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East 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

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Section A: The MSPACE project

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

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

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

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

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

Section B: Regional context

The east inshore marine plan area stretches from Flamborough Head to Felixstowe and extends inshore to the limit of mean high water springs out to the seaward limit of the territorial sea (approximately 12 nautical miles). The east offshore marine plan area extends from the seaward limit of the territorial sea out to the boundary of the Exclusive Economic Zone. The East Marine Plans cover a shallow (<50ms) tidal sea region with predominantly sublittoral coarse or sandy substrates of very low carbon storage capacity (< 0.5 Kg m^2) and no measurable organic carbon (OC) burial. An exception is the Outer Silver Pit, a deep mud (70-80m, 1000 Km^2) region south of the Dogger Bank that can store OC at levels of ~ 1Kg m^2 and burial of between 10 and 30 g C m^2 yr^{-1} Diesing et al. (2020); (Parker et al., 2022).

The plan areas are intensively used by approximately 30 industrial and environmental sectors. Those particularly prevalent in the east marine plan areas relative to other English marine plan areas include:

- carbon capture, usage, and storage (CCUS)
- coastal change and flooding
- dredging and disposal
- hydrogen energy
- marine aggregates
- marine protected areas
- offshore wind energy
- oil and gas
- ports and shipping

Marine sectors in the east marine plan areas are estimated to generate a combined gross value added (GVA) of £27.8 bn and employ over 126,000 people (MMO, 2024). In GVA terms, the renewable energy sector is the largest (£19.5bn) followed by the oil and gas sector (£4.6bn), whilst the aquaculture (£2.6m), commercial fishing excluding fish processing (£24m) and marine recreation (£57m) are the smallest (MMO, 2024). In terms of employment, the renewables sector is again the largest, employing an estimated 59,000 people, whilst the next largest are coastal tourism (~23,700), ports (~13,500), and oil and gas (~11,600) (MMO, 2024).

The east marine plan areas support the UK's commitments to energy security, net zero, economic growth and environmental sustainability. They also play a role in 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, as well as developing CCUS and hydrogen sectors.

The UK Government has pledged to protect at least 30% of land and sea for nature by 2030. The East Marine Plan areas are of significant ecological importance, and include MPA designations for migrating birds, saltmarsh, mudflats, seagrass and oyster beds. The Wash and the Humber are of global importance and the Dogger Bank is the largest sandbank in the UK. Due to the importance of sandeel as prey for a number of species of conservation interest, all sandeel fisheries in the area have been closed since 2024.

The east marine plan areas are particularly busy areas of English waters. The requirements to meet targets and ambitions on net zero, energy security, the environment and obligations under the Fisheries Act (2020) are leading to competition between industries and the environment for space. For example, fisheries are experiencing "spatial squeeze" (ABPmer, 2022), while other activities such as recreational and tourism activities in coastal areas and dredging and cabling offshore may experience restrictions in the future.

The first East Marine Plans were published on 2 April 2014. The second and third Three-year Reports on the East Marine Plans recommended that the plans be replaced. The Marine Management Organisation (MMO) has begun the process to replace the plans, which began with the publication of the Statement of Public Participation in April 2024. It is anticipated that the replacement East Marine Plan will be adopted in Autumn 2027. The Department for the Environment, Food and Rural Affairs (Defra) have established a cross-government Marine Spatial Prioritisation (MSPri) programme to optimise the use of English seas, maximise coexistence and colocation between sea users and prioritise the use of marine space. The MSPri outputs will feed into the replacement East Marine Plan process.

East Marine Plan objectives and any associated key sectoral policies and goals are developed as part of the ongoing development of the replacement East Marine Plans and thus have not been determined. Objectives will be set during the planning process and align with government targets and ambitions. The 2014 East Marine Plans contained explicit objectives for climate change adaptation and mitigation (objective 9), and to realise sustainably the potential of renewable energy, particularly offshore wind farms (objective 3).

Neighbouring North East and South East Marine Plans published in 2021 reflect more recent thinking on climate change and include three climate change specific plan policies:

- CC-1: supports proposals that conserve, restore or enhance habitats that provide flood defence or carbon sequestration, and requires proposals to manage impacts, enabling these important habitats to continue to provide valuable ecosystem services.
- CC-2: adds provision to enable enhanced resilience of developments, activities and ecosystems to the effects of climate change and coastal change.
- CC-3: ensures that proposals do not exacerbate coastal change, enabling communities to be more resilient and better able to adapt to coastal erosion and flood risk where identified.

Other plan policies within the marine plans published in 2021 also mitigate and adapt to climate change. For example, AIR-1 (Air Quality) ensures that proposals consider and address potential direct or indirect air pollution or greenhouse gas emissions. MPA-2 (Marine Protected Areas) ensures that proposals account for adverse impacts on each impacted individual marine protected area's ability to adapt to climate change, and aims to improve resilience to work towards a well-managed marine protected area network. Plan policies have indicators to enable monitoring and evaluation. Monitoring marine plans and plan policies is constantly evolving. Some plan policies, such as CC-2 which ensure that proposals consider their resilience to climate change, do not have indicators.

To determine stakeholder preferences for the use of marine space in England and thereby inform the development of the MSPACE climate-smart spatial management scenarios presented in this document (Sections D.4 – D.6), we used direct survey techniques during remote 1-2-1 interviews conducted from July 2022 through April 2023 (Reinhardt & Danahey Janin, 2025). We gave stakeholders a values questionnaire which asked participants which are active in either conservation, fisheries or aquaculture, to give a numerical value from 0-100 on several criteria associated with marine space. The number given was explicitly meant to represent the value, or level of importance, that the specific element of the marine space represented to them in their professional capacity. We sought this information as these sectors are seen as key stakeholders to the planning process in the East of England. 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 east marine plan (EMP area), 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

England - Sectors	Freq.	Percent
Aquaculture	4	11.76
Aquaculture, Conservation, Fisheries	1	2.94
Aquaculture, Conservation, Fisheries, Other	1	2.94
Aquaculture, Fisheries	2	5.88
Aquaculture, Fisheries, Other	1	2.94
Conservation	4	11.76
Conservation, Fisheries	4	11.76
Conservation, Fisheries, Other	1	2.94
Conservation, Other	2	5.88
Fisheries	7	20.59
Other	7	20.59
Total	34	100

The indicative value rankings of criteria by participants speaking about the East of England are summarised in Table B.2. On average, respondents rated biodiversity and climate change highest.

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	35	81.66	3.07	75.41	87.91
Biosecurity	30	52.53	5.42	41.45	63.62
Climate change	16	81.56	4.75	71.44	91.69
Conservation designation	35	75.11	3.45	68.11	82.12
Economy	33	70.39	4.45	61.32	79.47
Energy	15	63.07	6.70	48.70	77.44
Food provision	33	73.09	3.85	65.25	80.93
Governance	35	79.77	3.27	73.13	86.42
Health	33	59.82	5.19	49.24	70.40

Identity/culture/heritage	32	55.75	4.66	46.25	65.25
Learning and research	34	69.82	4.94	59.78	79.86
Leisure/recreation	30	47.93	4.28	39.18	56.69
Tourism	31	46.16	3.94	38.11	54.21
Transport and shipping	29	60.62	5.33	49.71	71.53
Water quality	32	71.16	4.41	62.17	80.15

Section C: Projected impacts of climate change in the east marine planning areas

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 (e.g. the ecosystem within the site remains within the bounds of its current variability) 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.

Feature of Conservation Interest (FOCI) list: Marine features that are particularly threatened, rare, or declining species and habitats. They were chosen to focus the process used to identify Marine Conservation Zones in England and Wales, and are listed in the Ecological Network Guidance issued by Natural England and the JNCC in 2010.

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

Marine Conservation Zone - MCZ: Marine protected areas designated under legal order made by Defra under section 116(1) of the Marine and Coastal Access Act 2009 (MCAA).

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.

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: Summary of the MSPACE Early Warning System results for the east marine plan areas

The development of scenarios in MSPACE begins with an assessment of climate-driven changes in the UK EEZ. Here, we summarise first the findings of an assessment carried out by the project to identify key challenges and opportunities emerging from climate change for the spatial management of UK seas. Specifically, the MSPACE Early Warning System 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 ("EWS", Queirós et al. 2024). In that report, climate change modelling datasets were analysed as a means to explore the potential to deliver climate-smart spatial management strategies for marine planning across the UK EEZ; that is, strategies that could promote climate change adaptation of marine sectors (including marine conservation) as well as climate change mitigation. The work focused specifically on identifying the location of areas which exhibit long-term sensitivity to climate change (climate change hotspots) and those more resilient to climate change (climate change refugia and bright spots). This was done through analyses designed specifically to estimate climate effects on marine conservation, fisheries and aquaculture, interpreted within the context of the broader UK blue economy. In the Early Warning System, we focused on identifying areas that fell into each of those three categories consistently over the 21st century, in both emissions 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 fisheries and aggregate extraction on UK habitats and species. In the EWS, we also explored how climate change effects relate to the distribution of those other pressures on seabed habitats, and that cumulative assessment can be found in the main report here.

What follows is a summary of the key findings outlined in the EWS report which are relevant to the east marine plan areas. When considering the locations of long-term climate change hotspots and refugia with high agreement between emissions scenarios, we found that the EMP areas are projected to be sensitive to climate change, with few long-term climate change refugia emerging for the three focal sectors (marine conservation, fisheries and aquaculture), when two emissions scenarios were considered together.

C.2.1 Climate change impacts on marine species and habitats in the EMP areas

Looking at the marine protected area (MPA) network across the EMP with a focus on biodiversity, it is likely that current conservation sites may not continue to provide the same benefits to designated features in the future as climate change unfolds across the region. This is due to the extensive distribution of climate change hotspots found to emerge for benthic and pelagic habitats, and benthic and pelagic megafauna, throughout the planning area (Figure C.1). However, focusing on seabed habitat conditions promoting carbon sequestration (see Queirós et al. 2024; Supplementary Information Table S3 for variables included in this analysis), we found that refugia for such "climate services" (Benyon et al., 2020; Flavell et al., 2020) emerged across the majority of the planning area, including some areas with comparatively high organic carbon content such as the Outer Silver Pit (Figure C.2), a habitat of deep circalittoral mud which is moderately to highly affected by mobile bottom contacting fishing gears at present (Queirós et al. 2024; Annex 2). Those areas hold promise with regard to the siting of protected areas that could help deliver resilient climate change mitigation.

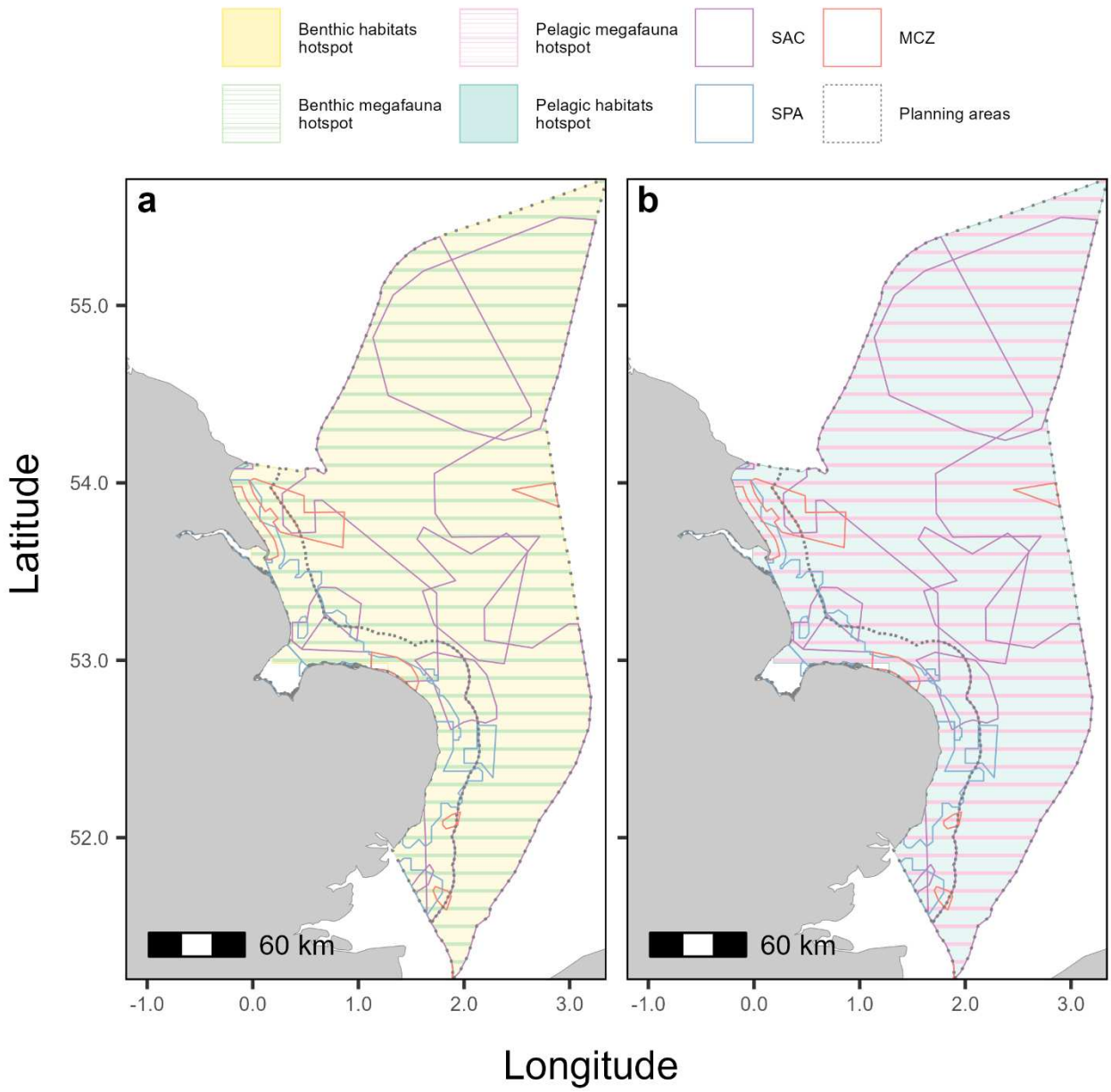

Figure C.1: Locations of climate change hotspots affecting the conservation of benthic habitats and megafauna (a) and pelagic habitats and megafauna (b) where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System. For a list of modelling datasets used in these analyses, please see Queirós et al. 2024; Supplementary Information Table S3.

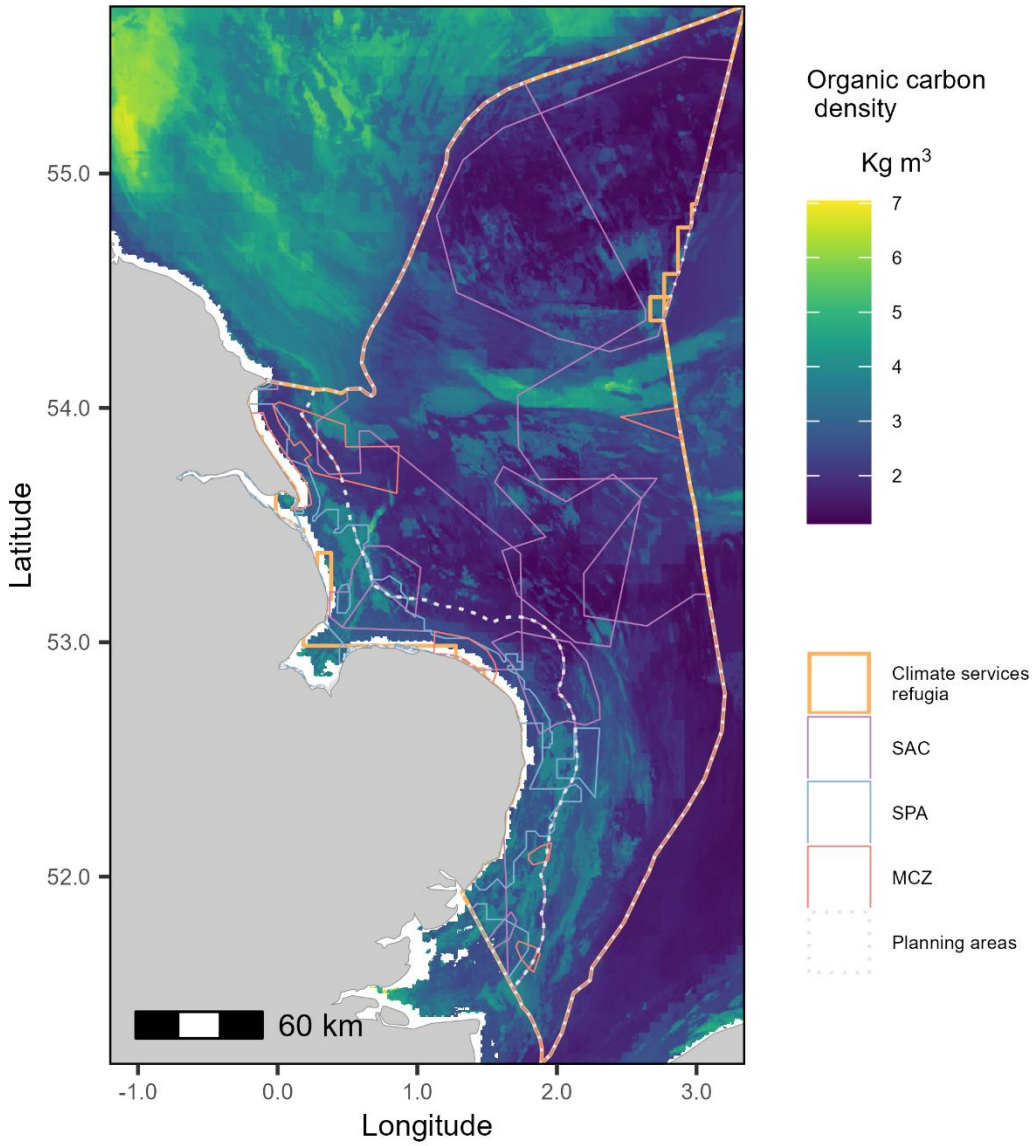

Figure C.2: Location of climate change refugia affecting marine conservation, along with an estimate of organic carbon content of the sediment (data from Diesing et al, 2021). The only refugia identified where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System was for climate services. For a list of modelling datasets used in these analyses, please see (Queirós et al. 2024; Supplementary Information Table S3).

C.2.2. Climate change impacts on marine fisheries and aquaculture in the EMP areas

Based on the EWS analyses, we find that demersal capture fisheries and seafloor and water column aquaculture (based on the current target species, Queirós et al. 2024; Supplementary Information Table S4) could be particularly vulnerable to climate change in the EMP area, as hotspots for these sectors were found to emerge across the majority of the planning area (Figure C.3). This would suggest that abundances of key species such as cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), and haddock (*Melanogrammus aeglefinus*) targeted by capture fisheries may decrease in the future, although hake (*Merluccius merluccius*) abundances may increase. Similarly, conditions for production

of important aquaculture species such as mussel (*Mytilus edulis*) may be less favourable. However, a refuge for pelagic fisheries is apparent across much of the planning area (Figure C.4), with abundances of species such horse mackerel (*Trachurus trachurus*) projected to remain climate-resilient into the future.

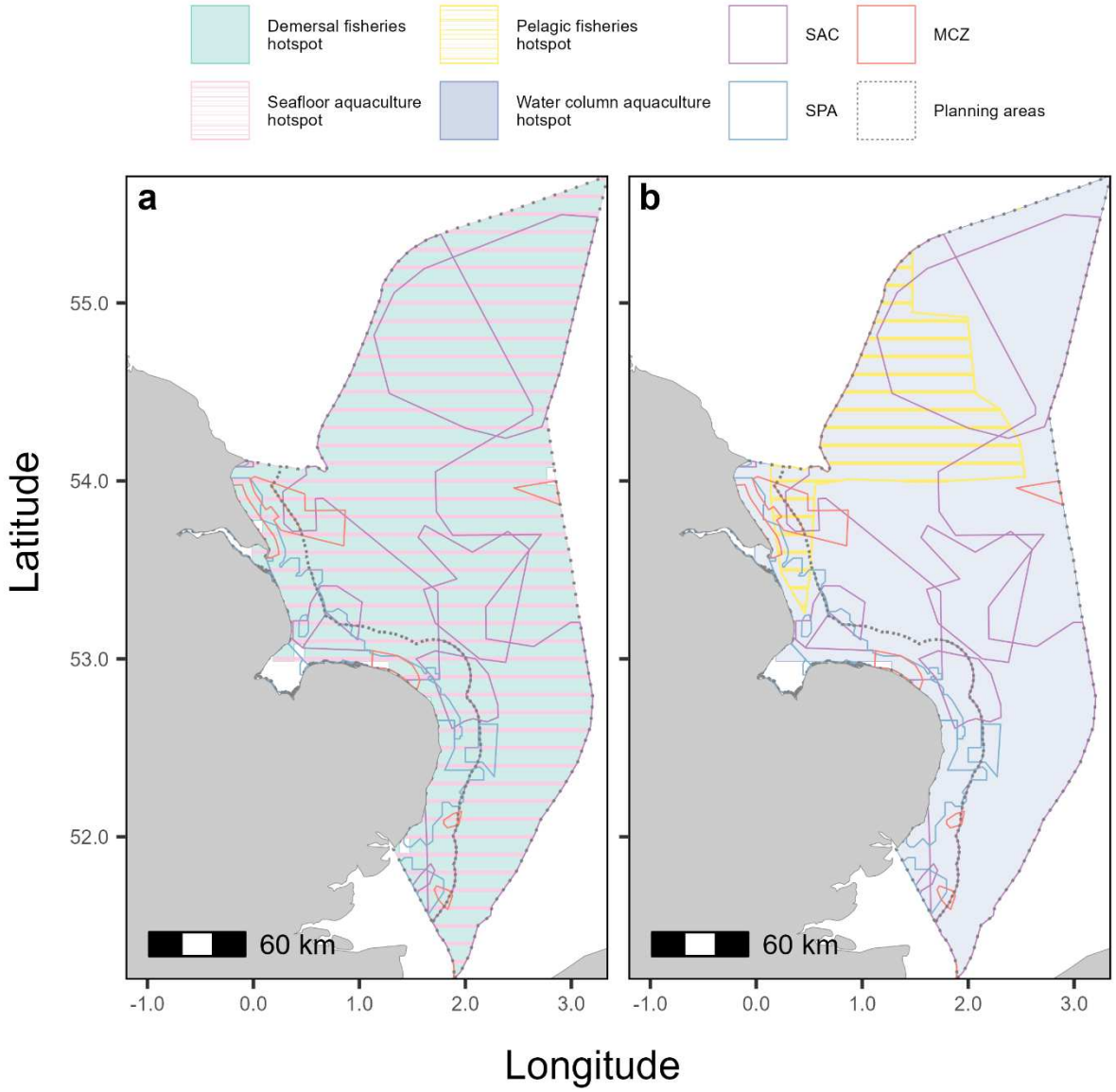

Figure C.3: Locations of climate change hotspots affecting the climate-resilience of demersal capture fisheries and seafloor aquaculture (a) and pelagic capture fisheries and water column aquaculture (b) where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System. For a list of modelling datasets used in these analyses, please see Queirós et al. 2024; Supplementary Information Table S4.

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 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. For this reason, in Section D below, **we consider EWS evidence for long-term climate change refugia emerging only under the moderate emissions trajectory RCP4.5,** as this is 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).

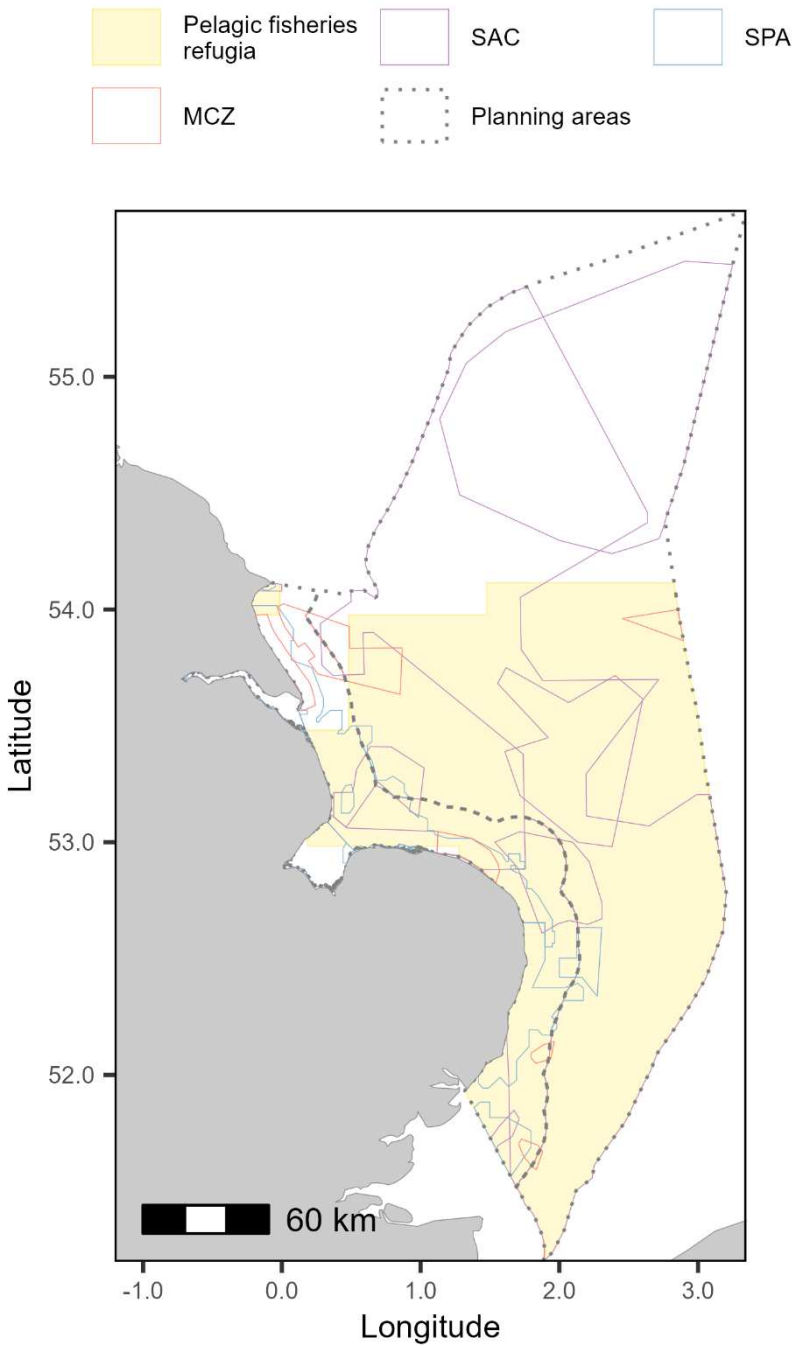

Figure C.4: Location of climate change refugia relevant to the climate-resilience of pelagic fisheries (there were no other fisheries or aquaculture refugia present in the EMP area, see main text for details), where there is high agreement between the two emissions scenarios (RCP4.5 and RCP8.5) considered in the MSPACE Early Warning System. For a list of modelling datasets used in these analyses, please see Queirós et al. 2024; Supplementary Information Table S4.

Section D: The MSPACE scenarios for the East Marine Plan

D.1. Scenario overview

We now outline four scenarios, co-developed with stakeholders in the region (Table A1, Annex 2), representing possible alternative futures for 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. These scenarios therefore represent alternative, hypothetical ways through which the potential for climate change adaptation and mitigation of marine wildlife and sectors in the EMP area could be encouraged through planning actions. They are expected to lead to different ecological, social and economic outcomes for the region, based on climate change impacts and opportunities. These scenarios are based on general formulations described in Annex 1, as follows:

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

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

2. **The Conservation Scenario:** prioritises climate change adaptation for the conservation sector (i.e. marine conservation and restoration), and the protection of areas delivering 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 EMP area where they occur in climate change refugia, and 2) areas which at present hold important carbon stocks (derived from observations) and which are projected to have climate resilient seabed carbon sequestration potential in the future.
3. **The Food Provision Scenario:** prioritises climate change adaptation for the fishing and aquaculture sectors. The spatial interventions outlined in this scenario aim to support and safeguard climate-resilient fisheries and to facilitate the development of climate-resilient aquaculture in the EMP area, by prioritising the access of these sectors where their resources occur in climate change refugia.
4. **The Compromise Scenario:** aims to promote a balance of improved outcomes for the conservation and food provision sectors, with a view for what other priorities stakeholders hold for the region with regard to other sectors of economic activity (Section B). The interventions considered aim to support climate-resilient fisheries, facilitate the development of climate-resilient aquaculture and seek to avoid, minimise or mitigate the impacts of activities which could negatively affect habitats and species of conservation interest in the EMP area. These aims are supported by prioritising access to areas of climate change refugia for each sector, or by prioritising conservation objectives where designated conservation areas overlap with climate change refugia. It is expected that the Compromise Scenario may meet a broader set of objectives with regard to stakeholders in the EMP area.

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

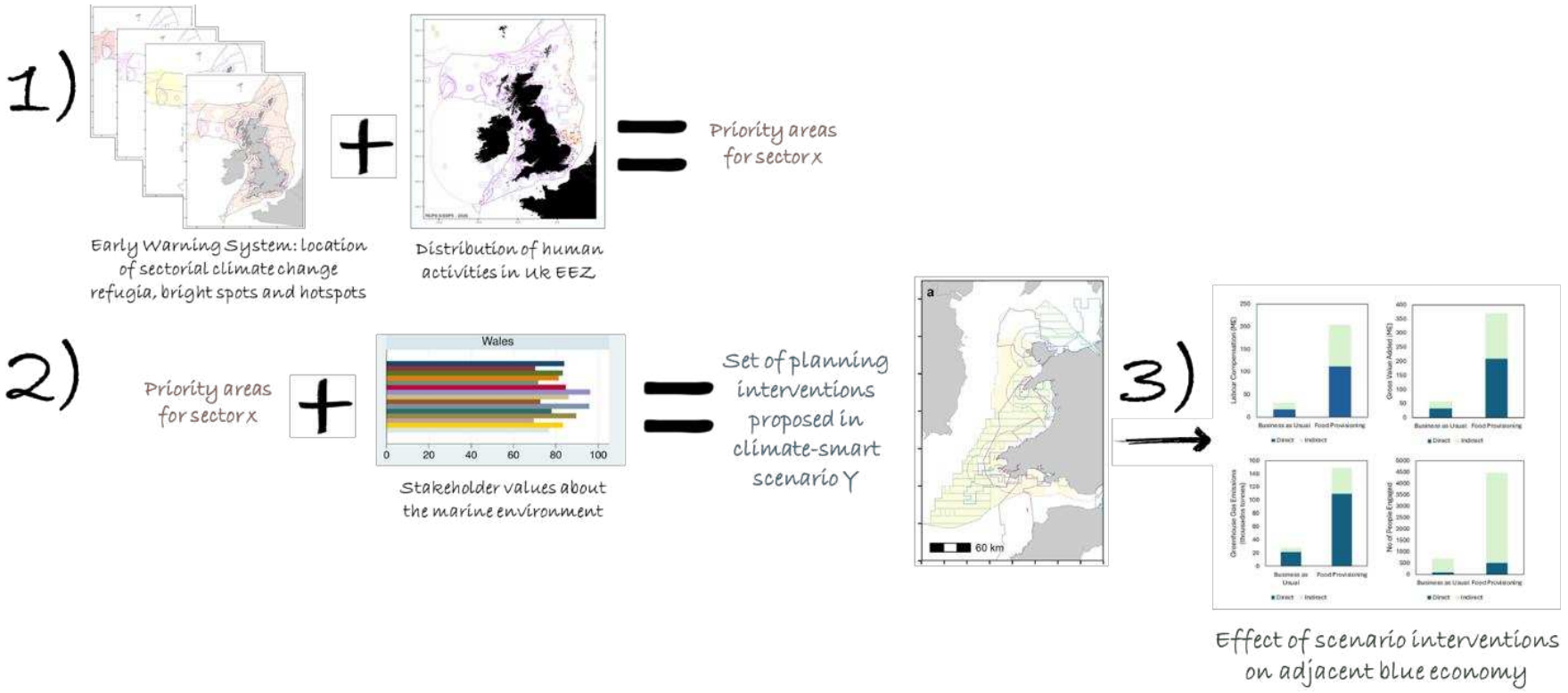

Figure D.2.1: Schematic representation of climate-smart scenario co-development. Stakeholders were consulted during all stages of co-development.

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 Km^2) could be lost to fisheries due to the development of the site? In such cases, it is possible that area lost to one sector due to the development of new activities by another would be strongly impacted by climate change effects on the first sector regardless, and these effects of climate change on cross-sector interactions are accounted for in our economic estimates (Figure D.2.1 3; Annex I). In this way, we attempt to identify possible conflicts and trade-offs between sectors, while also considering the overall climate effect on each MSPACE focal sector in the planning area. Once the spatial effect of each management scenario had been calculated (e.g. the area in Km^2 identified as priority areas or area lost for each sector), it was then possible to model the economic effect of each scenario (Figure D.2.1 3).

D.2.2. Economic analysis

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

The economic modelling method deployed is termed Input-Output modelling and focuses on how changes to the input (or resource) used by a given sector (e.g. changes in wild capture fisheries catch) affect economic metrics for that sector, as well as other sectors within that economic structure, both directly and indirectly (Roca Florido et al., 2025). Based on data availability emerging from extensive data searches at the UK and devolved nation level and co-development with stakeholders, the economic model has 19 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 8 of the 19 sectors (Roca Florido et al., 2025, Table 4). Whilst the renewable sector in particular is seen as a key sector in England, 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 England, since the outputs of that sector are not affected by individual scenarios co-developed in MSPACE, 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. As standard, the input-output table captures the value of all landings at ports in the EMP, regardless of where the fish are caught. Therefore, the table is adjusted to account for the fact that the scenarios only cover fish species caught within the EMP areas. Logbook data from MMO suggests that ~67% of East of England landings by value are demersal and benthic species caught within the EMP areas, and <1% of landings are pelagic species caught within the EMP areas. Output values for the relevant fishing fleets are therefore scaled in our analyses such that we do not account for catches from outside of the EMP landed within the EMP ports. 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 east of England blue economy. These estimates capture both the direct and indirect effects resulting from simulated changes in the area of activity (i.e. resource use) of the fisheries, aquaculture, and/or marine conservation sectors, based on detailed marine sectoral mapping presented in Roca Florido et al. (2025). Specifically, for each sector, we estimate labour compensation as the total cost of employment to an employer, including wages, overtime, pension contributions, employers national insurance contributions and other costs associated with employment. We also estimate the Gross Value Added (GVA), that is, labour compensation plus gross operating surplus plus taxes less subsides. Furthermore, we estimate greenhouse gas emissions of carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons, sulphur hexafluoride, nitrogen trifluoride in carbon equivalent resulting linearly from changes in activity of each sector, based on those direct and indirect effects. We also estimated, per sector, the number of persons engaged in the sector as the number of people employed, whether full or part time.

D.3: The Business as Usual Scenario (BAU)

This scenario estimated the effects of climate change within the East Marine Plan area if no additional climate-smart spatial management measures are implemented. Therefore, no additional spatial interventions are simulated 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 East Marine Plan areas under RCP4.5, as found in Chapter 3.1 of Queirós et al. 2024. Analyses focussed on those modelled variables that describe benthic and pelagic habitats, habitats and prey of value to benthic and pelagic megafauna, and climate services. Within the EMP area, climate change hotspots (hereafter, "hotspots") for pelagic habitats, pelagic megafauna and benthic habitats cover the majority of the planning areas, while hotspots for benthic megafauna cover the northern part of the marine planning areas, off the coasts of Lincolnshire and Yorkshire (Figure D.3.1, Table D.3.1). It is therefore possible that conservation areas falling within these 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); the majority of the planning area falls within a refuge for climate services, perhaps indicating a promising picture towards the current interest of using the UK marine protected area (MPA) network to deliver climate services when coupled with areas of high sedimentary organic carbon levels (Benyon et al., 2020; Flavell et al., 2020). It should be noted however, that observational data available for the validation of the numerical modelling data used for 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).

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

Climate change impact	Potential ecological effects	Expected economic effects
Conservation: • Widespread climate change hotspots for benthic habitats, pelagic habitats and pelagic megafauna • Climate change refugia for benthic megafauna cover the northern part of the planning area • Widespread climate change refugia for climate services	**Conservation:** • 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	35% decrease in labour compensation and GVA is projected under this scenario, along with a 34% decrease in the number of people employed in the fisheries sector, and a 62% decrease in GHG emissions
Fisheries: • Widespread climate change hotspots for demersal and benthic fisheries	**Fisheries:** • Abundances of key demersal species likely to decline in demersal fisheries hotspots	

• Widespread climate change refugia for pelagic fisheries	• Abundances of key pelagic fisheries likely to remain resilient in pelagic fisheries refugia	
Aquaculture: • Widespread climate change hotspots for seafloor and water column aquaculture • Climate change refuge for seafloor aquaculture off the Suffolk coast	**Aquaculture:** • Potential for sectoral expansion into refugia for seafloor aquaculture	

Focussing on biodiversity conservation, identified refugia for benthic megafauna overlap with a number of SACs and MCZs, including: substantial parts of the Dogger Bank SAC and Holderness Offshore MCZ; all of Markham's Triangle MCZ; North Norfolk Sands and Saturn Reef SAC; and Haisborough, Hammond and Winterton SAC. The seabed in these areas is predominantly composed of coarse sediment and sand (Annex 2, Figure A.2), and they have all been assessed as having low or moderate disturbance from demersal trawling at present (Queirós et al, 2024; Annex 2). Additionally, parts of Dogger Bank and North Norfolk Sands and Saturn Reef SACs; and Holderness Offshore MCZ are affected by artificial light a 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). Biologically relevant light penetrates the water column to a depth of >10m in these areas (Figure D.3.3), adding additional pressure to marine habitats and species beyond climate change and the above noted seabed impacts. Refugia for benthic habitats were identified in inshore areas off the Norfolk coast and a single offshore refuge was identified towards the edge of the planning area (Figure D.3.2, Table D.3.1). None of these benthic habitat refugia overlap with conservation areas designated for benthic features, although the refuge off the coast of Lowestoft is situated within the Outer Thames Estuary SPA. Again, the seabed in these refugia has been assessed as having low or moderate impacts from fishing, although there is some moderate impact from aggregate extraction in the nearshore refugia (Queirós et al, 2024; Annex 2). In these areas harbouring refugia, the ecosystem may continue to function in a comparable way to the present day under RCP4.5, suggesting that conservation areas which overlap with refugia may continue to be effective into the future.

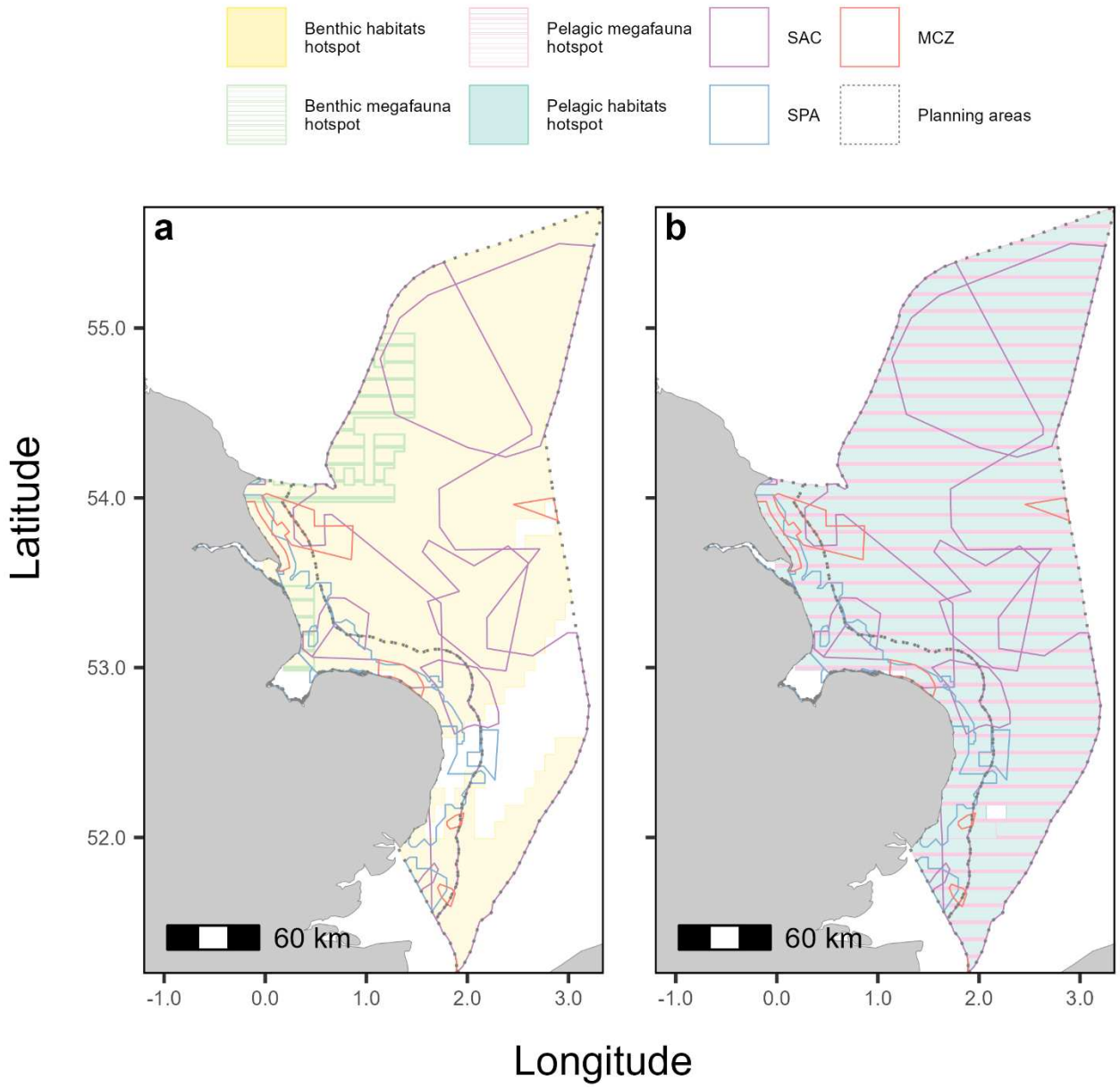

Figure D.3.1: Business as usual scenario with locations of climate change hotspots of relevance to marine conservation in the EMP area. Hotspots for benthic habitats (yellow shading, panel a), pelagic habitats (blue shading, panel b) and pelagic megafauna (pink stripes, panel b) cover the majority of the planning area. Hotspots for benthic megafauna (green stripes, panel a) are only apparent to the north of the planning area, off the coasts of Lincolnshire and Yorkshire.

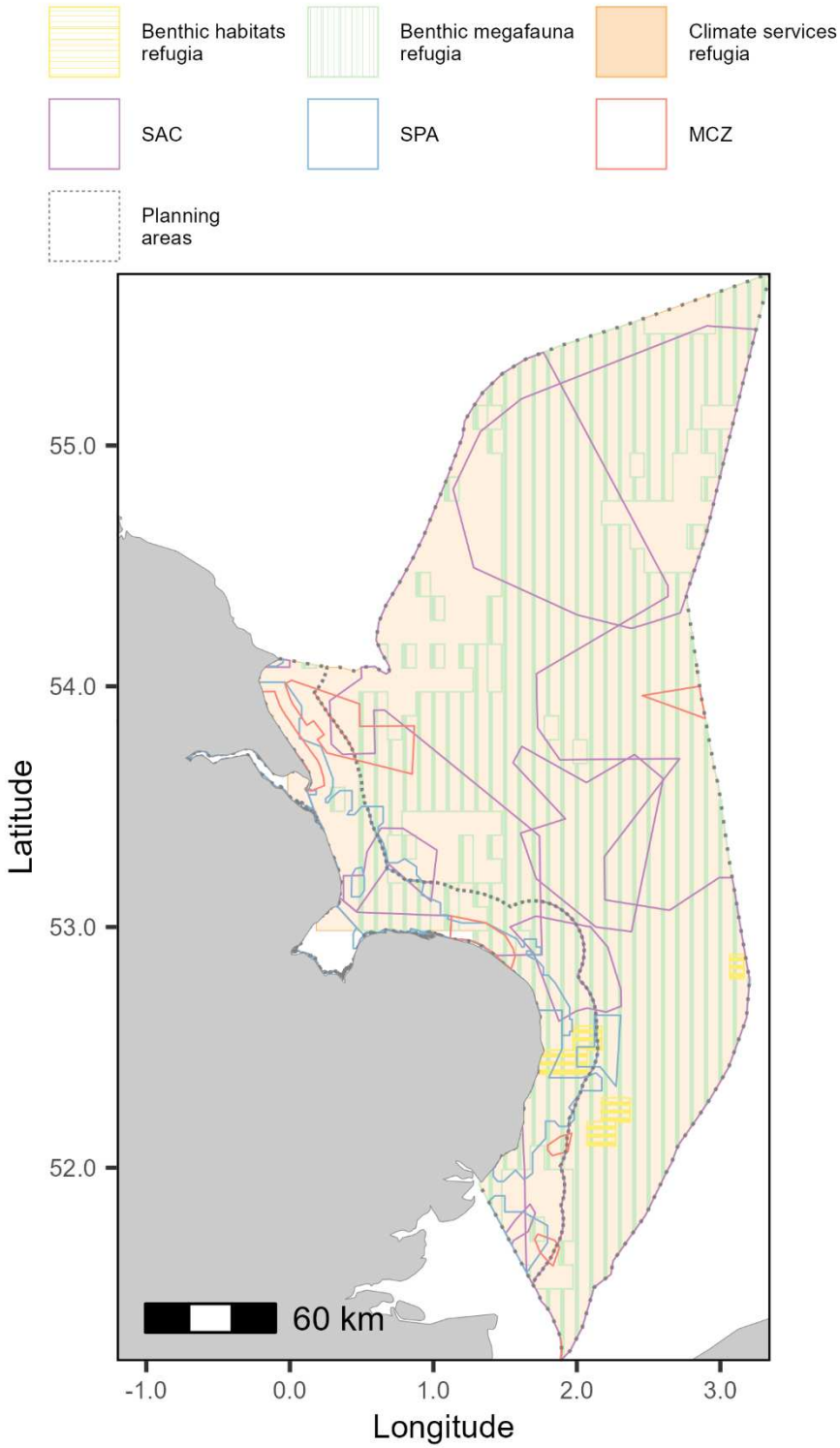

Figure D.3.2: Business as usual scenario with locations of conservation refugia. The whole of the planning area is a refuge for climate services (orange shading), and a large part of the area harbours refugia for benthic megafauna (green stripes). Refugia for benthic habitats (yellow stripes) are less widely distributed however.

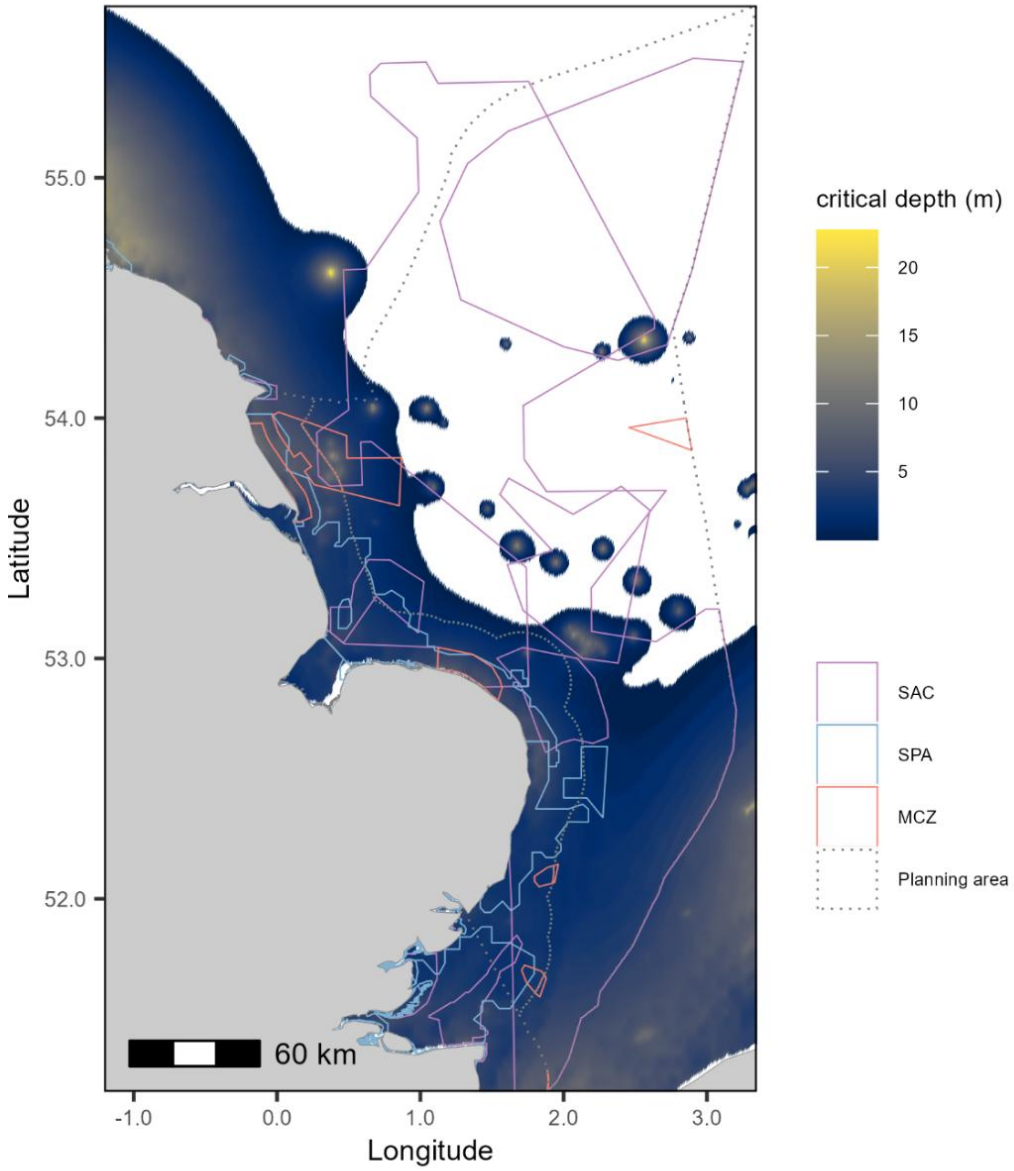

Figure D.3.3: Depth to which biologically relevant artificial light levels penetrate the water column (data from Smyth et al., 2024), along with the locations of designated conservation sites. Areas of high artificial light at night pollution may affect the shallower (e.g. 10-15m) regions of areas identified as climate change refugia for benthic megafauna or benthic habitats.

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 aquaculture species (sugar kelp *(Saccharina latissima)*, blue mussel *(Mytilus edulis)* and salmon (*Salmo salar*), and a range of modelled environmental data to represent key drivers of other target species distributions.

Identified food provision climate change hotspots cover a large part of the EMP area, with water column aquaculture hotspots encompassing the whole of the planning area, and demersal fisheries and seafloor aquaculture hotspots covering a significant part of the East Marine Plan area (Figure D.3.4, Table D.3.1). Demersal capture fisheries may therefore see losses in the future as abundances of key commercial species such as Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aegelfinus*) and plaice (*Pleuronectes platessa*) decline, but pelagic fisheries may remain resilient into the future, as the majority of the planning area is covered by a refuge for this sector (Figure D.3.5, Table D.3.1). Aquaculture facilities in the EMP area are in very nearshore coastal areas, which are not covered by the modelling data used in our analyses, so we cannot determine how climate change will affect production in these facilities moving forward. There is some possibility for seafloor aquaculture to expand into unexploited areas off the Norfolk coast, due to a climate change refuge in that area for the sector (Figure D.3.5). It should be noted that analyses for fisheries and aquaculture are based on the current catch distribution for fisheries and the production of the aquaculture sector in the UK. Results presented here do not take into account the role of new species that may become valuable for both sectors in future, as they move into the area as a result of climate change, due to uncertainty of their potential value for consumers or fleet adaptation needs (Queirós et al., 2024).

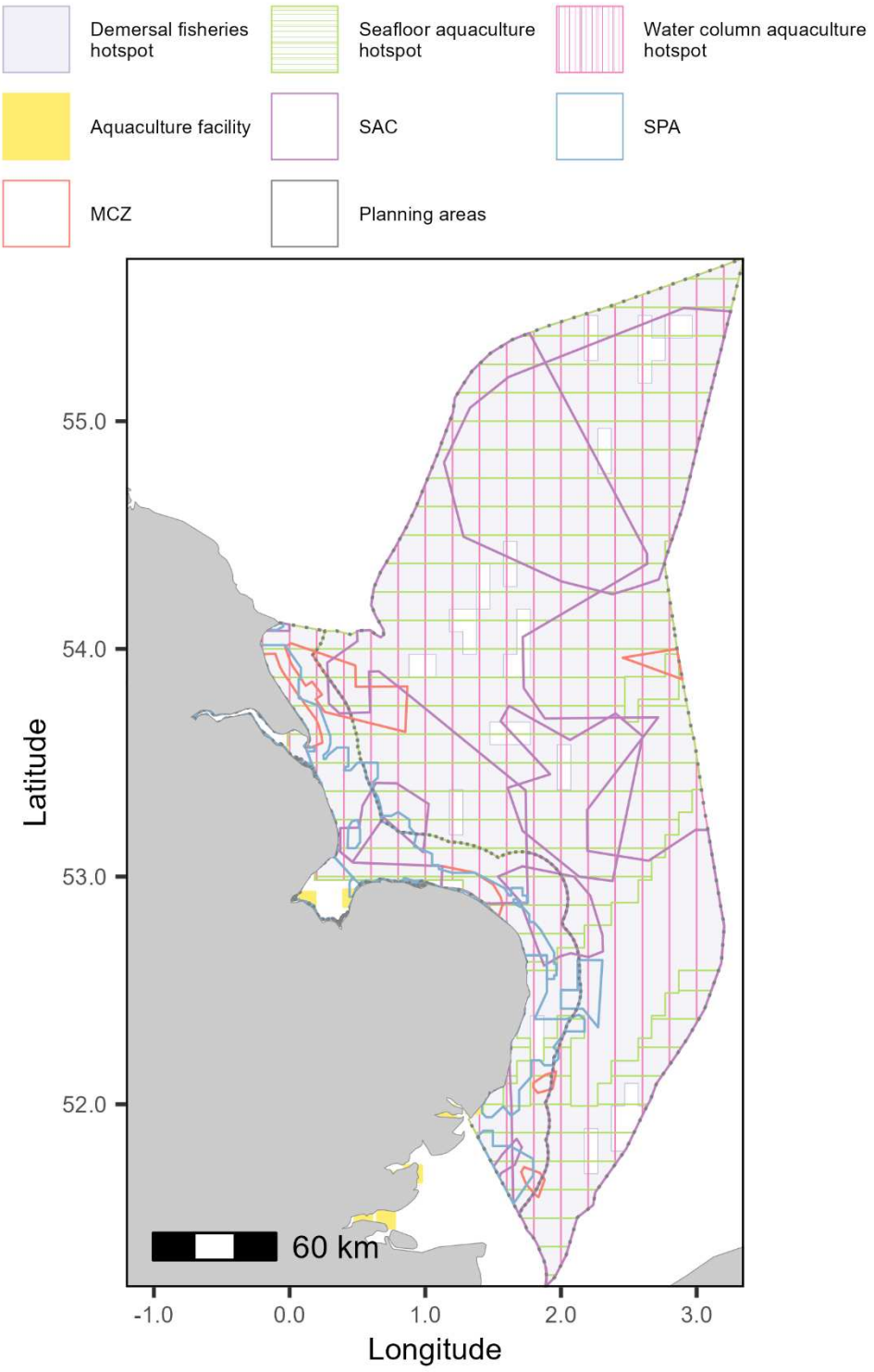

Figure D.3.4: Business as usual scenario with locations of food provision hotspots. The majority of the planning area harbours hotspots for demersal fisheries (lilac shading), seafloor aquaculture (horizontal green lines) and water column aquaculture (vertical pink lines).

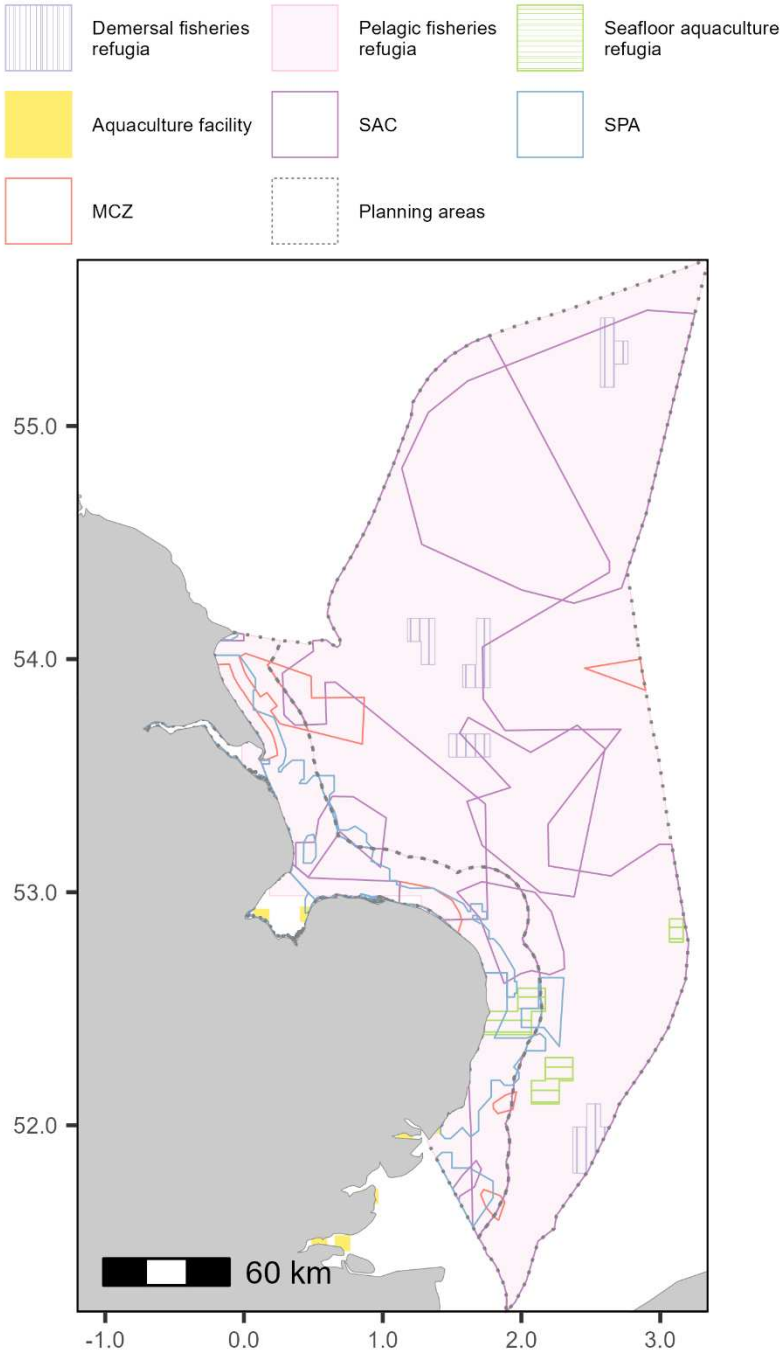

Figure D.3.5: Business as usual scenario with locations of food provision refugia. The whole of the planning area harbours a refuge for pelagic fisheries (pink shading), while some smaller refugia for demersal fisheries (vertical blue lines) are distributed across the EMP area. Refugia for seafloor aquaculture (horizontal green lines) are primarily limited to the coastal regions near Lowestoft.

D3.2 Economic outcomes for the adjacent blue economy

The Business as Usual Scenario represents a significant climate-driven loss to the marine economy in the EMP area, which makes a case for more climate-smart actions through planning. We estimate that hotspots could represent as much as 95% of area available to be fished for the demersal and benthic fleets within the marine plan area, based on the current catch composition from inside the EMP area. We note here again that catch landed in ports within the EMP area but caught outside the planning area is not accounted for in the economic modelling presented here, and that estimates are

based on the assumption that catch is equally distributed in each ICES statistical rectangle in the plan area accessible to the fleets, which is a necessary simplification. Consequently, this results in an approximately 95% reduction in demersal and benthic catch, given the species considered. This translates to reductions of around 35% in labour compensation, gross value added, and number of employees engaged, and around a 60% reduction in greenhouse gas emissions (Figure D.3.6) associated with fishing and aquaculture employment in the base case. The discrepancy between reductions in demersal and benthic catch and the impact indicators is in part due to the fact that aquaculture is a significant contributor to all indicators, and is unaffected by climate in our modelling. The biggest reductions are in the demersal and benthic fleet itself, though warehousing and wholesale sectors also see significant reductions, as does manufacture of prepared animal feed.

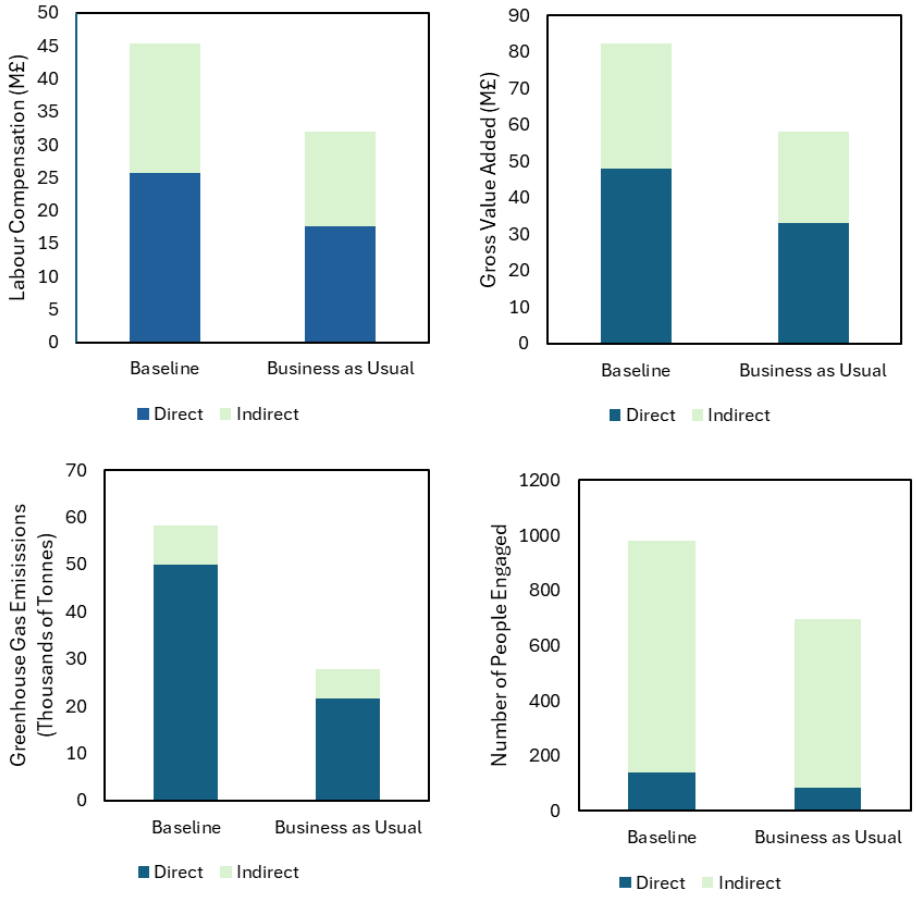

Figure D.3.6: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Business as Usual Scenario.

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 East Marine Plan area. Simulated interventions are located in climate change refugia for benthic habitats or megafauna (see Section D, Figure D.3.2. for locations of these refugia).
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 (see Section D, Figure D.3.2. for locations of these refugia).

The draft list of interventions considered below as a planning scenario was co-developed with key team members at the MMO involved in the EMP review, and representatives of the wild capture fisheries, aquaculture and offshore renewable industry in order to ensure that they were well aligned with the current needs of those reviewing and implementing the East Marine Plan.

The spatial interventions C1 and C2 below have the purpose of avoiding, minimising or mitigating the impacts of activities which could negatively affect benthic megafauna species of high conservation interest and the future provision of climate services (respectively) in the EMP area (Table D.4.1). In this hypothetical planning scenario, we simulate that these aims would be supported by additional byelaws by the MMO and DEFRA, potentially setting limits on access to identified priority areas for conservation to mobile demersal gears where it is still allowed. Furthermore, we simulate that offshore renewable energy development in some priority areas may be limited, and that this aim is supported by engagement of English planning and licensing authorities with the Crown Estate to ensure that these areas are not leased in future seabed bidding rounds.

Intervention C1: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for benthic megafauna identified in Dogger Bank, North Norfolk Sands and Saturn Reef and Haisborough, Hammond and Winterton SACs; and Holderness Offshore and Markham's Triangle Marine Conservation Zones (MCZ). 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, and which fall within already designated protected sites. These priority areas are used by a number of demersal sharks, skates and rays (Sguotti et al., 2016; Annex 2, Figure A.1), 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*).

Intervention C2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority area for climate services identified in the Outer Silver Pit. We identified a priority area for protection of blue carbon habitat in the Outer Silver Pit. This area is currently outside the marine protected area (MPA) network, but given the relatively high organic carbon (OC) content in the sediment in this area (Figure D.4.1), we highlight it as an area that could be beneficial for the future provision of climate services. It is worth noting however, that at present, English MPAs cannot be designated solely for the protection of blue carbon habitat.

Table D.4.1: Summary of spatial interventions C1 and C2 proposed in the planning 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 EMP 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	Expected ecological effects	Expected economic effects
C1: Avoid, minimise or mitigate activities which could be incompatible with the conservation of priority areas for benthic megafauna identified in Dogger Bank, North Norfolk Sands and Saturn Reef and Haisborough, Hammond and Winterton SACs, and Holderness Offshore and Markham's Triangle MCZs.	C1: Avoiding, minimising or mitigating the impacts of demersal trawls on several elasmobranch species of conservation interest could maximise the effectiveness of the identified climate change refuge in promoting the climate change resilience of these species. C1: Avoiding, minimising or mitigating the impacts of offshore wind development in the identified priority areas could act to avoid direct impacts of development on designated features and mitigate the impacts of development elsewhere in the EMP areas (e.g. providing compensatory measures).	When compared to the Business as Usual Scenario, there is an additional 1% loss labour compensation, GVA, and in the number of people directly employed by the fishing sector. There is also a 1% decrease in GHG emissions.
C2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for climate services identified in the Outer Silver Pit.	C2: Avoiding, minimising or mitigating negative impacts on the seabed in areas where sediment has a high carbon sequestration potential may limit direct carbon release and degradation (avoided emissions) from disturbed sediment or allow service recovery.	
	C1 and C2: Avoiding, minimising or mitigating seabed disturbances in identified priority areas could benefit the condition of wrecks in those areas.	

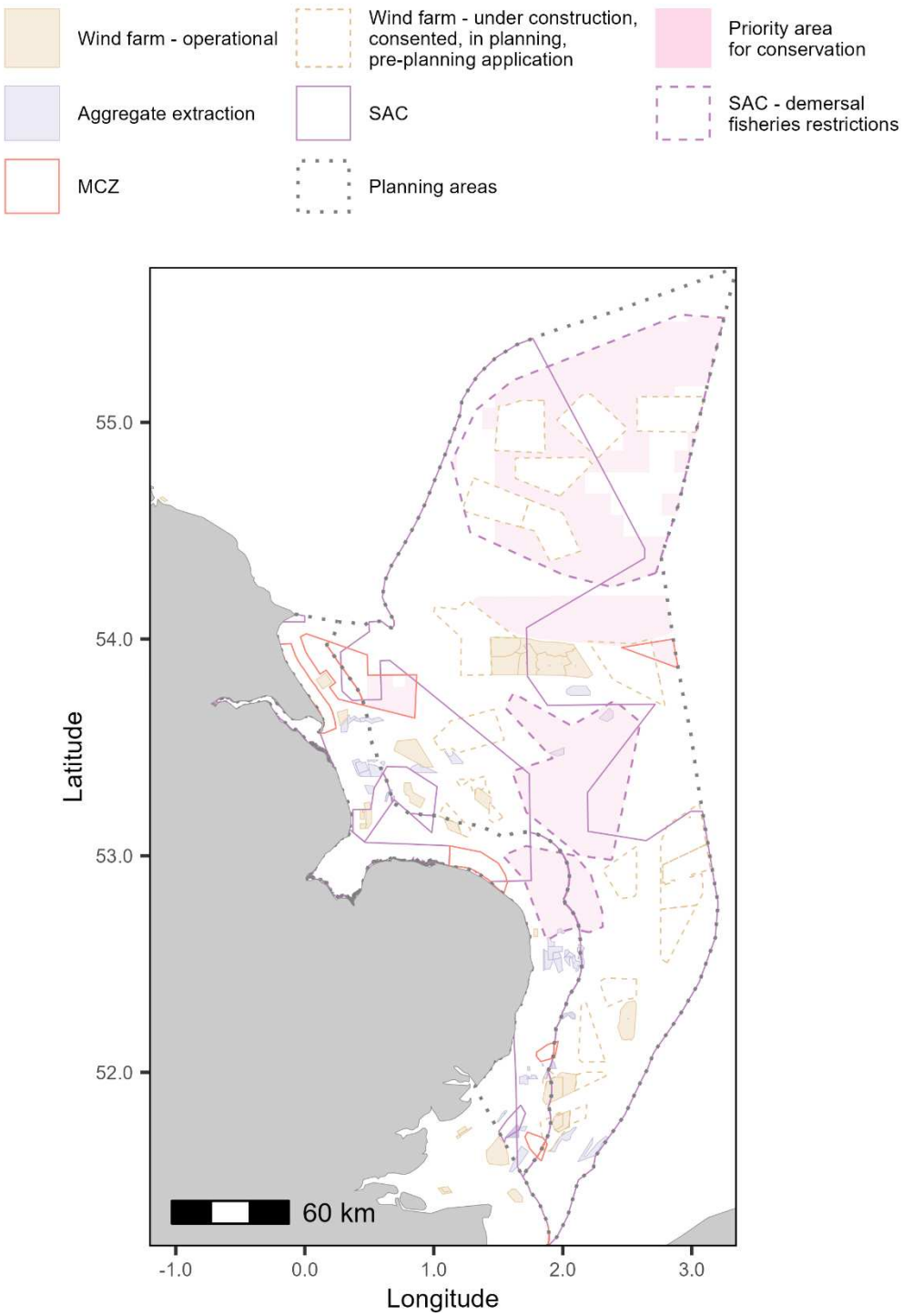

Figure D.4.1: Conservation Scenario highlighting priority conservation areas. Note that the priority area for climate services located in the Outer Silver Pit is outside the current MPA network.

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

Both of the simulated spatial management interventions listed above could result in the potential exclusion of vessels fishing with mobile demersal gears from priority areas for conservation. As noted

in section D3.1, vessels operating these gears are already prohibited from fishing in the Dogger Bank, North Norfolk Sands and Saturn Reef and Haisborough, Hammond and Winterton SACs. The proposed priority areas harbour refugia for benthic megafauna, 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). There is also some evidence that long-term survival of discarded skates and rays in the North Sea is lower than previously reported (Van Bogaert et al., 2020), so minimising bycatch of these species in fisheries targeting other stocks could be desirable in a scenario that maximises outcomes for conservation areas in refugia. In addition to any possible benefits conferred to sharks, skates and rays, the simulated interventions may also support the recovery to favourable condition of the designation features in the MPAs in which the priority areas sit. For example, in the Holderness Offshore and Markham's Triangle MCZs, the subtidal coarse sediment, subtidal sand, subtidal mud, subtidal mixed sediment and communities of the Ocean Quahog *(Arctica islandica,* Holderness Offshore only*)*, for which the sites were designated have been assessed as being in unfavourable condition (JNCC, 2021a, 2021b). Intervention C1 could therefore support the recovery and resilience of sharks, skates and rays of conservation and commercial interest in the EMP area, as well as helping to fulfil the conservation objectives of the MPAs in which they sit. In the case of the priority area identified for climate services in the Outer Silver Pit, it is possible that intervention C2 may limit direct carbon release and degradation (avoided emissions) from disturbed sediment. 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 even though the outcomes are complex (Epstein et al., 2022; Epstein & Roberts, 2022; Jankowska et al., 2022).

Large-scale offshore wind energy (OWE) developments may interact with benthic species and habitats of conservation importance. The expansion of offshore wind in the EMP area may therefore increase the cumulative risk of negative effects on the integrity of protected sites and species populations. Given that it may not be possible to avoid or mitigate against adverse effects on designated conservation sites, the provision of compensatory measures (i.e. measures taken to offset the negative impacts of developments/activities on habitats and species in conservation areas, such as setting aside sites with similar habitats) will be required (Department for Energy Security & Net Zero, 2025; Ward, 2022). Both interventions C1 and C2 could result in limitations on OWE development in priority areas as a way to deliver compensatory measures for development of energy infrastructure elsewhere in the marine planning areas. For example, the North Norfolk Sands and Haisborough, Hammond and Winterton SACs could be particularly useful as compensation sites for currently planned wind development elsewhere in the EMP area (especially the extensive development on the Dogger Bank), given the broad similarity in habitat type and mobile epifauna communities found at these sites (Annex 2, Figure A.2).

It should be noted that some parts of the proposed priority areas in the Dogger Bank and North Norfolk Sands SACs are affected by artificial light (ALAN) pollution as a result of the oil and gas infrastructure that is located in these areas (Figure D.4.2). Biologically relevant levels of light reach a depth of 10-15m in these areas, suggesting that in the shallower parts of affected sites, artificial light could be reaching the seabed, representing an additional pressure over and above that already provided by climate change (fishing with mobile demersal gears is already prohibited in these SACs, so there is no additional seabed disturbance from trawling). However, given that some of the infrastructure in both of these SACs is slated to be decommissioned in the future (One-Dyas, 2021), it is possible that ALAN pollution may become less of a feature in these sites, as infrastructure is either removed, or if left in place, lighting will be limited to that required to aid navigation of passing vessels, rather than full operational lighting.

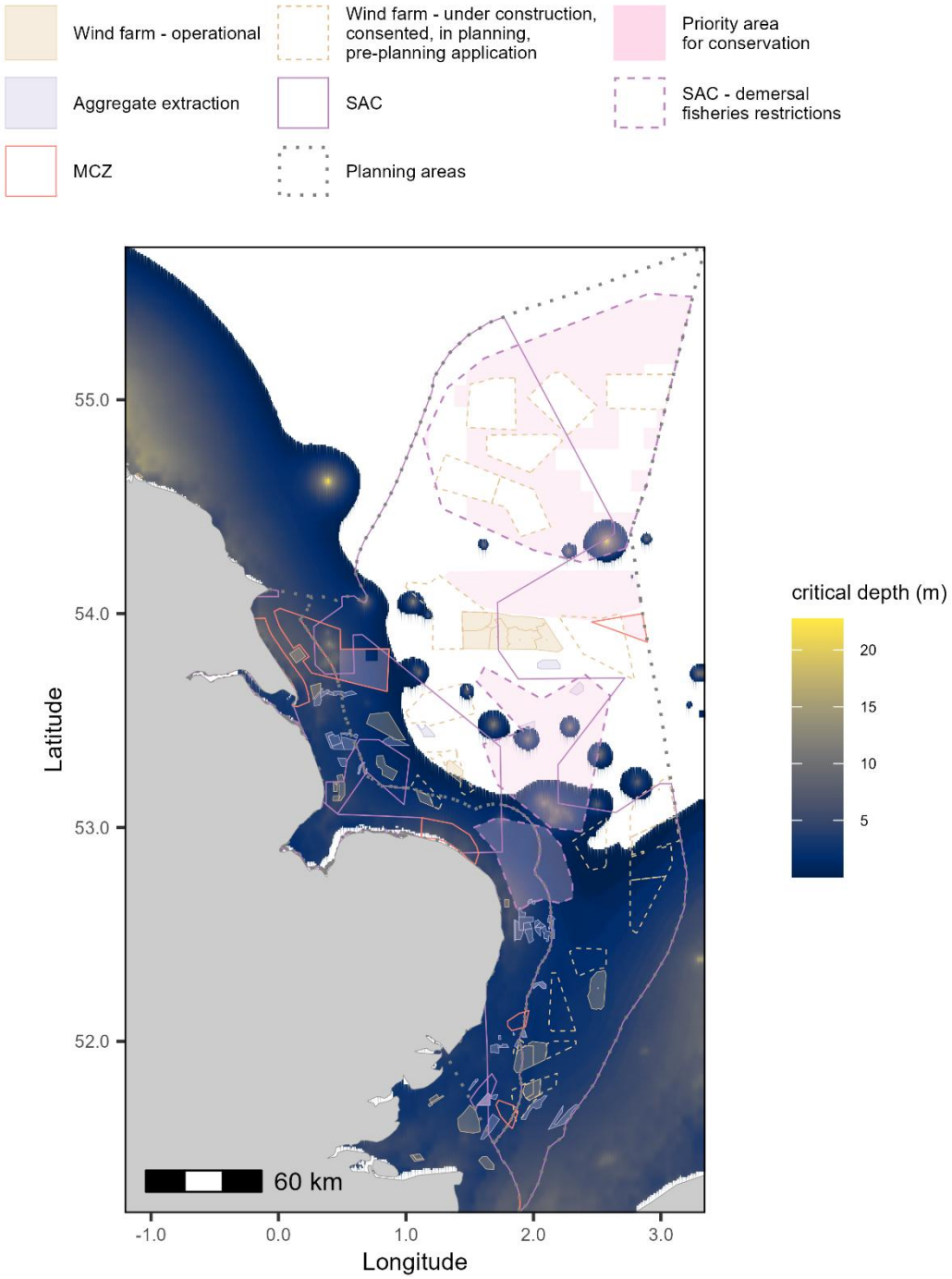

Figure D.4.2: Proposed conservation scenario showing the possible depth distribution of biologically relevant artificial light (critical depth). Data from Smyth et al. (2024). Identified priority areas are affected by ALAN to some degree - in the shallower parts of affected areas, artificial light could be reaching the seabed, representing an additional pressure over and above that already provided by climate change. See main text for full details.

While we did not evaluate the effects of climate change on heritage assets directly, we do account for possible effects of the simulated interventions on heritage assets in the area. The identified priority areas contain 368 wrecks (please note that “wreck” in this context denotes any obstruction on the seabed as well as sunken vessels) (Annex 2 Figure A.3), including some Auxiliary Patrol ships which were lost during WWI & WWII, 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 both of the simulated spatial management interventions if they result in less disturbance of the seabed. The simulated interventions will not affect access to priority areas for recreational anglers fishing with pole and line, although it is likely that only the priority areas in Holderness Offshore and Haisborough, Hammond and Winterton SACs are visited by sea anglers utilising charter boats, as they are the only sites close to the average distance travelled (~10nm) by recreational anglers to reach fishing grounds (Hooper et al., 2017). There are no recreational moorings in the identified priority areas, so anchorages for yachting would be unaffected by the simulated interventions.

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

Relative to the Business as Usual Scenario, the Conservation Scenario does not represent significant additional losses to the adjacent blue economy (Figure D.4.3). All additional losses are on the order of ~1% relative to business as usual. Given inherent uncertainties in the modelling approach, these are considered to be equivalent to *no additional impacts*. The driver for this is the fact that the additional area lost due to the interventions simulated in identified priority areas for conservation in this scenario is small relative to the loss of area due to climate change in the Business as Usual Scenario.

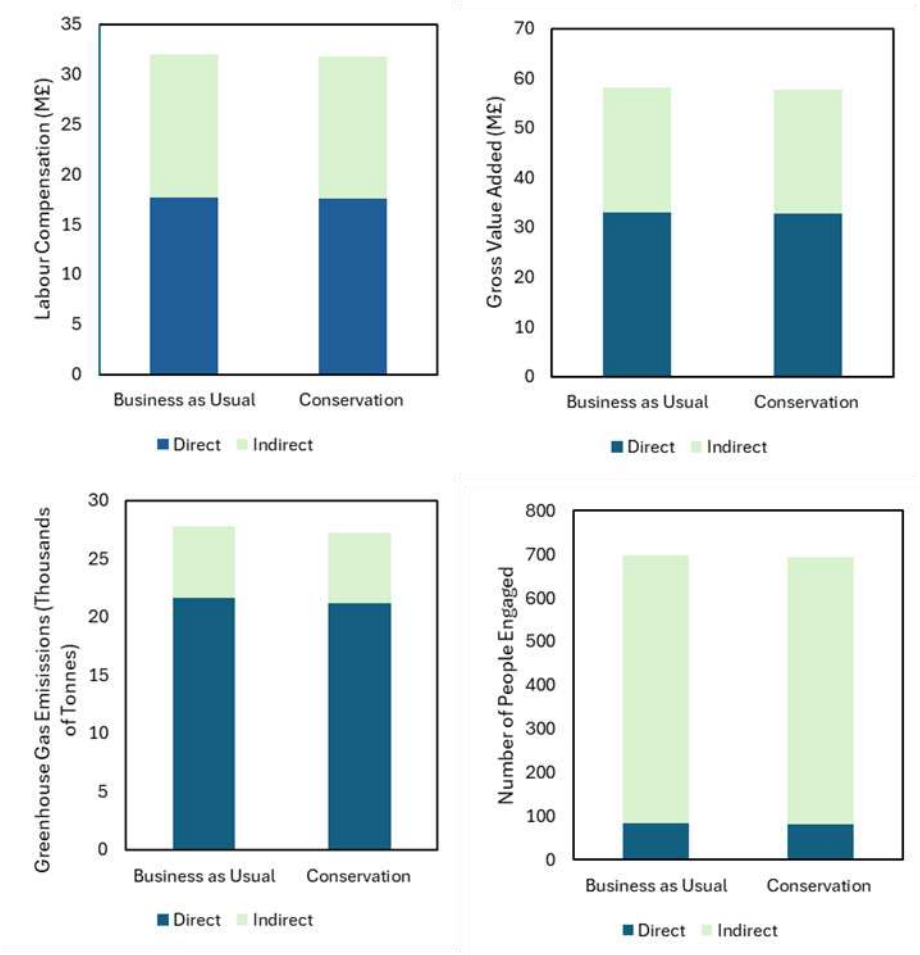

Figure D.4.3: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Conservation Scenario, as compared to the Business as Usual Scenario

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 EMP area. Simulated interventions are located in climate change refugia for demersal and pelagic fisheries.
2. aim to facilitate the development of climate-resilient aquaculture in the EMP area. Simulated interventions are located in climate change refugia for seafloor aquaculture.

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

The spatial interventions FP1 and FP2 below have the purpose of supporting and safeguarding climate resilient capture fisheries and facilitating the development of climate-resilient aquaculture in the EMP 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 English planning and licensing authorities considering the locations of identified priority areas for fisheries and aquaculture when evaluating applications for development of marine space by other industries and sectors.

Intervention FP1: a) 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. b) Avoid, minimise or mitigate proposals for uses that are incompatible with access for demersal fisheries in those areas identified as priority areas for demersal fisheries. A climate change refuge was identified for pelagic fisheries (see Queirós et al., 2024, Supplementary Information Table S4 for species included in the analyses) under RCP4.5, as abundances of Atlantic horse mackerel (*Trachurus trachurus*) and European sardine/pilchard (*Sardina pilchardus*) are projected to remain stable in much of the EMP area, even in the face of climate pressures. In the future, it is therefore possible that the pelagic fleet could move into currently unexploited areas within the EMP area which hold refugia for the sector. Accordingly, the whole of the EMP area is identified as a priority area for pelagic fisheries. Climate change refugia for demersal fisheries (see Queirós et al, 2024, Supplementary Information Table S4 for species included in the analyses) identified under RCP4.5 are smaller in extent and less consistently distributed (Figure D.5.1). Please note that our analyses identified some refugia for demersal fisheries that we believe were model artefacts. We have not shown these in any figures, and the identified priority areas for demersal fisheries are focussed on those areas that we are confident will be of practical use to the sector. Our analysis suggests that abundances of the key species such as cod (*Gadus morhua*) and plaice (*Pleuronectes platessa*) decline in the EMP area (moderate confidence, Queirós et al, 2024, Annex 1). However, abundances of hake (*Merluccius merluccius*) are projected to increase in the region (moderate confidence, Queirós et al, 2024, Annex 1). We also recognise that shifting species distributions may result in new species entering the region, 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 as yet unknown consumer attitudes and potential adjustments of fleet gear and practice, they are not included in these analysis.

Intervention FP2: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector. A refuge for seafloor aquaculture is present near Lowestoft, which covers an area which has been identified for aquaculture potential (DEFRA, 2014, East Marine Plans, Fig. 27). This site is therefore likely to be able to support aquaculture in the region in the long-term under RCP4.5, despite broader climate change pressures, and so we identify this site as a priority area for the sector. Although the site is quite shallow (~5-40m), we recognise that while offshore pelagic aquaculture is commonplace in Europe and growing in the UK, developing seabed aquaculture facilities in such areas may be more challenging than in coastal areas. Beyond this, there are further challenges to the use of this area to the sector in reality. For instance, there are important navigation routes along this section of the coast, and deployment of static sea surface infrastructure would not be permitted if it interferes with these routes. Finally, there are 134 wrecks located in the area identified here as a priority area for seafloor aquaculture. One of these wrecks is the HMS Exmoor, a naval destroyer sunk in 1941 which is protected under the Military Remains Act 1986, and which cannot legally be disturbed, so any development of the site would need to avoid this area. Of the remaining 133 wrecks listed in the area, 34 are categorised as "dead" meaning that the exact location (or confirmed presence) of the wreck cannot be determined, or that the wreck is no longer detectable via acoustic sensors. It is likely that for all these reasons, the whole site (approximately 380km^2) could not be developed, although some of it may still be suitable, and so the site is considered in this scenario as a potential home for seabed aquaculture. Scuba diving off the Norfolk coast is very popular, with several shallow, accessible sites located on the extensive sandbanks in the area. It is possible that new aquaculture infrastructure would interfere with, damage or limit access to these sites. There are no recreational moorings in the areas prioritised for food provision, so anchorages for yachting would be unaffected. However, any addition of new aquaculture infrastructure along the coast may impede navigation for recreational vessels. The value of this priority area for seabed aquaculture is therefore simulated here for comparison purposes, in a hypothetical scenario where outcomes for fishing and aquaculture are prioritised.

Table D.5.1: Summary of spatial interventions proposed in the Food Provision Scenario, and the expected ecological and economic effects of those interventions. Each intervention represents a possible mechanism which **supports climate-resilient fisheries and facilitates the development of climate-resilient aquaculture in the east marine plan areas**. 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 uses that may be incompatible with access by the pelagic fleet to currently unfished areas, identified as pelagic fisheries priority areas. b) Avoid, minimise or mitigate proposals for uses that are incompatible with access for demersal fisheries in those areas identified as demersal fisheries priority areas.	FP1: Continued/priority access to sites identified as priority areas for fisheries could contribute to the sustainability of the fishing sectors and help to support the industry in the face of climate change.	Increase of ~580% in labour compensation, GVA and number of people employed in the fisheries and aquaculture sectors when compared to the Business as Usual Scenario. GHG emissions also increase by ~545%

FP2: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector.	FP2: Development of the identified priority area for seafloor aquaculture represents a possible opportunity for sectoral expansion. FP2: Development of the identified priority area for aquaculture could interfere with, damage or prohibit access to recreational SCUBA diving sites in the area. FP2: Development of the identified priority area for aquaculture may impede navigational access for recreational sailors. FP2: Development of the priority area for aquaculture could disturb the 134 wrecks located in the area. One of these wrecks is the HMS Exmoor, a naval destroyer sunk in 1941 which is protected under the Military Remains Act 1986, and which cannot legally be disturbed, so any development would need to avoid this wreck.	
	FP1 and FP2: Restricting the future development of offshore wind in the identified priority fisheries and aquaculture areas could act to ensure that access to climate change refugia for the sectors is maintained.	

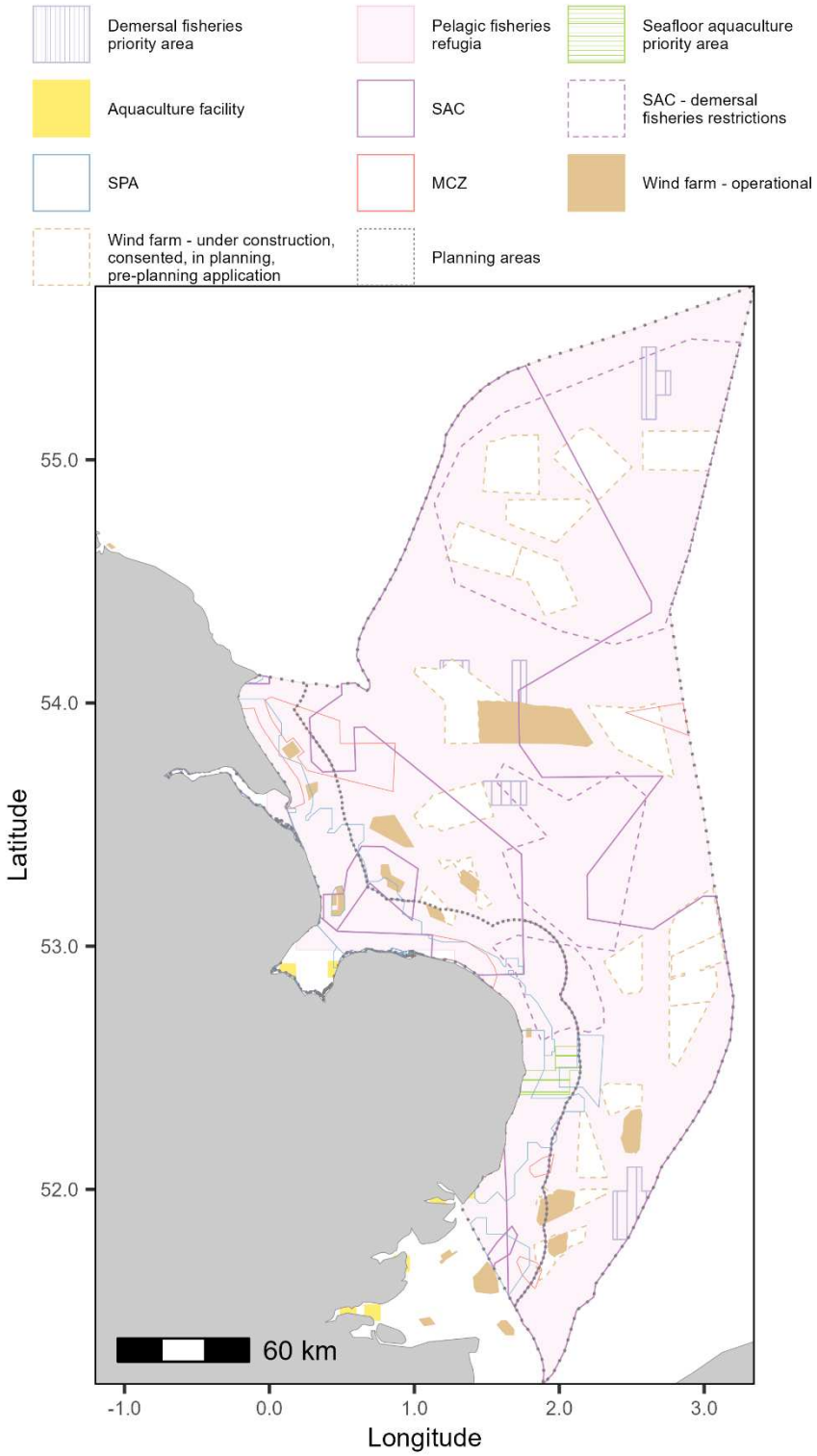

Figure D.5.1: Food provision scenario: all demersal fisheries refugia (vertical blue lines) are identified as priority areas for the demersal fleet, although due to existing restrictions, those areas located in Dogger Bank, North Norfolk Sands and Haisborough, Hammond and Winterton SACs would only be accessible to those parts of the fleet deploying static gears such as pots and traps. The whole area is identified as a priority area for the pelagic fleet. A priority area for seafloor aquaculture (horizontal green lines) has been identified close to the coastline near Lowestoft.

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

Relative to the Business as Usual Scenario, the Food Provision Scenario greatly increases all our indicators (Figure D.5.2). Accounting for direct and indirect effects we see increases in labour compensation, GVA and number of employees of around 580% and greenhouse gas emissions of around 550%. This is predominantly driven by the growth in seafloor aquaculture, because the hypothetical expansions simulated under intervention FP2 are so large relative to existing provision. Direct increases in seafloor aquaculture impact variables are around 600%, the fishing fleet segments see direct increases in impact variables of ~200%, driven by the simulation of substantive increases in pelagic fishing in the priority areas for the sector under intervention FP1.

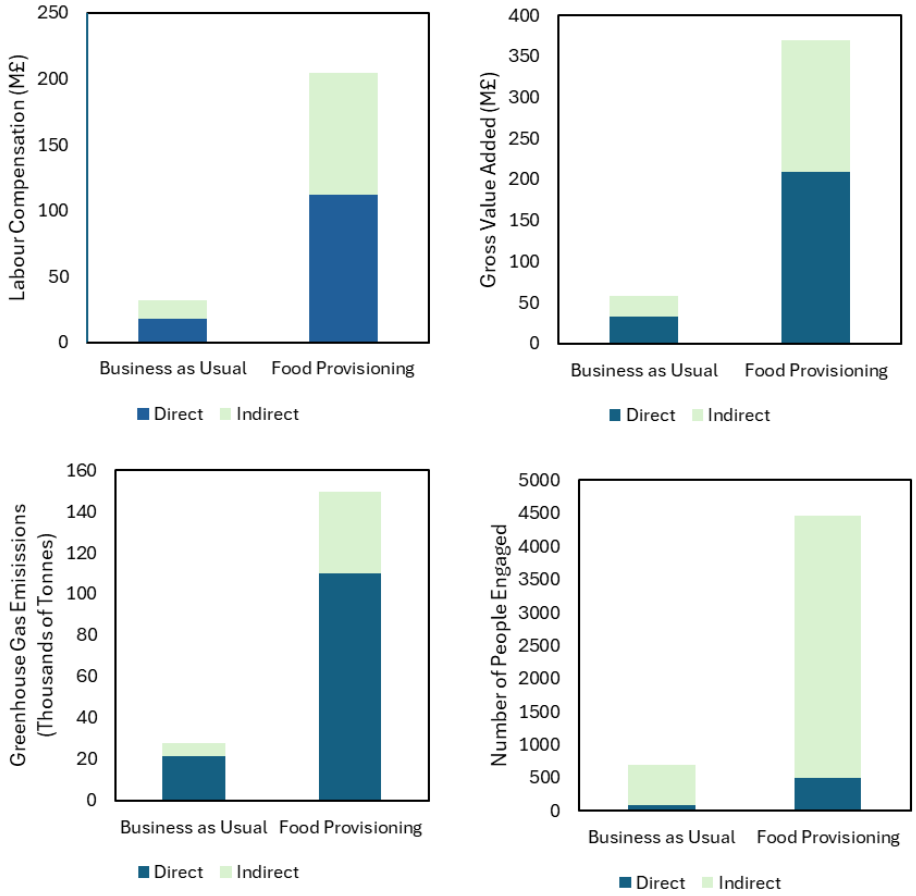

Figure D.5.2: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Food Provision Scenario, as compared to the Business as Usual Scenario

D.6. The Compromise Scenario

D6.1 Spatial interventions maximising outcomes under the compromise scenario

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

1. aim to encourage climate-resilient fisheries in the EMP area given the effects of climate change. Simulated interventions are located in climate change refugia for demersal and pelagic fisheries
2. aim to encourage the development of climate-resilient aquaculture in the EMP area given the impacts of climate change. Simulated interventions are located in climate change refugia for seafloor aquaculture
3. aim to avoid, minimise or mitigate the impacts of activities which could negatively affect the climate change resilience or adaptation potential of habitats and species of conservation interest in the EMP area. Simulated interventions are located in climate change refugia for 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

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

The spatial interventions CM1 and CM2 below have the purpose of avoiding, minimising or mitigating the impacts of activities which could negatively affect megafauna species of high conservation interest and the future provision of climate services in the EMP area (Table D.6.1). In this hypothetical planning scenario, we simulate that this aim would be further supported by additional byelaws by the MMO and DEFRA, potentially setting limits on access to identified priority areas for conservation to mobile demersal gears. The spatial interventions CM3 and CM4 have the purpose of encouraging climate-resilient fisheries and facilitating the development of climate-resilient aquaculture in the EMP region despite climate change impacts (Table D.6.1). We simulate that these aims would be further supported by English planning and licensing authorities considering the locations of identified priority areas for fisheries and aquaculture when evaluating applications for development of marine space by other industries and sectors. Finally, we simulate that offshore renewable energy development in some priority conservation, fisheries and aquaculture areas may be limited, and that this aim would be supported by engagement of English planning and licensing authorities with the Crown Estate to ensure that these areas are not leased in future bidding rounds. This prioritisation is informed by on evidence by the values of stakeholders shown in section B.

Intervention CM1: Avoid, minimise or mitigate activities which would be incompatible with the conservation of priority areas for benthic megafauna identified in Dogger Bank, Hammond, Haisborough and Winterton, North Norfolk Sands and Saturn Reef SACs, and Holderness Offshore and Markham's Triangle MCZs. This intervention could possibly result in limitations on all further extractive activities and development, with the exception of the OWE installations already planned, in the Dogger Bank priority area for conservation. The intervention could also result in the potential exclusion of vessels operating mobile demersal gears in the priority areas for conservation in Holderness Offshore SAC and Markham's Triangle MCZ. Finally, it could perhaps result in restrictions

on OWE development in the priority conservation areas within the North Norfolk Sands and Haisborough, Hammond and Winterton SACs, given their potential to provide compensation measures for planned OWE infrastructure in the Dogger Bank SAC.

Intervention CM2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for climate services identified in the Outer Silver Pit. The priority area for protection of climate services habitat in the Outer Silver Pit identified in the Conservation Scenario (Section D4), remains as such in this scenario. This priority area is currently outside the marine protected area (MPA) network, but given the relatively high organic carbon content in the sediment in this area (Figure D.4.2), we highlight it as an area that could be beneficial for the future provision of climate services.

Intervention CM3: a) Avoid, minimise or mitigate proposals for uses that may be incompatible with access by the pelagic fleet to currently unfished areas, where priority areas for pelagic fisheries are identified. b) Avoid, minimise or mitigate proposals for uses that are incompatible with access for demersal fisheries in identified priority areas for the sector. Based on the locations of climate change refugia identified for the fishing sector in the EWS, we have identified priority areas for the pelagic and demersal fleets.

Intervention CM4: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector. The priority area for seafloor aquaculture identified in the Food Provision Scenario, located in a climate change refuge for the sector, remains as such in this scenario (Figure D.6.1), although it is fractionally smaller in this scenario (approximately 310km^2) to account for the fact that some aggregate extraction takes place in the area at present , and which we simulate will continue. Although the site is quite shallow (~5-40m), we recognise that whilst offshore pelagic aquaculture is commonplace in Europe and growing in the UK, developing seabed aquaculture facilities in such exposed areas may be more challenging.

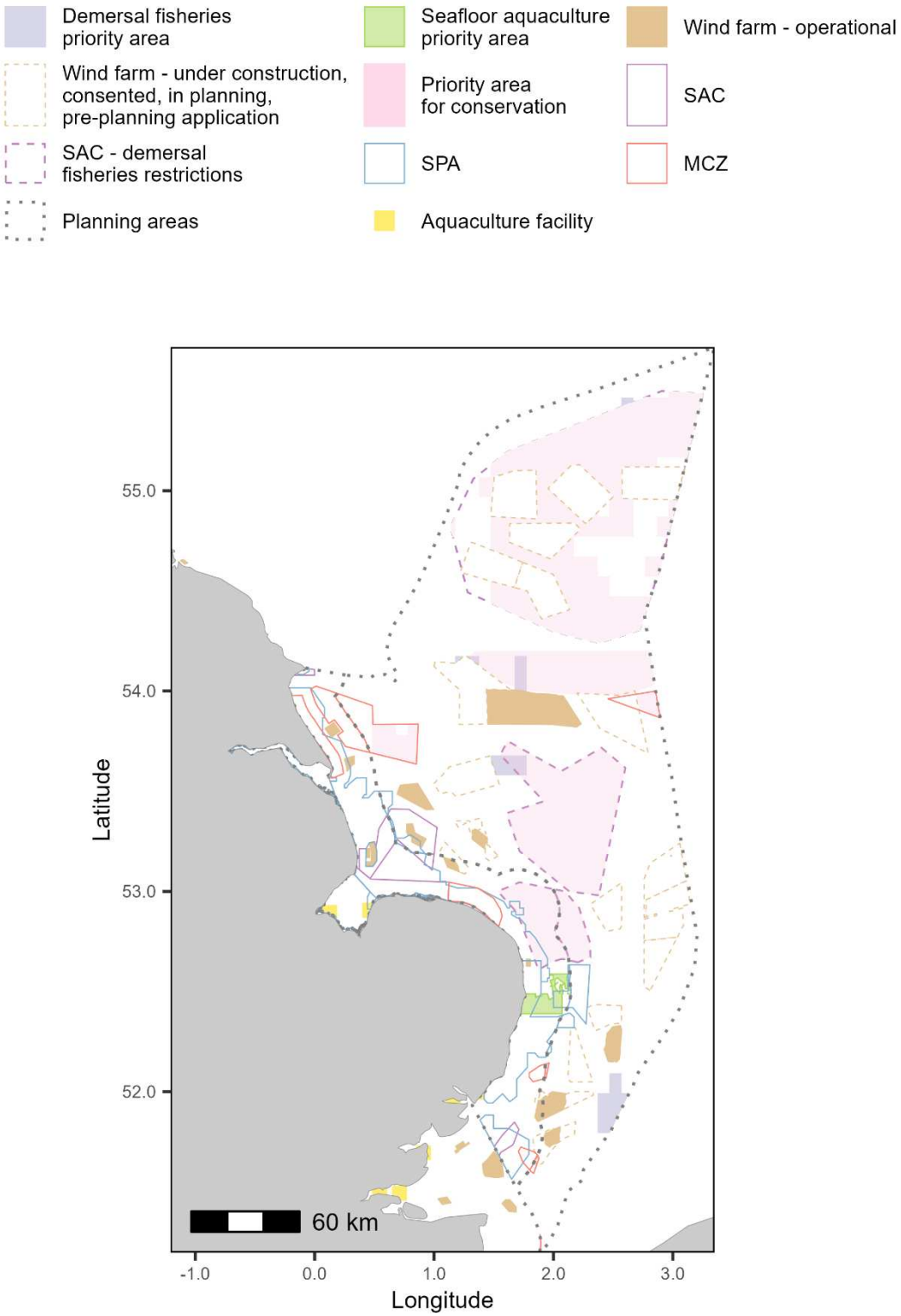

Figure D.6.1: Compromise scenario: The priority areas for conservation outlined in the Conservation Scenario remain, and we highlight the potential for North Norfolk Sands and Haisborough, Hammond and Winterton SACs to provide compensatory measures for development of OWE in the Dogger Bank SAC. Refugia for demersal fisheries have been identified as priority areas for the sector, and we simulate that any future planning or licensing decisions recognise that access to these areas should not be impeded by any other proposed activity.

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 EMP 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 the conservation of priority areas for benthic megafauna identified in Dogger Bank, Hammond, Haisborough and Winterton, North Norfolk Sands and Saturn Reef SACs, and Holderness Offshore and Markham's Triangle MCZs.	CM1: Avoiding, minimising or mitigating the impacts of demersal trawls on several elasmobranch species of conservation interest (such as tope (*Galeorhinus galeus*) and smooth-hound (*Mustelus mustelus*), could maximise the effectiveness of the identified priority areas for conservation in promoting the climate change resilience of these species. CM1: Avoiding, minimising or mitigating the impacts of offshore wind development in the identified priority areas for conservation could act to avoid direct impacts of development on designated features and mitigate the impacts of development elsewhere in the EMP area (e.g. providing compensatory measures).	When compared to the Business as Usual Scenario, there is an increase of ~450% in labour compensation, GVA and number of people employed in the fisheries and aquaculture sectors. There is also an increase in GHG emissions of ~ 416%
CM2: Avoid, minimise or mitigate activities which could be incompatible with the conservation of a priority area for climate services identified in the Outer Silver Pit.	CM2: Avoiding, minimising or mitigating negative impacts in areas where sediment has a high carbon sequestration potential may limit direct carbon release and degradation (avoided emissions) from disturbed sediment.	
CM3: a) Avoid, minimise or mitigate for proposals for uses that may be incompatible with access by the pelagic fleet to currently unfished areas, where priority areas for pelagic	CM3: Continued/priority access to sites identified as priority areas for fisheries could contribute to the resilience of the fishing sectors and help to support	

fisheries are identified. b) Avoid, minimise or mitigate proposals for uses that are incompatible with access for demersal fisheries in identified priority areas for the sector.	the industry in the face of climate change.	
CM4: Avoid, minimise or mitigate proposals for activities that could limit the development of seafloor aquaculture in the identified priority area for this sector.	CM4: Development of the identified priority area for seafloor aquaculture represents a possible opportunity for sectoral expansion. CM4: Development of the priority area for aquaculture could damage the 134 wrecks located in the area. One of these wrecks is the HMS Exmoor, a naval destroyer sunk in 1941 which is protected under the Military Remains Act 1986, and which cannot legally be disturbed, so any development would avoid this wreck. CM4: Development of the identified priority area for aquaculture could interfere with, damage or prohibit access to recreational SCUBA diving sites in the area and may impede navigational access for recreational sailors.	

D.6.2. Potential benefits of proposed spatial management interventions

It is possible that intervention CM1 could go some way to supporting high quality foraging habitat for a range of megafauna of conservation interest in the Dogger Bank SAC. As noted in the Conservation Scenario (Section D.4 above), this area is used by several elasmobranch species, including a number listed as “vulnerable” by the IUCN Red List. The area also provides an important foraging habitat for several seabird and marine mammal species (Ransijn, 2023) of conservation importance, due to the high abundance of sandeels (DEFRA, 2014, East Marine Plans, Fig. 26) and sprat (Munk et al., 2024) found in the area. In the wider EMP area, the priority areas for conservation have been shown to be spawning grounds for plaice, sole and sandeel and nursery grounds for cod and sandeel (Ellis et al., 2010). 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. Intervention CM1 could also result in limitations on OWE development in priority areas for conservation as a way to deliver compensatory measures for development of energy infrastructure

elsewhere in the marine planning areas, where it is deemed necessary. For example, the North Norfolk Sands and Haisborough, Hammond and Winterton SACs may be useful as compensation sites for currently planned wind development elsewhere in the EMP area (especially the extensive development on the Dogger Bank), given the broad similarity in habitat type and mobile epifauna communities found at these sites (Annex 2, Figure A.2). In the case of the priority area identified for climate services in the Outer Silver Pit, it is possible that intervention CM2 may limit direct carbon release and degradation (avoided emissions) from disturbed sediment. Although we acknowledge that it is unproven that protecting seafloor sediments from disturbance improves carbon storage or sequestration potential, the protection of marine carbon sinks may represent a sensible precautionary policy (Epstein et al., 2022; Epstein & Roberts, 2022; Jankowska et al., 2022).

Interventions CM3 and CM4 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 EMP area under intervention CM3. Intervention CM4 could allow for the expansion of seafloor aquaculture in the EMP region, utilising the priority area for seafloor aquaculture off the coast of Lowestoft that we have identified. However, the wreck of the HMS Exmoor, sunk off Lowestoft in 1941 (See Annex 2, Figure A.3 for locations of protected wrecks) and protected under the Military Remains Act 1986, would need to be avoided in any future development. Finally, as noted in the Food Provision Scenario, it is likely that the entirety of the priority aquaculture area could not be developed by the sector to ensure that navigation routes are not impeded.

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

Relative to the Business as Usual Scenario, the Compromise Scenario substantially increases all our indicators, though to a lesser extent than the Food Provision Scenario (Figure D.6.2). Again, results are predominantly driven by the growth in aquaculture, because the simulated expansions under intervention CM3 are large relative to existing provision. However, the proposed increases in area for aquaculture are less than in the Food Provision Scenario. As a result, increases in direct impact variables for aquaculture are approximately 470%. The fishing fleet segments see small decreases in direct impacts of around 15%.

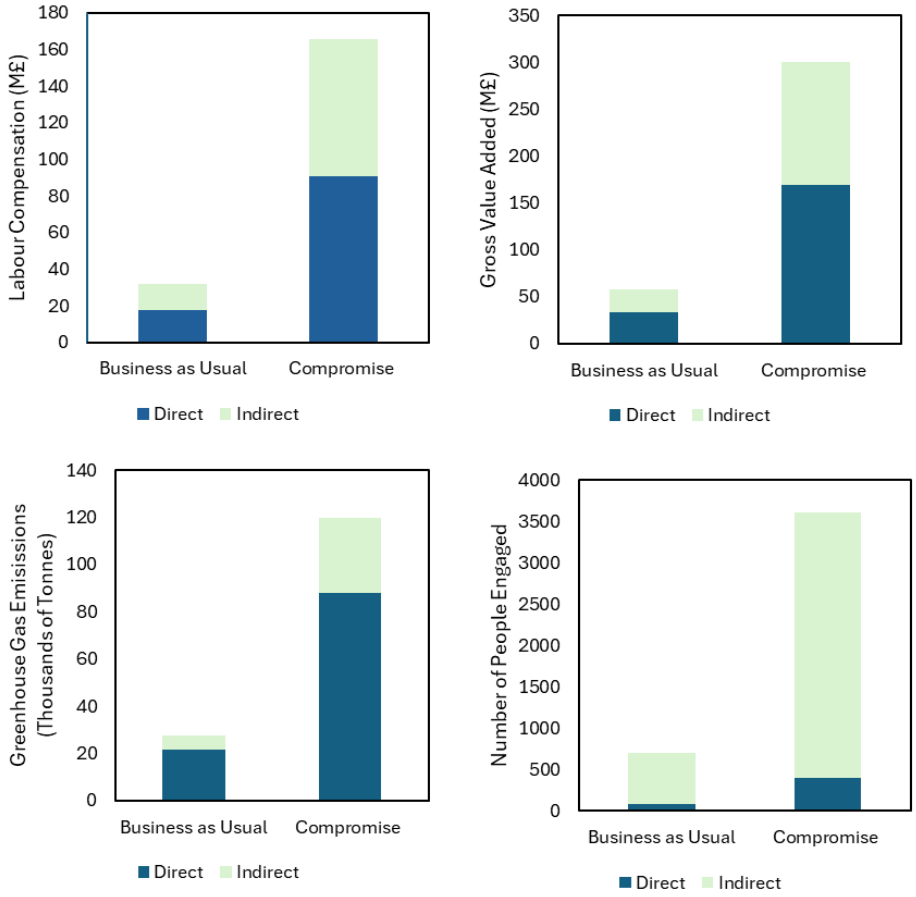

Figure D.6.2: Modelled changes in wages, GVA, GHG emissions and employment due to climate change in the Compromise, as compared to the Business as Usual Scenario.

D.7. Cross scenario economic analysis

The model captures a variety of mechanisms mediating the link between marine resources and the adjacent blue economy in the EMP area: 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 is a major factor impacting the results. This is a major source of uncertainty in the model because of the assumption that all areas of the marine plan areas accessible to a particular fishing fleet segment or aquaculture producer are equally productive.

Another element to be aware of is that in all scenarios with the exception of the Food Provision Scenario, the pelagic fleet has a small impact on the results. This is because the pelagic logbook data indicates that in 2018 (our baseline year) the pelagic fleet activity within the east marine plan areas represented less than 1% of landings by value in the area.

There are significant differences in the distribution of direct and indirect effects, driven by differences in supply chain and also impact intensities by industry. On average, the fishing fleet and aquaculture sectors are relatively greenhouse gas intensive but relatively employment light (Roca Florido & Mair, 2024). Of the 134 sectors in the model, the fishing fleet and aquaculture are all in the top quartile for direct greenhouse gas emissions intensity but the lowest third for direct employment intensity. This is reflected in the results where we see most greenhouse gas emissions/savings occurring in the direct portion of activity, but most additional employment in the indirect (supply chain) activity.

Annex 1: Scenario co-development formulae

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

1. Business as Usual Scenario

Example with Revenue (R):

Total R_{BAU} = $R_p - R_h$

1.1. Effects on Fisheries

BAU = business as usual scenario

p = area fished at present

h = area fished at present that overlaps with fishery hotspot

1.2. Effects on Aquaculture

BAU = business as usual scenario

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

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

Climate-smart scenarios

2. Food Provision Scenario

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

Example with Revenue (R):

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

FS = fishery scenario

p = area fished at present

h = area fished at present that overlaps with fishery hotspot

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

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

Example with Revenue (R):

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

AS = aquaculture scenario

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

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

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

2.3. Final Estimate

Combines overall estimates from the above Fishery and Aquaculture scenarios

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

FP = Food Provision scenario

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

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

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

3. Conservation scenario

3.1 For impacts on fishing

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

CS = conservation scenario

p = area fished at present

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

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

3.2. For impacts on tourism/recreation

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

CS = conservation scenario

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

h = area protected at present that overlaps with hotspot

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

4. Compromise Scenario.

4.1 For impacts on fishing

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

FS = conservation scenario

p = area fished at present

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

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

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

4.2 For impacts on fishing

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

AS = aquaculture scenario

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

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

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

4.3. For impacts on tourism/recreation

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

TRS = Tourism/recreation scenario

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

h = area protected at present that overlaps with hotspot

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

4.4 Final Estimate

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

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

CS = Compromise scenario

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

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

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

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

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

Annex 2: Supplementary Information

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

Name	Organisation
Charlotte Brill	Cefas
Christopher Sweeting	MMO
Ruth Parker	Cefas
Sian McGuinness	MMO
Tim Marjoram	Cefas
Michael Clarke	Cefas

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

	Sector
1	Under 10m drift and/or fixed nets
2	Under 10m pots and traps
3	North Sea beam trawl under 300kW
4	UK scallop dredge under 15m
5	Demersal trawlers
6	Other static gears using vessels
7	Low activity vessels
8	Aquaculture
9	Processing and preserving of fish, crustaceans and molluscs
10	Building of ships and floating structures
11	Building of pleasure and sporting boats
12	Repair and maintenance of ships and boats
13	Construction of water projects
14	Wholesale of other food, including fish, crustaceans and molluscs
15	Retail sale of fish crustaceans and molluscs in specialised stores
16	Sea and coastal passenger water transport
17	Sea and coastal freight water transport
18	Service activities incidental to water transportation

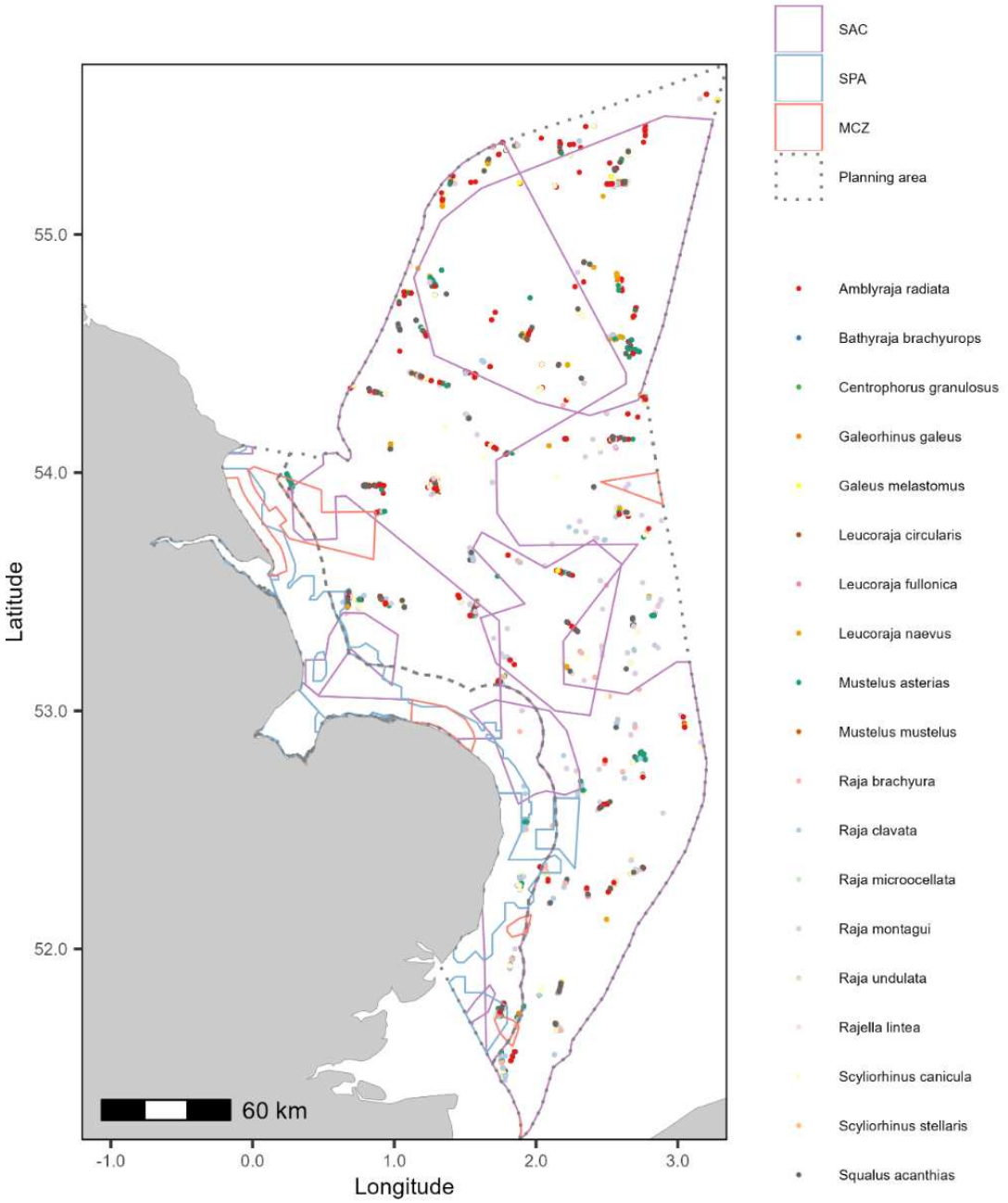

Figure A.1: Observed distributions of sharks, skates and rays in the East Marine Plan area. Survey data from the North Sea International Bottom Trawl Survey 2000-2022, downloaded from https://datras.ices.dk/

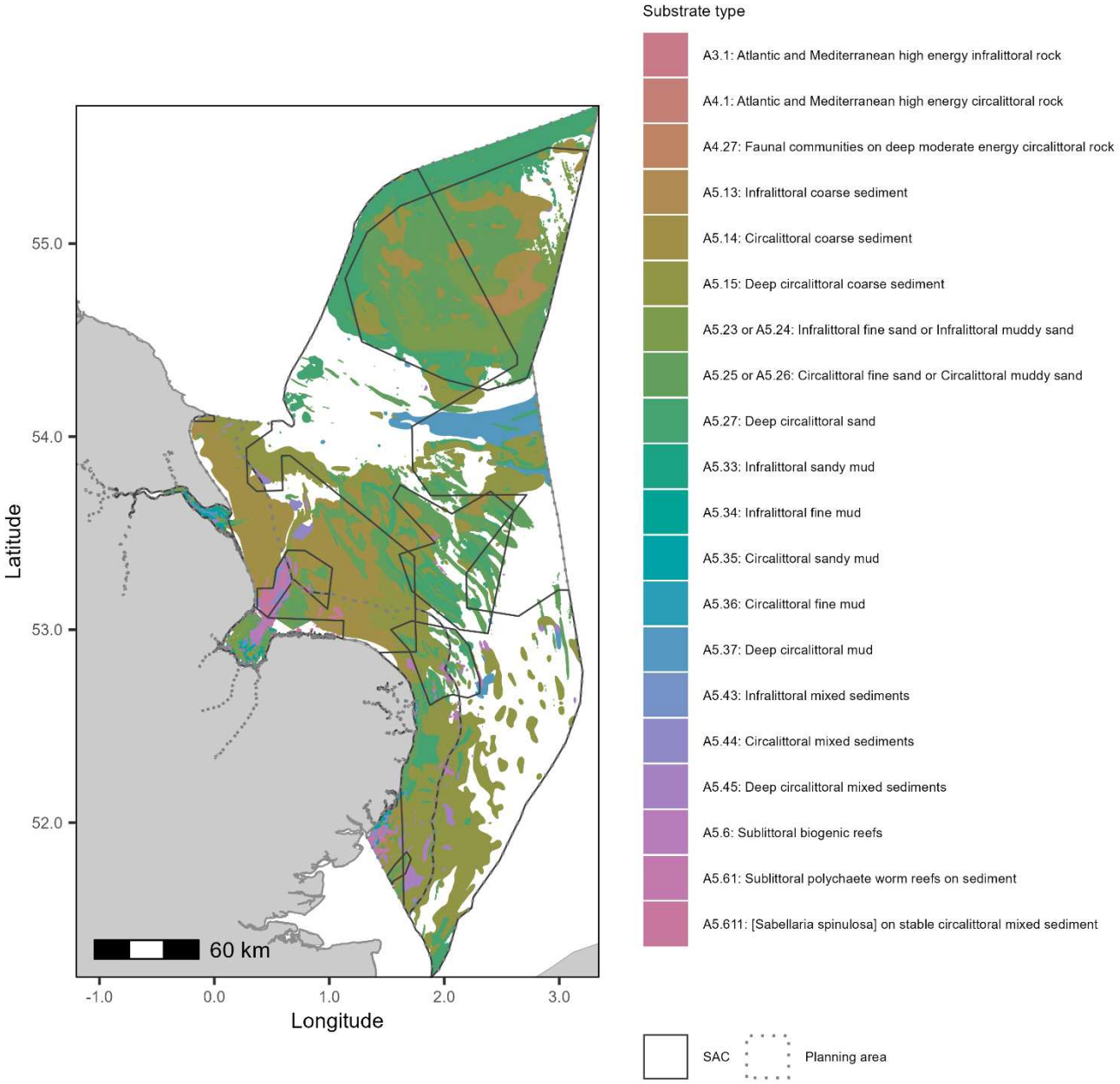

Figure A.2: EUNIS habitat types in the EMP area. It is possible that the North Norfolk Sands and Haisborough, Hammond and Winterton SACs could provide compensatory measures for other OWE developments in the planning areas, particularly the extensive developments planned for the Dogger Bank, given the similarity of sediment types in all three MPAs.

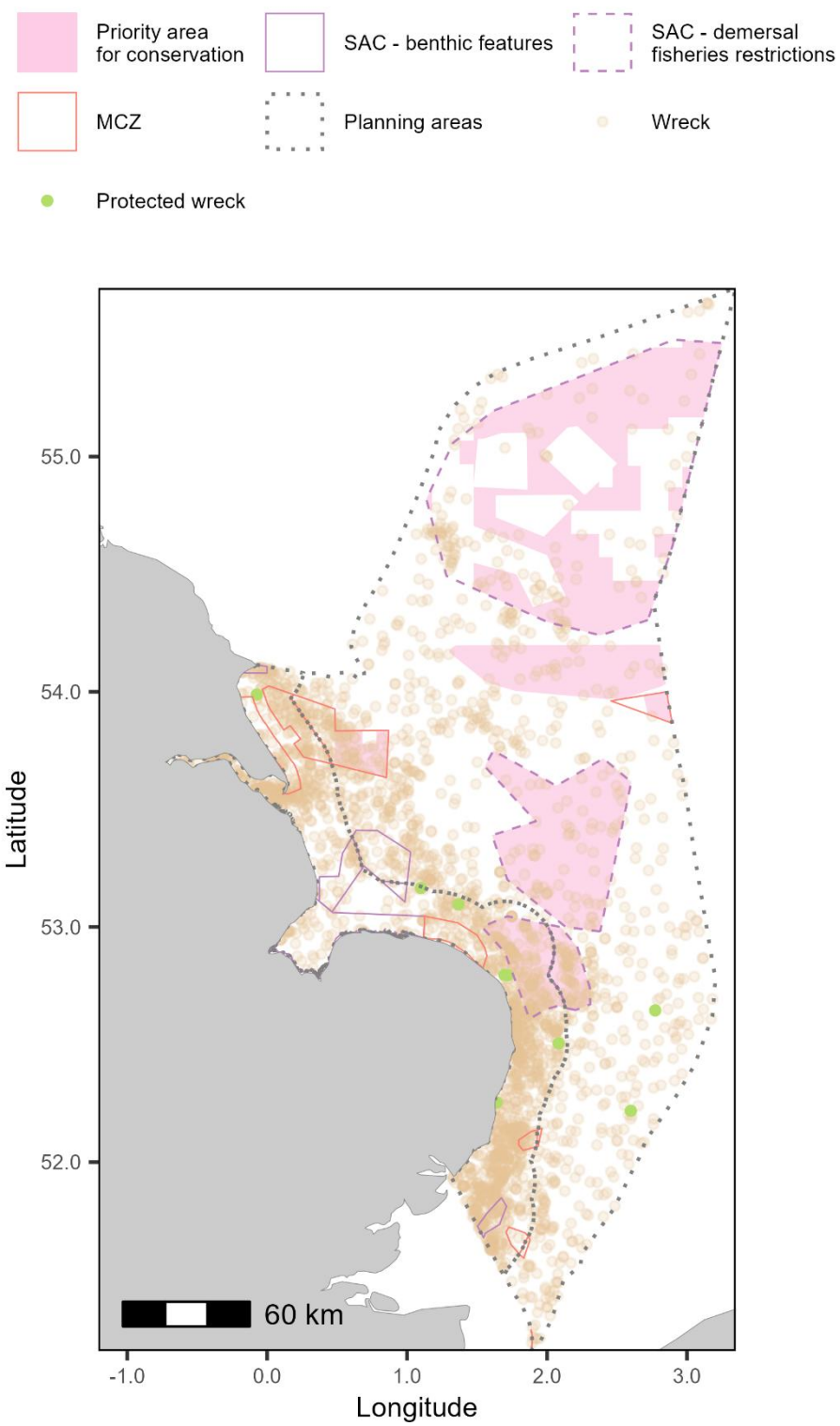

Figure A.3. Proposed conservation scenario showing the locations of wrecks. There are 368 wrecks in the priority conservation areas, although none of them have been granted legal protection under the Protection of Wrecks Act 1975 or the Protection of Military Remains Act 1986.

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