments are commercially viable

Although the effects of climate change on Orkney waters are likely to be significant, it is possible to balance climate resilient conservation ambitions with continued access to fishing grounds and sectoral expansion for aquaculture

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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 within the lens of marine planning. Opportunities signposted in the report are based on the identification of areas of our marine waters where the ecosystem underpinning each of those sectors show greater resilience to ongoing climate change. We compared this evidence with a detailed assessment of the distribution of human activities in our waters, pressures on the marine environment resulting from those activities, and thus to identify where spatial management could be used to enhance the climate-resilience of our marine species and habitats, our marine resources, and livelihoods depending on them.

In this document, we now build on that evidence about the “where” to co-develop and the “how” of delivering those opportunities through spatial management, by co-developing alternative spatial management scenarios with our end-users. Specifically, focusing on the four MSPACE case-study Marine Plans (East of England, Northern Ireland, Orkney Islands and Wales), 4 alternative possible spatial management scenarios for each (Section D) were co-developed as follows:

1. The first scenario represents the current marine plan for a region (*Business-as-Usual Scenario*) which formalises and estimates the impacts of climate change in the marine plan area should no changes be made to planning.
2. The second is a climate-smart scenario that uses the evidence on opportunities for climate-resilience identified in the MSPACE Early Warning System to help identify priorities for changes in spatial uses to maximise environmental and economic goals for marine conservation (*Conservation Scenario*).
4. The third scenario is a climate-smart scenario that uses the evidence on opportunities for climate-resilience identified in the MSPACE Early Warning System to help identify priorities for changes in spatial uses to maximise environmental and economic goals for fisheries and aquaculture (*Food Provision Scenario*).
4. The fourth scenario is also a climate-smart scenario, which takes elements from the other three scenarios to maximise environmental and economic goals for the region based on national or regional stakeholder priorities identified in section B (*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, (ASPACE) 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 Orkney Islands Regional Marine Plan area consists of approximately 9258 km² of sea, with more than 1000 km of coastline. [The Orkney Islands Regional Marine Plan](#) (OIRMP) covers the inshore region from mean high water spring tides out to 12 nm, and includes Sule Skerry and Sule Stack. The plan area is adjacent to three other Scottish marine planning regions: the North Coast, Moray Firth and Shetland Islands marine plan areas.

The plan area is used by several industrial and environmental sectors. Key sectors include:

- Marine wind, wave and tidal energy generation
- Ports, harbours and shipping
- Oil and gas
- Commercial fishing
- Aquaculture
- Tourism and recreation
- Pipeline, electricity and telecommunications infrastructure
- Zero carbon fuels, oil and gas transition

The consultation draft of the OIRMP was published in 2024. The vision for the OIRMP area is to ensure that it is clean, healthy, safe and productive, and that Orkney's marine and coastal environment is rich in biodiversity and managed sustainably to support thriving and resilient local communities. It also plays a role in Scotland's (and the UK's) ability to mitigate and adapt to climate change and will experience the continued development of the renewable energy sector and associated cabling. The OIRMP area is of significant ecological importance, and includes MPA designations for seabirds, marine mammals, and benthic habitats.

The OIRMP includes 10 high-level objectives, supported by further general and sector-specific policies and objectives. Sector specific policy intent includes:

- Commercial fishing: To support and enable a thriving and sustainable commercial fishing sector.
- Aquaculture: To support and enable a thriving and sustainable aquaculture sector, including technical development to allow industry expansion into offshore areas, and supporting integrated aquaculture sites.
- Renewable energy: To support and enable thriving and sustainable offshore wind, wave and tidal renewable energy generation, and support inclusive growth and a just transition to net zero.
- Zero fossil carbon: To support and enable a thriving and sustainable zero fossil carbon fuels sector and a just transition for the oil and gas sector. Zero fossil carbon fuels include, but are not limited to, green hydrogen and ammonia.
- Tourism and recreation: To support and enable a thriving and sustainable tourism, recreation, leisure and sport sector, and to promote Orkney as a world-class tourist and leisure destination.

In addition to the sectoral policies above, the OIRMP also contains explicit objectives and policy for climate change adaptation and mitigation (General Policy 3), safeguarding natural capital and ecosystem services (General Policy 5), supporting the resilience of coastal areas to climate change impacts such as flooding and sea level rise (General Policy 7), and on protecting the historic environment (General Policy 8).

To determine planning stakeholder preferences for the use of marine space in Orkney 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 focused on stakeholders of the planning process that especially associated with the three focal sectors of MSPACE (conservation, fisheries and aquaculture). We gave stakeholders a values questionnaire which asked participants 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 Orkney. 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 OIRMP, 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

Scotland - Sectors	Freq.	Percent
Aquaculture	3	21.43
Aquaculture, Conservation	1	7.14
Aquaculture, Conservation, Fisheries, Other	1	7.14
Conservation	4	28.57
Conservation, Fisheries	1	7.14
Fisheries	1	7.14
Fisheries, Other	2	14.29
Other	1	7.14
Total	14	100

The indicative value rankings of criteria by participants speaking about the Orkney Islands are summarised in Table B.2. On average, respondents rated water quality, economy, and

climate change highest. These rankings of values or priorities were used in the co-creation of the Compromise scenario (Section D).

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

Element of marine space	Obs	Mean	Std. Dev.	95% Conf.	Interval
Biodiversity	14	79.07143	16.88178	69.32418	88.81868
Biosecurity	13	64.23077	21.98543	50.94511	77.51643
Climate change	6	81.33333	13.55974	67.10325	95.56341
Conservation designation	14	67.50000	25.93409	52.52610	82.47390
Economy	14	82.07143	16.03585	72.81261	91.33025
Energy	6	62.83333	13.42262	48.74716	76.91951
Food provision	13	76.23077	19.62632	64.37070	88.09083
Governance	13	80.76923	25.76869	65.19736	96.34110
Health	12	70.41667	27.05704	53.22544	87.60789
Identity/culture/heritage	13	67.38462	25.3625	52.05821	82.71102
Learning and research	14	79.07143	12.48053	71.86538	86.27747
Leisure/recreation	11	62.63636	28.99404	43.15790	82.11483
Tourism	11	53.45455	29.29288	33.77532	73.13377
Transport and shipping	12	57.75	27.08279	40.54242	74.95758
Water quality	12	89.16667	14.00541	80.26805	98.06528

Section C: Projected impacts of climate change in the Orkney Islands Regional Marine Plan 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 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.

Input-Output modelling: A well-established mathematical and statistical framework used in the MSPACE project that quantifies the interdependencies between industries within an economy, showing how the output of one sector serves as the input for another. It uses Input-Output Tables to analyse the flow of goods and services and estimate the economic ripple effects (direct, indirect, and induced impacts) of changes in final demand.

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 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, 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.

Nature Conservation Marine Protected Area - NCMPA: Marine protected areas in Scottish territorial and offshore waters designated under legal order by Scottish ministers under section 116(1) of the Marine and Coastal Access Act 2009 (MCAA), and the Marine (Scotland) Act 2010.

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 Orkney waters

The development of scenarios in MSPACE begins with an assessment of climate-driven changes in the UK EEZ, how they relate to the current distribution of human activities in our marine waters and associated pressures, and the resulting identification of where opportunities may exist for spatial management to act to increase the climate change resilience of marine species and habitats, our resources, and of livelihoods dependent on them. That evidence is compiled in the MSPACE [Early Warning System](#) (“EWS”, Queirós et al. 2024) report, which 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. 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](#)) for each of the MSPACE focal sectors (conservation, fisheries and aquaculture), through the lens of marine planning.

In that report, we focused on identifying areas that fell into each of those three categories consistently over the 21st century, in both emissions scenarios 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°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 fishing methods and aggregate extraction, using methods employed by both OSPAR and ICES. 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 in this section is a summary of the key findings outlined in the EWS report which are relevant to the Orkney Islands Regional Marine Plan area. When considering the locations of long-term climate change hotspots and refugia with high agreement between emissions scenarios (e.g. those areas that appear consistently as either refugia or hotspots, regardless of the emissions scenario considered), we found that Orkney waters are projected to be relatively sensitive to climate change, with few long-term climate change refugia emerging for MSPACE’s three focal sectors.

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

When considering the locations of long-term climate change hotspots and refugia with high agreement between emissions scenarios RCP4.5 and RCP8.5, we found that the Orkney region is projected to be sensitive to climate change, with only one long-term climate refuge emerging. This refuge is for climate services, and extends across the majority of the planning area (Figure C.1.), 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 (Benyon et al., 2020; Flavell et al., 2020). However, when we consider the continued effectiveness of the marine protected area (MPA) network across Orkney waters through a biodiversity conservation lens, it is likely that current conservation sites may not continue to provide the same benefits to

designated features in the future, due to the extensive distribution of climate change hotspots for benthic and pelagic habitats, and benthic and pelagic megafauna throughout the planning area (Figure C.2).

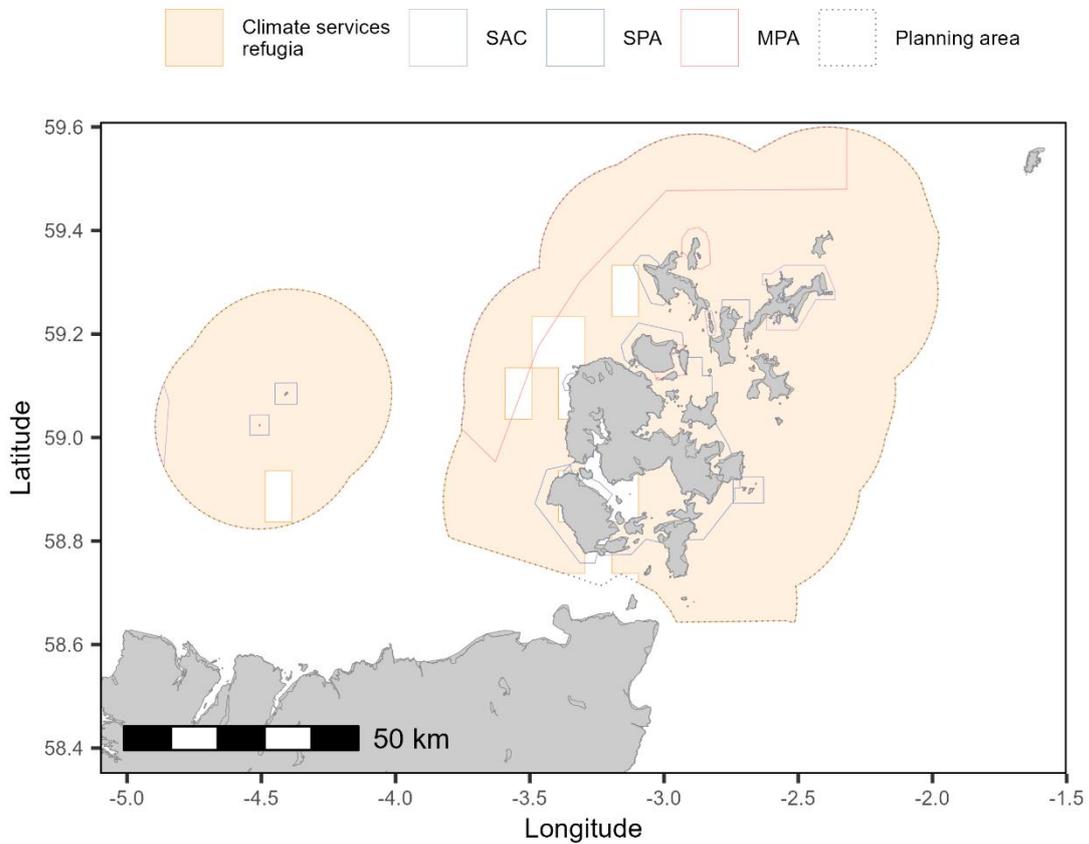


Figure C.1: Location of climate change refugia relevant to marine conservation in the OIRMP area. The only refugia identified where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System was for climate services and carbon sequestration.

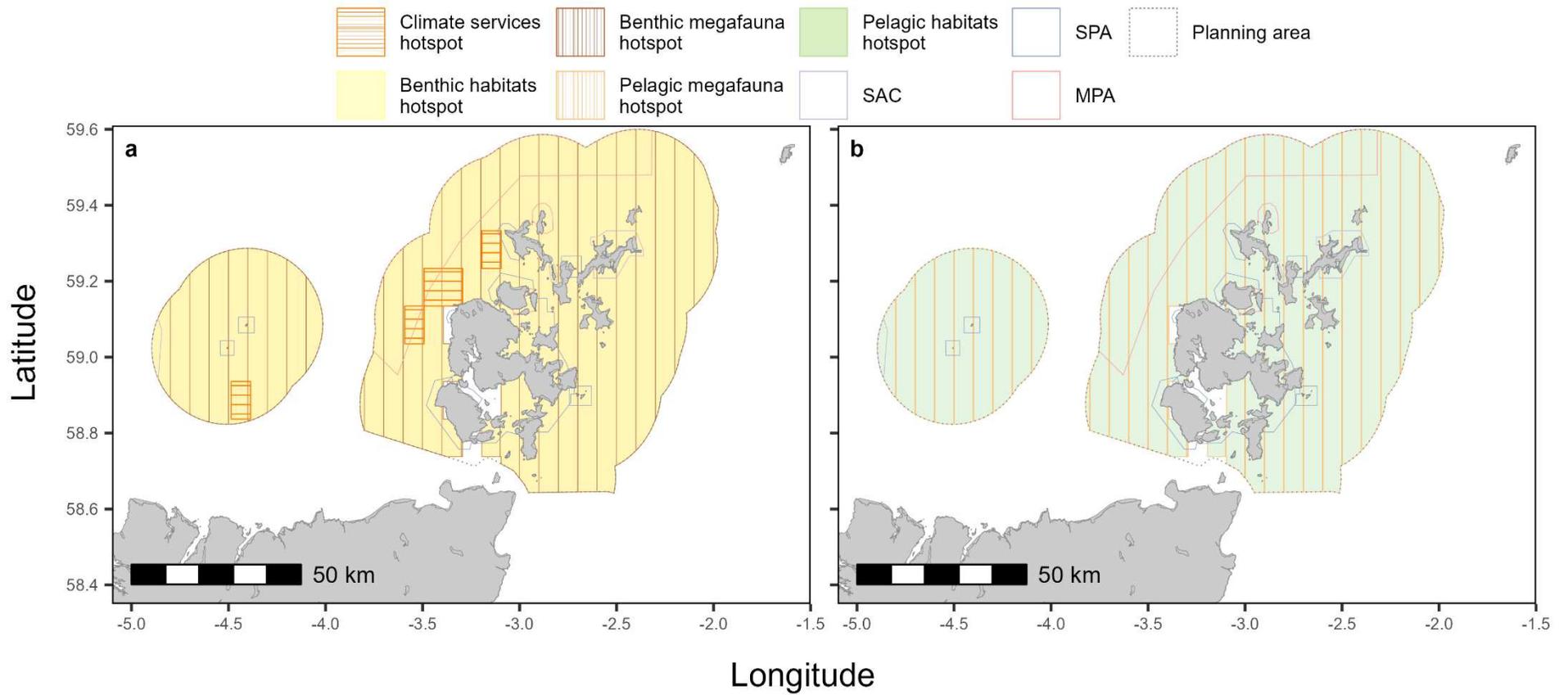


Figure C.2: Locations of climate change hotspots affecting the conservation of benthic habitats and megafauna (a) and pelagic habitats and megafauna (b) where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System.

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

We found that capture fisheries and aquaculture (based on the current target species, Queirós et al. 2024; [Supplementary Information Table S4](#)) could be particularly vulnerable to climate change. Namely, hotspots for demersal fisheries, seafloor aquaculture, and water column aquaculture cover the planning area. This would suggest that abundances of key species targeted by capture fisheries, such as brown crab (*Cancer pagurus*), may decrease in the future. Similarly, production of important aquaculture species such as salmon (*Salmo salar*) and mussel (*Mytilus edulis*) may produce lower yields due to climate-driven change (Figure C.3). However, a refuge for pelagic fisheries which covers a substantial part of the planning area was also identified (Figure C.4). This suggests abundances of species such as European sardine or pilchard (*Sardina pilchardus*), Atlantic mackerel (*Scomber scombrus*) and horse mackerel (*Trachurus trachurus*) may remain climate-resilient into the future, regardless of the emissions trajectory. While these species do not currently represent a large proportion of landings in Orkney specifically (Scottish Government, 2023), as climate change re-distributes marine species, they could become a more important resource for Orkney.

Overall, evidence uncovered in the EWS indicated that there is variability between emissions scenarios, leaving less room for the development of no-regrets decisions with regard to marine planning: that is, decisions based on findings that would hold across the range of future greenhouse gas emissions simulated by RCP4.5 and RCP8.5, which include a global mean warming of 2°C or higher. For this reason, in Section D below, **we consider EWS evidence for long-term climate change refugia emerging under the moderate emissions trajectory RCP4.5** (2°C mean global warming), a likely outcome if current climate action plans are implemented, and nationally determined contributions are achieved (United Nations Environment Programme, 2024; Wang et al., 2023). The development of scenarios described below therefore builds on that assumption and underlines the importance of curbing emissions for a sustainable future for marine wildlife and livelihoods in Orkney.

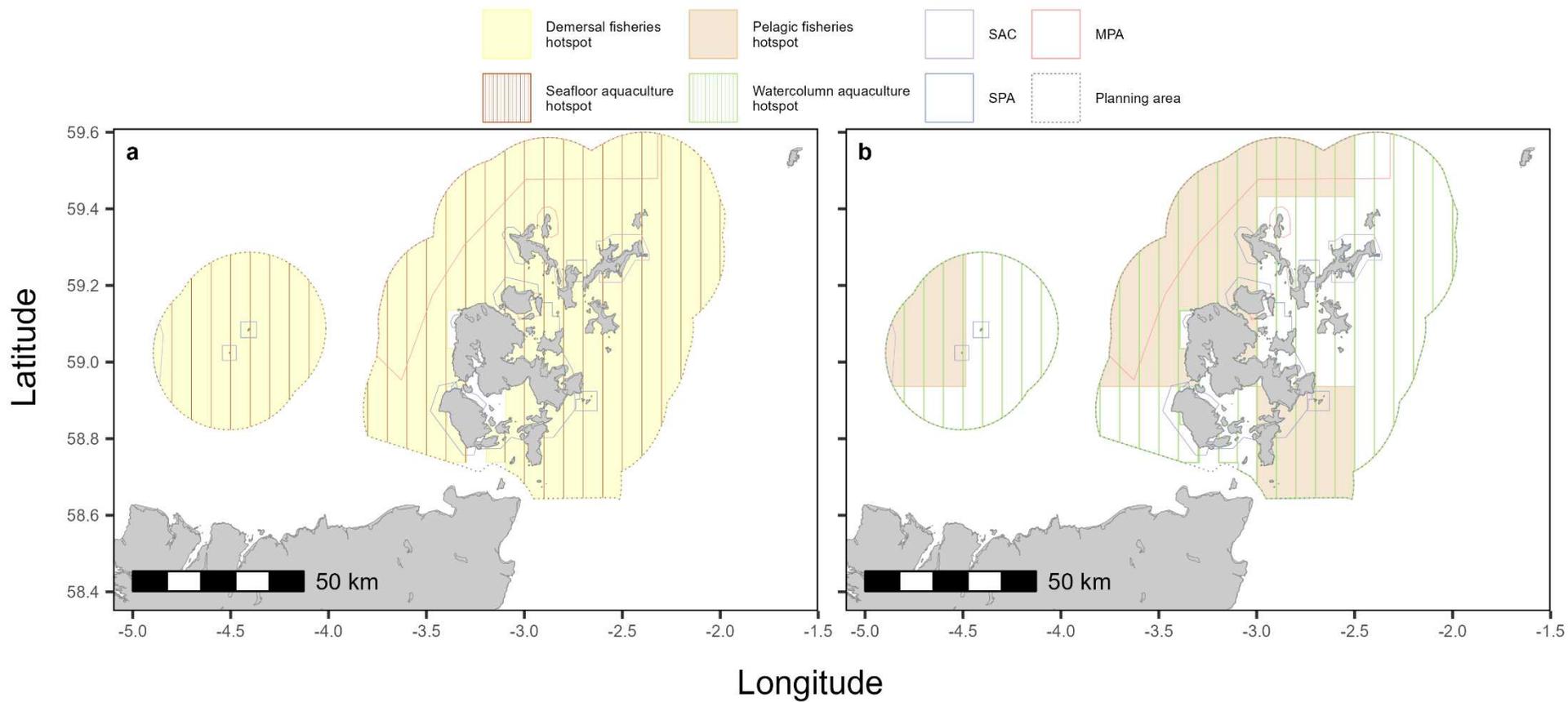


Figure C.3: Locations of climate change hotspots affecting the climate-resilience of demersal capture fisheries and seafloor aquaculture (a) and pelagic capture fisheries and water column aquaculture (b) where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System.

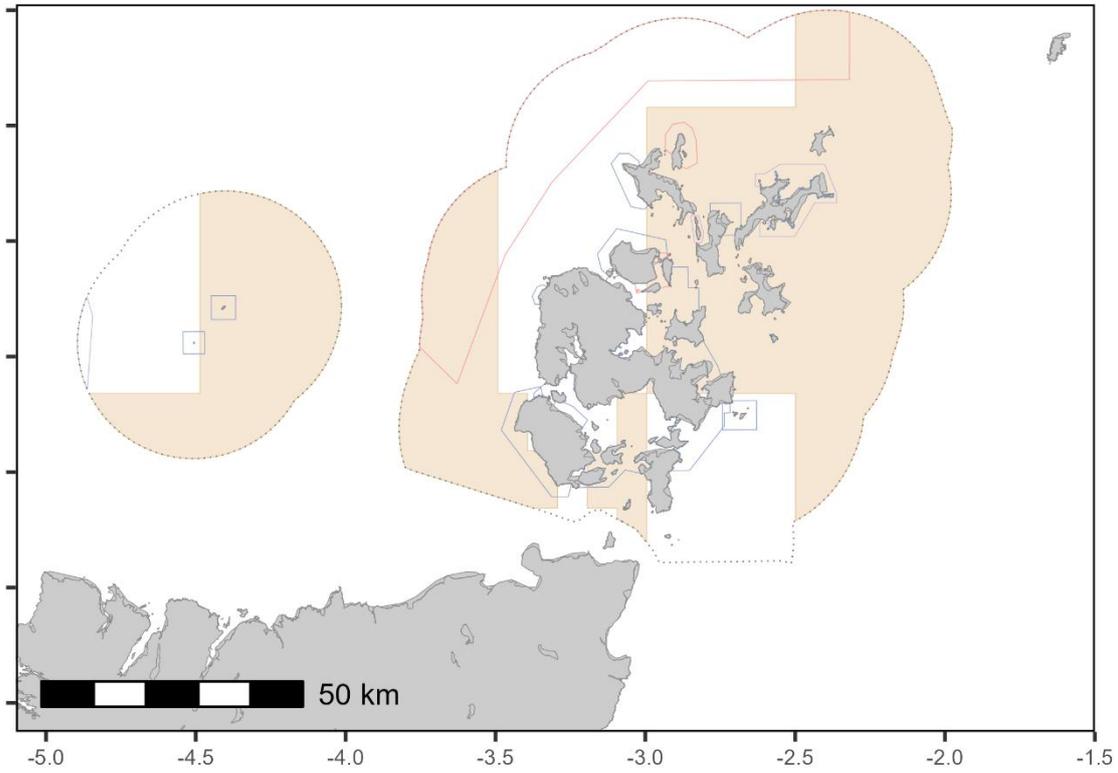


Figure C.4: Location of climate change refugia affecting food provision. The only refugia identified where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System was for pelagic fisheries.

Section D: The MSPACE scenarios for the Orkney Islands Regional Marine Plan area

D.1 Scenario overview

We now outline four scenarios, co-developed with key planning stakeholders in the Orkney Islands (Table A1, Annex 2). The four scenarios represent four possible alternative futures for Orkney 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 climate change adaptation and mitigation could be encouraged through planning actions, with benefits for nature, and marine sectors in Orkney. They are expected to lead to different ecological, social and economic outcomes for the region, based on climate change impacts and opportunities. These scenarios are based on general formulations described in Annex 1, as follows:

- 1. The Business-as-Usual scenario:** represents a possible future for Orkney waters which does not provide spatial planning policies that act on climate change and simply estimates the modelled effects of climate change on the region and its associated economic impacts, considering the current distribution of human uses and conservation areas.

Additionally, three climate-smart scenarios then prioritise outcomes for specific sectors, and propose spatial interventions that promote climate change adaptation and mitigation, based on specific uses of climate change refugia for those sectors identified in the MSPACE early-warning system:

- 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 the plan area 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 considered aim to support and safeguard climate-resilient fisheries and to facilitate the development of climate-resilient aquaculture in the plan area by prioritising the access of these sectors to their respective 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 the region, by prioritising access to areas of climate change refugia for each sector, or by prioritising conservation objectives where designated conservation areas or other areas of ecological importance overlap with climate change refugia. It is expected that the Compromise Scenario may meet a broader set of objectives with regard to stakeholders in the Orkney marine planning area (Section B).

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 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.) as part of the MSPACE Early Warning System. 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. a MPA designated for benthic features located in a projected 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 activity sectors and correspondent refugia (or bright spots) were termed here “priority areas” for each sector in each spatial management scenario co-developed (Figure D.2.1, 1). Specific spatial management interventions for priority areas were then co-developed with stakeholders through 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 take into account the values that previously surveyed stakeholders in the region were found to place 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 demersal fisheries refuge was identified in an area where demersal fisheries occur, the scenario may simulate that planning (and associated governance mechanisms) thereafter seek to avoid, minimise or mitigate any proposed activity that limits access of demersal fishers to that site, as a means to help safeguard the climate-resilience of that sector. 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/demersal 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.

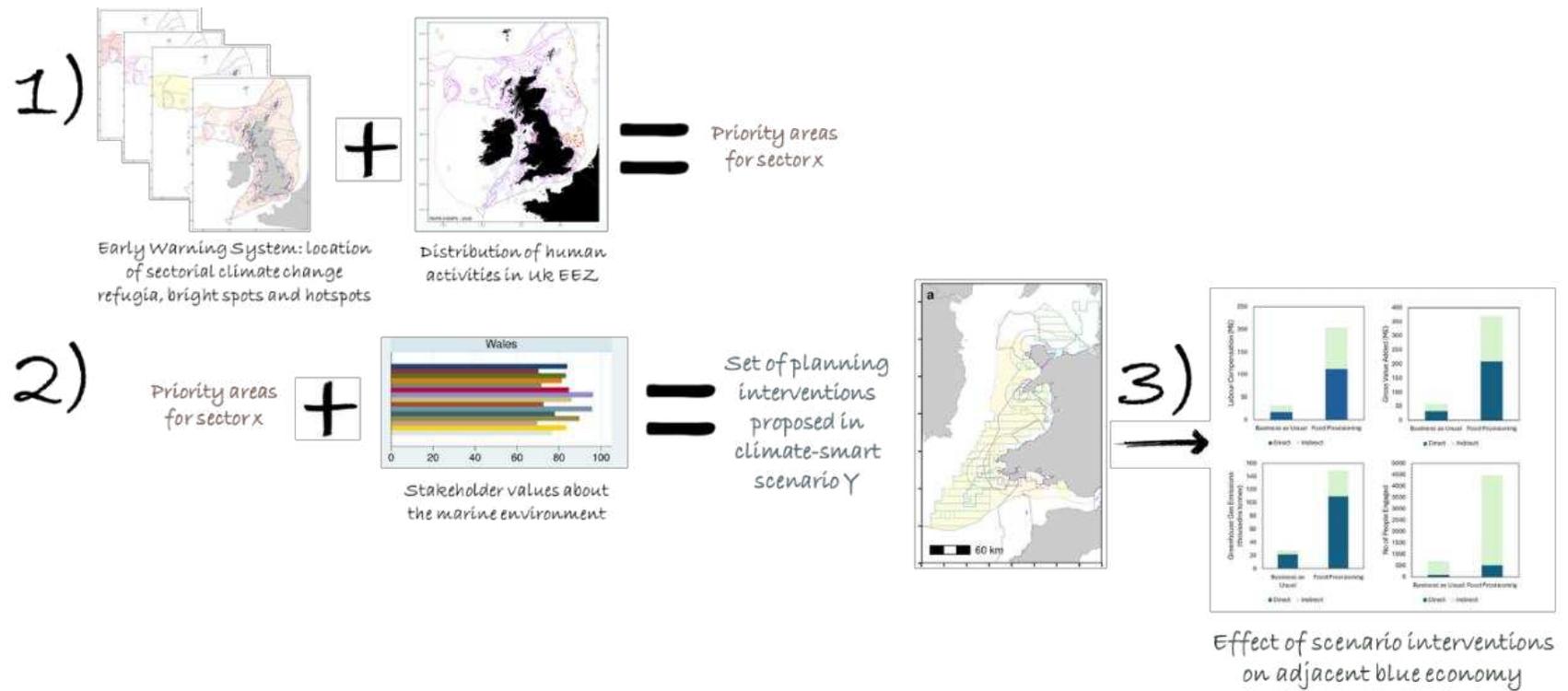


Figure D.2.1: Schematic representation of climate-smart scenario co-development. Stakeholders were consulted during all stages of co-development.

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 Km²) 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 Km² 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 8 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 2 of the 8 sectors (Roca Florido et al., 2025; Table A2, Annex 2). Whilst the renewable sector in particular is seen as a key sector in Orkney, we did not estimate the effects of climate change on the future activity of that sector due to a lack of available modelling data at the start of the project, and no scenarios simulate changes to the area available to this sector. Hence, all estimates presented exclude the background effect of a growing renewable sector in Orkney, since the outputs of that sector are not affected by individual scenarios, whilst analyses presented here focus on scenario comparison.

The economic model necessitates linear assumptions between resource availability to a sector and the particular area within the marine plan: for instance, for demersal 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 Orkney 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 subsidies. 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 The Business-as-Usual Scenario

This scenario estimated the effects of climate change within the Orkney Islands Regional Marine Plan area if no additional climate-smart spatial management measures are implemented. Therefore, no new spatial management interventions are suggested as part of this scenario.

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 order to establish the effect of climate change on marine conservation objectives in the plan area under RCP4.5 in the MSPACE Early Warning System. 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](#)). Climate change hotspots (hereafter, “hotspots”) for habitats and species of conservation interest within the Orkney planning area are extensive, even under RCP4.5 (Table D.3.1, Figure D.3.1), with hotspots for both pelagic and benthic habitats and pelagic and benthic megafauna covering a significant part of the planning area. Hotspots for climate services are much more limited however, with only two areas to the west of Orkney appearing as hotspots. 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 region.

Some climate change refugia were also identified (Figure D.3.2, Table D.3.1), with the majority of the planning area falling within a refuge for climate services. While there is an interest in using the UK marine protected area (MPA) network to deliver climate services (Benyon et al., 2020; Flavell et al., 2020) and climate change mitigation, it should be noted that the sediment around Orkney is largely coarse sediment and sand (Annex 2, Figure A.1), which makes it suboptimal for carbon sequestration (Burrows et al., 2024). It should also be noted that observational data available for the validation of the numerical modelling used in our analysis is sparse, so the results presented for climate services should be taken with a note of caution, given uncertainty (Queirós et al., 2024; Annex 1). Focussing on biodiversity conservation, refugia for both benthic habitats and benthic megafauna were identified in the planning area. Sule Skerry and Sule Stack SPA and Sanday SAC overlap with refugia for benthic megafauna, but refugia of biodiversity conservation value largely fall outside currently designated protected areas (Figure D.3.2). As noted above, the substrate in these refugia is generally composed of sand and coarse sediment, which has been assessed as having low or moderate impacts from demersal trawling at present, and the status of the benthic environment in the planning area as a whole has been assessed as good (Queirós et al., 2024; [Annex 2](#)). None of the identified refugia appear to be impacted by artificial light at night (ALAN) pollution, which has been shown to interfere with a number of life history processes in marine organisms (Marangoni et al., 2022 and references therein). Looking more widely at the MPA network in the Orkney region, biologically relevant ALAN penetrates the water column to a depth of ~15m around Flotta in Scapa Flow (Figure D.3.3, data from Smyth et al., 2024), likely due to the presence of an oil terminal in this area. The majority of the designated conservation areas in the region (with the exception of the parts of Scapa Flow SPA near the terminal), appear to be largely unaffected by ALAN however.

Table D.3.1: Summary of the expected climate change effects on the OIRMP area in the Business as Usual Scenario, and their potential ecological and economic effects.

Climate change impact	Potential ecological effects	Expected economic effects
<p>Conservation:</p> <ul style="list-style-type: none"> Widespread climate change hotspots for benthic habitats, pelagic habitats, pelagic megafauna and benthic megafauna Climate change refugia for benthic megafauna and benthic habitats sit predominantly outside the current MPA network Widespread climate change refugia for climate services 	<p>Conservation:</p> <ul style="list-style-type: none"> MPAs overlapping with hotspots may not continue to provide the same benefits in the future as they do now Climate services refugia may be useful for climate change mitigation in areas where they overlap seabed with high sedimentary organic carbon levels 	<ul style="list-style-type: none"> ~75% reduction in Labour compensation and Gross Value Added ~75% reduction in employment ~80% reduction in GHG emissions
<p>Fisheries:</p> <ul style="list-style-type: none"> Widespread climate change hotspots for demersal and benthic fisheries Widespread climate change refugia for pelagic fisheries 	<p>Fisheries:</p> <ul style="list-style-type: none"> Abundances of key demersal species likely to decline in demersal fisheries hotspots Abundances of key pelagic fisheries likely to remain resilient in pelagic fisheries refugia 	
<p>Aquaculture:</p> <ul style="list-style-type: none"> Widespread climate change hotspots for seafloor and water column aquaculture Climate change refuge for seafloor and water column aquaculture in offshore waters to the west of Orkney 	<p>Aquaculture:</p> <ul style="list-style-type: none"> Potential for sectoral expansion into refugia for water column aquaculture 	

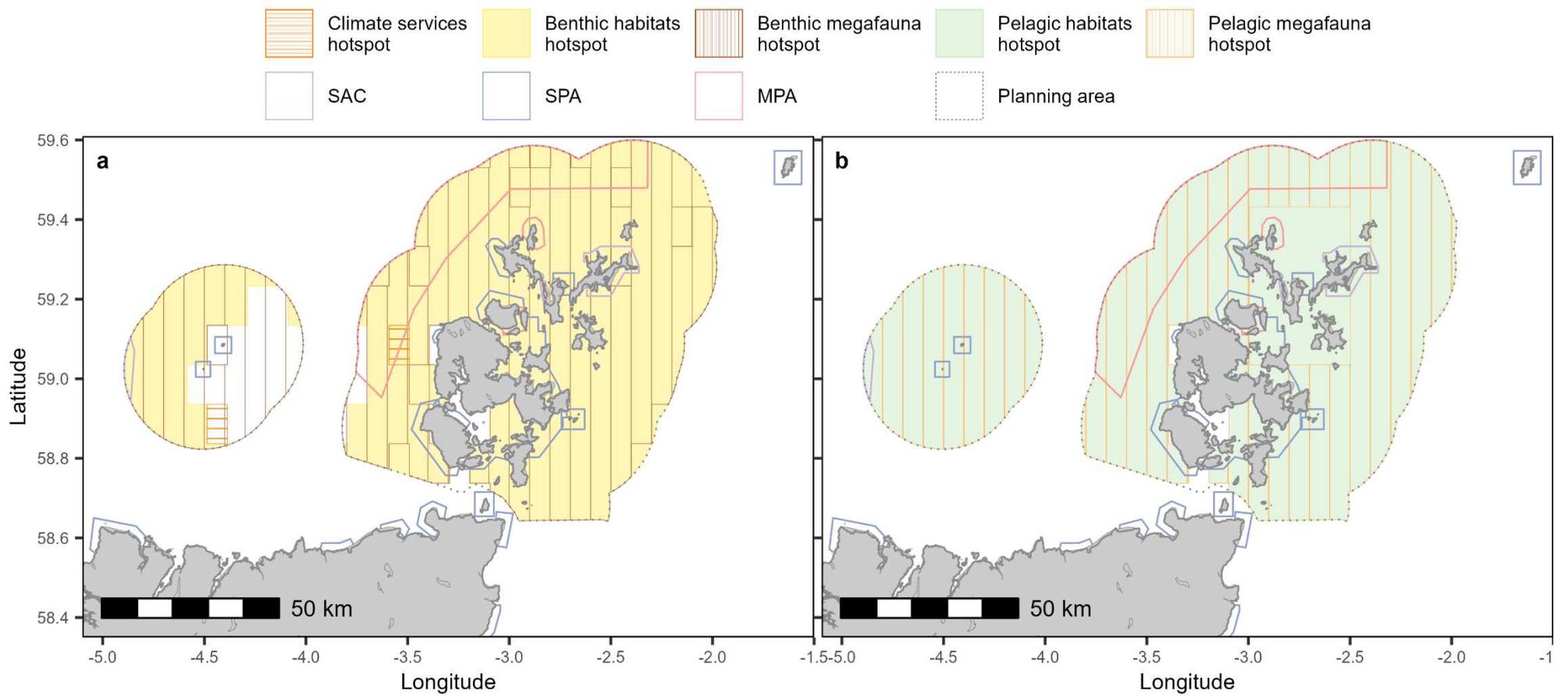


Figure D.3.1: Business as usual scenario with locations of conservation hotspots highlighted. Hotspots for benthic habitats, benthic megafauna and climate services (a); hotspots for pelagic habitats and pelagic megafauna (b).

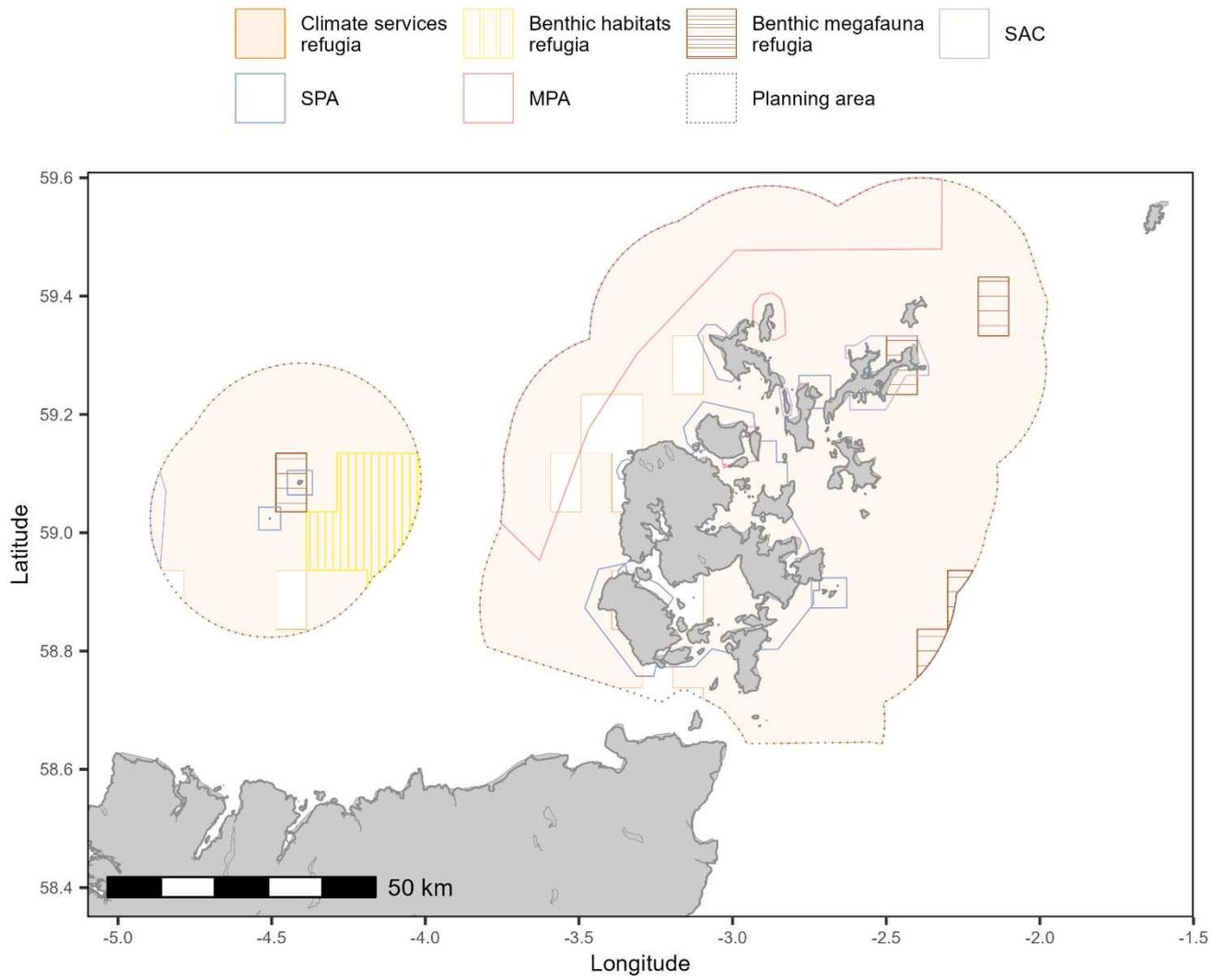


Figure D.3.2: Business as usual scenario with locations of conservation refugia (benthic habitats, benthic megafauna and climate services) highlighted.

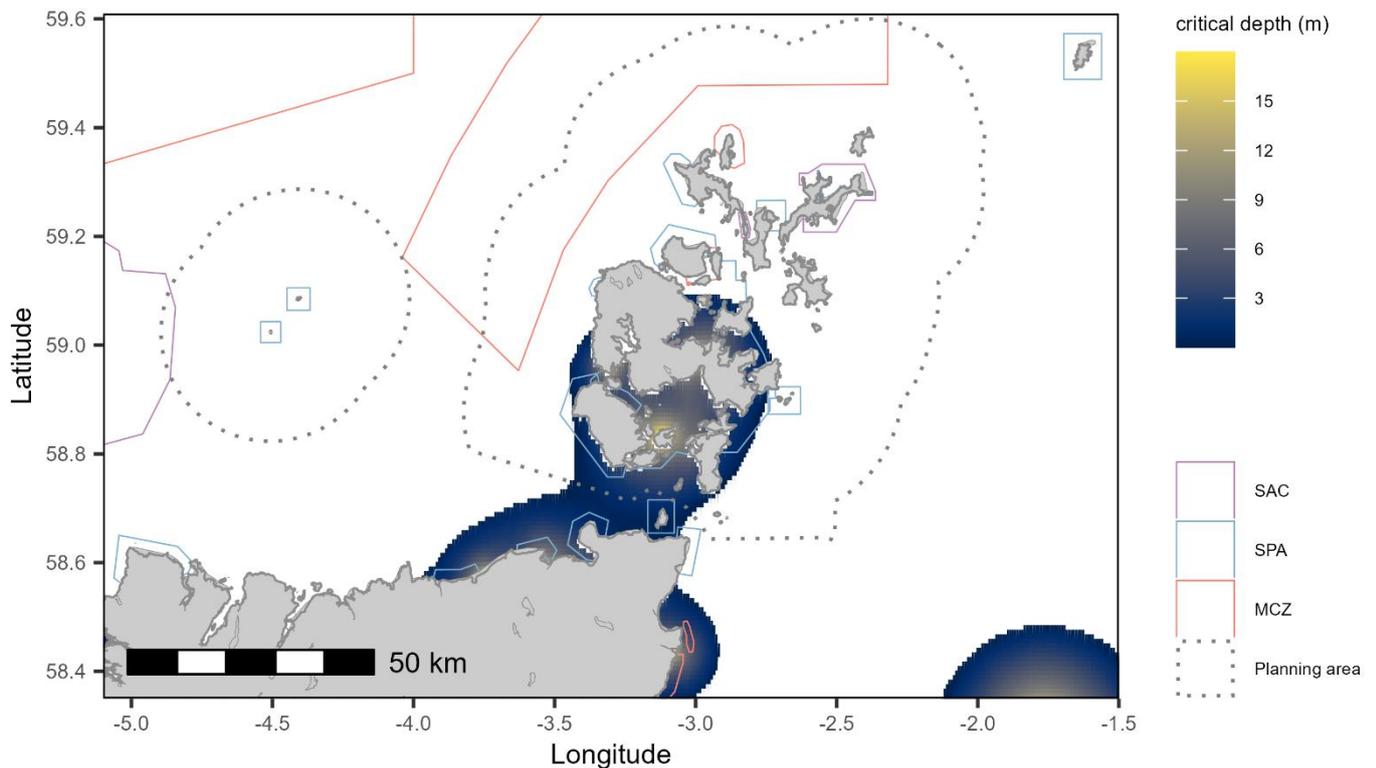


Figure D.3.3: Depth to which biologically relevant artificial light levels penetrate the water column (data from Smyth et al., 2024), along with the locations of designated conservation sites. The only area in the Orkney region likely to be impacted by biologically relevant ALAN pollution is the area around the Flotta oil terminal in Scapa Flow.

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

Four analyses were undertaken 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 Atlantic salmon (*Salmo salar*)), and a range of modelled environmental data to represent key drivers of species distributions. Capture fisheries and aquaculture are projected to be sensitive to climate change under the RCP4.5 emissions trajectory (Figure D.3.4), with extensive identified hotspots for both water column and seabed aquaculture in the region. Many existing water column (predominantly salmon) aquaculture facilities fall within these identified hotspots for the sector. We also identified climate change hotspots for demersal fisheries which encompass the whole of the planning area (Figure D.3.4). However, we note that much of the demersal fisheries effort in the region is particularly focussed on pot fishing for shellfish (Orkney Islands Council, 2023), with European lobster (*Homarus gammarus*), velvet crab (*Necora puber*), King scallop (*Pecten maximus*) and especially brown crab (*Cancer pagurus*) targeted in the region. While species distribution modelling data for *C. pagurus* was available to us at the time of analysis, we were not able to find data for *H. gammarus*, *N. puber* or *P. maximus*, and these are important omissions. For this reason, when evaluating the effects of climate change on demersal fisheries in Orkney in the Food Provision Scenario (Section D.5), we have used the locations of

hotspots and refugia for benthic habitats instead of those identified in the modelling analysis carried out for benthic and demersal fisheries using that incomplete set of species (Figure D3.1a and D.3.2). Focusing instead on benthic habitats more generally we are able to assess the exposure of all benthic and demersal target species to climate change, though this analysis is not sensitive to species specific responses to that exposure, which is likely to vary across species and potentially lend resilience to the sector (Queirós et al., 2024; Queirós et al., 2021). While hotspots for benthic habitats are still widespread in the region, we identified a large refuge to the west of Mainland, towards Sule Skerry and Sule Stack (Figure D.3.2), which may support climate resilient target species abundances into the future.

The whole Orkney Islands Regional Marine Plan area is covered by a refuge for pelagic fisheries under RCP4.5 (Figure D.3.5). This suggests abundances of species such as blue whiting (*Micromesistius poutassou*) may remain comparable to the present day into the future under the lower emissions scenario. We note, however, that Atlantic mackerel (*Scomber scombrus*) abundances are projected to decrease around Orkney (data not shown). While there are some refugia for both water column and seafloor aquaculture in the planning area, these are in offshore waters close to Sule Skerry. The distance from land and exposed nature of these refugia suggests that development of aquaculture infrastructure in these areas may be challenging (Figure D.3.5), although co-location with the West of Orkney may be possible if this advancement is pursued in the UK. It should be noted that analyses for fisheries and aquaculture are based on the current catch composition for fisheries and the species-specific farming in the UK. They do not take into account the role of new species that may become valuable for both sectors in future as a result of climate change, due to uncertainty of their potential value for consumers (Queirós et al., 2024).

D3.2 Economic outcomes for the adjacent blue economy

The Business as Usual Scenario represents a significant loss to the marine economy in Orkney in the future. We estimate that the hotspot areas represent approximately a loss of around 85% of area available to be fished for the demersal fleets within the Orkney marine plan area and 75% of the area available to aquaculture. In this and all other scenarios 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. Together, losses to fishing and aquaculture due to climate change hotspots translate to reductions of around 75-80% for all modelled variables (labour compensation; gross value added; number of people employed, and carbon emissions, Figure D.3.6) relative to those currently associated with fishing and aquaculture in the Orkney marine plan areas in the base case (i.e. with no climate effects). The biggest reductions across all impact variables are in the fishing fleet segments and aquaculture (direct effects) themselves. Indirect effects account for an additional 10-20% of impacts. Reduction of emissions is directly linked to loss of activity.

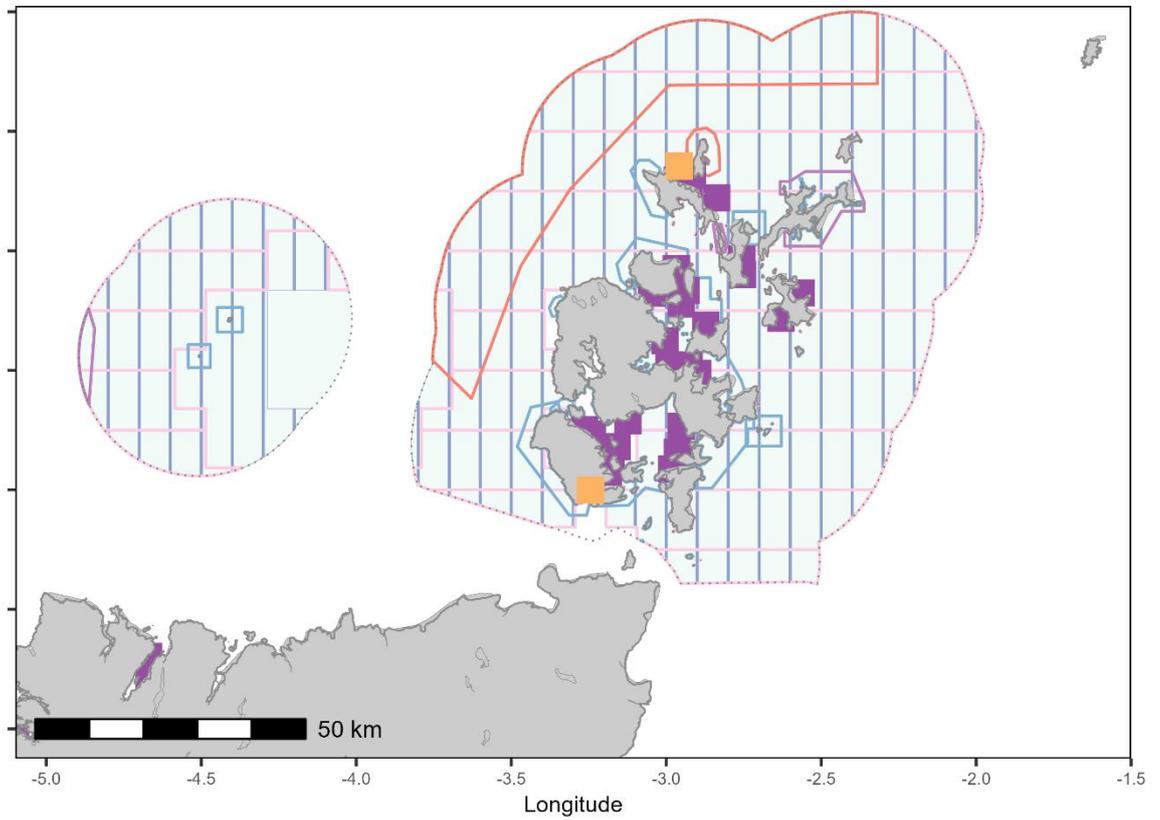
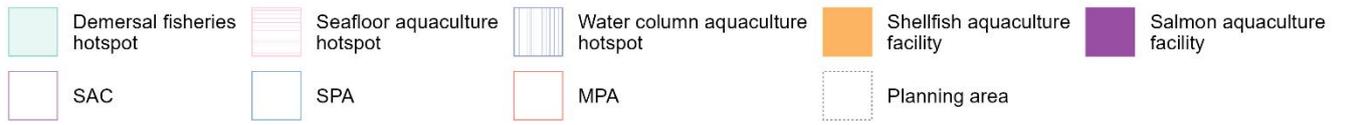


Figure D.3.4: Business as usual scenario with locations of food provision hotspots (demersal fisheries, seafloor and water column aquaculture) highlighted.

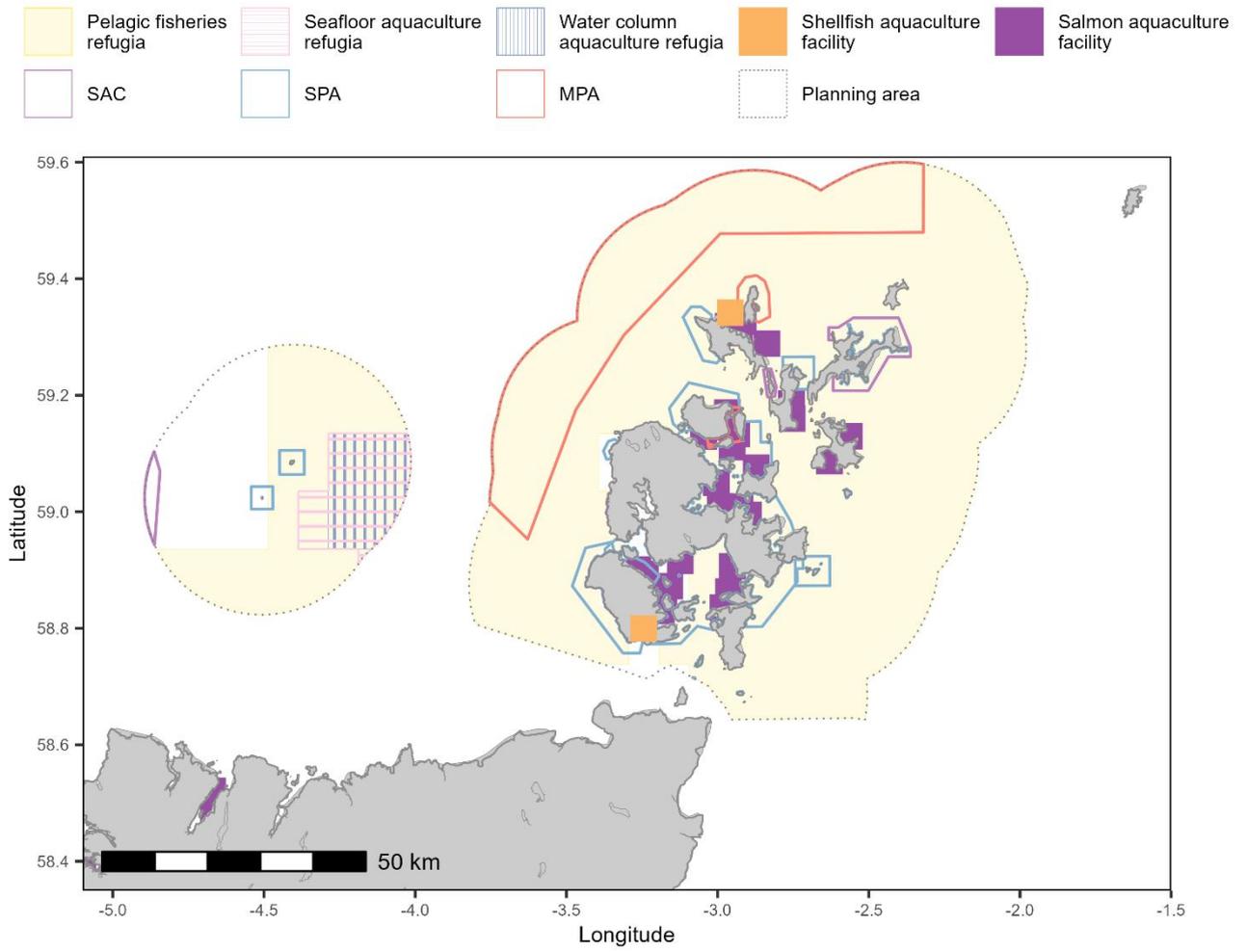


Figure D.3.5: Business as usual scenario with locations of food provision refugia (pelagic fisheries, and water column and seafloor aquaculture) highlighted.

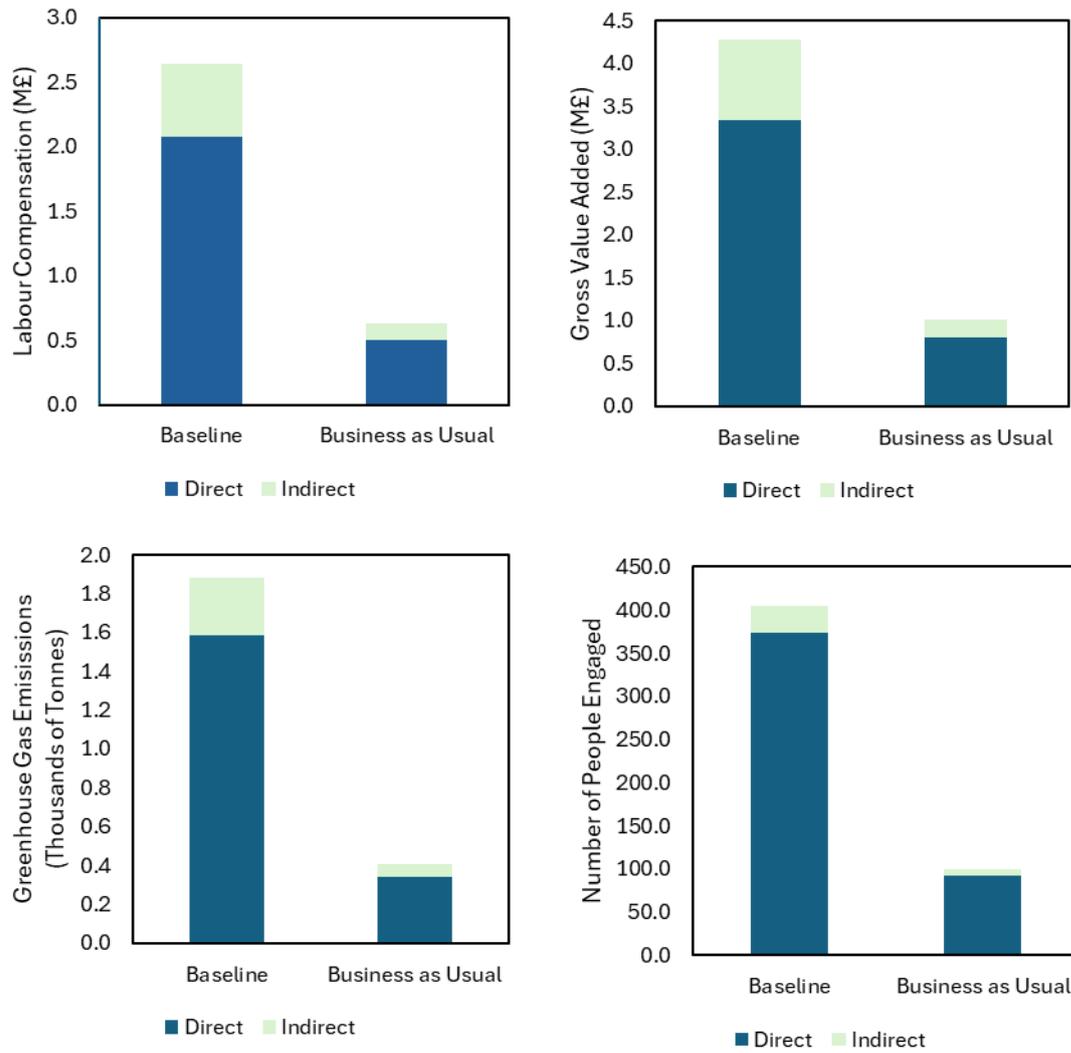


Figure D.3.6: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Business as Usual Scenario.

D.4. The Conservation Scenario

D4.1 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 the Orkney planning area. Simulated interventions are located in climate change refugia for benthic habitats or benthic megafauna.
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 stakeholders involved in the region. In this way, we hoped to ensure that they were well aligned with the current needs of those reviewing and implementing the Orkney Islands Regional Marine Plan.

The spatial interventions C1, C2 and C3 below have the purpose of avoiding, minimising or mitigating the impacts of activities which could negatively affect benthic megafauna species, benthic habitats of high conservation interest and the future provision of climate services (respectively) in the Orkney region (Table D.4.1). In this hypothetical planning scenario, we simulate that these aims would be supported by 1) additional legislation by Scottish Government, potentially restricting access to identified priority areas for conservation to mobile demersal gears (NB the use of these gears and fixed nets are already prohibited in Sanday SAC). 2) A change in the way Scottish MPAs are managed e.g. with a whole site approach to management, rather than for designated features specifically; and 3) that offshore renewable energy development in priority areas may be restricted, and that this aim is supported by engagement with the Marine Directorate of the Scottish Government, Crown Estate Scotland and other relevant stakeholders to ensure that these areas are appropriately considered within Sectoral Marine Plans for offshore renewable energy and future leasing rounds.

Intervention C1: Avoid, minimise or mitigate activities which would be incompatible with the conservation of priority areas for benthic megafauna identified in Sanday SAC and Sule Skerry and Sule Stack SPA, and in waters to the east of the islands. We identified five priority areas for conservation which reflect the locations of long-term (2026-2069) climate change refugia for benthic megafauna under RCP4.5 (Figures D.4.1 & D.4.2). Two of these priority areas, in the waters around the Sule Skerry and Sule Stack SPA and in waters to the east of Orkney, fall outside the MPA network. Given that the Sule Skerry and Sule Stack SPA was designated solely for birds, and there is therefore no provision to protect benthic megafauna within it, we consider the waters within the SPA to also be outside of the MPA network in this case, as a separate designation would likely be necessary to protect benthic megafauna in this area. All the priority areas for conservation identified for benthic megafauna fall in regions used by a number of demersal sharks, skates and rays (Annex 2, Figure A.2), including species listed as “vulnerable” in Europe by the IUCN, such as tope (*Galeorhinus galeus*, also protected under Section 9 of the Wildlife and Countryside Act 1981), common smoothhound (*Mustelus mustelus*) and shagreen ray (*Leucoraja fullonica*). Also present in the Orkney region are species listed as priority marine features (PMF, Tyler-Walters, 2016), such as the sandy ray (*Leucoraja circularis*, classed as “vulnerable” by the IUCN), the spiny dogfish (*Squalus acanthias*, classed as “critically endangered” in the NE Atlantic by the IUCN), and the flapper skate (*Dipturus intermedius*, classed as “critically endangered” by the IUCN). We note that only those species listed as PMF can be protected in their own right and serve as designating features for new MPAs in Scottish waters.

Intervention C2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for benthic habitats identified in waters to the west of Orkney. We have identified a priority area for benthic habitat conservation based on the location of long-term (2026-2069) climate change refugia for benthic habitats under RCP4.5 (Figures D.4.1 & D.4.2) in a region containing the Annex 1 habitat “Reef”, and the PMF “offshore subtidal sand and gravel”. Another species classed as a priority marine feature, Ocean Quahog (*Arctica islandica*) has also been reported in the area (NatureScot, 2018). This area is outside the current MPA network.

Intervention C3: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for climate services identified in the North West Orkney MPA. This area has been identified as a priority area for climate services as it is located in an area with muddier sediment than the majority of that found in the Orkney region (Figures D.4.1 & D.4.2, Annex 2, Figure A.1), and it falls within a refuge for climate services.

Table D.4.1: Summary of spatial interventions C1 - C3 proposed in the Conservation Scenario, and the potential 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 the OIRMP area 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	Potential ecological effects	Expected economic effects
C1: Avoid, minimise or mitigate activities which would be incompatible with a) the conservation of priority areas for benthic megafauna identified in Sanday SAC, Sule Skerry and Sule Stack SPA, and in waters to the east of the islands.	C1: Avoiding, minimising or mitigating adverse impacts of marine activities on elasmobranch species listed as PMF (such as spiny dogfish <i>Squalus acanthias</i> and flapper skate <i>Dipturus intermedius</i>), could maximise the effectiveness of the identified climate change refuge in promoting the climate change resilience of these species.	Effect of all three interventions, relative to economic effects of BAU: <ul style="list-style-type: none"> • <5% reduction in Labour compensation; Gross Value Added; and Employment • <10% reduction in Greenhouse gas emissions
C2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for benthic habitats identified in waters to the west of Orkney.	C2: Avoiding, minimising or mitigating any adverse impacts of marine activities on habitat features (e.g. PMF offshore subtidal sand and gravel), could maximise the effectiveness of the identified climate change refuge in promoting the climate change resilience of these habitats.	
C3: Avoid, minimise or mitigate activities which could adversely affect the climate services associated with protected features in the priority area for climate	C3: Avoiding, minimising or mitigating any adverse impacts of marine activities in areas of softer sediment which may have carbon sequestration potential (e.g. muddy sediments in North West	

services identified in the North West Orkney MPA.	Orkney MCZ) may limit direct carbon release and degradation (avoided emissions) from disturbed sediment.	
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D.4.2. Potential ecological benefits of proposed spatial management measures

All of the simulated spatial management interventions listed above could result in the potential exclusion of vessels fishing with mobile demersal gears from priority areas for conservation. As noted above, mobile demersal gears and fixed nets are already excluded from Sanday SAC. The proposed priority areas harbour refugia for benthic megafauna and benthic habitats, and many shark, skate and ray populations exploiting these areas are considered vulnerable to fishing pressure due to their slow growth, late maturity and low fecundity (Rindorf et al., 2020). Furthermore there is some evidence to suggest that the priority area identified in the waters surrounding the Sule Skerry and Sule Stack SPA represent locations where elasmobranchs are bycaught in the commercial scallop fishery (data from Régnier et al., 2024, Annex 2, Figure A.3). It is therefore possible that these interventions would support the recovery and resilience of sharks, skates and rays of conservation and commercial interest in the Orkney area, as well as supporting the spatial management of fisheries for these species in the region. Beyond the benefits to elasmobranchs in the area, the interventions simulated here may also support the recovery and conservation of marine habitats that are listed on the European Red List of Habitats (Gubbay, 2016). For example, *Atlantic lower circalittoral sand* (classified as “Endangered” on the Red List), *Faunal communities in marine Atlantic infralittoral coarse sediment* and *Atlantic upper circalittoral coarse sediment* (both classified as “Vulnerable” on the Red List) are all present in the region and overlap with the identified priority areas (Annex 2, Figure A.1). All three habitats are vulnerable to damage from mobile demersal gears, which can change both the sediment characteristics of the habitat and the species associated with it (North East Atlantic Habitat Group, 2016a, 2016b, 2016c). In the case of the priority area identified for climate services in the North West Orkney MPA, 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).

While we did not evaluate the effects of climate change on historic environment assets directly, we do account for possible effects of the simulated interventions on historic environment assets in the area. The proposed priority areas contain six wrecks (Figure A.4), although none of them are protected under the Protection of Wrecks Act 1975 or the Protection of Military Remains Act 1986. Regardless, the condition of these vessels may benefit from the three simulated spatial management interventions if they result in less disturbance of the seabed and historic environment assets due to abrasion. The simulated interventions will not restrict access to priority areas for recreational anglers fishing with pole and line, although data from the Marine Recreation and Tourism Survey (Scottish Government Marine Directorate, 2015) suggests that sea angling activity in Orkney is relatively low when compared to other parts of Scotland. There are no recreational moorings in the identified priority areas, so anchorages for yachting would be unaffected by the simulated interventions. Many of the priority areas for conservation are popular for SCUBA diving and wildlife watching (Orkney Islands Council, 2022), and any future improvements in habitat conditions and biodiversity resulting from the simulated interventions may provide better recreational experiences for these water users.

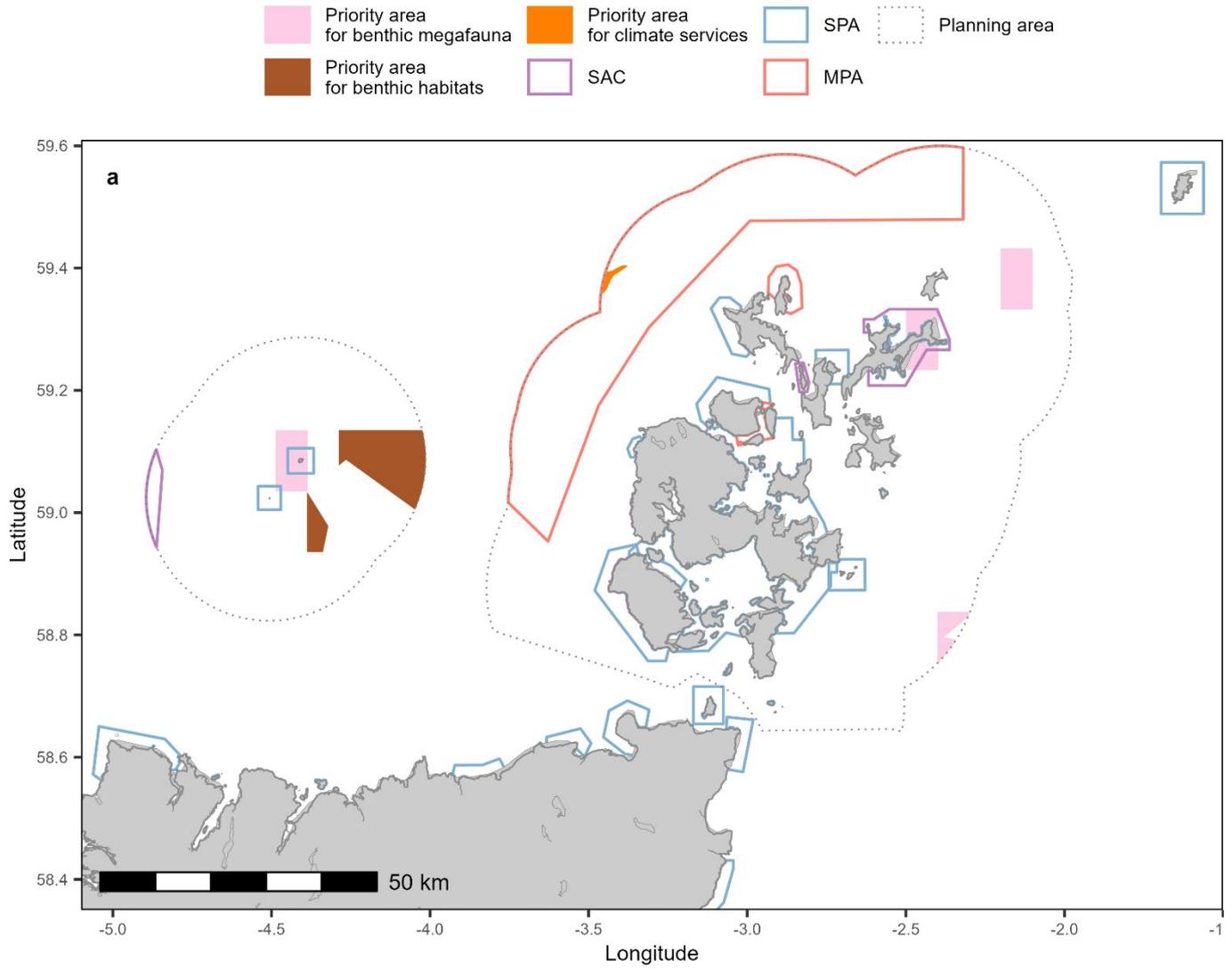


Figure D.4.1: Locations of the priority areas for conservation of benthic habitats, benthic megafauna and climate services.

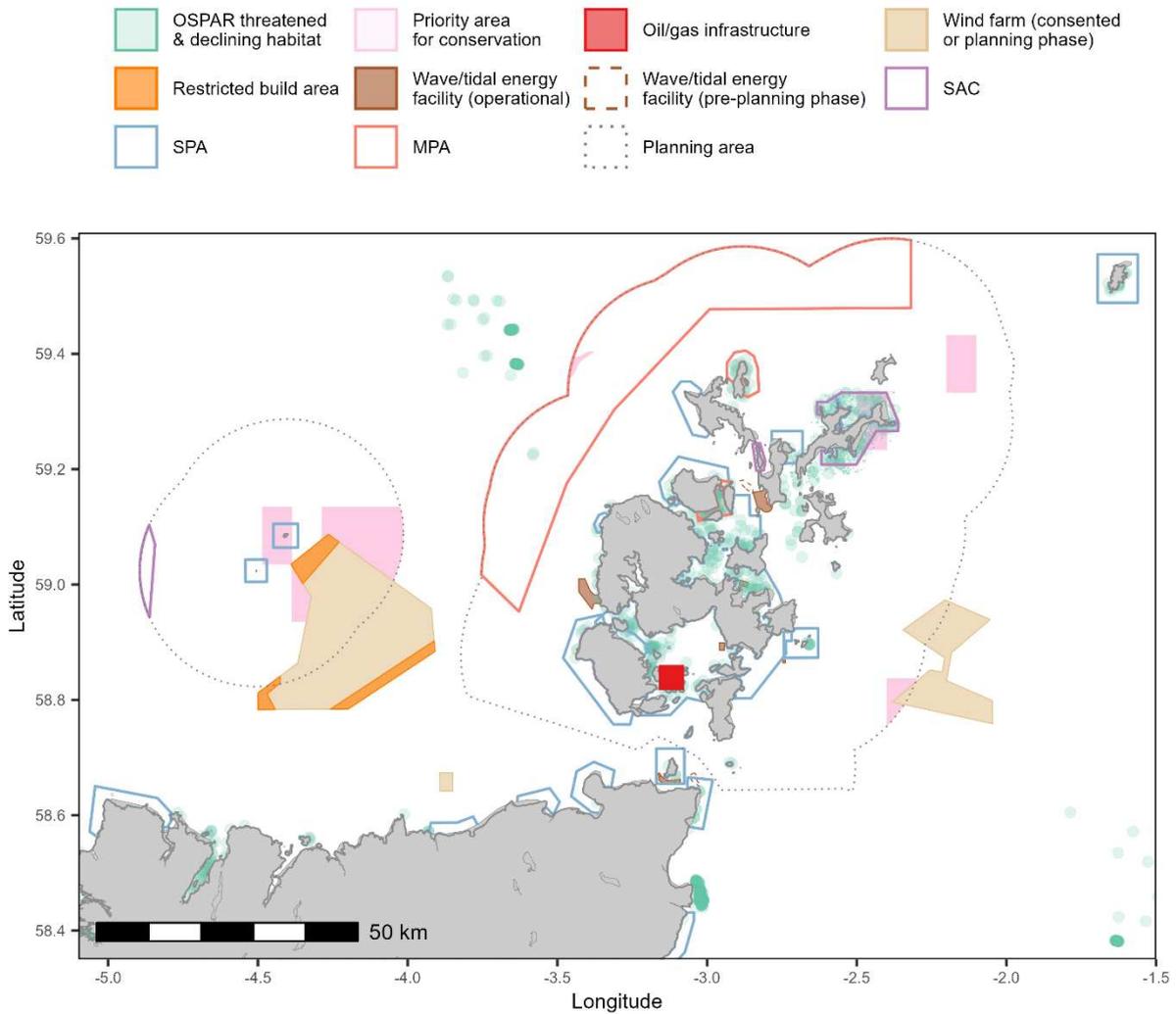


Figure D.4.2: Conservation scenario with all priority areas for conservation highlighted, along with other uses of marine space in Orkney.

D.4.3 Economic outcomes for the adjacent blue economy of the Orkney region

In the Conservation Scenario we see only marginal further reductions in all impact variables relative to the Business-as-Usual Scenario (Figure D.4.3). Differences for Labour Compensation, Gross Value Added, and Employment are all less than 5% (2%, 3% and 1% respectively). Given uncertainties in the economic modelling, there is effectively no difference between the two scenarios for these variables. We forecast a marginally bigger reduction in carbon emissions of 8% against Business-as-Usual. The small difference in reductions in impact variables is because of the very large reductions due to climate change hotspots in the Business as Usual scenario. In comparison, simulated additional closures for conservation reasons are marginal.

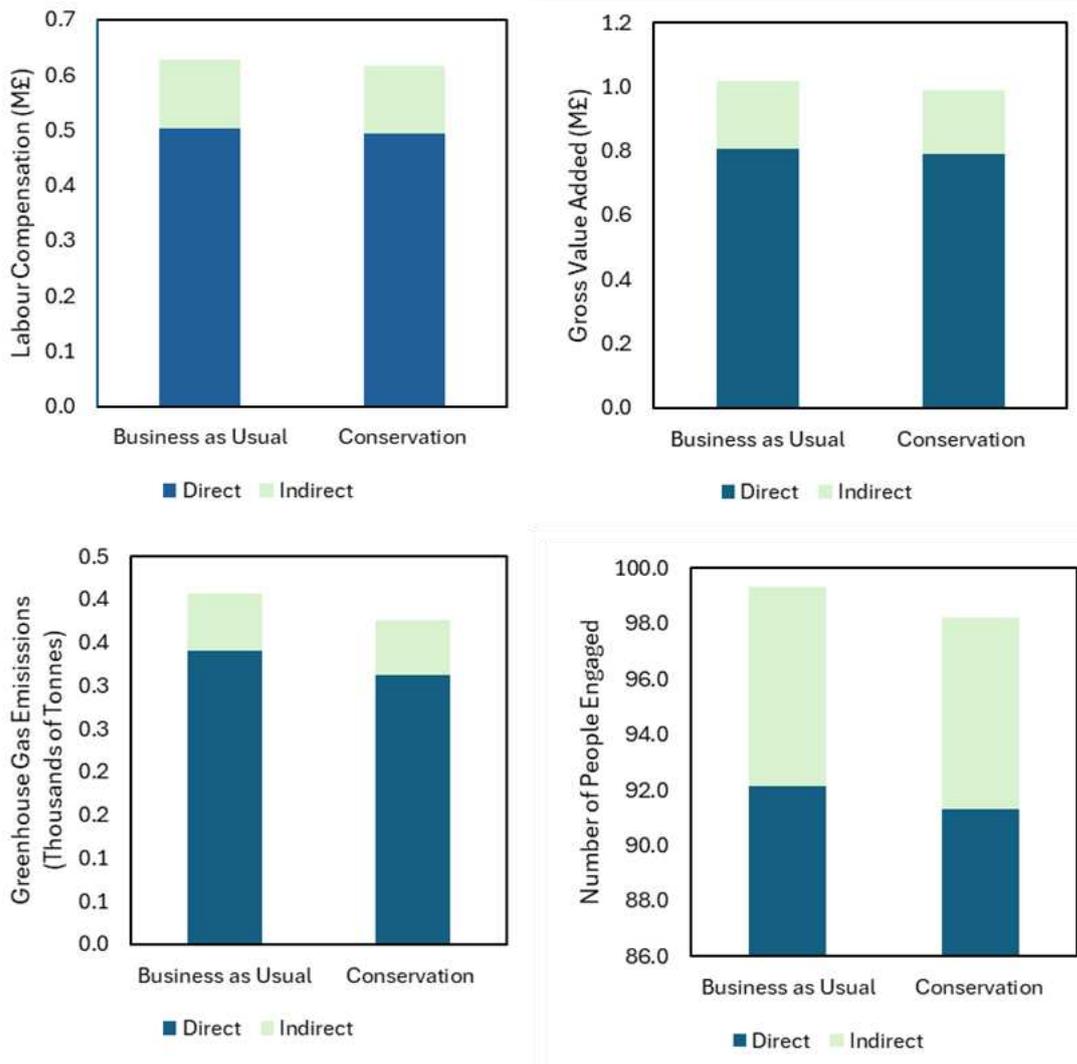


Figure D.4.3: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Conservation Scenario, as compared to the Business as Usual Scenario.

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 Orkney planning area. Simulated interventions are located in climate change refugia for pelagic fisheries and benthic habitats (see [Section D.3.1b](#) for details).
2. aim to facilitate the development of climate-resilient aquaculture in the Orkney planning area. Simulated interventions are located in climate change refugia for water column 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 preparing and implementing the Orkney Islands Regional Marine Plan, as well as those affected by the planning and management 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 the planning area, in the face of climate change impacts in the region (Table D.5.1). In this hypothetical planning scenario, we simulate that these aims would be supported by marine planning and licensing authorities when considering the locations of identified priority areas for fisheries and aquaculture, and when evaluating applications for development of marine space by other industries and sectors.

Intervention FP1: a) Avoid, minimise or mitigate proposals for uses that are incompatible with access to priority areas for demersal fisheries. b) Avoid, minimise or mitigate proposals for uses that may be incompatible with access by the pelagic fleet to currently unfished areas, identified as priority areas for pelagic fisheries (Figures D.5.1 & D.5.2). A priority area for demersal fisheries (based on the location of a refuge for benthic habitats, see [Section D.3.1b](#) for details) was identified to the west of Orkney, close to Sule Skerry and Sule Stack. The best available evidence of fishing effort distribution suggests that this area is exploited by crab and lobster pot vessels (Annex 2, Figure A.5), otter trawlers and to a lesser degree, scallop dredgers (Annex 2, Figure A.6). At the present time, shellfish such as edible crab and velvet crab, European lobster and king scallop represent the majority of Orkney capture fisheries landings (Scottish Government, 2023), although other demersal and pelagic fish such as haddock, cod, herring and mackerel are also targeted (Marine Scotland, 2016). While modelling for European lobster (*Homarus gammarus*), king scallop (*Pecten maximus*) and velvet crab (*Necora puber*) was not available to us, our analysis suggests that abundances of key species such as edible crab (*Cancer pagurus*) will decline in the planning area, perhaps indicating that the Orkney demersal fleet may have to diversify in order to remain sustainable under climate change pressures. For example, hake (*Merluccius merluccius*) and sole (*Solea solea*) are both projected to increase in abundance in the planning area, which could represent opportunities for the sector in the future. We also recognise that shifting species distributions may result in new species entering Orkney waters, and these species could prove to be commercially valuable. We note that the modelling that we used for this analysis is based on the current catch composition across the whole of the UK EEZ. This did not include any “new” species moving into the region due to climate change, and which may become available to the demersal fleet in the future. Because the value to the sector of those potential catches of new species will depend on consumer attitudes, they are not included in these analysis. However, is possible that there may be opportunities for the sector, even in the

face of climate driven losses of currently exploited species. Based on analyses in the EWS, all of the planning area emerges as a climate change refuge for pelagic fisheries (Figure D.5.1), as abundances of Atlantic mackerel (*Scomber scombrus*), and blue whiting (*Micromesistius poutassou*) are projected to remain stable even in the face of climate pressures. We recognise that at present, landings of pelagic species into Orkney are quite low (Scottish Government, 2023), and much of the effort is focussed in the north east of the planning area towards Shetland (Marine Scotland, 2024). In the future however, it is possible that the pelagic fleet could move into currently unexploited areas in Orkney waters.

Intervention FP2: Avoid, minimise or mitigate proposals for activities that could limit the development of water column aquaculture in priority areas for this sector. Refugia for both seafloor and water column aquaculture were identified in the planning area. Due to the exposed, offshore location of these refugia (west of Orkney, towards Sule Skerry), and the current status of technological development within the industry, it make take time for commercially viable water column aquaculture to operate in this area. Regardless, we identify the refuge for water column aquaculture as a priority area for the sector in this scenario, as we also note that there is potential for co-location of aquaculture facilities with the planned West of Orkney wind farm development, though the feasibility of this potential colocation opportunity has not been explored in detail (Figures D.5.1 & D.5.2).

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

Spatial intervention	Potential sectoral effects	Expected economic effects
FP1: a) Avoid, minimise or mitigate proposals for development and activities that are incompatible with access to priority areas for demersal fisheries. b) Avoid, minimise or mitigate proposals for development and activities that may be incompatible with access by the pelagic fleet to currently unfished areas, identified as pelagic fisheries priority areas.	FP1: Priority access to sites identified as refugia for fisheries could contribute to the sustainability of the Orkney fishing sectors and help to support the industry in the face of climate change.	FP1: Relative to economic effects of Business-As-Usual <ul style="list-style-type: none"> • ~1800% increase in Labour compensation • ~2000% increase in Gross Value Added • ~800% increase in employment • ~5800% increase in GHG emissions
FP2: Avoid, minimise or mitigate proposals for activities that could limit the development of water column aquaculture in the identified priority areas for this sector.	FP2: Development of the identified priority area for water column aquaculture represents a possible opportunity for sectoral expansion.	FP2: Full expansion of Aquaculture, relative to economic effects of Business-as-Usual: <ul style="list-style-type: none"> • ~14000% increase in Labour compensation, Gross Value Added • ~15000 increase in Employment

		<ul style="list-style-type: none"> • ~10000% increase in Greenhouse Gas Emissions <p>FP2 Use of 5% of available area for aquaculture expansion, relative to economic effects of Business-as-Usual:</p> <ul style="list-style-type: none"> • ~270% increase in Labour Compensation and Gross Value Added • ~290% increase in Employment • ~ 180% increase Greenhouse Gas Emissions
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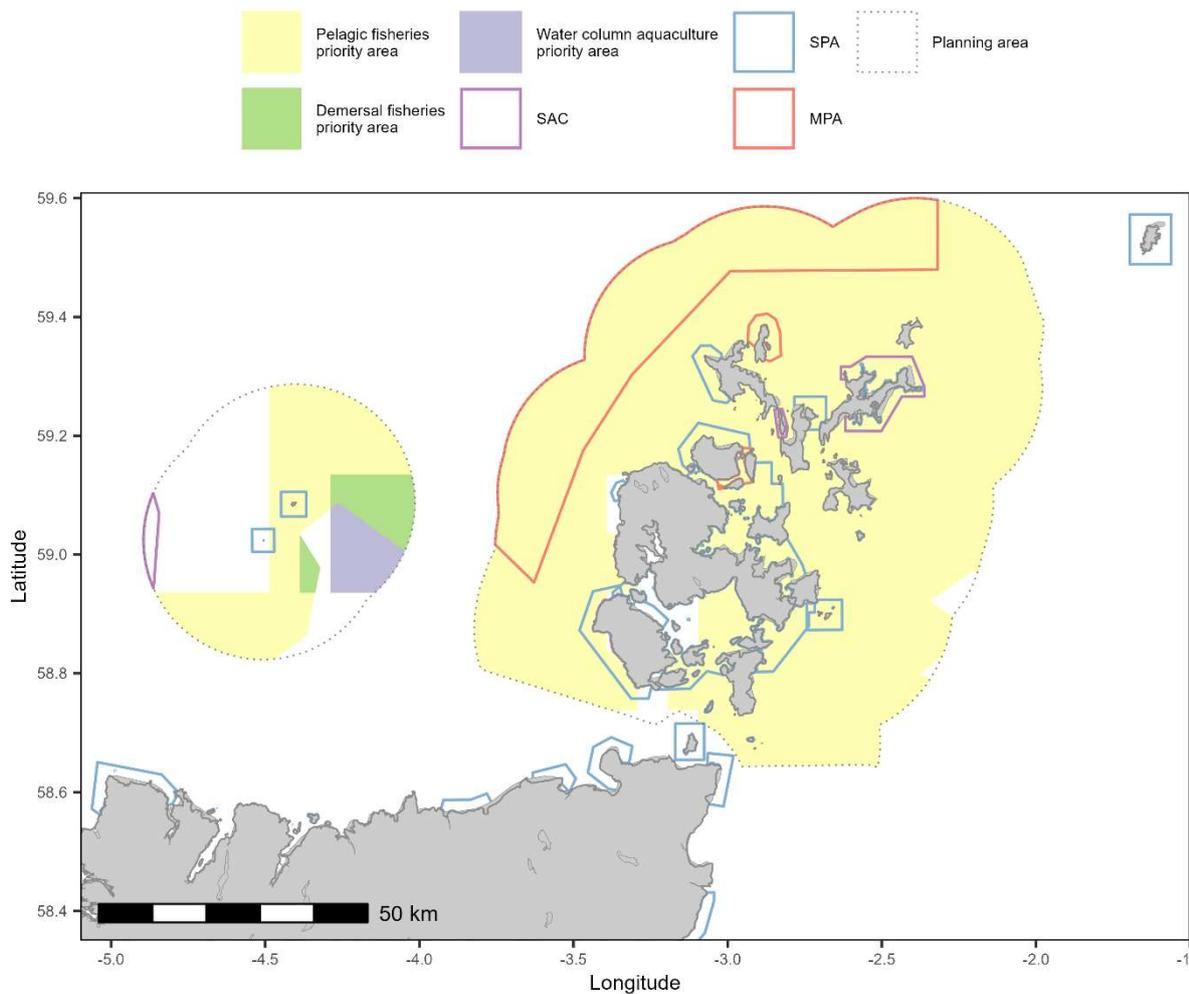


Figure D.5.1: Locations of priority areas for demersal fisheries, pelagic fisheries and water column aquaculture.

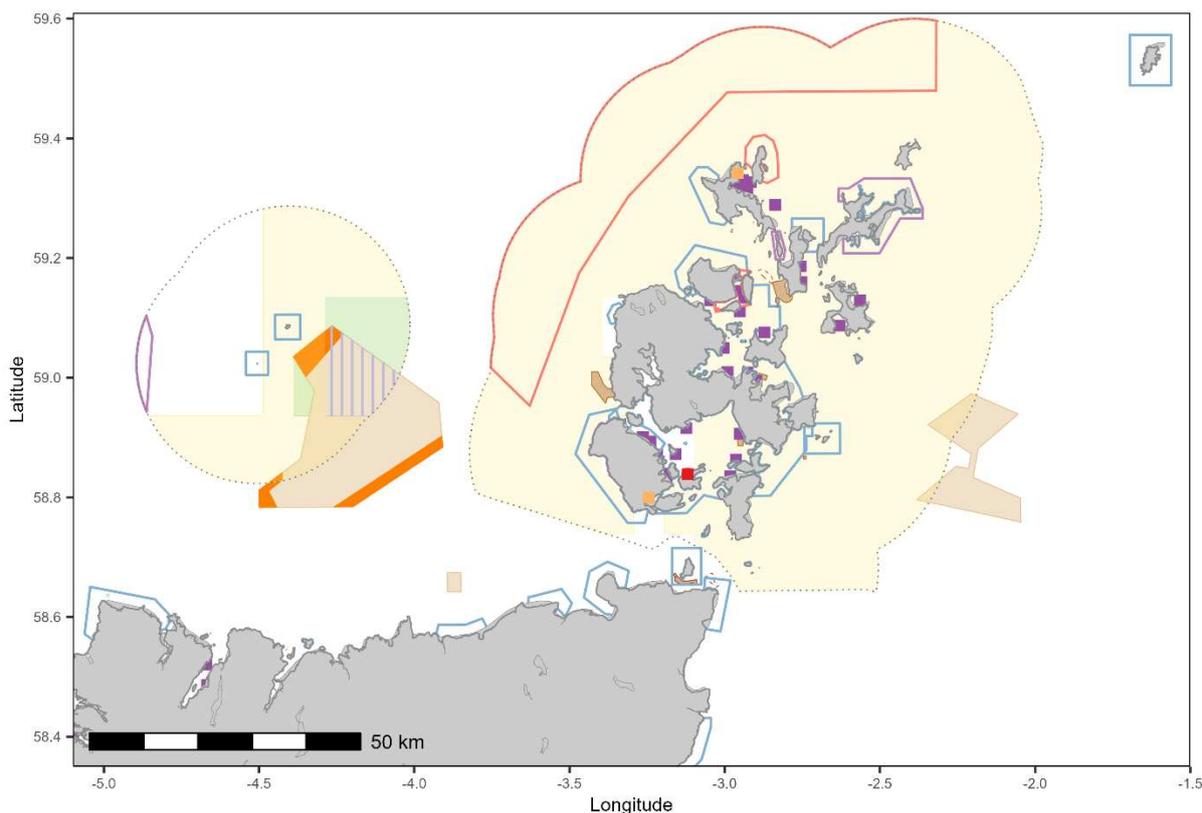
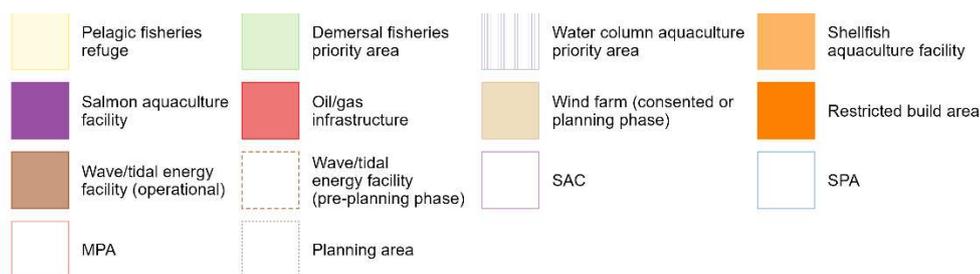


Figure D.5.2: Proposed Food Provision scenario, with locations of priority areas for demersal fisheries, pelagic fisheries and water column aquaculture highlighted.

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

Relative to the Business as Usual Scenario, the Food Provision Scenario increases all our indicators (Figure D.5.3 and D.5.4). Intervention FP1 shows the impacts of an indicative 10 times increase in pelagic fishing effort in the Orkney marine plan area (alongside the negative climatic impacts on demersal fishing effort). Here we see significant increases in impact variables relative: ~1800% for labour compensation, ~2000% for GVA, ~800% increase for number of employees and ~6000% for Greenhouse Gases. Intervention FP2 shows the effects of increasing the areas available for water column aquaculture. The total potential area available for aquaculture is ~ 40 times the currently used area (NB, the currently used area was calculated using data from Crown Estate Scotland). Because of limitations in the economic modelling, such a large expansion is hard to forecast with any

degree of reliability – the model assumes a linear relationship between area and output with no economies of scale or changes in production structure. These assumptions are unlikely to hold for a 40 times increase so these results should be treated as indicative. Therefore we also model the effects of using only 5% of the area available for new aquaculture developments. Assuming a 5% increase in area used for Aquaculture, we see all impact variables increase by 200-300%. If the full available area is used for aquaculture then increases of 10,000-15,000% are modelled. Despite uncertainties, our results suggest significant potential for economic development if pelagic catch and water column aquaculture can be expanded, though with an associated carbon cost.

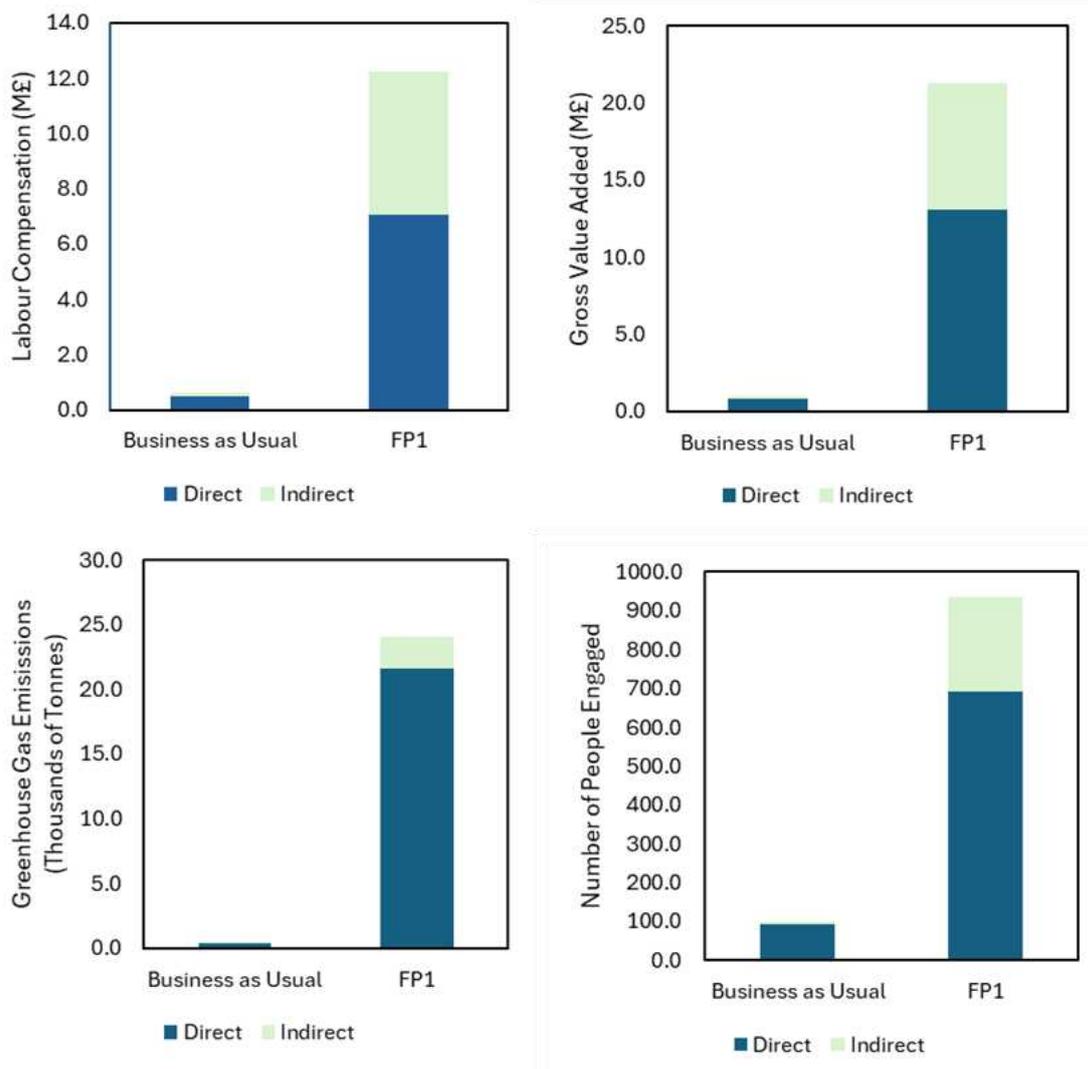


Figure D.5.3: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Food Provision Scenario intervention FP1, as compared to the Business as Usual Scenario

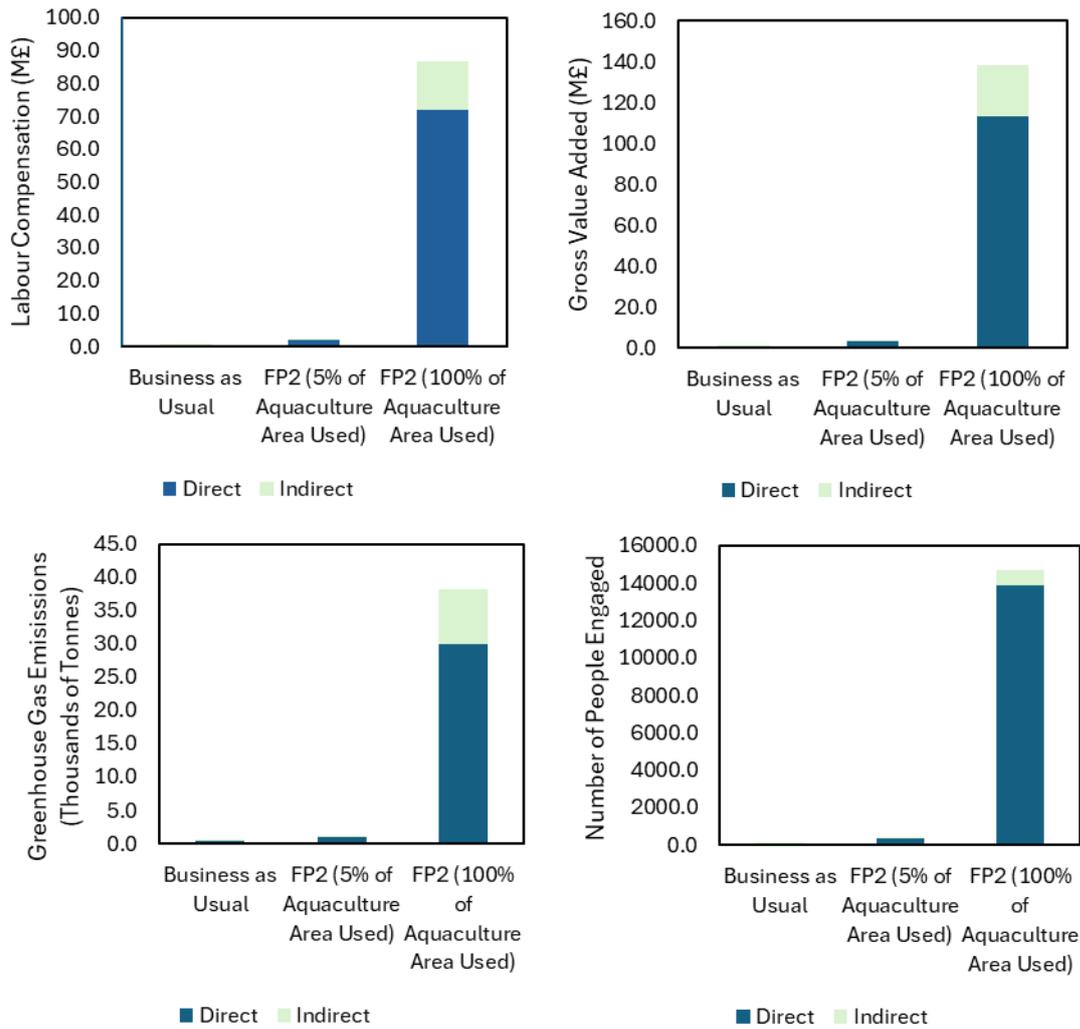


Figure D.5.4: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Food Provision Scenario intervention FP2, as compared to the Business as Usual Scenario

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 the Orkney planning area. Simulated interventions are located in climate change refugia for pelagic fisheries and benthic habitats (see [Section D.3.1b](#) for details).
2. aim to facilitate the development of climate-resilient aquaculture in Orkney waters. Simulated interventions are located in climate change refugia for water column aquaculture
3. 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 the Orkney region. Simulated interventions are located in climate change refugia for benthic habitats or benthic megafauna
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 capture fisheries and aquaculture production with the need to ensure that the marine environment in the Orkney area 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 Orkney stakeholders than the other three scenarios.

The spatial interventions CM1 - CM3 below have the purpose of avoiding, minimising or mitigating the impacts of activities which could negatively affect benthic megafauna species and benthic habitats of high conservation interest and the future provision of climate services in Orkney waters (Table D.6.1). In this hypothetical planning scenario, we simulate that these aims would be supported by additional governance mechanisms and legislation by Scottish Government, potentially setting limits on access to identified priority areas for conservation to mobile demersal gears (NB the use of these gears and fixed nets are already prohibited in Sanday SAC). The spatial interventions CM4 and CM5 have the purpose of supporting and safeguarding climate-resilient capture fisheries and facilitating the development of climate-resilient aquaculture in the OIRMP area (Table D.6.1). These aims would be supported by marine planning and licensing authorities when considering the locations of identified priority areas for fisheries and aquaculture, and when evaluating applications for development of marine space by other industries and sectors. Finally, we simulate that offshore renewable energy development in priority areas for conservation and aquaculture may be restricted, and that this aim is supported by engagement with the Marine Directorate of the Scottish Government, Crown Estate Scotland and other relevant stakeholders to ensure that these areas are appropriately considered within Sectoral Marine Plans for offshore renewable energy and future leasing rounds. This proposed prioritisation is informed by the values of regional stakeholders (Reinhardt & Danahey Janin, 2025).

Intervention CM1: Avoid, minimise or mitigate activities which would be incompatible with the conservation of priority areas for benthic megafauna identified in Sanday SAC and Sule Skerry and Sule Stack SPA, in waters surrounding Sule Skerry and Sule Stack SPA, and in waters to the east of the islands, outside MPAs (Figures D.6.1 & D.6.2). Under the Compromise Scenario, the five priority areas for conservation identified for benthic megafauna in the Conservation Scenario all remain as such. As in the Conservation Scenario, we consider the waters within the Sule Skerry and Sule Stack SPA to be outside of the MPA network in this case, as it was designated solely for birds, and a separate designation would likely be necessary to protect benthic megafauna in this area. The identified areas are used by a number of demersal sharks, skates and rays (Annex 2, Figure A.2), including species listed as priority marine features (PMF, Tyler-Walters, 2016), such as the sandy ray (*Leucoraja circularis*), the spiny dogfish (*Squalus acanthias*), and the flapper skate (*Dipturus intermedius*). Species listed as PMF can serve as designation features for new MPAs.

Intervention CM2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for benthic habitats identified in waters to the west of Orkney (Figures D.6.1 & D.6.2). A small part of the priority area for benthic habitats identified in the Conservation Scenario, and which contains the Annex 1 habitat “Reef”, and the PMF “offshore subtidal sand and gravel”, remains as a priority area in this scenario.

Intervention CM3: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for climate services identified in the North West Orkney MCZ (Figures D.6.1 & D.6.2). This area has been identified as a priority area for climate services as it is located in an area with muddier sediment than the majority of that found in the Orkney region (Annex 2, Figure A.1), and it falls within a refuge for climate services.

Intervention CM4: a) Avoid, minimise or mitigate proposals for uses that are incompatible with access to the priority area for demersal fisheries. b) 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 (Figures D.6.1 & D.6.2). The priority area for demersal fisheries (based on the location of a refuge for benthic habitats, see [Section D.5.1](#) for details) identified to the west of Orkney remains as such in this scenario, although it is slightly smaller than in the Food Provision Scenario. As noted in Section D5 above, all of the planning area emerges as a climate change refuge for pelagic fisheries, suggesting that the sector could remain productive even under climate change. For this reason, the whole planning area is identified as a priority area for pelagic fisheries, with the exception of the area identified for possible aquaculture development. Although at present, the majority of pelagic landings in Orkney are caught in the north east of the planning area (Marine Scotland, 2024), it is possible that in the future, the pelagic fleet could move into currently unexploited areas in Orkney waters.

Intervention CM5: Avoid, minimise or mitigate proposals for activities that could limit the development of water column aquaculture in priority areas for this sector (Figures D.6.1 & D.6.2). We simulate that the priority area for water column aquaculture identified in the Food Provision Scenario, located in a climate change refuge for the sector and co-located with the planned West of Orkney windfarm, is developed in this scenario.

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 priority areas for habitats and species of conservation interest in the Orkney region**. Full descriptions of each intervention, and the reasoning behind them, can be found in the main text.

Spatial intervention	Potential ecological effects	Expected economic effects
CM1: Avoid, minimise or mitigate activities which would be incompatible with a) the conservation of priority areas for benthic megafauna identified in Sanday SAC, Sule Skerry and Sule Stack SPA, and in waters to the east of the islands.	CM1: Avoiding, minimising or mitigating adverse impacts of marine activities on elasmobranch species listed as PMF (such as spiny dogfish <i>Squalus acanthias</i> and flapper skate <i>Dipturus intermedius</i>), could maximise the effectiveness of the identified climate change refuge in promoting the climate change resilience of these species.	CM1-4: Relative to economic effects of Business-As-Usual <ul style="list-style-type: none"> • ~1800% increase in Labour compensation • ~2000% increase in Gross Value Added • ~800% increase in employment • ~5800% increase in GHG emissions
CM2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for benthic habitats identified in waters to the west of Orkney.	CM2: Avoiding, minimising or mitigating any adverse impacts of marine activities on habitat features (e.g. PMF offshore subtidal sand and gravel), could maximise the effectiveness of the identified climate change refuge in promoting the climate change resilience of these habitats.	
CM3: Avoid, minimise or mitigate activities which could adversely affect the climate services associated with protected features in the priority area for climate services identified in the North West Orkney MPA.	CM3: Avoiding, minimising or mitigating any adverse impacts of marine activities in areas of softer sediment which may have carbon sequestration potential (e.g. muddy sediments in North West Orkney MCZ) may limit direct carbon release and degradation (avoided emissions) from disturbed sediment.	
CM4: a) Avoid, minimise or mitigate proposals for uses that are incompatible with access to priority areas for demersal fisheries. b) 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.	CM4: Continued/priority access to sites identified as priority areas for fisheries could help to support the industry in the face of climate change.	
CM5: Avoid, minimise or mitigate proposals for activities that could limit the	CM5: Development of the identified priority area for water column aquaculture	

development of water column aquaculture in the identified priority areas for this sector.	represents a possible opportunity for sectoral expansion.	
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D.6.2. Potential benefits of proposed spatial management measures

It is possible that interventions CM1 and CM2 could support high quality foraging habitat for a range of elasmobranchs of conservation interest in the identified priority areas for conservation for benthic megafauna and benthic habitats. As noted in the Conservation Scenario (Section D.4 above), these areas are used by several elasmobranch species, including species listed as priority marine features (PMF, Tyler-Walters, 2016), such as the sandy ray (*Leucoraja circularis*, classed as “vulnerable” by the IUCN), the spiny dogfish (*Squalus acanthias*, classed as “critically endangered” in the NE Atlantic by the IUCN), and the flapper skate (*Dipturus intermedius*, classed as “critically endangered” by the IUCN). These two interventions may also support the recovery and conservation of marine habitats that are listed on the European Red List of Habitats (Gubbay, 2016). For example, *Atlantic lower circalittoral sand* (classified as “Endangered” on the Red List), *Faunal communities in marine Atlantic infralittoral coarse sediment* and *Atlantic upper circalittoral coarse sediment* (both classified as “Vulnerable” on the Red List) are all present in the Orkney region and overlap with the identified priority areas (Annex 2, Figure A.1). Furthermore, the priority areas for both benthic megafauna and benthic habitats have been shown to be spawning grounds for sprat (*Sprattus sprattus*), and spawning and nursery grounds for haddock (*Melanogrammus aeglefinus*) and lemon sole (*Microstomus kitt*) (Marine Scotland, 2024). This intervention may therefore benefit spawning aggregations and early life stages for key commercial and ecologically important species, which could be beneficial to fisheries in the long-term. In the case of the identified priority area for climate services in the North West Orkney MPA, it is possible that intervention CM3 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).

Interventions CM4 and CM5 could both present opportunities to support the fishing and aquaculture sectors in the face of climate change pressures. In the case of the fisheries sector, it is possible that the pelagic fleet could expand into currently unexploited priority areas in the OIRMP area under intervention CM4. Intervention CM5 could allow for the expansion of water column aquaculture in the Orkney region, utilising the priority area for water column aquaculture to the west of Orkney that we have identified. It should be noted that development of the site is dependent on co-location of new infrastructure with the planned West of Orkney wind farm, though the feasibility of this potential colocation opportunity has not been explored in detail.

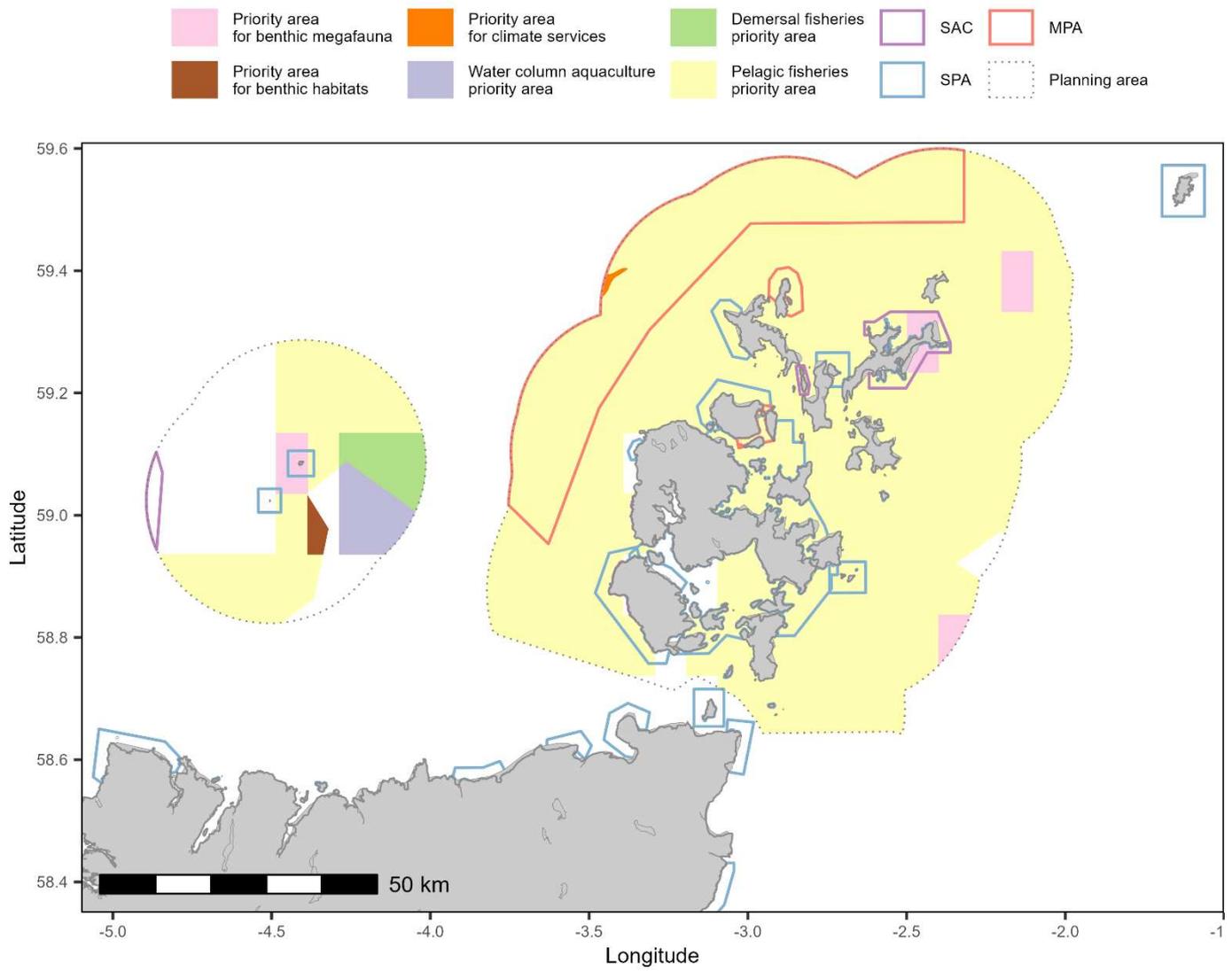


Figure D.6.1: Locations of priority areas for conservation, demersal fisheries, pelagic fisheries and water column aquaculture under the Compromise Scenario.

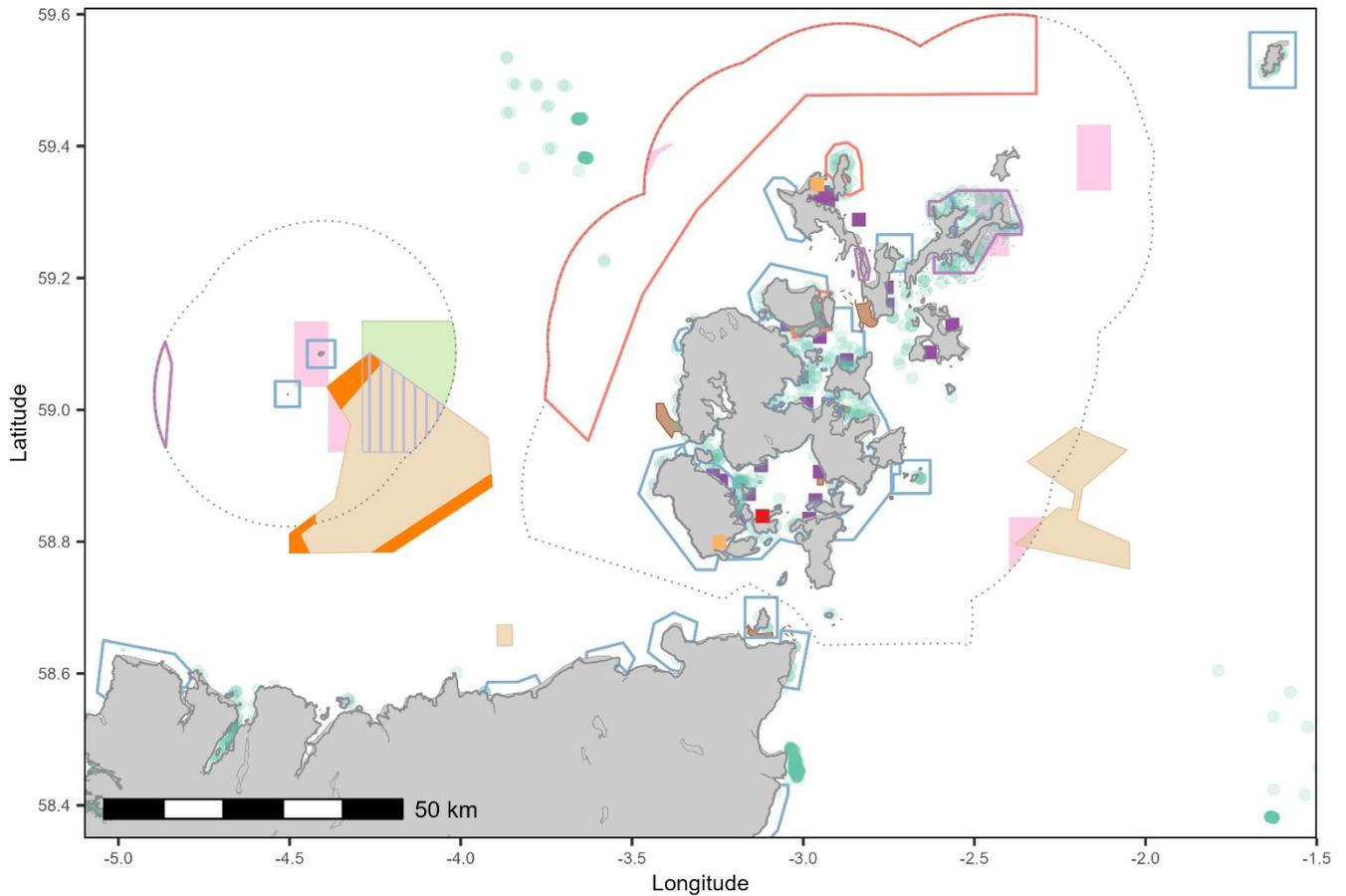
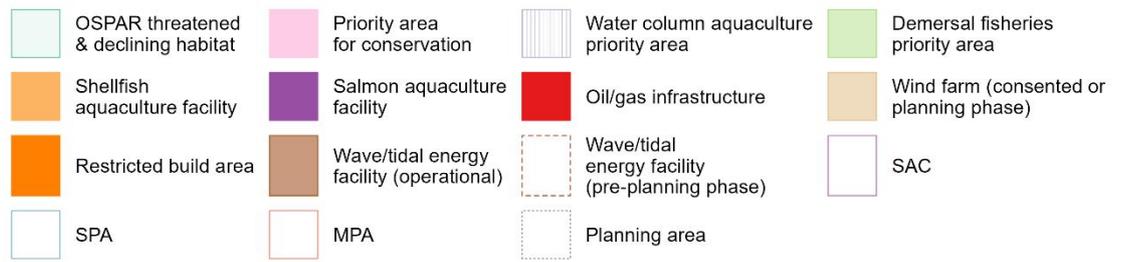


Figure D.6.2: Proposed compromise scenario with the locations of priority areas for conservation, demersal fisheries and aquaculture highlighted, along with other uses of marine space in Orkney

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

Relative to both the Business as Usual, the Compromise Scenario increases all our indicators (Figure D.6.3 and D.6.4). Economic impacts are very similar to the food provision scenarios, as the main drivers of impact, a potential increase in pelagic fishing effort and expansion of aquaculture are left unchanged. Therefore, the analysis and qualifiers from the food provision scenario are largely unchanged here, indicating potential for economic development despite additional conservation efforts relative to food provision.

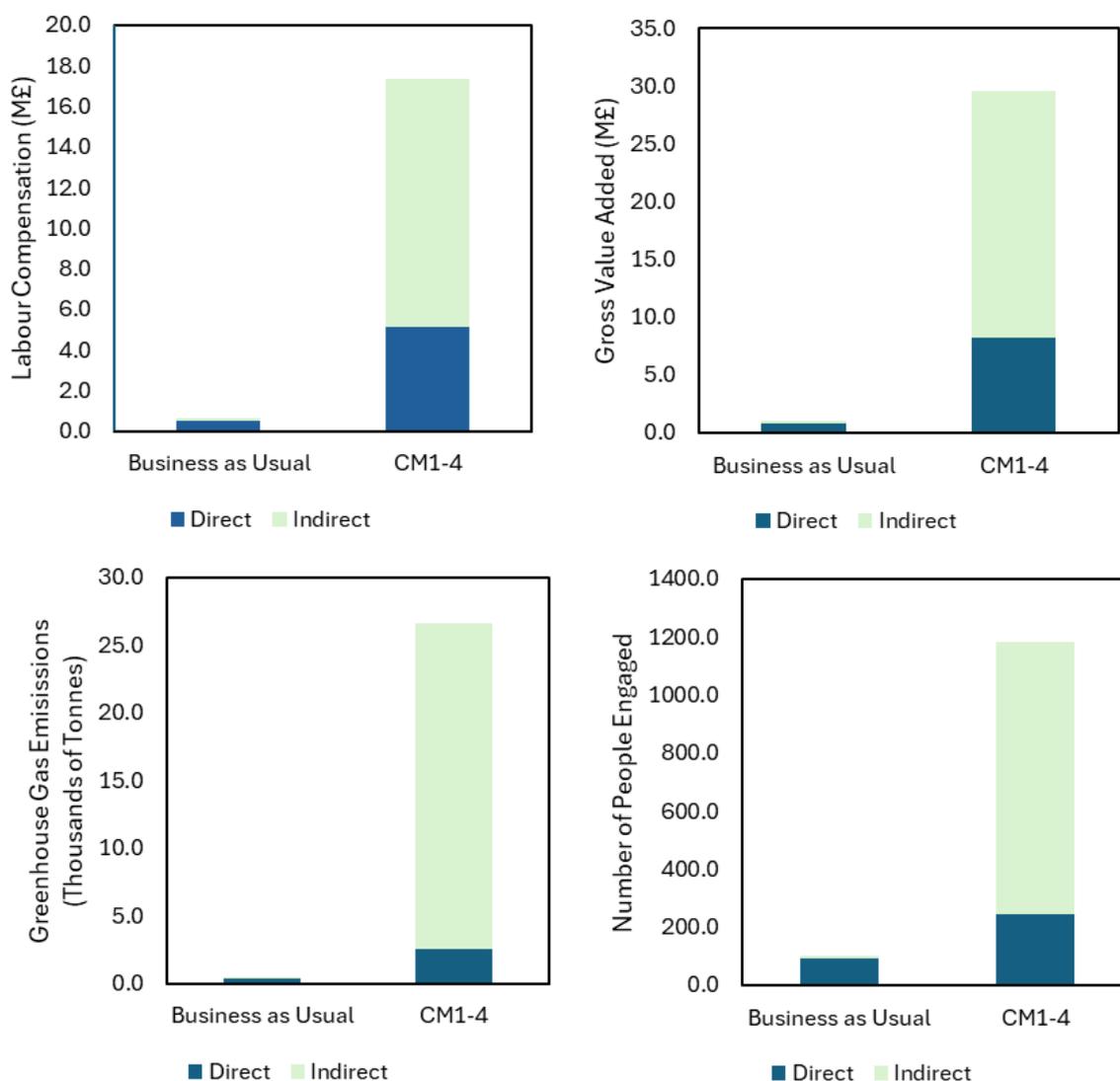


Figure D.6.3: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Food Provision Scenario interventions CM1-4, as compared to the Business as Usual Scenario

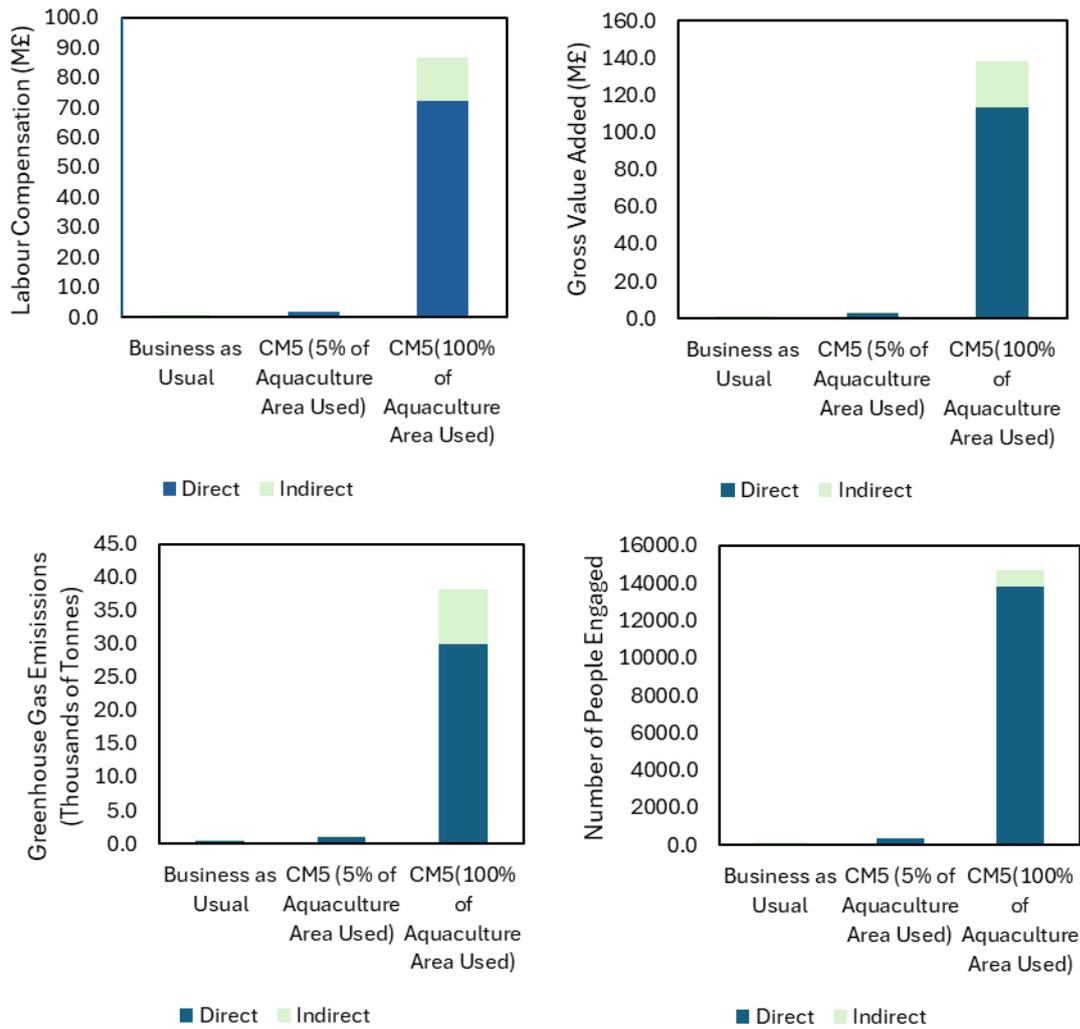


Figure D.6.4: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Food Provision Scenario interventions CM5, as compared to the Business as Usual Scenario

D.7 Cross scenario economic analysis

The key takeaways across the scenarios are that although losses due to climate are expected to be significant, there may be substantial potential for mitigating the economic impacts of these. If pelagic fishing effort and aquaculture can be developed beyond current areas, then this should be able to support significant economic development.

The model captures a variety of mechanisms that link marine resources and the adjacent blue economy in Orkney waters: 1) the area available for fishing or aquaculture 2) the supply chain structures of marine industries 3) the intensity of impact (labour compensation, gross value added, greenhouse gas emissions and number of people engaged) of a unit of output in different industries 4) the relative share of output of different industries. The relative area available for fishing or aquaculture and how it is affected by climate change and interactions with conservation areas is the major factor impacting the results. This is a major source of uncertainty in the model because of the assumption that each ICES statistical rectangle in the marine plan area accessible to a particular fishing fleet segment is equally productive.

Another element to be aware of is that as there is currently only very small active catch in Orkney, as such there is very little data to guide scenarios with expansion of this activity. Modelled expansions of the pelagic fleet estimated here should be taken as indicative of a hypothetical scenario, where the fleet is adapting to changes in resource driven by climate change.

In all estimated indicators, the impacts are dominated by direct effects. Most income, value added, jobs and greenhouse gas emissions are lost or gained due to changes in the aquaculture or fishing fleet. However, indirect effects are not inconsequential, being between 10 and 20% of total impact in most cases.

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):

$$\text{Total } R_{\text{BAU}} = R_p - R_h$$

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):

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

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):

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\text{Total } R_{CS} = R_p - R_h - R_f + R_r + R_c$$

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 contributing to the co-development of the MSPACE management scenarios.

Name	Organisation
James Green	Orkney Islands Council Marine Planning Team Lead
Daniel Morris	Orkney Islands Council Marine Planning Team
Professor Joanne S. Porter	Heriot Watt University
Emily Murphy Gray	Orkney Islands Council Marine Planning Team
Nick Blyth	Orkney Islands Council
Carol Coleman	Orkney Islands Council
Nina Caudrey	Orkney Islands Council
Thomas Regnier	Scottish Government Marine Directorate

Table A2: Marine sectors used in the economic model. For a full list of sectors included, please see Roca Florido et al. (2025)

	Sector
1	Retail sale of fish crustaceans and molluscs in specialised stores
2	Sea and coastal passenger water transport
3	Aquaculture
4	Service activities incidental to water transportation
5	Wholesale of other food, including fish, crustaceans and molluscs
6	Building of ships and floating structures
7	Fishing
9	Renting and leasing of water transport equipment

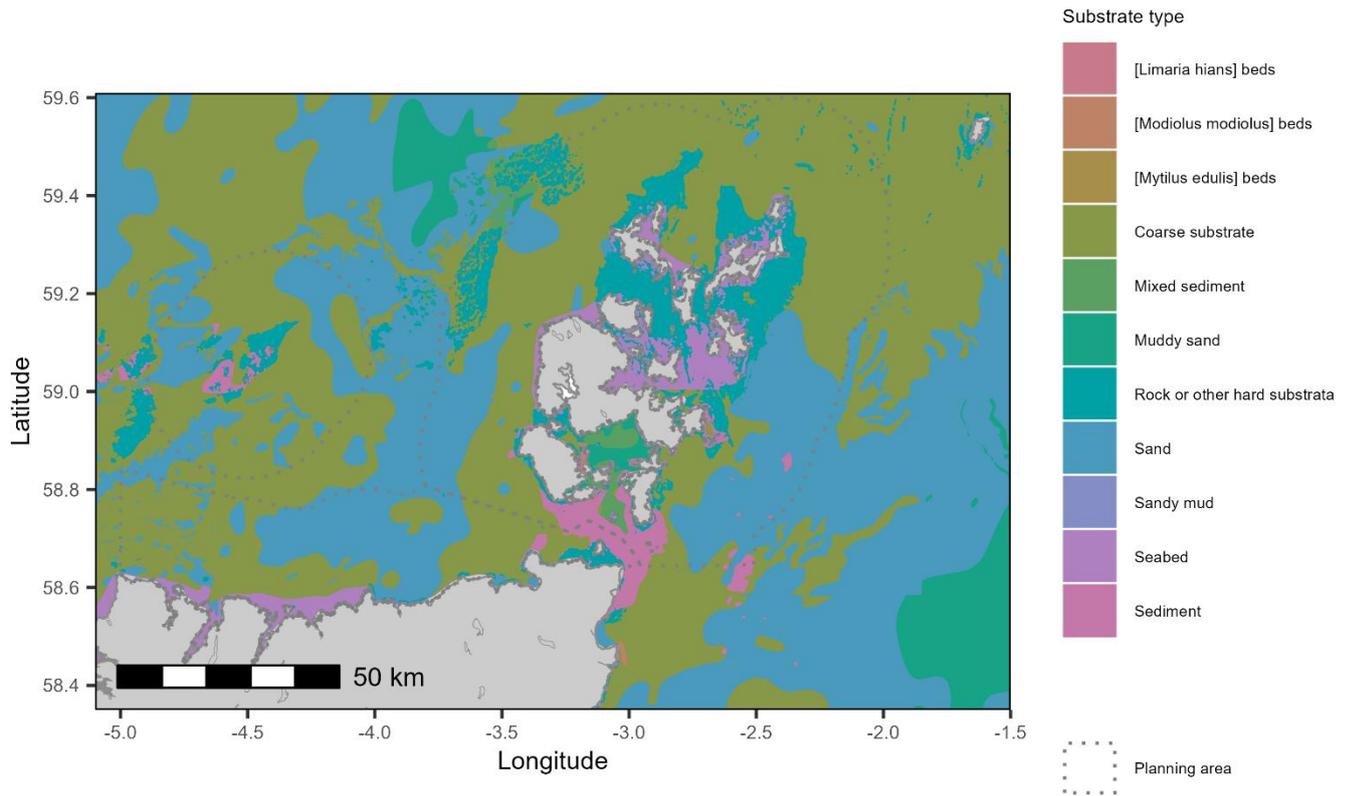


Figure A.1: Marine sediment type around the Orkney islands. The area is characterised by predominantly coarse sediments and hard seabed, with some muddier areas in Scapa Flow. Sediment data is from the EUSeaMap model, downloaded from EMODnet (<https://emodnet.ec.europa.eu/geoviewer/>)

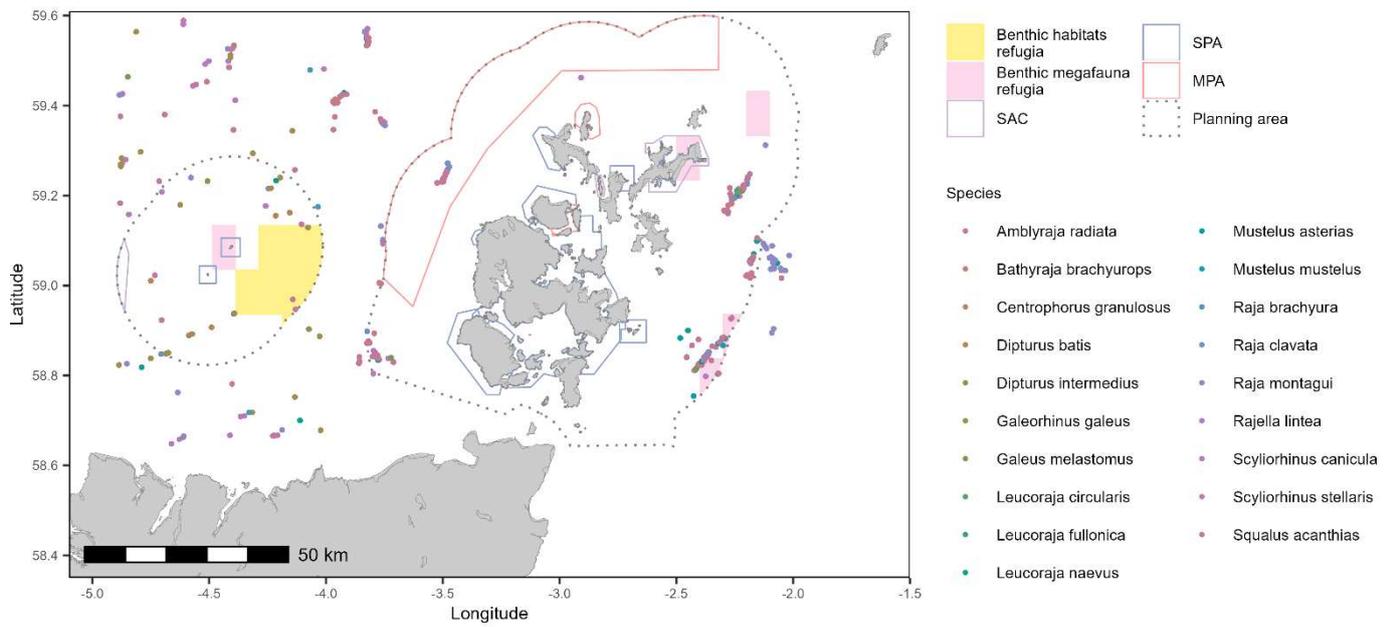


Figure A.2: Observed distributions of sharks, skates and rays in the Orkney marine plan area. Survey data from the North Sea International Bottom Trawl Survey 2000-2022 and the Scottish West Coast Groundfish Survey 2000-2022, downloaded from <https://datras.ices.dk/>

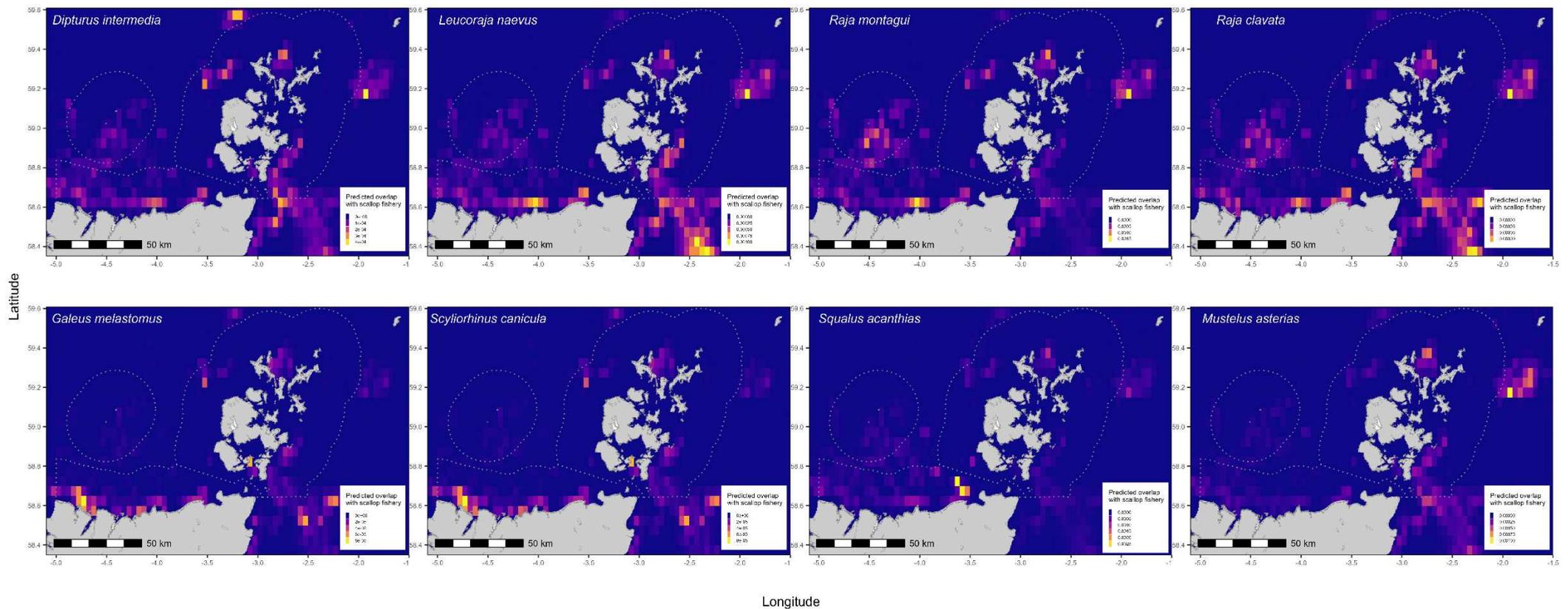


Figure A.3: Predicted bycatch hotspots for elasmobranch species of conservation interest in the OIRMP area. Hotspots were estimated based on the overlap between scallop dredging locations and modelled distributions of each species. Blue/purple indicates low bycatch risk, yellow indicates higher bycatch risk. Data from Régnier et al. (2024)

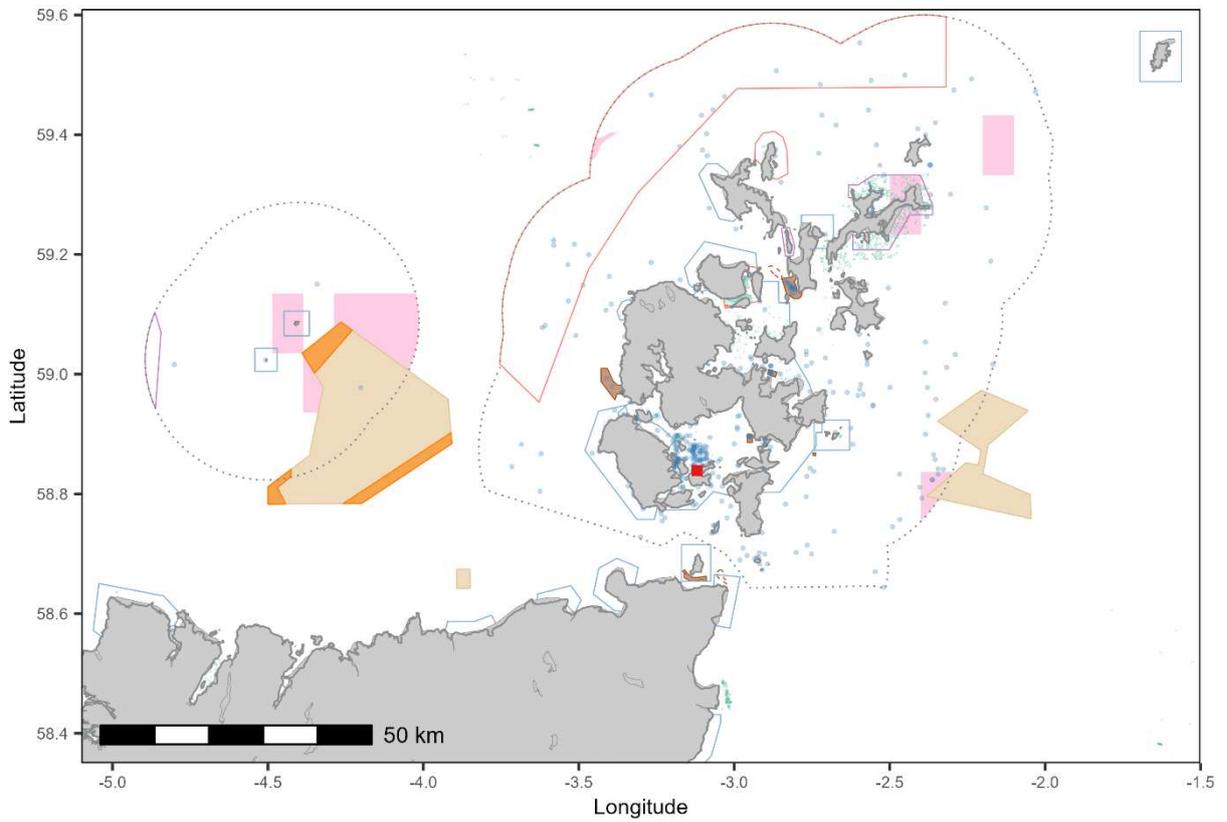
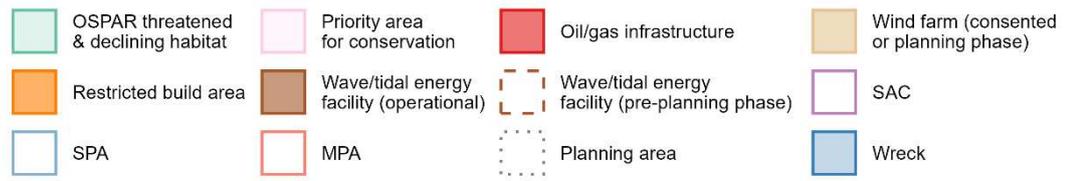


Figure A.4: Conservation scenario showing the locations of wrecks

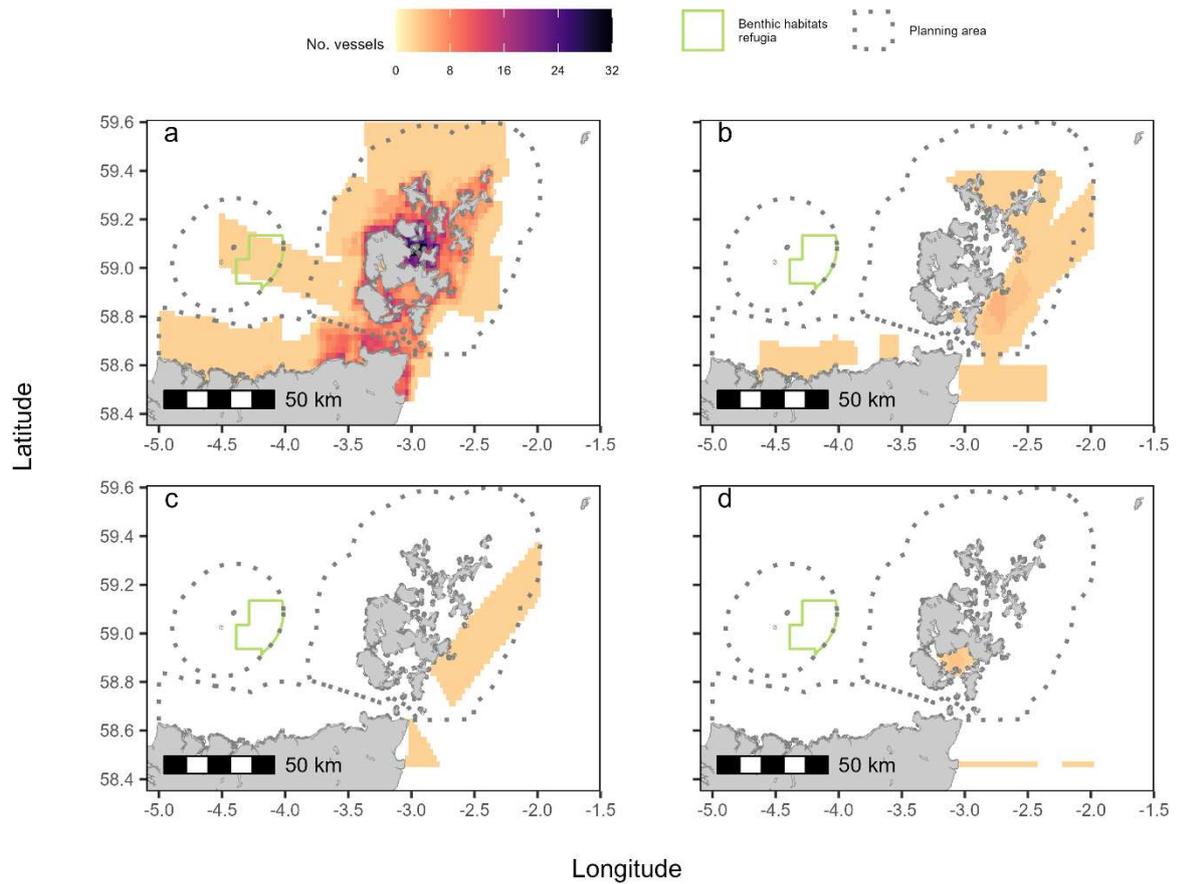


Figure A.5: Fishing effort distribution (number of vessels) of the <12m fleet. Crab/lobster pots (a), scallop dredgers (b), demersal trawls (c) and *Nephrops* trawls (d). Distributions were taken from the ScotMap project (Kafas et al., 2014) and can be downloaded here <https://data.marine.gov.scot/dataset/scotmap-inshore-fisheries-mapping-scotland-recording-fishermen%E2%80%99s-use-sea>

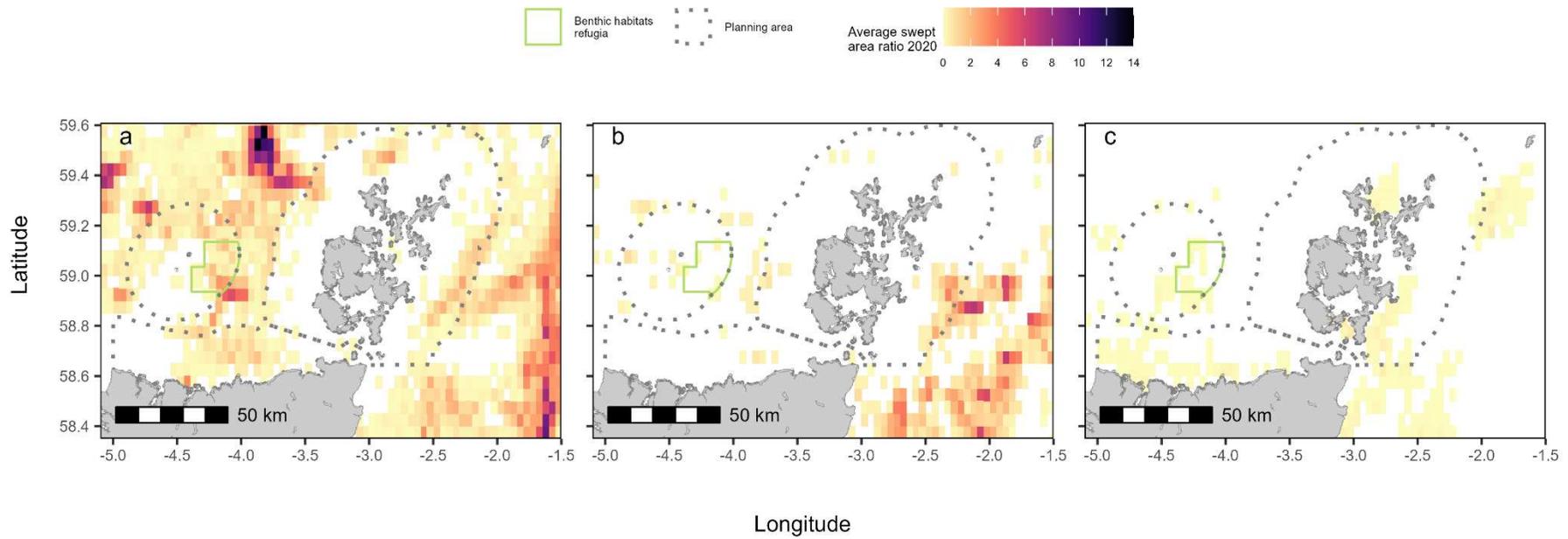


Figure A.6: Fishing effort distribution (mean swept area ratio in 2020) of the >12m fleet. Otter trawls (a), demersal seines (b) and scallop dredgers (c). Data are from ICES (2021) and can be downloaded here <https://doi.org/10.17895/ices.data.8294>

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