Early-warning system

Climate-smart spatial management of UK fisheries, aquaculture and conservation

MSPACE
Marine Spatial Planning Addressing Climate Effects

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PML Plymouth Marine Laboratory
MCCIP Marine Climate Change Impacts Partnership
Heriot Watt University
JNCC
Cefas
afbi
SMMR Sustainable Management of UK Marine Resources
UKRI Natural Environment Research Council
UKRI Economic and Social Research Council
Marine Management Organisation
Cyfoeth Naturiol Cymru
Natural Resources Wales
Scottish Government
Riaghaltas na h-Alba

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Executive Summary

Our coast and our ocean are undergoing unprecedented changes as a result of the breakdown of our global climate system.[1] These changes represent a significant challenge to the delivery of marine policy that effectively protects ecosystem health, biodiversity and the communities depending on these resources.[2] Creating new, climate-adaptive management strategies for these ecosystems, and for economic sectors reliant on them, is thus an ongoing challenge facing diverse marine policy frameworks across the UK Nations. This is compounded by an ever-increasing reliance on marine space to meet our need to transition to greener energy supply[3] and economic growth, which have to be carefully balanced against the pressing need to preserve our marine species and habitats, and their ability to adapt to climate change.[4, 5, 6, 7]

Marine planning is a public process to document, consult and set priorities about how we manage and share our marine space.[8] Indeed, across our Nations, marine plans thus far enshrine key policies that set out the ambition to deliver climate change adaptation.[9,10,11] As a devolved process, operating at national and regional level, marine planning has the potential to serve a key, harmonizing role. It can bring together our broader marine policy mechanisms to help tackle the impacts of global climate change across our waters. Additionally, because planning is a deeply consultative process, it further offers the potential to ensure the voices of those that are affected by marine plans help shape this journey.

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

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

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

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

In order to harness opportunities for effective marine conservation and economic growth that emerge from spatial variation in the sensitivity of our marine ecosystems to climate change, climate-smart marine plans are necessary. However, key capability gaps have this far hindered the ability of UK Nations to deliver such marine plans; i.e. plans that are truly adaptive to the effects of climate change. In this report, we begin to close these gaps.

First, we explore areas where policy mechanisms could be strengthened to deliver on this ambition. Second, we capitalize on world-class UK ocean climate modelling capability, to deliver a climate change assessment for the entire UK EEZ that, for the first time, demonstrates the spatial variation in sensitivity of our marine ecosystems to climate change. Third, we make recommendations about how marine planning could support the management of areas identified as climate change refugia for three key sectors – marine conservation, fisheries and aquaculture. We highlight that these areas could be utilized by future climate-smart policy design, to promote the climate change adaptation of our natural marine ecosystems. Our identification of these areas also offers opportunities for sectoral policy design by highlighting where risk from climate change may be lower for our fishing and aquaculture sectors.

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

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

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

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

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

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

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

Physical

- Change in seasonal temperature patterns
- Long term warming
- Increased frequency of heatwaves
- Changes in circulation
- Increased stratification
- Sea-level rise

Biogeochemical

- Long-term deoxygenation
- Localised seasonal oxygen deficiency
- Ocean acidification

Foodwebs

- Change is species composition
- Changes in productivity

Conservation of Wild Ecosytems

- Biodiversity ghanges
- Loss of previously abundant species
- New species arrival
- Potential loss of efficiency of designated areas for specific species
- Harmful agal blooms

Fisheries

- Loss of catch of previously abundant species
- Stock migration
- Change in spatial distribution of resource
- New target species

Aquaculture

- Reduced predictability of spat collection sites and events
- Increased incidents of disease and infestation

Figure i

Marine climate change in the UK

The key findings from this report

1
Some marine uses within these three sectors (marine conservation, fisheries and aquaculture) will be broadly impacted by climate change in our immediate future (high confidence). This highlights an immediate need for climate-adaptive spatial management strategies for our marine environment.

2
Marine climate change refugia also identified for those sectors could be capitalised upon as part of no regrets, climate-resilient spatial management strategies. These could focus sectoral activities in areas exhibiting natural, long-term resistance to broad climate change pressures.

3
Transboundary coordination of climate-smart approaches to planning is needed across UK nations, to deliver on climate change adaptation for our marine ecosystems and related economic sectors.

4
Strong limits on greenhouse gas emissions at the global scale are likely to deliver the best outcomes for UK marine ecosystems and the maritime sectors we explore in this report.

This report is produced by the Marine Spatial Planning Addressing Climate Effects (MSPACE) project, part of the NERC/ESRC Sustainable Management of UK Marine Resources Programme. MSPACE is a 4 year project (2021 – 2025) co-designed and co-delivered with key Governments', marine policy and industry representatives. MSPACE's ambition is to help deliver climate-smart, economically viable and socially acceptable marine planning across the UK Nations. Economic analyses and social value assessments are now being used in the project, in conjunction with this report, in the co-development of spatial management strategies that could be used within those planning processes.

This report is supported by a Summary for Policy Makers written by the UK Marine Climate Change Impacts Partnership, and an infographic.

Contents

Glossary

TERM	DESCRIPTION
Brightspot	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 and Sutton 2012; Queirós et al. 2021), but where this state is defined by trends that are incosistent 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 (Queirós et al. 2021).
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 and Sutton 2012; Queirós et al. 2021).
Climate change refuge	A sites that remains climate-resilient within a given period of analysis
Climate change resilience of habitats	The ability 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 and Sutton 2012; Queirós et al. 2021).
Climate-smart strategies	Marine management strategies that support climate change adaptation of marine ecosystems, species and habitats, and of maritime sectors reliant on these, by considering climate change effects by design. Such strategies consider the distribution of climate change resilience (cf. vulnerability) within a given management area, and seek to manage human activities against such distribution, with a view to reduce cumulative pressures on marine ecosystems and promote climate change adaptation. Such strategies recognise that marine species and habitats will not be resilient to climate-change everywhere. However, they capitalise on the distribution of that resilience (where it may be found), to promote sustainable uses of the marine environment.

1
Introduction

1.1
The Challenge

Climate change, resulting from anthropogenic excess greenhouse gas emissions, is expressed in the ocean through changes in many ecosystem attributes (warming, acidification, deoxygenation, changes in productivity and current patterns among others; Pörtner, Scholes et al. 2021, 2022), unfolding at different speeds and magnitudes over space and time. The position of the UK exposes it to changes in conditions in the Atlantic Ocean, from the north and west, and from regional changes in the North Sea in the east and south, which bring important challenges to our marine species and habitats. As in other areas of the globe, climate-driven changes in the UK marine environment are already being observed and include: changes in spatial and seasonal temperature patterns leading to long-term warming (Tinker, Howes et al. 2020); increased frequency of heatwaves (Cornes, Tinker et al. 2023); changes in the structure of thermal habitats resulting from stronger water-column stratification (Sharples, Holt et al. 2020); deoxygenation leading to seasonal oxygen deficiency in some areas (Mahaffey, Hull et al. 2023); ocean acidification (Ostle, Willliamson et al. 2016); sea-level rise (Horsburgh, Rennie et al. 2020); and potential changes in ocean circulation (McCarthy, Smeed et al. 2017). Marine species respond to these multiple changes in ocean conditions, tracking their optimum habitat when possible, therefore changing their distributions (Dulvy, Rogers et al. 2008). This is expressed locally as changes (and often loss) of species biodiversity (Pecl, Araújo et al. 2017). Such changes deeply affect the sustainable use of wild species and species cultivation in the ocean (Pörtner, Scholes et al. 2021, IPBES 2022), as well as the effectiveness of area-based marine conservation measures (i.e. Marine Protected Areas (MPAs) and Other area-based Effective Conservation Measures (OECMs); Pörtner, Scholes et al. 2021).

In the UK, climate-driven effects are already being detected across marine food-webs (Hiddink, Burrows et al. 2015, Edwards, Atkinson et al. 2020, Moore and Smale 2020, Mahaffey, Hull et al. 2023). These include declines of previously abundant species, arrivals of new species, and occurrences of harmful algal blooms. These changes are already affecting commercial fisheries (Cheung, Pinnegar et al. 2012, Engelhard, Righton et al. 2014, Queirós, Fernandes et al. 2018). Observed changes in the predictability of spat collection areas and events, and increasing incidence of invasive species, have been highlighted as direct effects of climate change on the UK aquaculture sector, and disease and infestations are already an indirect link exacerbated by warming among other pressures (Garrett, Buckley et al. 2015). These impacts are projected to increase in the mid-term (Callaway, Shinn et al. 2012, Collins, Bresnan et al. 2020). Solutions for climate-adaptive ocean management are thus widely recognised as needed, as species move across national and international waters in response to climate change. Such approaches are seen as necessary to support sustainable conservation, fisheries and aquaculture into the future (Hoegh-Guldberg, Northrop et al. 2019, Pörtner, Scholes et al. 2021). However, the design of these solutions can be challenging, and their implementation has been slow. Indeed, the allocation of marine space requires buy-in from many actors (Ehler and Douvere 2009, Queirós, Talbot et al. 2021). Regulatory landscapes across the UK Nations are changing to promote such climate adaptation measures.

Specifically, theUK Climate Change Act (2008) established the Committee on Climate Change (CCC) alongside a duty to assess risks and opportunities and produce such strategies. As a result, the UK's National Adaptation Programme and the Third Strategy for Climate Adaptation Reporting ("NAP", 2018) outlined how the UK's Marine Protected Area network, the Fisheries Bill (now the UK Fisheries Act 2020) and Marine Plans (in England) are expected to: help increase the marine environment's resilience to climate change; reduce the pressure of fishing and aid the movement of species in response to climate change. These ambitions are to a great extend reflected in devolved policies such as the Scotland's National Marine Plan and Second Climate Change Adaptation Programme 2019 – 2024. However, the climate change resilience of habitats (i.e. the ability to remain within a present-day ecosystem state despite climate change) has not been a criterion, this far, in the designation of marine conservation sites or in protected area network design, which focus on maintaining or recovering of existing features of conservation importance and representative habitats (depending on the designation). A lack of focus on climate change resilience is also a feature of the more recent drive to designate Highly Protected Marine Areas across the UK (Benyon, Barham et al. 2020), which are intended to deliver a higher degree of protection for sites within the MPA network, potentially including sites that also deliver climate services (i.e. nature-based climate change mitigation). The siting of the first three HPMAs in England has been identified (February 2023), and the consultation is ongoing in Scotland (due March 2023). Therefore, as in most instances around the world, these two processes have delivered the designation of sites that protect marine features and habitats needed by emblematic species at present, not in the future. These mechanisms are also static in nature, and thus not sensitive to possible changes in the distribution of species and habitats used as designation criteria, as they respond to climate change.

Capability gap 1

Processes informing the designating of marine conservation sites do not take into account the response of species and habitats distributions to climate change.

There is, therefore, an opportunity to improve the effectiveness of long-term conservation of the UK's unique marine biodiversity and marine sectors reliant on it. A number of recent initiatives (Flavell 2020, Oaten, Brooks et al. 2021) have begun assessing the sensitivity of the UK MPA network to climate pressures. A key feature of these works, however, is that climate pressures are assessed individually, when it is well established that species distributions respond to multiple climate change pressures simultaneously (Pörtner, Roberts et al. 2022).

Climate-resilient policy ambition is also a feature of the UK's management of fisheries and aquaculture. For instance, the UK Fisheries Act (2020) set out that "fish and aquaculture activities adapt to climate change" with fisheries climate adaptation measures across the four UK administrations included specifically in the Joint Fisheries Statement (2022). Delivering on this ambition will thus require spatial evidence to be made available that identifies challenges and opportunities that result from climate change impacts on target species and assemblages. That evidence could enable the design of spatial measures that support the climate-resilience of these sectors and the ecosystems they rely upon, but at present, this is not yet defined (e.g. in the design of fisheries management plans; in the implementation of the Scottish Fisheries Management Strategy).

Capability gap 2

There is no clear procedural guidance on how spatial evidence on the re-distribution of species of interest to the fisheries and aquaculture sectors under climate change will be taken into account in their spatial management.

Finally, the Marine Policy Statement ("MPS") and the Marine (Scotland) Act 2010 ("MSA") were made statutory planning documents in the absence of plans (developed thereafter), both including several references to climate change. Consistent with the MPS and the MSA, climate-resilience ambition was then recognized in the 6 English Marine Plans (covering 11 planning areas) as well as in the Welsh National Marine Plan, Scotland's plans for its 11 Marine Regions (under development), and the draft Marine Plan for Northern Ireland. This ambition is often enshrined in specific marine plan policies, at the national and sub-national level. However, gaps remain between policy ambition and policy implementation mechanisms.

Capability gap 3

Marine plans and associated legislation do not provide guidance on how potential impacts of activities (under their umbrella) on the spatial distribution of climate resilience of natural species and habitats should be assessed or managed.

There is thus scope to improve a climate-smart delivery of marine planning across the UK. That is, the design and implementation of marine plans that consider and limit impacts on the climate change adaptation potential of our marine environment, its species and habitats. Without such delivery, we fall short of the ambitions set out in climate change adaptation policies across the UK Nations. This presents a particular challenge, since planning provides a harmonizing framework under which all other marine regulations, and the development of our blue economy, are implemented.

1.2
Our Ambition

The MSPACE project was designed to help address the three capability gaps identified previously. The delivery of this report aims to inform the development of marine policy across the UK to promote a more climate-resilient spatial management of marine sectors directly reliant on the UK marine environment, its species and habitats: conservation, fisheries and aquaculture.We approach this challenge through the lens of marine spatial planning, because providing effective spatial management strategies for these sectors, that accommodate re-distributions of marine species and habitats under climate change, also requires a view of the distributions of the different marine sectors currently distributed across the UK EEZ (e.g. the growth of our renewable sector, HM Government 2020). Recent, state-of-the-art climate-change assessment techniques have advanced our ability to detect how marine ecosystems change holistically under climate change pressures (Queirós, Talbot et al. 2021). We apply those techniques here, to inform the design of climate-resilient spatial management measures for three marine sectors, namely conservation, fisheries and aquaculture, within the context of marine planning across the UK. Specifically, we aim first to provide planners with advice that can enable the implementation of policies aimed to support climate-smart management of these three sectors, as stated in objectives of marine plans where they already exist, and to inform their design where they lack. Second, we aim to provide this advice also to those with responsibility over the designation of marine conservation sites, and in the fisheries and aquaculture sectors and management, which may allow them to deliver on those shared climate-smart goals. These analyses are therefore expected to help inform a more climate-resilient design for the UK marine protected area network, helping to deliver on the goals of the Global Ocean Alliance: "30by30" initiative[12] of the Convention on Biological Diversity (to protect at least 30% of the global ocean by 2030), spearheaded by the UK. This work also supports the UK ambition to provide a climate change risk assessment for our MPA network, by moving beyond an individual pressure assessment (e.g. Flavell 2020) to a more holistic view of ecosystem-wide effects of climate change and climate cycles (Queirós, Talbot et al. 2021). Finally, it is hoped the results presented here could be used to support the progress towards the achievement of Good Environmental Status targets for biodiversity and fisheries components of the UK Marine Strategy (Her Majesty's Government 2018) as well as the implementation of tasks under OSPAR's 2030 North East Atlantic Environmental Strategy (OSPAR Commission 2021). Specifically, of tasks linked to species and habitat recovery plans, and to mitigation and adaptation to climate change impacts.

[12] https://www.gov.uk/government/topical-events/global-ocean-alliance-30by30-initiative/about

1.3 This Assessment's Structure

The preparation of this report (Fig.1) was carried out under continuous consultation with stakeholders across marine policy and industry in the four UK Nations (2.1.2). This ensured its scope is well aligned with the current needs of those designing and implementing marine plans across the UK Nations, as well as those affected by them in the three core sectors of this report: conservation, fisheries and aquaculture. This assessment is thus delivered in three parts. The present document, is the "Early-warning system" report, delivering on our main ambition to assess the risks and opportunities for the sustainable spatial management of UK marine conservation, fisheries and aquaculture brought about by climate change. It includes detailed state-of-the-art analyses of UK ocean climate modelling, that culminates in a set of recommendations for the climate-smart management of these sectors under a marine spatial planning lens (Section 4). The modelling data used as inputs have been produced by UK marine research institutions as a result of a number of research initiatives funded by UK Research & Innovation and the European Union (2.1.1-3).

The second part of this report, Annex 1: "Model validation" provides a quantitative estimate of the skill of those modelling datasets used as input, in representing observations in our marine waters. The aim for this second part of the assessment was to provide our end-users with a transparent analysis of the confidence we have in the results presented in the "Early-warning system", with a view to support future stakeholder engagements, inherent to UK marine planning. This may help create buy-in for the climate-smart strategy recommendations made here. Some of these consultations are also to be explored in the later stages of the MSPACE project, which additionally aims to ensure that climate-resilient strategies for UK marine planning are also socially and economically feasible.

Thirdly and finally, in Annex 2: "Seabed habitats", we detail the assessment of the current status of benthic habitats across the UK EEZ, given the intensity of physical pressures derived from fishing and aggregate extraction. That work is done employing the best available methodologies, coherent with the work that UK institutions do as part of our contributions to the implementation of the OSPAR convention and ICES assessments. The results from that analysis are also used in our "Early-warning system", in combination with the climate change assessment. Consequently, recommendations made in the "Early-warning system" express recommended strategies for the climate-smart spatial management of conservation, fisheries and aquaculture in UK marine waters, given the recent history of physical disturbance that our habitats already experience (i.e. cumulative pressures assessment).

2
Methodology

2.1 Which methods did we employ?

Marine ecosystems are highly dynamic so determining whether climate change is a driver of changes in habitat conditions, or of species distributions, requires careful assessment of both environmental and species mean trends over time, as well as their variability. (Hawkins and Sutton 2012)In this context, ocean climate modelling is an essential decision-support tool for planners seeking climate-smart design. It allows for testing of plans under different possible future scenarios, and an assessment of potential trade-offs required to inform stakeholder consultations fundamental to planning (Pınarbası, Galparsoro et al. 2017, Frazão-Santos, Agardy et al. 2020). However, the uptake of climate modelling evidence, and the climate-smart design of marine plans, has been slow due to inherent differences between traditional climate modelling analyses and the scales and ambitions of planners. To bridge this gap, the spatial meta-analysis of climate modelling methodology described in Queirós, Talbot et al. (2021) was developed, and is applied here (Fig. 1). Specifically, this methodology uses techniques established in the meta-analysis statistics field to identify the emergence of ecosystem-level climate change signals. In summary, climate change is expressed in nature through changes in many ecosystem attributes simultaneously (e.g. temperature, pH, dissolved oxygen, productivity, water current patterns), changing over space and time at different speeds and with different magnitudes (Pörtner, Roberts et al. 2022). In contrast with traditional techniques, this analysis method identifies ecosystem-wide climate change signals (cf. pressure by pressure), allowing the investigation of the effects of climate change as a holistic process that species respond to through changes in species distributions, affecting the activity of sectors that rely on them. This allows for a mapping of the emergence of climate change hotspots (areas where climate driven trends lead these ecosystem components into a new state beyond their natural variability) over space and time, thus indicating areas where the current level of activity of sectors reliant on those species and habitats may no longer be sustainable (Queirós, Talbot et al. 2021). Importantly, because planners need to know also about what can be done, not just what will be lost, this methodology allows the identification of climate change refugia, where the ecosystem underpinning a sector remains in its current state, and thus where current uses may be sustainable. Lastly, the methodology also identifies bright spots (where conditions are temporarily improved due, predominantly, to climate cycles). Harnessing bright spots and climate change refugia within climate-smart planning design may thus provide information about how the spatial management of individual sectors may be done in a climate resilient way, so as to provide potential for sectoral growth within the spatial structure of a national or sub-national blue economy, despite climate change (Queirós, Talbot et al. (2021). This is of particular interest to planners. Capitalising on refugia and bright spots may thus also provide opportunities for mid-term delivery of sectoral sustainability goals as a time-buying strategy, while we decarbonise the global economy and slow the pace of climate change. The potential need for re-distribution of activities, focused on preserving the climate-resilience of marine ecosystems, and of the sectors that directly depend on them, may thus be done, for instance: by identifying spatial strategies focused on co-location of activities; and assessing compatibilities between different uses leading to potential prioritisation of goals. This method has already been deployed in globally distributed research programmes informing marine management in Ireland (Queirós, Talbot et al. 2020), Tanzania (Queirós, Talbot et al. in review), Philippines (Talbot, Jontila et al. in review) and Vietnam (Queirós, Talbot et al. 2022), and is currently being deployed across 14 locations in the European Union (futuremares.eu).

2.1.1

Who did we consult?

This assessment is delivered in consultation with institutions responsible for designing, steering, or informing the design of, marine plans across the UK (Fig.1,1.1). Many of these agencies are represented in the authorship of this report, including the Marine Management Organisation, Marine Scotland Science, National Resources Wales and the Agri Food and Biosciences Institute. Additionally, from design to recommendation, we engaged with the Department for Environment, Fisheries and Rural Affairs, Marine Scotland, Northern Ireland Department for Agriculture, Environment and Rural Affairs and Welsh Government. We also engaged with key industry representatives, including the Scottish Pelagic Fishermen's Association, National Federation of Fishermen's Organisations, Ørsted UK, and Seas the Opportunity. This work was further informed by dialogues stimulated by the International Council of the Exploration of the Sea's Working Group on Marine Planning and Coastal Zone Management.

2.1.2

Which climate modelling datasets and scenarios have been used?

This report uses a wealth of state-of-the-art publicly available ocean climate modelling for UK marine waters, primarily derived from UK Research and Innovation, Natural Environmental Research Council National Capability, and European research framework modelling projects (Fig.1,1.2).Use of available datasets ensured all data were readily available for consultation at the time of report publication, that the report could be delivered without delay, and added-value use of legacy modelling already produced in 2022, without extra cost to our funders.

Physical biogeochemical modelling data was produced using the coupled Proudman Oceanographic Laboratory Coastal Ocean Modelling System ("POLCOMS", Holt and James, 2001) – European Regional Seas Ecosystem Model ("ERSEM", Butenschön, Clark et al. 2015). These simulations were generated as part of the H2020 programme CERES, and are in-line with modelling used within the 6th Assessment Report of the Intergovernmental Panel on Climate Change. Species distribution modelling data used was generated using the Size-Spectrum Dynamic Bioclimate Envelope Model ("SS-DBEM", Fernandes, Cheung et al. 2013), also developed during the CERES programme. These data are all publicly available (Kay, Clark et al. 2020, Miller, Clark et al. 2020, Sailley, Kay et al. 2020).

Where additional species of interest to the UK were found to be needed for this report, SS-DBEM runs were made available from the FP7 programme DEVOTES. That dataset is available upon request from Jose Fernandes (AZTI), and employed scenarios consistent with the 5th Assessment Report of the Intergovernmental Panel on Climate Change. Both models (POLCOMS-ERSEM and SS-DBEM) represent state-of-the-art modelling tools, and are widely recognised as having a good track record both in the UK and globally.

The skill of all modelling datasets used in representing observations in the UK EEZ is assessed at length in Annex 1 of this report, "Model Validation".

The analysed ocean climate modelling datasets were forced using global greenhouse gas concentration scenarios (i.e. Representative Concentration Pathways, "RCP", Van Vuuren, Edmonds et al. (2011)) used by the Intergovernmental Panel on Climate Change. Specifically, RCP4.5 and 8.5 are contrasted in each of the report's focal sector analyses. These two scenarios were chosen because, at the time of the study, they were seen to represent a likely range of future global greenhouse gas and aerosol concentrations (Bindoff, Cheung et al. 2019, Hausfather and Peters 2020, Schwalm, Glendon et al. 2020, Masson-Delmotte, Zhai et al. 2022). 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, which is a low to moderate rise compared to a range of global climate models (Annex 1). A small percentage of species distribution modelling projections used in the fisheries analyses, and the megafauna analyses produced for the conservation sector, were generated under RCP2.6 (the "strongly declining emissions" scenario) when no equivalent could be found under RCP4.5, and these derive from the FP7 programme DEVOTES. Notably, all scenarios considered overshoot the Paris Agreement goal of keeping global warming below 1.5°C, and are a good illustration of the current progress in global emissions cuts at the time of this report (United Nations Environment Programme 2022). As climate action accelerates, lower emissions scenarios should be considered.

In the fishing sector analyses, the scenarios employed combine RCP with more general views about climate change mitigation and environmental concerns, into a type of scenario termed shared socio-economic pathways ("SSP"), as also used by the IPCC (O'Neill, Kriegler et al. 2014). For fishing analyses purposes, these modelling datasets include an element of fishing mortality in addition to mortality terms linked to environmental conditions. For each analysis described in subsequent sections, the specific modelling datasets used and their sources are clearly listed.

PHASE		ACTIVITY	INPUT FROM
DATA GATHERING	1.1	Select focal MSP sectors	Draft marine spatial plan; MSP process practitioners
	1.2	Select modelling datasets representing environmental conditions, species and habitats underpinning sectors activity	Peer reviewed literature, stakeholders, reports, policy documents
	1.3a	Identify the expected climate change trend for each database	Climate change literature review
	1.3b	Per dataset: prepare present and future time-slices (i.e. projections for mean, standard deviation, & n)	
ANALYSIS	1.4a	Calculate individual effect-size (Hedges' g) per dataset & grid cell	
	1.4b	Run random-effects spatial meta-analysis model per grid cell: 0 ∉ 95% CI (M) → M < 0: Climate change hotspot; M > 0: Bright spot. 0 ∈ 95% CI (M) → Climate change refuge	
	1.4c	Map spatial distribution of ecosystem climate vulnerability*	
OUTPUT	1.5	Sectorial GIS data overlain onto climate vulnerability maps indicates climate-driven sector effects and cross-sector interactions	
INTERPRETATION	1.6	Inform climate-resilient MSP Strategy	Spatial data gathered from practitioners, reports, data repositories

Figure 1 Workflow diagram, showing details of the co-design process underpinning this assessment. Re-drawn from Queirós, Talbot et al. (2021).

2.1.3

Which temporal and spatial resolution have we employed?

We co-designed analyses with the ambition to provide the best ocean climate change evidence for the UK EEZ in the format that best suited the needs of our end-users (the planning communities across the UK nations, industries affected by plans). To this end, we focused on contrasting the current state of UK coastal and marine habitats with those of these systems in the short, medium and long-term. In this way, we hoped to inform immediate planning policy and industry development in the UK, and also to provide information about long-term changes in UK marine ecosystems driven by climate change. All physical-biogeochemical modelling datasets analysed have the spatial resolution of the physical model simulations used (POLCOMS) which is a regular grid of 0.1° latitude × 0.1° longitude, approximately 5–7 km × 11km per grid cell (or 60–80 km^2).

This is a regional model, parameterised for the North Western European Shelf, with 40 vertical layers which are more closely resolved in shallower areas. We analysed surface, bottom, seabed or vertically integrated data, as needed and described in subsequent sections. Modelling data from the SS-DBEM has a coarser grid of 0.5° latitude × 0.5° longitude. These datasets were therefore projected onto the POLCOMS grid without further processing, to allow for joint analysis of data where needed (e.g. section 2.2).

2.1.4

How did we consider broader effects on other sectors affected by planning?

The results from the climate modelling analyses were then interpreted in the context of the current distributions of the key sectors of the report (e.g. siting of MPAs and HPMAs; distribution of different types of fishing grounds and aquaculture infrastructure) and of other key sectors of the UK blue economy (Supplementary Information Table S1). We also included the known distribution of key habitats of interest, such as the best available evidence on the distribution of carbon sequestration rates in the east of the UK EEZ (SI Table S1). The overlay of modelling data with this GIS information then allowed us to identify opportunities for co-location and prioritisation of activities that may, in future, help support the climate resilient spatial management of marine conservation, fisheries and aquaculture in the UK. We liaised extensively with actors involved in all the agencies responsible for, and involved in, planning across the four UK nations to ensure that the datasets used at this stage matched, as closely as possibly, those used in their own processes. These are detailed in Supplementary information (SI) Table S1.

2.2
Focal sector analyses

2.2.1

Conservation

2.2.1.a — Species and Habitats

A review was carried out to map each marine area of conservation interest within the UK EEZ to its corresponding marine plan region, and to list the species and habitats underpinning the designation of each of those sites. Specifically, open access online information pertaining to SAC (Special Areas of Conservations), RAMSAR (Convention on Wetlands of International Importance), SPA (Special Protected Areas), SSSI (Sites of Special Scientific Interest) and MCZs (Marine Conservation Zones) was sought, as collated by the Department of Agriculture, Environment and Rural Affairs, Joint Nature Conservation Committee, Marine Scotland and Welsh Government. Species lists were collated, alongside geographical information, environmental and biological characteristics.

All designated qualifying marine criteria regarding habitat and species were then identified for each level of UK protection. This review generated an original database with 3505 entries (hereafter, the “Species List”, Supplementary Information Table S2), which guided further analyses for the conservation sector. We excluded from further analyses species and habitats identified if their location extended beyond the domain of ocean climate modelling datasets available to this report. To this end, species and habitats restricted to land and intertidal areas (e.g. salt marsh, seagrass, wading birds) were excluded. Seabird species were included in these analyses when at least their feeding grounds were located subtidally, although many locations of interest to these species (e.g. nesting areas in sea cliffs) are in areas under the umbrella of terrestrial plans.

After detailed examination of the Species List, we selected modelling data layers for input into the meta-analysis that allowed us to map the spatial distribution of climate resilience and vulnerability in the environmental conditions required by those species and habitats during the 21st century, under RCP 4.5 and 8.5, as well as of the species themselves or their prey. Three sub-group analyses were conducted, using different sets of modelling data (SI Table S3): megafauna (covering birds, mammals, sharks, skates and rays); benthic habitats; and pelagic habitats. The sub-group (spatial meta-) analysis for megafauna species included species distribution modelling datasets for prey species as well as ocean climate modelling of key environmental drivers for these species. In the absence of mechanistic species distribution modelling for those species, this approach was deemed appropriate, because: those modelling datasets have excellent track record (Section 2.1.2); and because the alternative (statistical base modelling) tends to perform poorly in long term scenarios of interest to this report. The sub-group analyses for benthic and pelagic species and habitats included ocean climate modelling of key environmental drivers only for the same reasons.

We used this analysis structure to match the receptor-based assessment structure recommended by OSPAR, as used in planning assessments in the UK, e.g. for the assessment of impacts of harnessing resources for particular areas of interest in planning undertaken by Welsh Government (Welsh Government 2021). These analyses allowed us to assess the climate-resilience of each site of conservation value (SI Table SI), given unfolding, multiple climate pressures over time. This is particularly important since the designation of protected areas in the UK has focused primarily on protecting benthic species & habitats which often have limited mobility (at least during adult phases), and thus being particularly vulnerable to changing local conditions.

To the climate vulnerability maps generated by these climate modelling analyses, we overlaid GIS data representing the current structure of marine sectors within the UK EEZ (Fig.1 , 1.5; Section 2.1.4). This allowed us to ascertain how spatial prioritization of activities and co-location could be used in the update or design of new marine plans across the UK, to maximize the climate-resilience of species and habitats of conservation value.

Lastly, we related these analyses with the assessment of seabed habitat condition presented in Annex 2, where the Relative Benthic Status ("RBS", Rijnsdorp, Bolam et al. 2018, Pitcher, Hiddink et al. 2022) and the Extent of Physical Disturbance to Benthic Habitats ("BH3", Matear, Vina-Herbon et al. 2023a, Matear, Vina-Herbon et al. 2023b) indices are estimated, in line with the UK contributions to ICES and OSPAR Commission activities.

This allowed us to determine how the location of climate change refugia and hotspots identified here for seabed habitats may relate to the current distribution of physical impacts of fisheries and aggregate extraction on seabed habitats, considering both EUNIS broad scale habitats (RBS and BH3); and the occurrence of OSPAR Threatened and/or Declining habitats (OSPAR 2008; BH3). This analysis informed final recommendations provided by this report.

2.2.1.b — Climate Services

There is currently interest at the UK level, and within individual Nations' governments, in increasing the degree of protection from destructive uses of some sites within the MPA network, and that these sites may also harbor habitats delivering climate change services (such as carbon sequestration): i.e. Highly Protected Marine Areas ("HPMAs", Benyon Review (2020)).In support of this process, we also undertook meta-analyses focused on such habitats. These analyses focused on the blue carbon capability of the UK EEZ and its resilience to climate change. Blue carbon refers to marine and coastal habitats where organic carbon is stored and is amenable to management (Herr, Pidgeon et al. 2012). More specifically, we focused here on organic carbon stores in marine sediments, because the UK EEZ is thought to contain large pools of sedimentary organic carbon (Smeaton et al., 2021; Gregg et al., 2021; Parker et al., 2021), due mainly to their broad spatial scale. Carbon stores in marine sediments can be an important reservoir for long-term storage (>100 years) (Bianchi, Cui et al. 2018, Legge, Johnson et al. 2020, Diesing, Thorsnes et al. 2021). However, there is still no internationally recognized method available for their inclusion in nationally determined contributions to the Paris agreement or for national carbon inventory accounting. It is also important to note that large gaps still exist in the coverage of observations of this potential across the UK marine sediments and in the confidence in modeling predictions on the extent and distribution of those (Annex 1).

Blue carbon habitats help to cycle carbon as part of a natural and variable system, with different elements contributing to the removal, release, and storage of carbon over space and time, through both natural and anthropogenic processes (Parker, Benson et al. 2022). Climate mitigation benefits can then be achieved through two blue carbon habitat management approaches. The first approach includes actions to maintain the integrity of existing natural carbon stores, thereby avoiding the release of greenhouse gases (known as "avoided emissions"). Examples of this include protection from, or sustainable management of, activities which damage these habitats: (e.g., by establishing Marine Protected Areas (MPAs) that limit or eliminate human activities disturbing the seafloor, Epstein, Middelburg et al. 2022). The second approach includes actions, such as habitat restoration or creation, that enhance or recover the habitat's ability to provide long-term removal of greenhouse gases from the atmosphere (these are classed as "emission savings").
However, sedimentary carbon stores are sensitive to climate change, which affects the processes leading both to uptake and storage of carbon on the seafloor (Ravaglioli, Bulleri et al. 2019, Queirós, Talbot et al. 2021). Whilst the conservation of sites providing such climate services in the UK has been recommended, the Benyon review did not provide guidance on how to identify such sites that may also be climate-resilient. Subsequent work has focused on the sensitivity of marine habitats to climate pressures individually, in contrast to the holistic way in which habitats experience climate change (Queirós, Talbot et al. 2021), and not on their effects on carbon storage specifically (Flavell et al. 2021). To help bridge this gap, we include in this report spatial meta-analyses of ocean climate on modelling layers that represented environmental variables that contribute to seafloor carbon sequestration potential (SI Table S3). In this way, we aimed to identify which areas of the seafloor may continue to sequester carbon into the future, despite climate change, with the goal to inform on the potential design of a climate-smart HPMA network that also delivers climate change services. We include, in this assessment, the exploration of how any climate resilient sites compare to the current distribution of seabed uses that perturb the sediment structure, and thus its carbon stores.

2.2.2

Fisheries

For the fishing sector analysis, species distribution modelling datasets were sought aiming to cover, as best as possible, the species representing the top landings by value landed by international and UK registered vessels in the UK (Table 1, Eurostat 2019). To meet our statistical analysis framework requirements (Queirós, Talbot et al. 2021), modelling data had to be: spatially explicit (i.e. gridded data); cover the UK Exclusive Economic Zone; cover the period between 2006 and 2099; and allow for the estimation of species' abundance means and standard deviations, at least on an annual basis. These three requirements were met by modelling data for 23 species, contributing to more than 90.5% of the landings by value into the UK (Eurostat 2019) (Supplementary Information Table S4). We note, as an important data gap, the unavailability of species distribution modelling for the species Buccinum undatum (the common or waved welk) that could be used, as this species represented just under 46% of landings into Wales in 2019 (Eurostat). We carried out separate analyses for the pelagic and benthic/demersal fleets, at the UK scale. We did not carry our separate analysis differentiating vessel size within each of these fleets. All modelling layers used, and their sources, are detailed in SI Table S4.

Table 1

Landings by value ("LBV") into the UK in 2019.

SCIENTIFIC NAME	COMMON NAME	VALUE (EURO)	FISHERY TYPE	% OF TOTAL LBV	CUMULATIVE % CAPTURED IN THIS STUDY	USED
Nephrops norvegicus	Norway lobster	€128,394,412.65	Benthic	16.98	16.98	Yes
Scomber scrombrus	Atlantic mackerel	€101,602,511.52	Pelagic	13.44	30.42	Yes
Cancer pagurus	Edible crab	€71,894,302.55	Benthic	9.51	39.92	Yes
Gadus morhua	Atlantic cod	€67,158,434.73	Demersal	8.88	48.8	Yes
Pecten maximus	Great Atlantic scallop	€65,301,681.18	Benthic	8.64	57.44	Yes
Homarus gammarus	European lobster	€52,241,579.80	Benthic	6.91	64.35	Yes
Merluccius merluccius	European hake	€43,984,408.58	Demersal	5.82	70.16	Yes
Solea solea	Common Sole	€35,254,199.66	Demersal	4.66	74.83	Yes
Buccinum undatum	Whelk	€29,334,334.02	Benthic	3.88	0	No
Pollachius virens	Saithe	€21,816,206.71	Demersal	2.89	77.71	Yes
Clupea harengus	Atlantic herring	€21,731,895.99	Pelagic	2.87	80.59	Yes
Merlangius merlangus	Whitling	€18,829,004.49	Demersal	2.49	83.08	Yes
Molva molva	Ling	€15,574,657.36	Benthic	2.06	0	No
Loligo spp	Common squids nei	€14,793,338.90	Demersal	1.96	85.03	Yes
Lepidorhombus spp	Megrims nei	€11,669,547.28	Benthic	1.54	0	No
Pleuronectes platessa	European plaice	€9,397,365.10	Benthic	1.24	86.27	Yes
Microstomus kitt	Lemon sole	€8,447,694.42	Benthic	1.12	87.39	Yes
Dicentrarchus labrax	European seabass	€4,813,361.81	Pelagic/Demersal	0.64	88.03	Yes
Pollachius pollachius	Pollack	€4,801,773.99	Demersal	0.63	88.66	Yes
Micromesistius poutassou	Blue whiting	€3,257,233.79	Pelagic	0.43	89.09	Yes
Sardina pilchardus	European pilchard	€2,960,463.86	Pelagic	0.39	89.49	Yes
Aequipecten opercularis	Queen scallop	€2,870,839.47	Benthic	0.38	89.87	No
Trachurus spp	Jack and horse mackerels nei	€2,463,830.37	Pelagic	0.33	0	Yes
Hippoglossus hippoglossus	Atlantic halibut	€2,186,318.10	Benthic	0.29	90.15	Yes
Raja brachyura	Blonde ray	€2,038,847.79	Benthic	0.27	0	No
Raja clavata	Thornback ray	€1,997,279.78	Benthic	0.26	0	No
Zeus Faber	John dory	€1,711,631.29	Pelagic	0.23	0	No
Glyptocephalus cynoglossus	Witch Flounder	€1,466,645.44	Benthic	0.19	0	No
Mytilus edulis	Blue mussel	€990,559.93	Benthic	0.13	90.29	Yes
Sprattus sprattus	European sprat	€885,101.98	Pelagic	0.12	90.4	Yes
Maja squinado	Spinous spider crab	€790,792.33	Benthic	0.1	0	No
Crangon crangon	Crangon Shrimp	€780,006.38	Benthic	0.1	90.51	Yes

2.2.3

Aquaculture

Aquaculture in the UK is dominated by four species (Salmon, mussel, pacific cupped oyster and rainbow trout). Fish (especially salmon) dominate the sector in Scotland, and mollusks dominate the sector in the other three nations (O'Biern, Ojaveer et al. 2022). Our assessment thus focused on these species. We further included modelling data pertinent to the representation of seaweed farming, since this is a nascent but fast growing sector in the UK (O'Biern, Ojaveer et al. 2022), and the fastest growing sector of aquaculture in Europe and around the world.

Modelling-data selection was informed by climate change sensitivity analysis in O'Biern, Ojaveer et al. (2022) and Collins, Bresnan et al. (2020) who provide recent overall analyses of the UK aquaculture sector, though not in a spatially explicit way, and without assessing potential for ecosystem-wide tipping points driven by climate change. We provide here sub-group analyses focused on activities on or near the sea surface (e.g. pole and rope mussel and scallop farming; kelp farming; salmon and other finfish such as halibut); and of those focused on seabed habitats (e.g. mussel and scallop beds; oyster trestle). In each case, modelling data used is summarised in SI Table S5. In addition to considering species distribution modelling (as available to this report: Saccharina latissima, Mytilus edulis, Salmo salar), we used a range of modelled environmental data to represent key drivers of species distributions in each sub-group analysis. We included relevant seawater temperature variables as experienced by individuals (affecting individual physiology and resistance to parasites); available estimates of ecosystem productivity; and variables expressing the carbonate system (e.g. pH and saturation state of aragonite) which affect the viability of shellfish, that grow calcified exoskeletons (Townhill, Artioli et al. 2022, SI table S4). Furthermore, heatwaves are known to be one of the largest climate-driven challenges to the continuation of sustainable aquaculture in temperate regions, such as the UK (Bricknell, Birkel et al. 2021). Accordingly, model-based heatwave estimates, based on sea surface temperature patterns, were also included in both subgroup analyses, as seabed-based aquaculture activities tend to happen nearshore, in shallow waters.

2.3 Shapefile creation

To facilitate the use of information contained in this report, we further created shapefiles that summarise the main findings of each of our sectorial analyses, summarising the distribution of climate change refugia and climate change hotspots across the UK EEZ, in each case. Because climate change created wide distributions of climate change hotspots across much of the EEZ in most analyses, we restricted the analyses leading to the creation of shapefiles to the period between 2026 – 2069. To this end, we analysed the outcomes of all sectorial analysis in each analysed 20 year time slice compared to the reference period, using the "magick" package in R. This allowed the stacking of all plots shown for each analysis, for all 20 year time periods and both emissions scenarios. Areas consistently identified as refugia (or contrastingly, hotspots) were marked using the "draw" function in the terra package in R. The resulting polygons were stored as shapefiles made available with this report, which summarise the location of climate refugia and climate change hotspots in the UK EEZ up to 2069, where agreement exists between emissions scenarios.

3
Results

3.1 Spatial management of marine conservation

The analysis of modelling data allowed for the identification of potential pathways for climate-smart spatial management of habitats of conservation value, despite regional sensitivity, and these differed between emissions scenarios. Indeed, climate change was found to present a substantial challenge to the effectiveness of the UK's "30by30" target (i.e. the UK ambition to protect 30% of UK waters by 2030, in support of the United Nations Convention on Biological Diversity). This is because the extent of the UK EEZ which may be able to accommodate climate-resilient designated sites (i.e. within climate change refugia) was strongly limited under higher emissions.Indeed, the slower trajectory for global emissions represented by RCP4.5 leads the projected extent of climate-resilient habitats of conservation value to decline more slowly, remaining larger by the end of the century than under RCP8.5. However, climate change sensitivities varied between habitat types (conservation sector meta-analyses summaries, Fig. 2). For instance, the extent of benthic habitats delivering climate services (some of which could come to host HPMAs) that appeared to remain climate-resilient corresponded to >80% of the UK EEZ, throughout the 21st century (Fig. 2). Contrastingly, the extent of pelagic habitats of interest to the conservation of megafauna remained well below 25% throughout all periods and scenarios analyzed (Fig. 2). In most analyses, the extent of habitats of conservation value that remains climate-resilient in the second half of the 21st century is only about 10% or lower, under both emissions scenarios assessed (RCP4.5 and RCP 8.5).

The location of areas where sensitivity and resilience to climate change were observed did not necessarily always overlap when the different habitat categories were considered. In some cases, areas identified as harboring long-term climate change refugia of value to the conservation sector also appeared to host refugia for species of interest to the fishing and, in cases, the aquaculture sector. Those areas may be of great interest to marine planning. The subsequent sections assess the spatial patterns in climate signals that underpin those results.

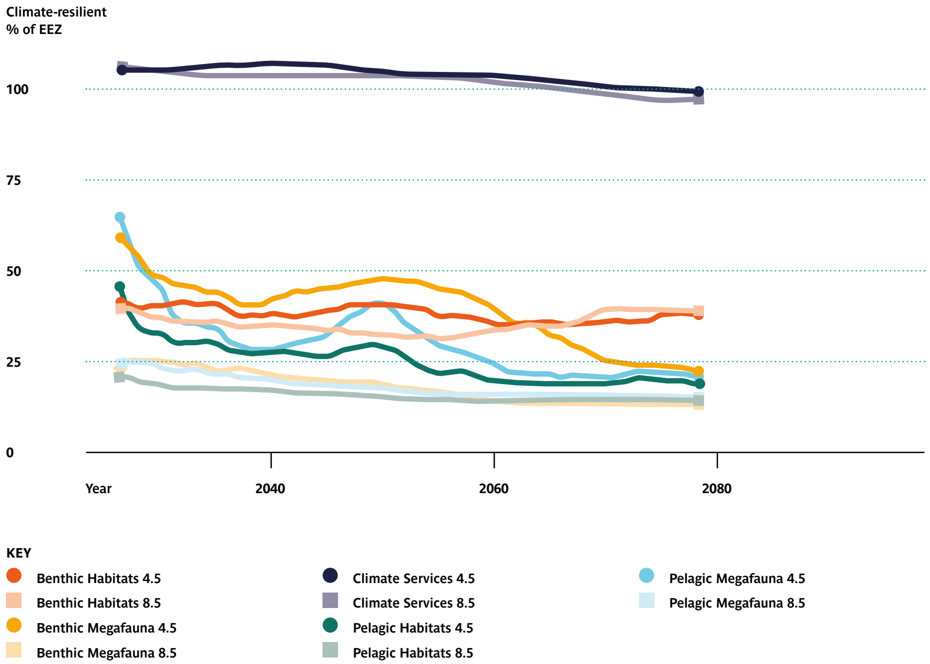


Figure 2

Extent of climate change refugia of value to the conservation of listed species and habitats, identified via modelling meta-analysis, expressed as proportions of the UK EEZ (773,676 km^2). Each year denotes the first year of each 20 year time-slice contrasted with the reference period (2006 – 2025) in meta-analysis calculations, such that e.g. "2080" refers to the period 2080-2099. Estimates under global emissions trajectories RCP4.5 and RCP8.5 are shown.

3.1.1

Megafauna

The analysis of habitats and prey of value to the conservation of marine megafauna (marine mammals, seabirds, sharks, skates and rays) suggests that the emissions scenarios considered represent substantially different futures. For benthic habitats and prey species of interest to the conservation of megafauna, substantial areas in the Celtic Sea, across the S of England, and in the central North Sea where MPAs occur show as climate resilient (white background, no triangles) under RCP4.5 but as climate change hotspots (purple triangles) under RCP8.5 (Fig. 3). Under RCP4.5, though they reduce in size over time, large areas in the East and SW coast of England, small patches off the East coast of Scotland, the Welsh coast and regions offshore to the West of the EEZ may harbor climate refugia (white background, no triangles) well into the 2070s (Fig.3). Many of those sites are already designated areas or areas that have other types of restrictions in place (Fig.3, top panel, purple, pink, yellow and grey). Many of these sites are also concentrated in offshore areas in the east and south-east where oil & gas platforms and wind farms occur (Fig. 3, top panel). However, many of the climate refugia identified in this analysis occur in areas that experience light pollution and are also exploited by bottom gears (Fig. 3, bottom panel, red and green shading). The latter is notably the case for areas offshore to the west of Scotland that are some of the very few climate refugia that remain until the end of the century under RCP4.5. Light pollution overlaps with many designated sites serving as climate refugia in coastal areas, e.g. in the Severn, the Welsh coast and the coast of Northern Ireland (Fig. 3, bottom).

For pelagic habitats and prey of value to the conservation of megafauna species, fairly striking results were found. Most areas of the EEZ were found to host climate change hotspots (purple triangles) already into the next decade (Figure 4) under both emissions scenarios. Under RCP4.5, several (if small) areas appeared to harbour climate refugia well into the 2070s and 2080s, and these include the SW of England and the Severn Estuary, the Rockall bank off of Scotland, and small patches to the North west of Orkney and North of Shetland (Fig.4, left). Most of these disappear by the end of the century, and are absent throughout under RCP8.5 (Fig 4. right). Refugia identified under RCP4.5 do not overlap consistently with designated areas but in many there are some restrictions in place on some pelagic gears, although other types of pelagic fishing and shipping occur throughout their vast majority, with the exception of those in the most offshore areas around Scotland (Fig. 4, bottom panel, green).

An edible crab *(Cancer pagurus)* on maerl bed ©Graham Saunders/SNH

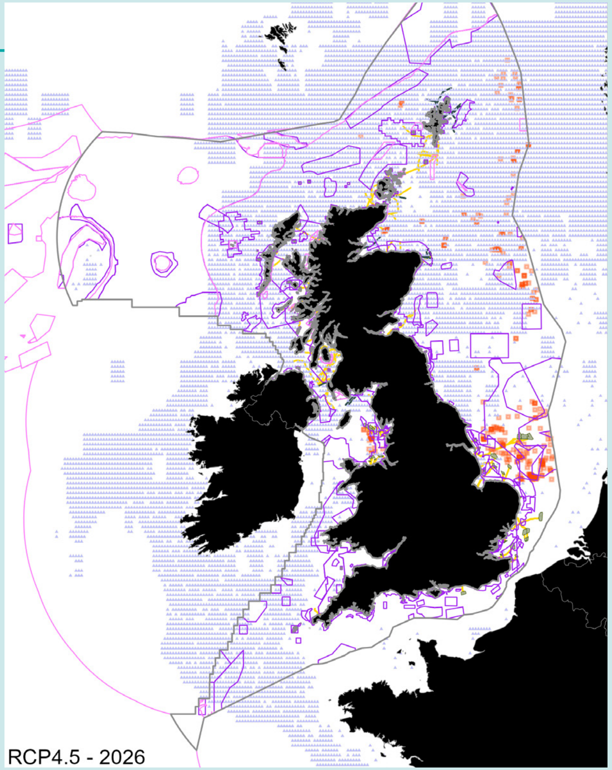
3.1.2

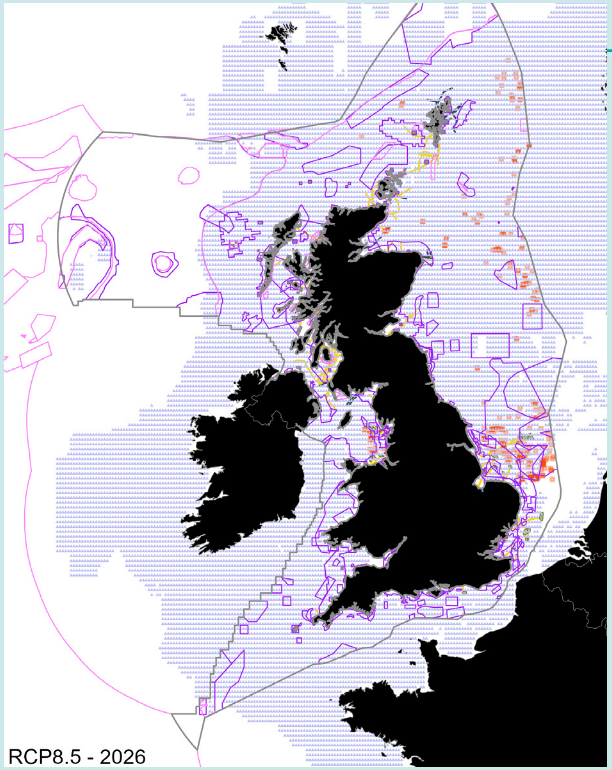
Pelagic Habitats

The analysis of pelagic habitats important to support the conservation of habitats of conservation value also suggested substantial differences between the two emissions trajectories considered (Fig.5). Under RCP8.5, less than 10% of the EEZ was estimated to be climate-resilient already from the period of 2026 – 2045, dropping to just 2% by the end of the century, with climate change hotspots otherwise emerging elsewhere (Fig.5, right). Under RCP4.5, the progress of emergence of hotspots is slower. Climate refugia are initially widely distributed across the West coast of Scotland and waters between Orkney and Shetland, the West coast of England, the coasts of Wales and Northern Ireland. From 2050 onwards, some remain in patches off of the SW of England, in the Irish Sea, the west coast of Scotland (in the Inner Hebrides, and the Rockall and George Bligh Banks), into the 2070s (Fig.5, left). Designated sites already occur across many of the resilient areas, including the Welsh coast, the coast of Northern Ireland (Fig. 5, top). However, several of these and other resilient areas are open to exploitation by pelagic gears, which are widespread in all climate-resilient sites identified (Fig.5, bottom). Light pollution is also prevalent at these sites, especially in coastal areas (Fig.5, bottom). The prediction of impacts under different climate change scenarios are important for the identification and designation of HPMAs as those sites will consider a whole ecosystem approach which could include a pelagic component. (please see 3.1.3).

Pelagic waters © Sarah Lee

Figure 3



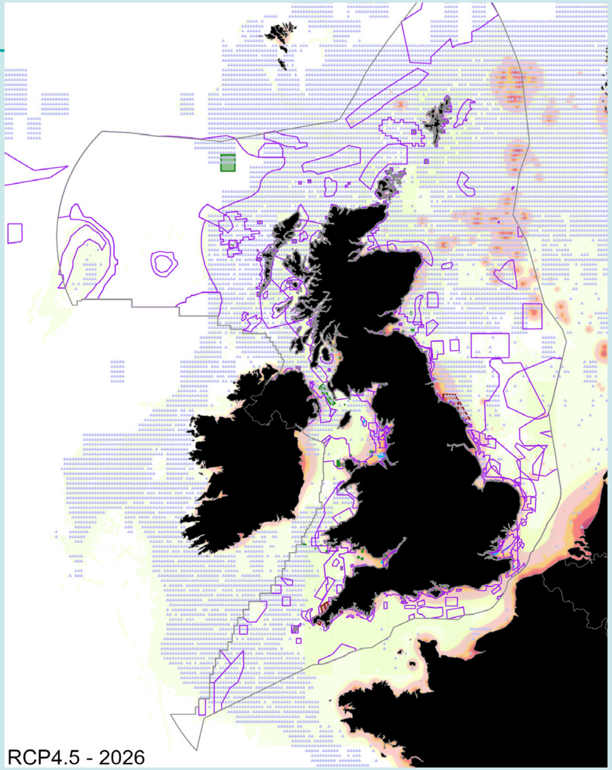


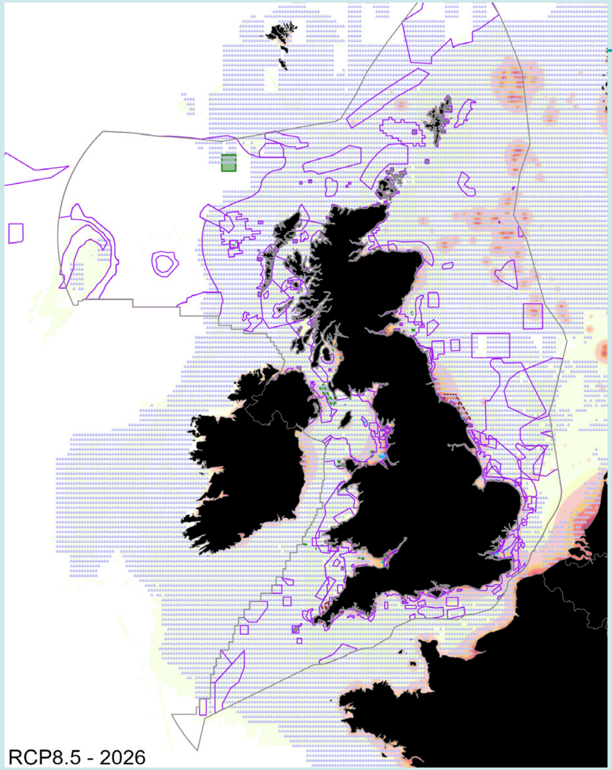
KEY

- Cables
- Pipes
- Oil/gas platform
- Wind farm
- Restricted fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

Figure 3





KEY

- Dredging
- Mining lease
- Spoil dumping
- Fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

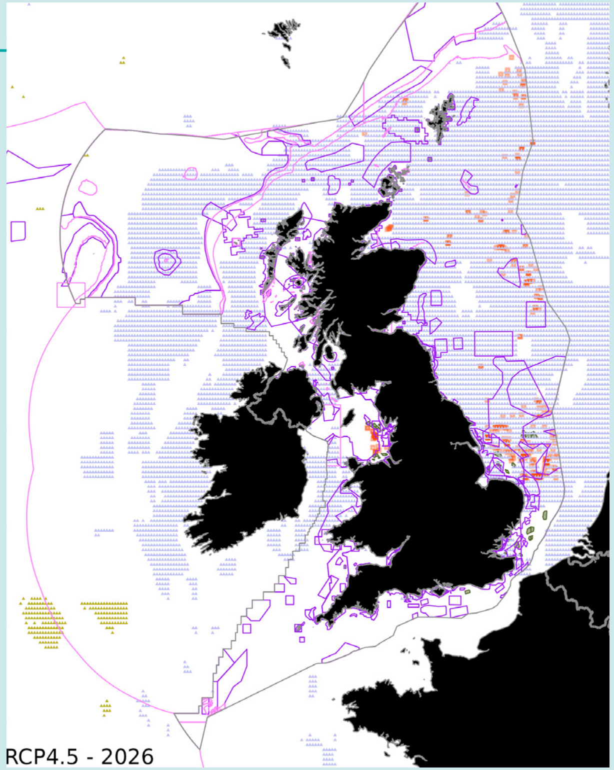
* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

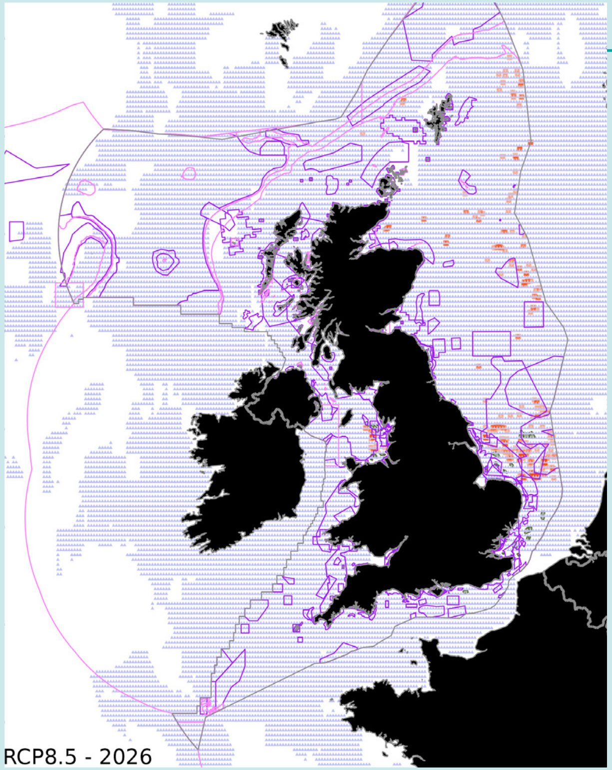
LIGHT INTENSITY
mCd m²

100.0
10.0
1.0
0.1

Changes in environmental conditions and prey species of relevance to megafauna exploiting benthic habitats (SI Table S3) throughout the 21st century relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles (none) and hotspots are purple triangles. GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses to these habitats (top) or those that represent additional sources of impacts (bottom). Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that “2040” refers to the period 2040 – 2059.

Figure 4





KEY

- Oil/gas platform
- Wind farm
- Restricted fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

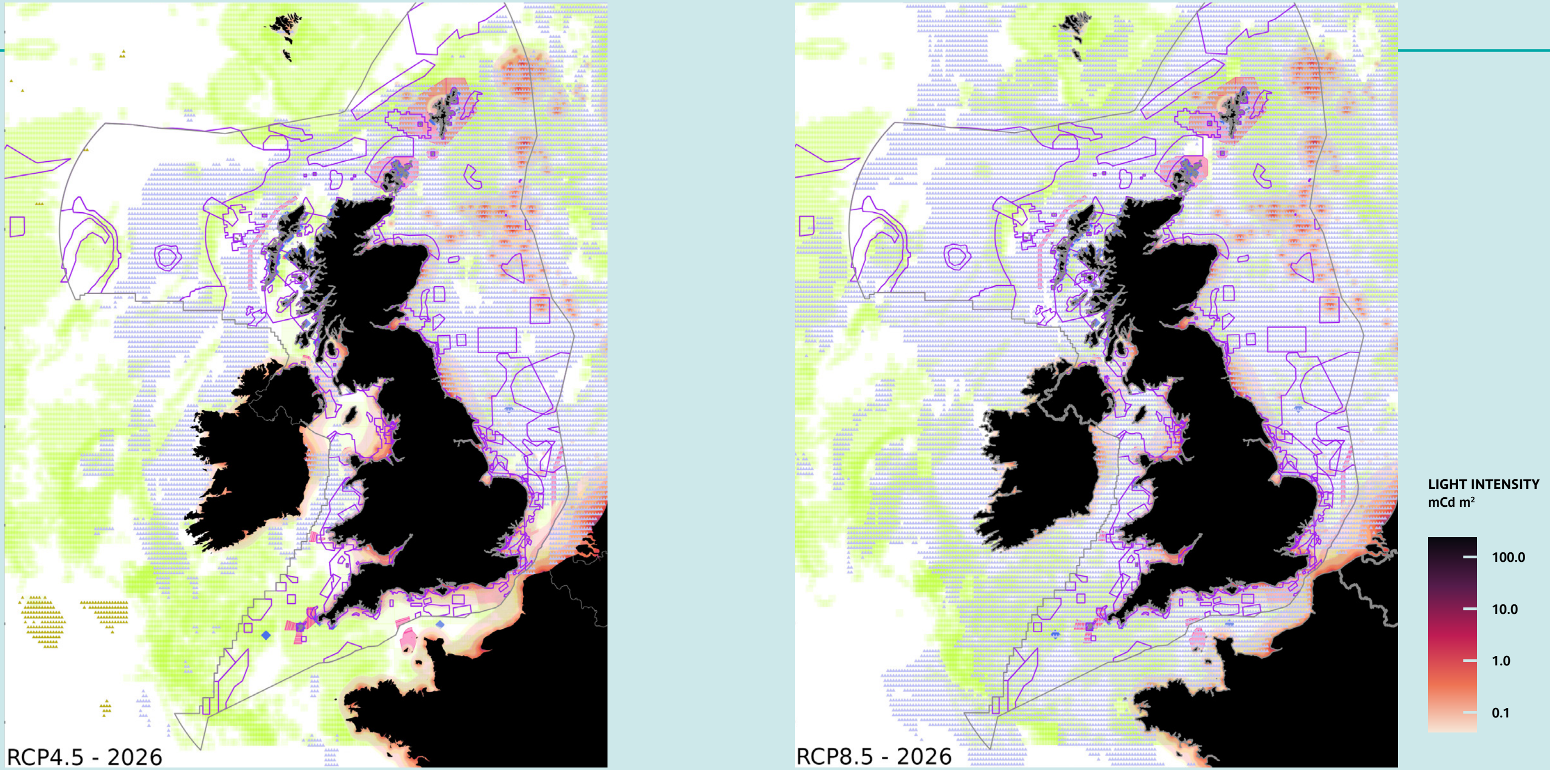
* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

Figure 4

KEY

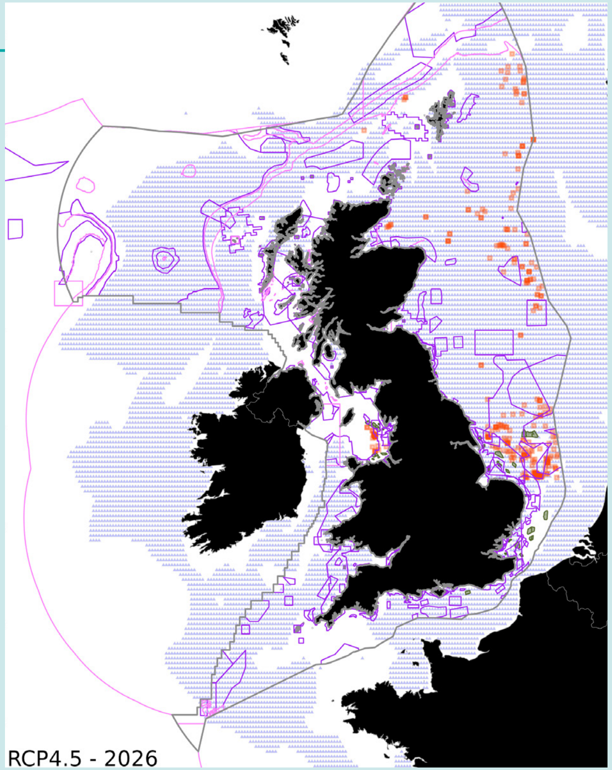
- Fishing*
- High density shipping
- Waste water discarge
- Conservation site**
- Climate change hotspot
- Climate change brightspot

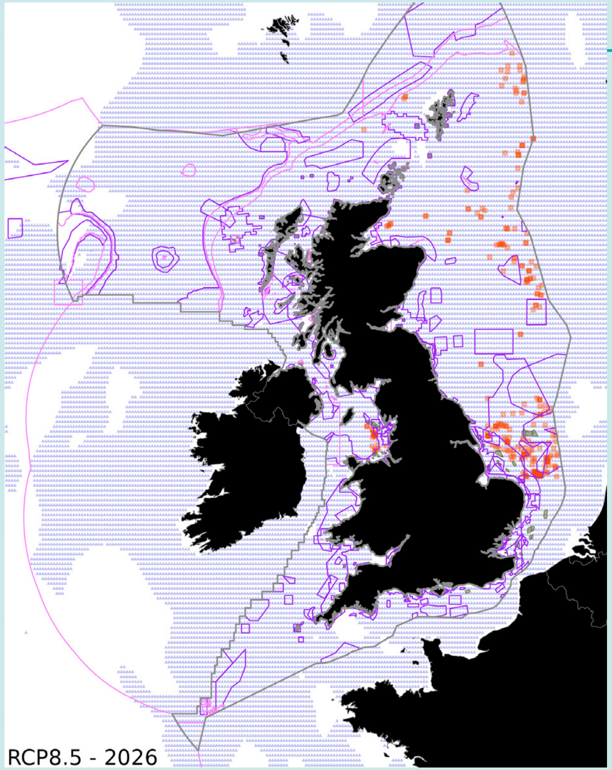
* Pelagic gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar



Changes in environmental conditions and prey species of relevance to megafauna exploiting pelagic habitats (SI Table S3) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles (none) and hotspots are purple triangles. GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses to these habitats (top) or those that represent additional sources of impacts (bottom). Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that “2040” refers to the period 2040 – 2059.

Figure 5



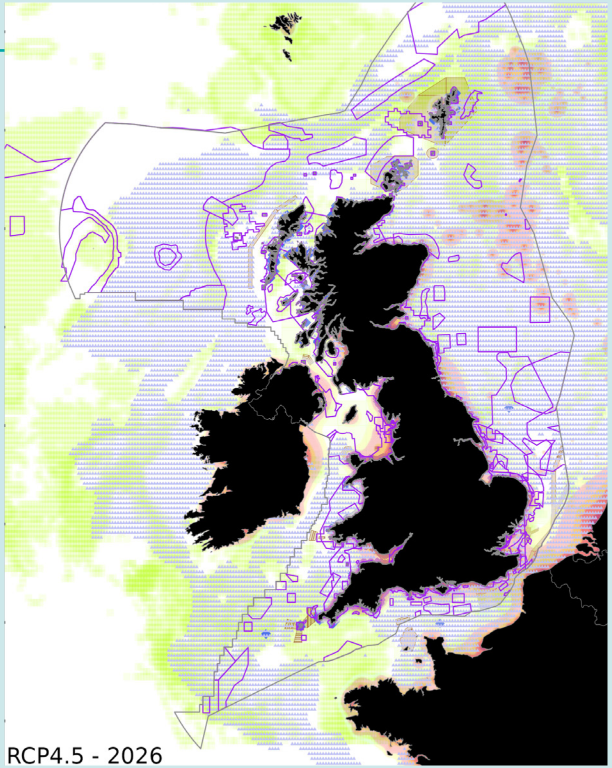


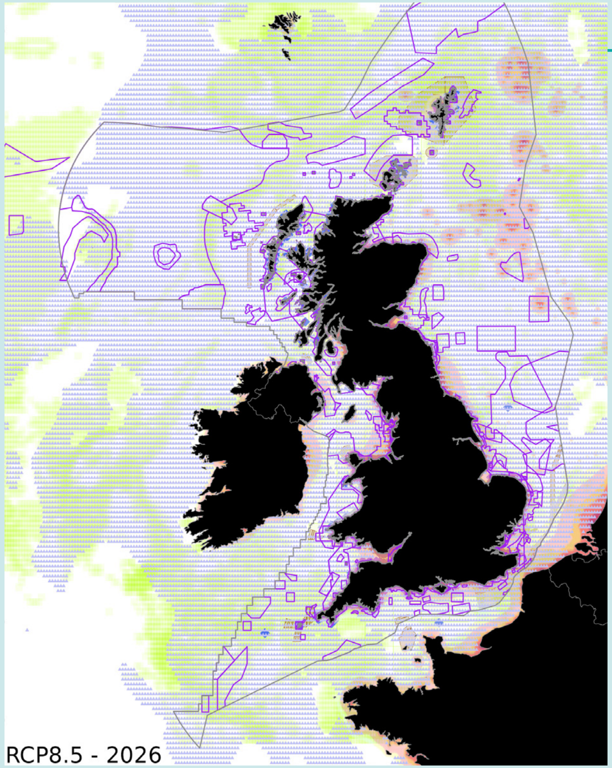
KEY

- Oil/gas platform
- Wind farm
- Restricted fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

* Pelagic gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

Figure 5





KEY
- Fishing*
- High density shipping
- Waste water discarge
- Conservation site**
- Climate change hotspot
- Climate change brightspot

* Pelagic gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

LIGHT INTENSITY
mCd m²

100.0
10.0
1.0
0.1

Climate-driven changes to pelagic habitats that may affect their conservation value (SI Table S3) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles (none) and hotspots are purple triangles. GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses to these habitats (top) or those that represent additional sources of impacts (bottom). Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that “2040” refers to the period 2040 – 2059.

3.1.3

Benthic habitats

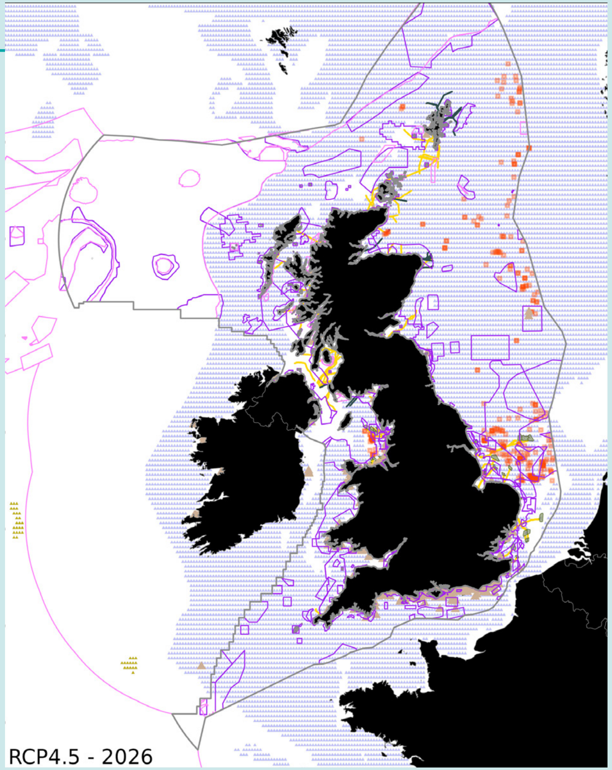
Regarding the conservation of benthic habitats, we identify that considerable areas in the Irish Sea, the coast of Northern Ireland and the West coast of Scotland emerge as climate change refugia in both emissions scenarios analyzed, and these areas remain more or less stable thought the 21st century (circa 20% of EEZ, figures 2 and 6). A site recently identified as one of the three first English HPMAs is located here (Allonby Bay). These areas already host several designated sites for conservation, thus representing a pathway towards climate resilient marine conservation in UK waters. Other sites, where other types of restrictions on uses are in place (e.g. due to the location of cables and pipelines, purple, yellow and grey, Fig. 6, top) also overlap with climate change refugia and could thus also be considered towards increasing the extent of UK marine habitats that may provide some degree of

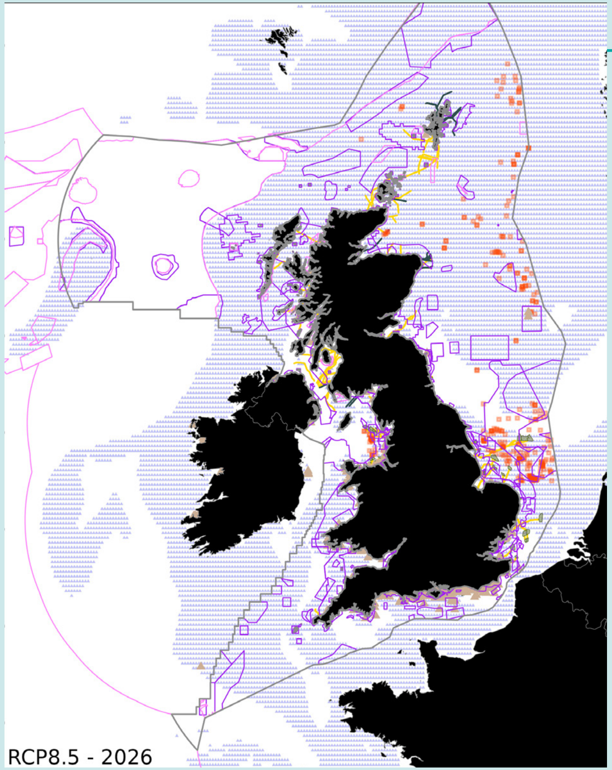
Seabed (benthic) habitat, horse mussel bed with dead mans finger and common starfish ©Graham Saunders/SNH climate-resilient conservation potential. Both types of areas may become seedbanks for benthic species across the UK under climate change. Some of these areas identified as climate change refugia of interest to conservation currently also host a substantial level of seabed fishing (and in some cases aggregate extraction), including high levels of bottom trawling, causing disturbance of the seabed as well as impacts on the benthic communities, currently assessed in some areas as not in good status (BH3 and RBS, Annex 2, Fig.7). For example, long term climate change refugia for benthic habitats identified along the coast of Northern Ireland overlap with the current location of OSPAR Threatened and/or Declining Habitats (Fig.7), which were estimated to be in poor condition due to seabed activities (BH3, Annex 2). This type of evidence highlights the crucial role that climate-smart marine planning may serve in future, in helping to provide long-term solutions that serve conservation and commercialinterests as species move in and adapt to climate change.

The need to consider strategies promoting sectoral and ecosystem adaptation to climate change as part of our spatial management of human activities is made clear in Fig.7, where the widespread cumulative pressure of climate change and bottom contact fishing gears on UK seabed habitats and associated benthic communities is visible. Many areas estimated to be highly disturbed by bottom extraction practices including mostly fishing but also some dredging (BH3, Annex 2), and where the seabed communities are estimated to be in poor state (RBS, Annex 2), are also identified here as hosting climate change hotspots through most of the 21st century (e.g. the Fladen grounds, off of the east coast of Scotland, Fig.7). Without consideration for these potential cumulative effects it may thus be difficult to implement sustainable sectoral management practices (Queirós, Fernandes et al. 2018), but plans across the UK seek to support decision making well informed on such cumulative pressures.

Some of the longer term climate change refugia identified for seabed habitats also host some spoil dumping, and mining leases, and coastal habitats there also experience a degree of light pollution (Fig.6, bottom) which can reach the seabed around the coast (Davies, McKee et al. 2020). Other, smaller refugia emerge, with variations between scenarios and time periods in different locations, including the south-east and south west of England, the East of England and Scotland, and the Rockall bank. In the two scenarios considered, the remaining areas emerge and remain as climate change hotspots throughout the 21st century, presenting long-term challenges for the benthic features and habitat types considered for many co-located designated sites. Climate change assessments such as this one may thus provide important evidence that could help inform the designation of conservation sites in future, toward longer-term efficacy. Indeed, two of the three recently identified sites for England's HPMAs (Dolphin Head and Northeast Farnes Deep) are located in climate change hotspots (Fig. 6). The same was observed for the locations of several oyster restoration sites across the coast of England, Wales and Scotland (Fig. 6). As in previous analyses, no bright spots are evident.

Figure 6





KEY

- Cables
- Pipes
- Oil/gas platform
- Wind farm
- Restricted fishing*
- Conservation site**
- Oyster bed restoation potential
- Climate change hotspot
- Climate change brightspot

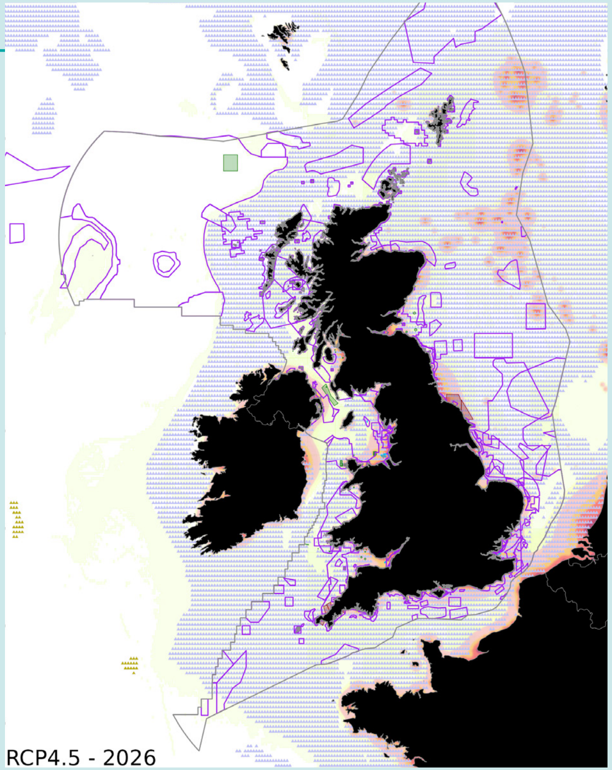
* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

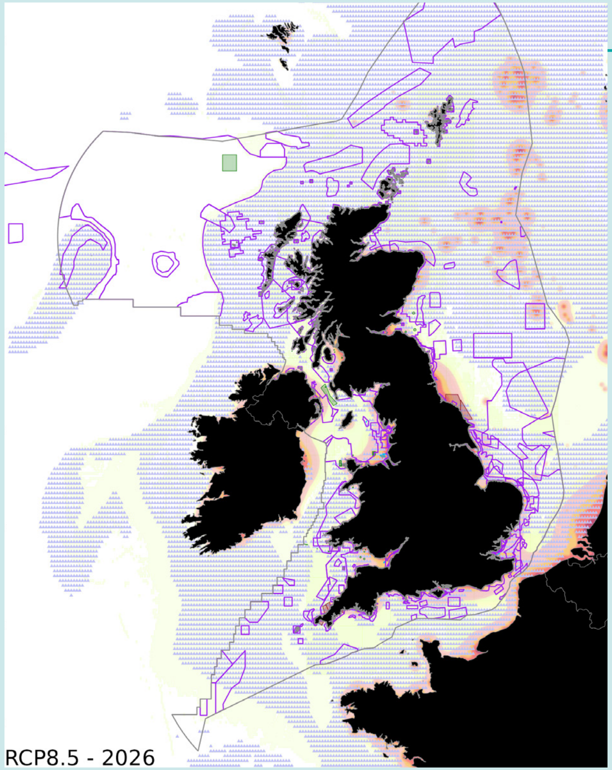
Figure 6

KEY

- Dredging
- Mining lease
- Spoil dumping
- Fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

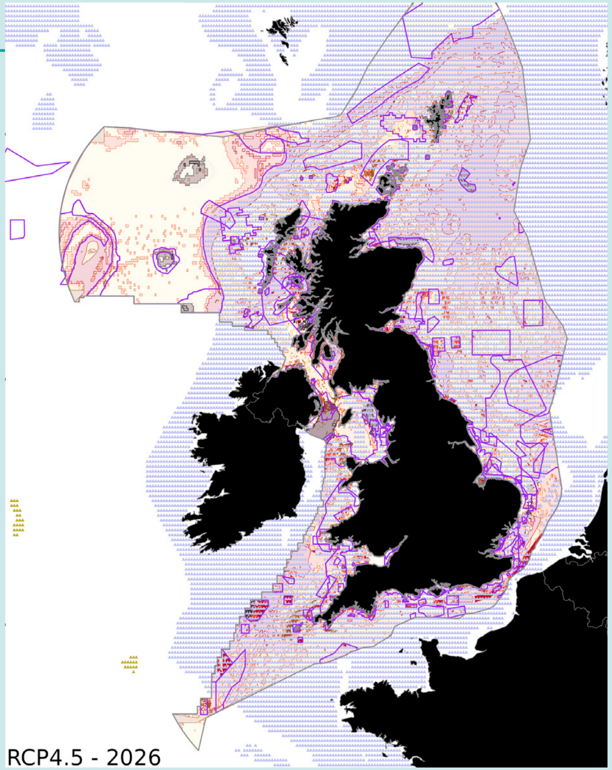


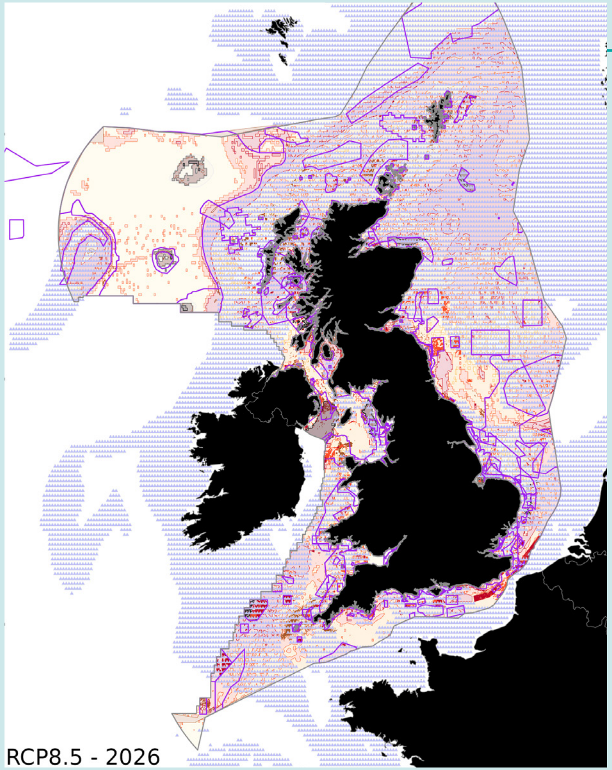


LIGHT INTENSITY
mCd m²

Climate-driven changes to benthic habitats that may affect their conservation value (SI Table S3) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles (none) and hotspots are purple triangles. GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses (top) or those that represent additional sources of impacts (bottom). Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that "2040" refers to the period 2040 – 2059.

Figure 7





KEY

- Conservation site*
- Climate change hotspot
- Climate change brightspot
- * MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

EUNIS BROAD SCALE AND MOSAIC HABITATS

Disturbance from bottom trawling

- Zero (absence of VMS data)
- Low
- Moderate
- High
- Insufficent data for assesment

THREATENED/ DECLINING HABITATS

Disturbance from bottom trawling

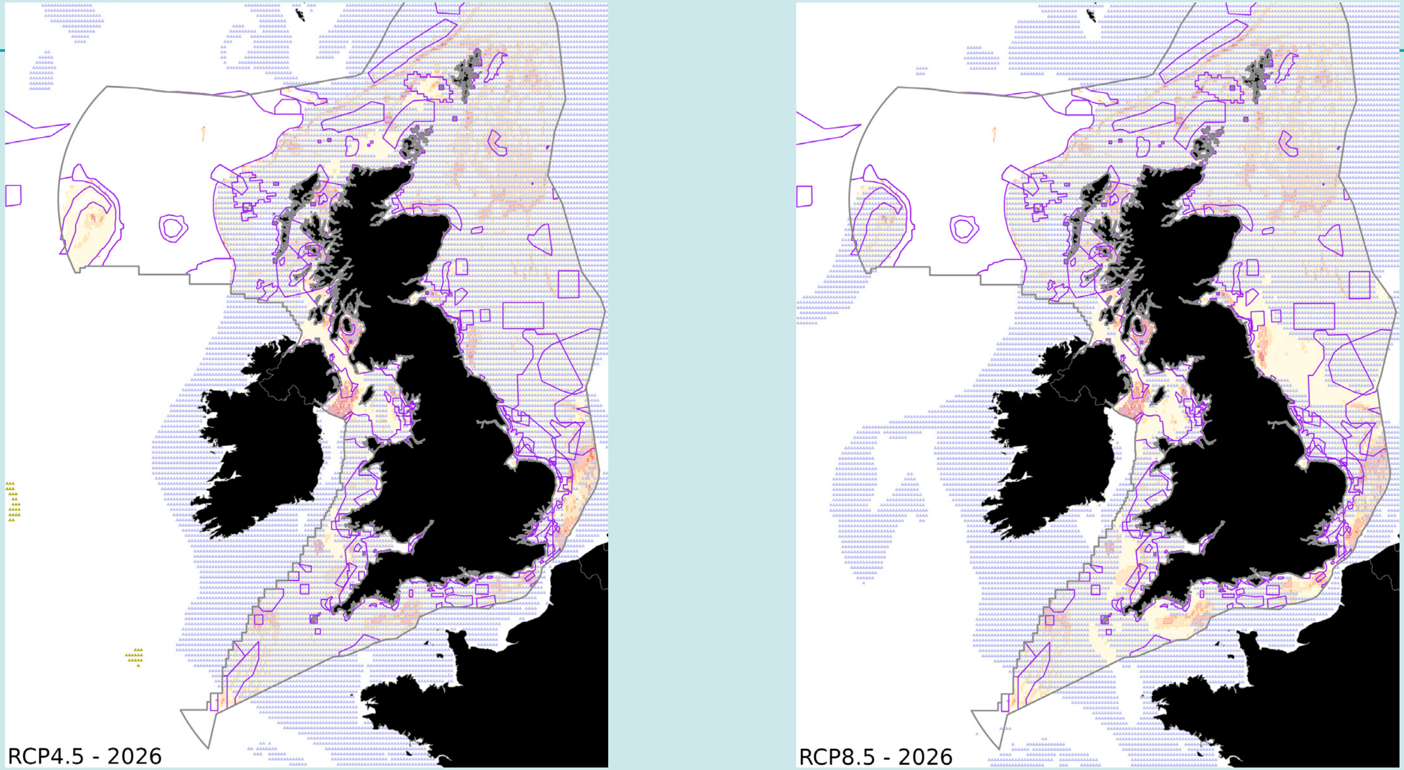
- Zero
- Low
- Moderate
- High

Figure 7

KEY

- Conservation site*
- Climate change hotspot
- Climate change brightspot

* MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar



RELATIVE BENTHIC STATUS

- <0.25
- 0.25 – 0.5
- 0.5 – 0.75
- >0.75

Climate-driven changes to benthic habitats that may affect their conservation value (Figure 6) overlaid onto estimates of the condition of benthic habitats at present, resulting from the impact of bottom gears. Specifically, the Benthic Habitats 3 indicator (BH3) indicator (background colour, top panel; Annex 2); and the Relative Benthic Status (RBS) indicator (background colour, bottom panel). The former layer includes BH3 estimates for both EUNIS broadscale habitat mosaics and OSPAR Threatened and/or declining habitats. Climate change hotspots are blue triangles, bright spots are yellow triangles (none), and climate change refugia occur where no triangles are plotted. Results estimated under RCP4.5 (left) and RCP8.5 (right) are contrasted. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that "2040" refers to the period 2040 – 2059.

3.1.4

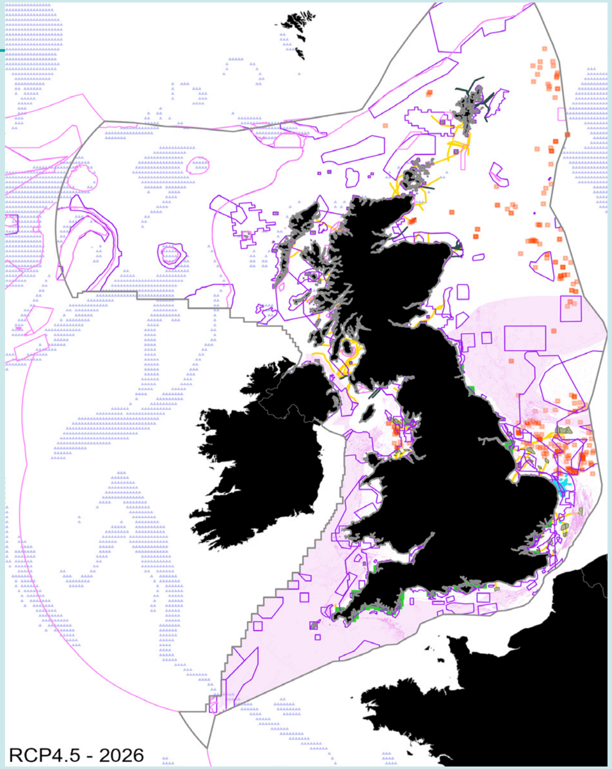
Climate services

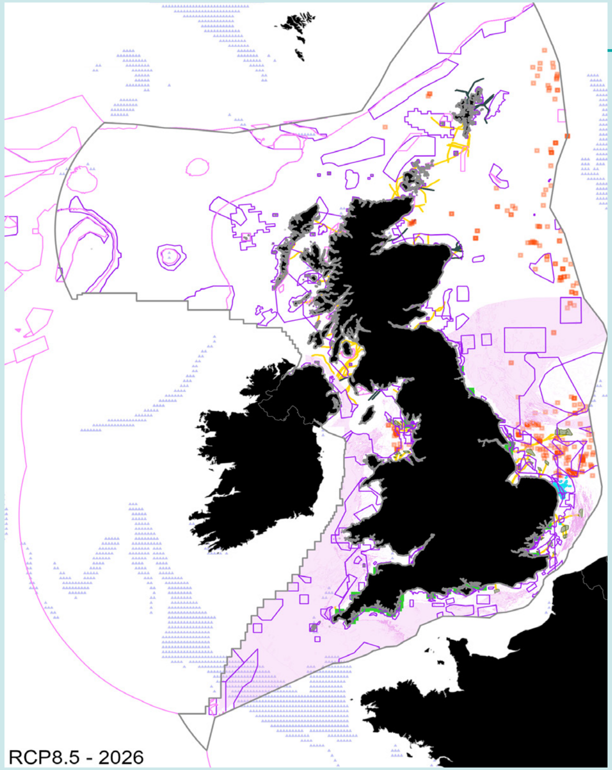
With regard to the ability of benthic habitats to capture carbon, we found that, in both emissions trajectories a-ssessed, such seabed habitats remain as climate change refugia, that is, they display a level of relevant ecosystem processes (SI Table S3) within the range of their current variability throughout the 21st century (Fig.8). With regard to the ability of benthic habitats to capture carbon, we found that, in both emissions trajectories assessed, such seabed habitats remain as climate change refugia, that is, they display a level of relevant ecosystem processes (SI Table S3) within the range of their current variability throughout the 21st century (Fig.8). These areas cover more than 80% of the EEZ in both scenarios, and this result may present a promising picture towards the current interest of using the UK MPA network to deliver climate services (Benyon, Barham et al. 2020).

Small and spatially and temporally dynamic climate change hotspots appear temporarily in the south-west of England, and in other far distributed coastal areas. Those sites do not overlap with areas within the UK EEZ thought to have higher organic carbonaccumulation at present (as estimated by Diesing, Thorsnes et al. (2020); bottom panel of Fig. 8). It should be noted that whilst the seafloor variables assessed in this analysis (SI Table S3) could thus lead to climate-resilient carbon sequestration potential over time, this doesn't mean that the benthic habitat features used as criteria in the designation of a given marine conservation site are resilient to climate change (Species List, SI Table S2). The latter are explored in Section 3.1.3.

Diesing, Thorsnes et al. (2020) includes statistical modelling of the available (if sparse) field data in the UK: that dataset is the most current and widely distributed estimate of UK marine sediment carbon accumulation. It is noteworthy, however, that that dataset (Fig.8) still only covers a fraction of the UK EEZ, highlighting the scope for improved observation capability. As a result, there was oftentimes insufficent observational data available for the validation of the numerical modelling data analysed in the present report, and available field observations often did not match modelled vairables exactly (Annex 1). So the results presented in the present section should be read with care, as uncertainty is likely high (Annex 1). For instance, the modelling derived carbon content projections used in the present analysis (SI Table S3) is likely to reflect new or modern carbon added to sediments as a result of primary production. Modelling data for the latter was found to have good skill (Annex 1). However, long term carbon stores in marine sediments also include much older and deep deposits, less amenable to recycling (Bianchi, Cui et al. 2018) and these are not captured in the observational seabed carbon datasets currently available for the UK (Annex 1). The modelled carbon content projections of sediments we used as input variable to the present meta-analysis may thus be a good indicator of the intensity of modern, annual addition of carbon to the seafloor, given its good reflection of primary productivity measurements (Annex 1). However, not all of this carbon (and in some areas likely very little of it) will be sequestered in the long term. So whilst an exercise such as this one could be a useful way to inform the future siting of MPAs to the end of protecting climate services naturally delivered by benthic habitats, it will be important to improve the skill of the models used in such an exercise in future. Fig.7 also highlights that the currently wide distribution of bottom towed gears in the UK EEZ may present a challenge to the implementation of that aim, as noted by others (Epstein, Middelburg et al. 2022).

Figure 8



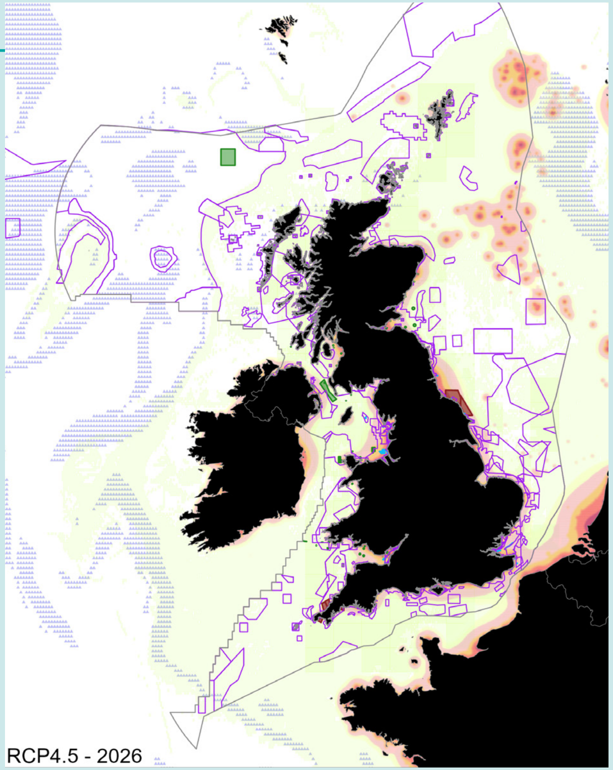


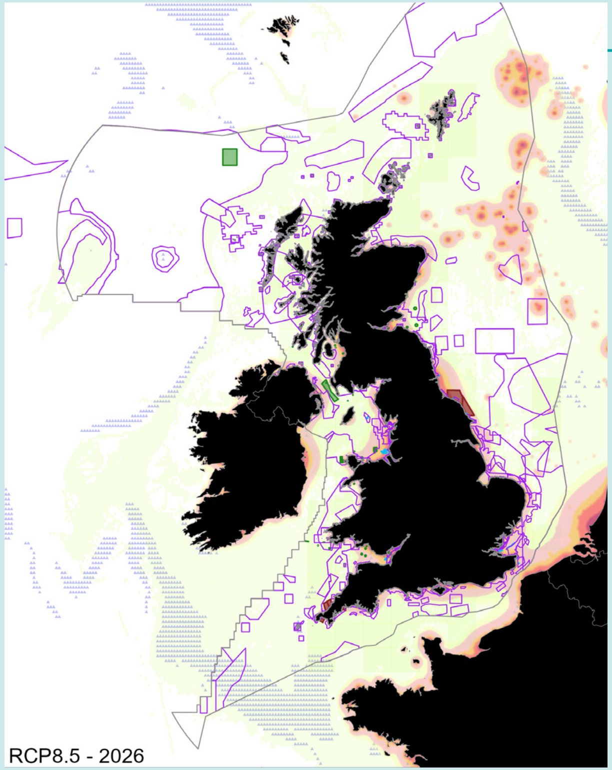
KEY

- Cables
- Pipes
- Oil/gas platform
- Wind farm
- Optimum tidal resource
- Optimum wind resource
- Restricted fishing*
- Conservation site**
- Potential fo seagrass restoration
- Climate change hotspot
- Climate change brightspot

* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

Figure 8





KEY

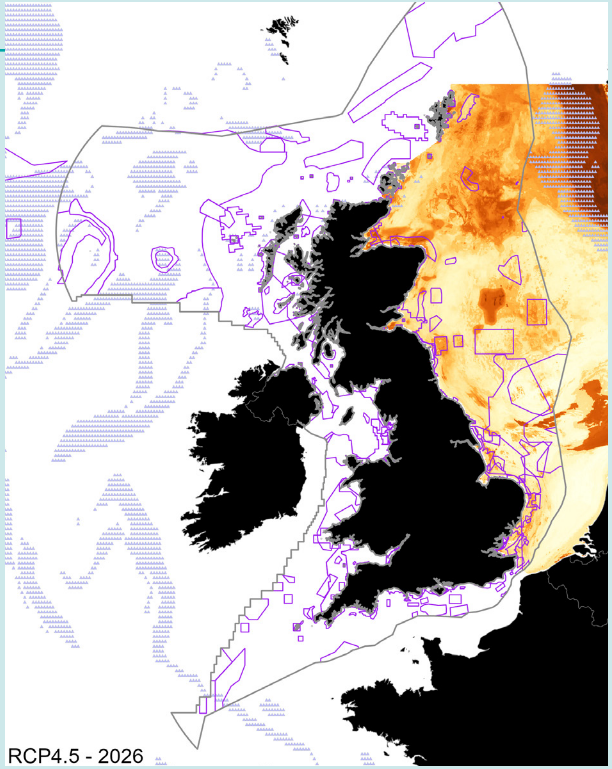
- Dredging
- Mining lease
- Spoil dumping
- Fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

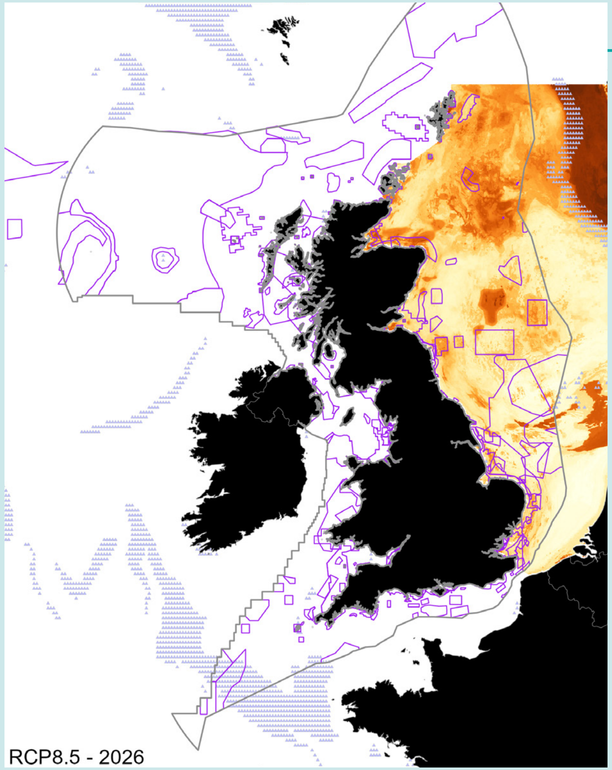
* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

LIGHT INTENSITY
mCd m[2]

100.0
10.0
1.0
0.1

Figure 8

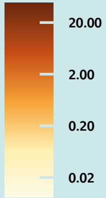




KEY

- Conservation site*
- Climate change hotspot
- Climate change brightspot
- * MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

ORGANIC CARBON ACCUMULATION



Changes to benthic habitats providing climate services (SI Table S3) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles.Bright spots are yellow triangles (none) and hotspots are purple triangles. GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses (top) or those that represent additional sources of impacts (middle). Bottom figure shows the overlay of the meta-analysis results on the carbon stock of sediments, as statistically estimated by Diesing, Thorsnes et al. (2020). Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that "2040" refers to the period 2040 – 2059.

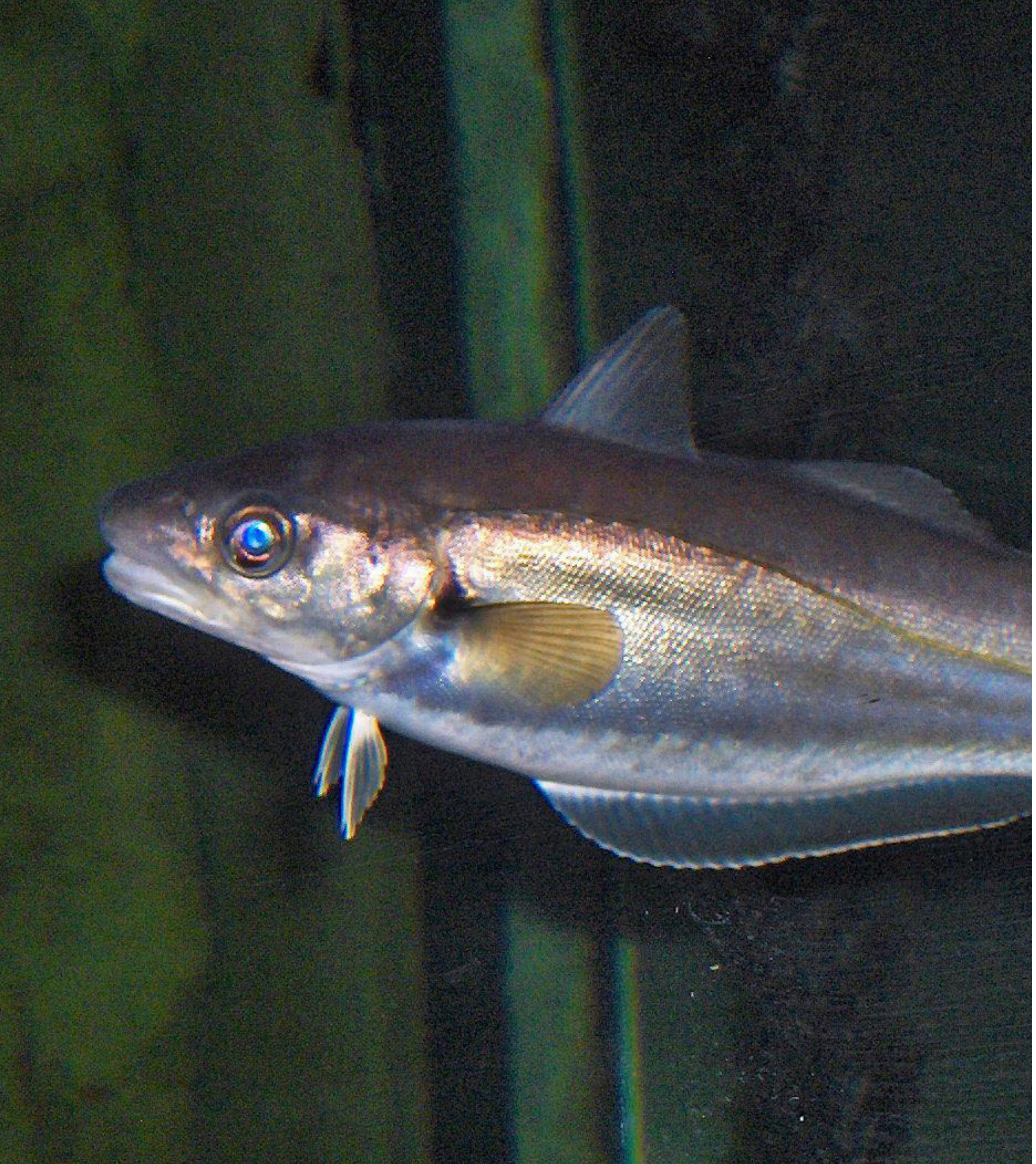
3.2 Spatial management of fisheries

Overall, the model validation assessment suggests that there is generally good agreement between observations and the majority of modelling layers used in the analyses undertaken in this part of the assessment (DBEM model forced by ERSEM projections, Section 2.1.2 and SI Table S4), at the resolution we employed. It is worth recalling that SSP scenarios were used in the setup of the modelling data used in this section (cf. RCPs, Section 2.2). We assessed datasets from contrasting global emissions trajectories (4.5 and 8.5) with comparable levels of fishing effort (SI Table S4), to highlight the potential role of different degrees of anthropogenic greenhouse gas emissions forcing on the activities of the UK fishing sector.

3.2.1 Pelagic fisheries

The analyses undertaken suggest that the emissions scenarios analysed represent substantially different possible futures for the activity of pelagic fishing fleets across the UK, throughout the 21st century. Climate trends were visible in target assemblages in many areas (negative summary effects estimated via meta-analysis), though climate change hotpots were not widely distributed under RCP4.5, remaining short-lived (Figure 9, left). Under this scenario, hotspots only became more widespread towards the last 30 years of the century (Figure 9, left) in areas offshore of the west coast of Scotland, the Hebrides and the northern and central North Sea. These patterns were led by a decline in several top target species, including mackerel, herring, sardine, blue whiting, and sprat; compensated by other species increasing in abundance, such as horse mackerel and sardine, exhibiting more dynamic changes over space and time; and species such as whiting and squid increasing substantially in some areas, over time (English channel and southern North sea, and English channel and northern North sea, respectively). Estimated changes in species distributions reflect the response of individual species Dynamic Bioclimate Envelope Model (Section 2.1.2) to environmental drivers, including temperature, availability of food sources and currents, among others (Fernandes, Cheung et al. 2013).

Where spatial restrictions on pelagic fishing gears exist, it is likely that the UK's network of conservation sites may provide some degree of protection to climate refugia for species targeted by pelagic fishing fleets. For instance, in the central and parts of the southern North Sea and western Scotland, (Figure 9, bottom left), with MPAs throughout

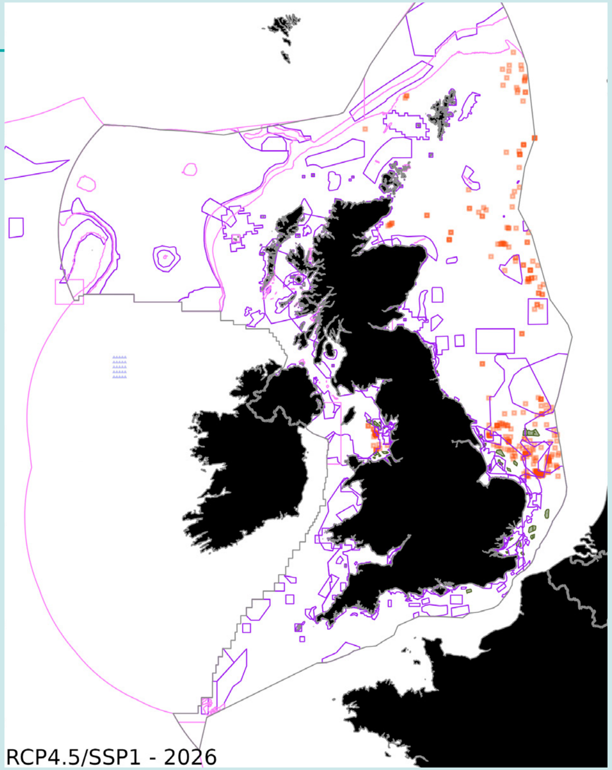


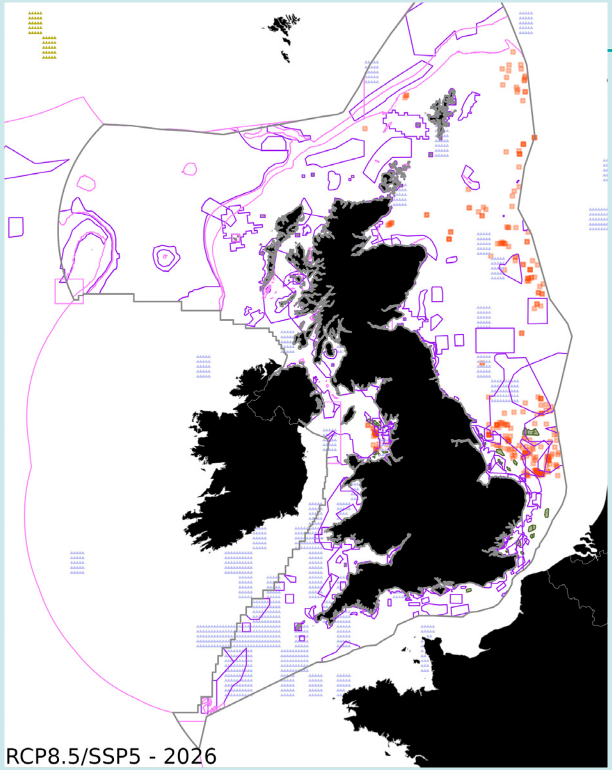
overlapping with climate change refugia for species targeted by pelagic fleets (Figure 9, top left). The south-east of England and English Channel emerged as hosting many climate change refugia in both emissions scenarios considered, potentially suggesting this could be an area to prioritise in terms of supporting the climate resilience of the sector (Figure 9).

Under higher emissions scenarios portrayed by 8.5 (Figure 9, right), climate change hotspots emerge in most areas of the UK EEZ, already into the middle of the century offshore of the south-west of England, and then covering most of the EEZ by the end of the 21st century. After mid-century, all target species considered (SI Table S5) may potentially decline in the UK EEZ, with the exception of squid in the south-east of England. In this scenario, the MPA network provides very little support for the sustainability of these assemblages since climate change pressures appear to have a widespread effect (Fig.9, top right). Substantial climate pressure on these species, compounded by fishing effort, thus leads to low natural sustainability of this natural, traditionally exploited resource (Fig.9, bottom right). Climate-driven northward movement of newer species into the region may thus become ever more important components of adaptation potential for the sector (Cheung, Pinnegar et al. 2012). Reduced emissions may, nevertheless, represent a key aspect of this process.

Two Whiting. Source: Georges Jansoone (JoJan), CC BY 3.0

Figure 9



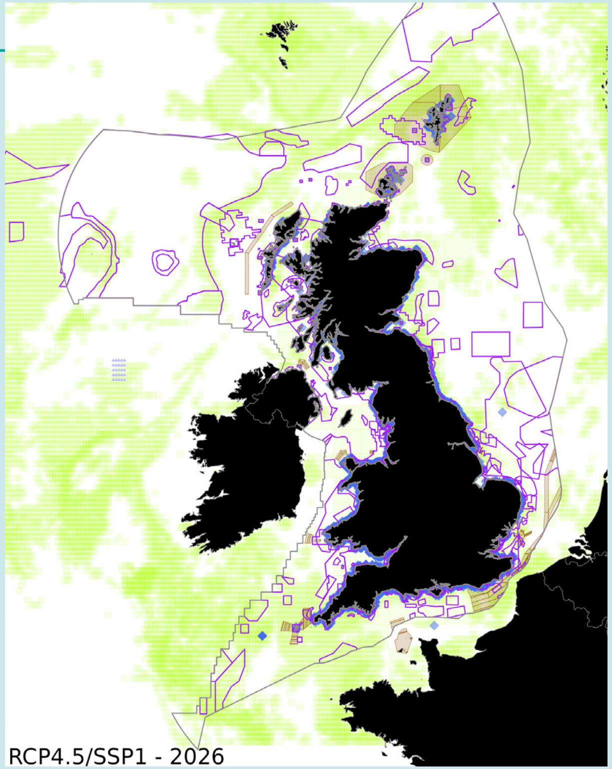


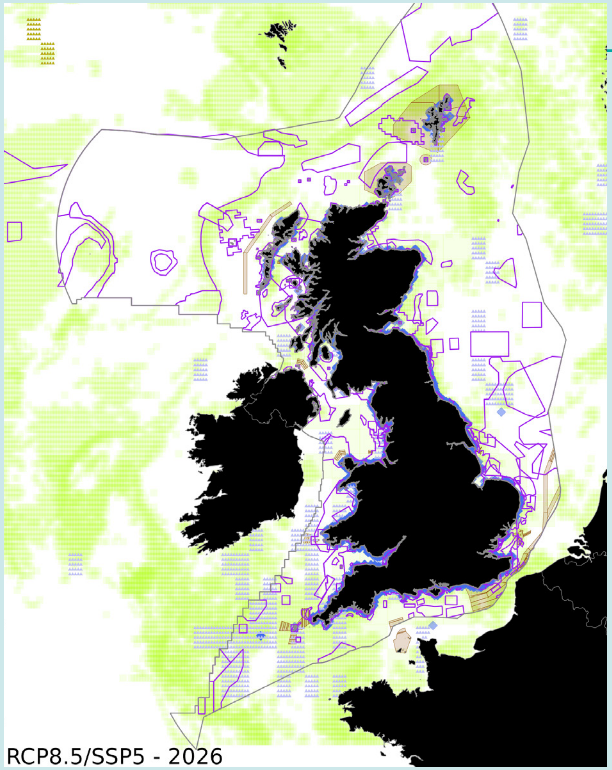
KEY

- Oil/gas platform
- Wind farm
- Restricted fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

* Pelagic gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

Figure 9





KEY

- Fishing*
- High density shipping
- Waste water discarge
- Conservation site**
- Climate change hotspot
- Climate change brightspot

* Pelagic gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

Changes pelagic species targeted by UK pelagic fleets (Table S2) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles and hotspots are purple triangles. GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses to these species (top) or those that represent additional sources of impacts (bottom), beyond climate change. Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that “2040” refers to the period 2040 – 2059.

3.2.2

Demersal fisheries

The assessment of the effects of climate change on the species assemblages targeted by UK benthic and demersal fleets presents a good example of how species interactions may lead to complex changes in the resource exploited by the sector over time (Figure 10). In this case, climate change trends were widespread in both scenarios, but around mid-century, under intense climate change trends expressed by RCP8.5, an increase in warm affiliated species actually leads to the widespread (though temporary) occurrence of climate change refugia in the North Sea (Fig.10, left). This pattern is not observed under lower emissions (Fig.10, right). Indeed, under lower emissions, most species decline through the 21st century (Nephrops, cod, haddock, plaice, turbot and even warm affiliated sole), but not sufficiently to reduce competition and allow for increases in warmer water species (such as hake) or other species (mussels, edible crab, and saithe) to provide climate-resilience to this aggregated resource (Fig.10, left). However, as climate trends become more severe over time, under RCP8.5, an increase in hake, saithe and white monkfish in the region is observed, which appears to drive the assemblage towards climate resilience in the North Sea, accompanied by the loss of species otherwise occurring there, such as plaice (Fig.10, right). There is, therefore, potential scope to consider management measures related to the distribution of demersal fishing pressure in this region (Fig.10, bottom right), where MPAs also occur (Fig.10, top right), that could be used to protect the natural climate-resilience of these assemblages locally, though difference between scenarios provide a source of uncertainty. The location of oil and gas platforms in the region may also provide some protection from extraction. Notably, the south and south east of the UK appear to harbour climate refugia for benthic and demersal target species assemblages in both scenarios assessed, until mid-century, and these disappear thereafter and earlier under 8.5 (Figure 10). Limiting benthic fishing in these areas in the near future may thus help sustain the climate-resilience of this fishing resource.

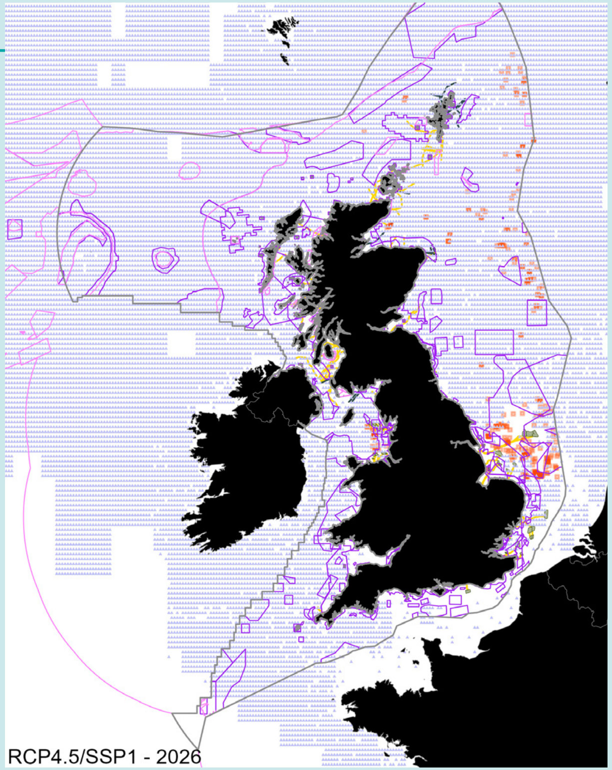
Scallop dredger in the Irish Sea
© Claire Szostek

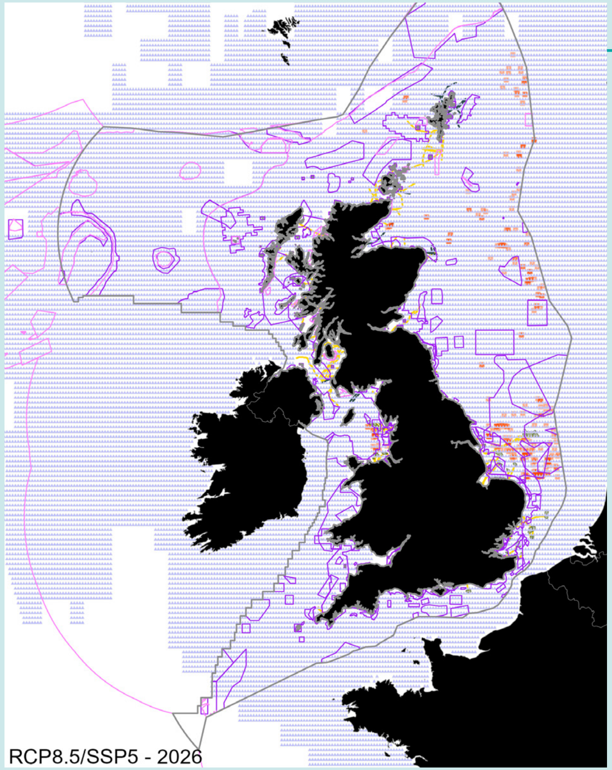
3.3 Spatial management of aquaculture

We assessed the potential impacts of climate change on aquaculture sector activities by applying meta-analysis (Section 2.2) to modelling data that expressed key environmental drivers for farmed species, as well as species distribution modeling for some of the key farmed species, as available (SI Table S5). It is important to note, that species distribution modelling used here does not account for potential mitigating effects of technological solutions that farmers may use to counter changes in environmental conditions, such as artificial aeration to limit low oxygen conditions. These models are detailed in Annex 1, and include species distribution modelling for salmon (Salmo salar), sugar kelp (Saccharina latissima) and mussel (Mytilus edulis). These models also capture the whole life-cycle of organisms, which in a commercial setting may not necessarily apply, since spat and juveniles may be used that have been grown elsewhere. However, these data still provide a picture of where conditions for growth of adults may or may not be adequate under climate change. These models are also driven by more environmental conditions beyond those which are typically considered (i.e. temperature), known to influence the health and growth of farmed species (SI Table S5).

All other datasets analyzed pertain to those additional environmental conditions, also known to influence the health of farmed species (2.1.3). These datasets allowed us to assess potential patterns in estimated changes in the sector due to climate change.

Figure 10





KEY

- Cables
- Pipes
- Oil/gas platform
- Wind farm
- Restricted fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

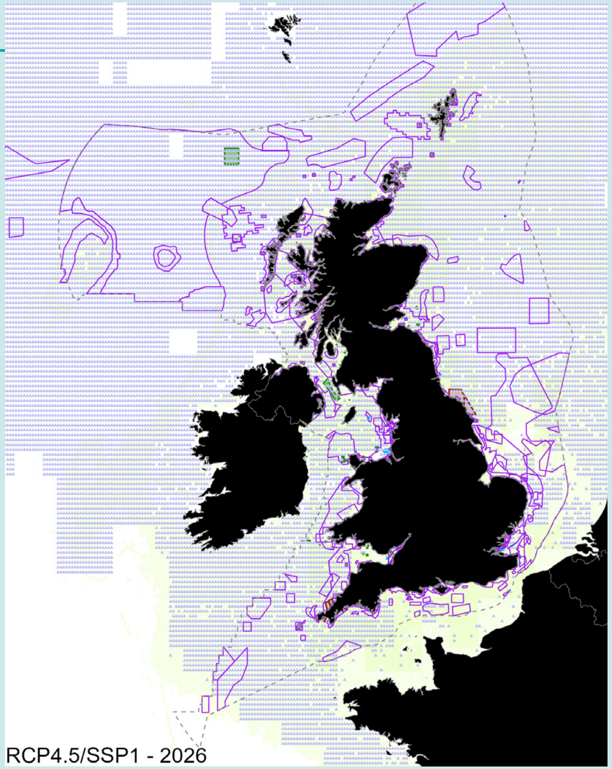
* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

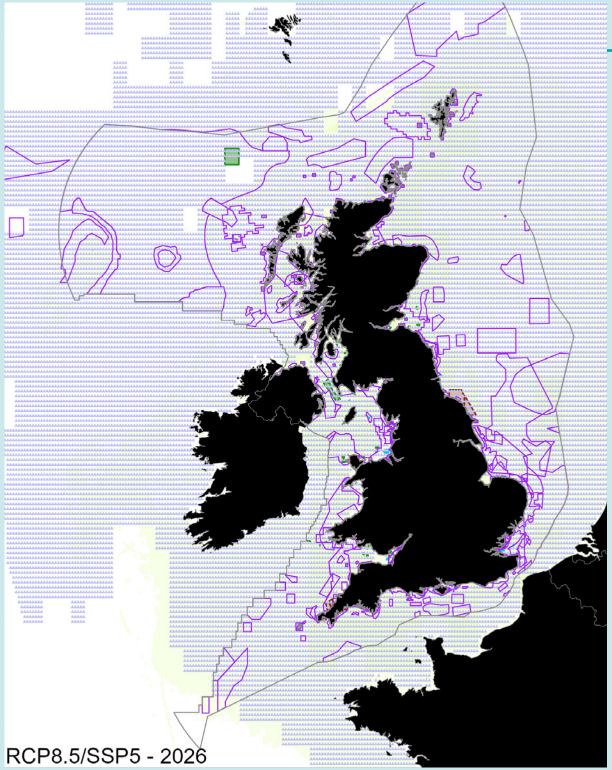
Figure 10

KEY

- Dredging
- Mining lease
- Spoil dumping
- Fishing*
- Conservation site**
- Climate change hotspot
- Climate change brightspot

* Bottom towed gears
** MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar





Changes in benthic and demersal species targeted by UK demersal fleets (SI Table S2) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles and hotspots are purple triangles GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses to these species (top) or those that represent additional sources of impacts (bottom), beyond climate change. Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that “2040” refers to the period 2040 – 2059..

3.3.1

Pelagic aquaculture

In this section, we focused on aquaculture sector activities that take place in the water column such as finfish culture in cages, and suspended mussel and seaweed farming, as opposed to those that take place on the seafloor (3.3.2). Species distribution modelling available suggested that, without active management measures (where possible), growing potential for the key species salmon and sugar kelp may reduce in the near future due to climate drivers, throughout the EEZ and under both emissions trajectories considered (Figure 11). The same spatial patterns were observed at the end of the century (not shown).

Open Sea Fish Pens
©Jimmy Ramirez

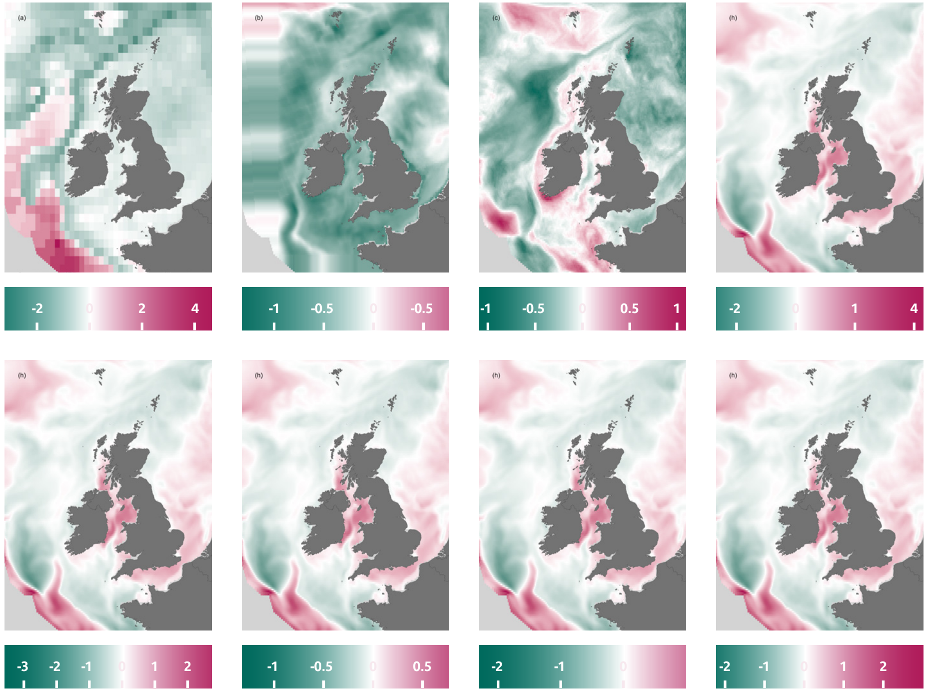


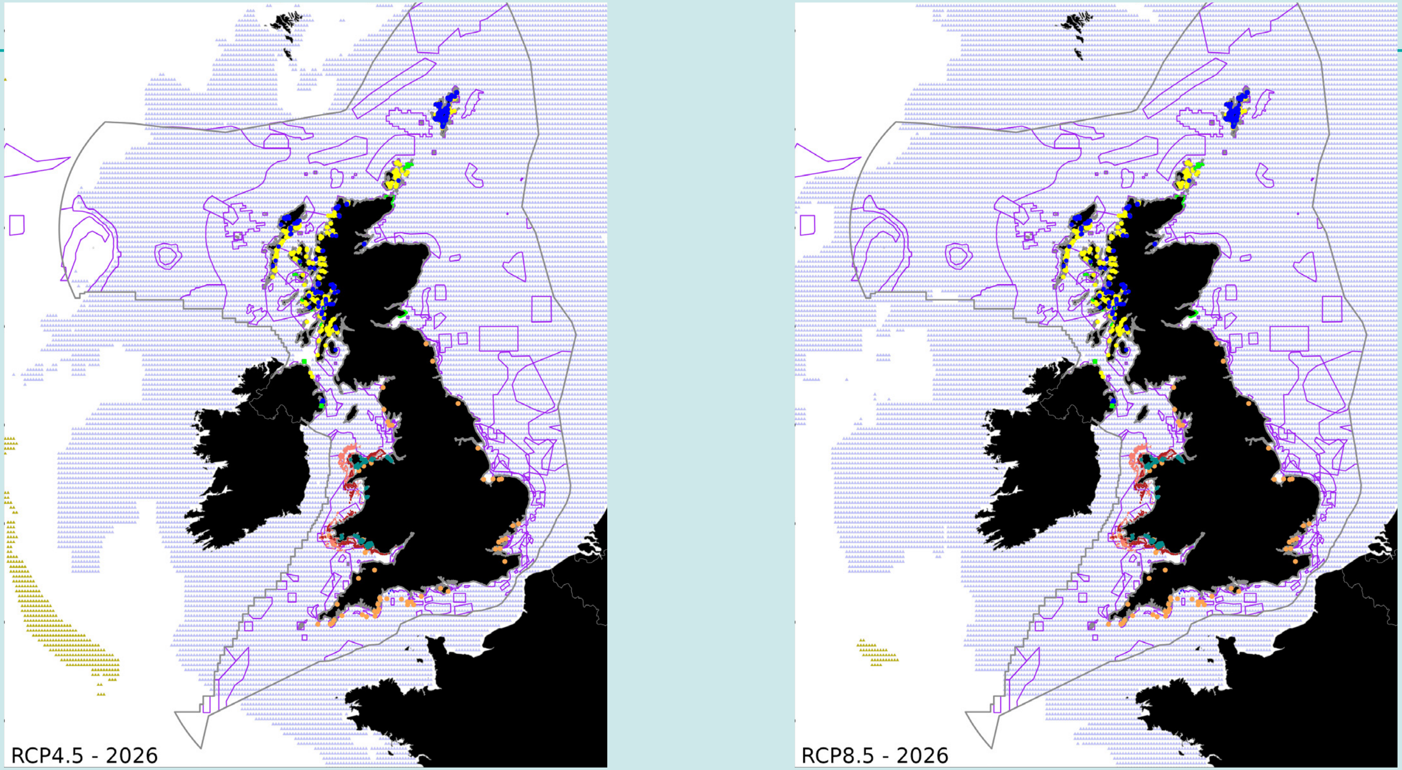
Figure 11

Projected changes in the distribution (a,b,e,f) and potential growth conditions (c, d, g,h) of key species farmed in UK marine waters, between the period of 2026-2045 relative to the reference period (2006 – 2025), under RCP4.5 (top) and RCP8.5 (bottom). Colour provides the value of the estimated normalised mean different estimator (Hedge's g), with green indicating a decline and pink an improvement of conditions. a & e: Salmon abundance. b &f: Sugar kelp habitat suitability. c & g: heatwave frequency (green is greater frequency). d & h: saturation state of aragonite (indicative of whether conditions are supportive of calcification in shellfish). Datasets detailed in SI Table S3.

When these data were considered together with environmental conditions needed to grow other species of interest to the sector in the water column (SI Table S5) we found that a similar picture presented (Figure 12). Specifically, in both scenarios, climate change hotspots emerged throughout the EEZ covering all areas where aquaculture is currently located (Fig.12). The exceptions, under RCP4.5 only, are areas of the Irish Sea and the very western offshore areas of the EEZ, where refugia for the sector emerge temporarily, mid-century, but these areas are rapidly replaced by climate change hotspots later in the 21st century. These results suggest that management measures may be needed to sustain the sector into the future.

It is noteworthy that important spatial patterns emerge across the UK that may allow for a more concrete deployment of climate-resilient management of the sector. For instance, under RCP4.5, and before the mid-2040s, the north and west coast of Scotland, the Welsh coast, and patches in the south and east of England seem less sensitive to heatwaves than the rest of the UK (Fig. 11c and g). And in both scenarios, the saturation state of aragonite, essential for the healthy growth of calcifying species such as bivalves, declines more slowly in the north-west and south-east of the UK than in other areas (Fig.11d and h).

Figure 12



KEY

- Conservation site*
- Shellfish rope culture potential
- Caged salmon culture potential
- Seaweed culture potential
- Shelfish protected waters
- Mussel (suspended culture)
- Salmon culture
- Seaweed culture
- Unspecified shellfish culture
- Climate change hotspot
- Climate change brightspot

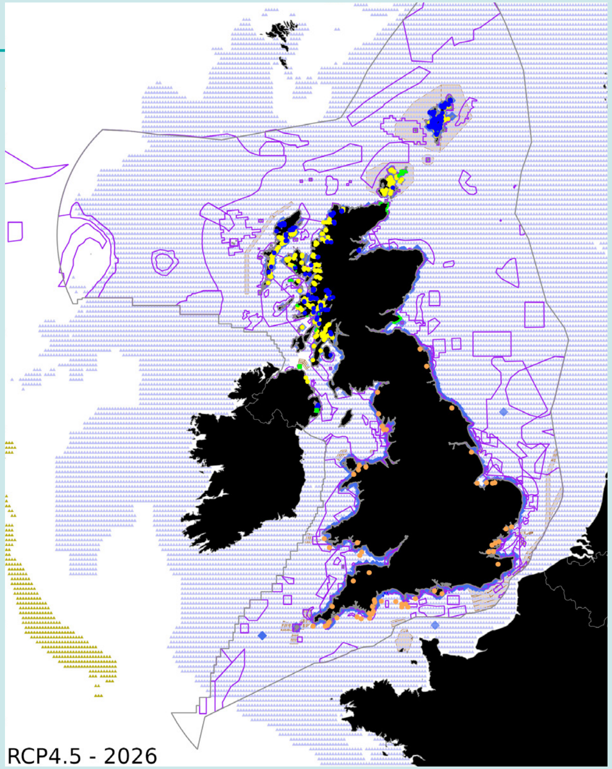
* MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

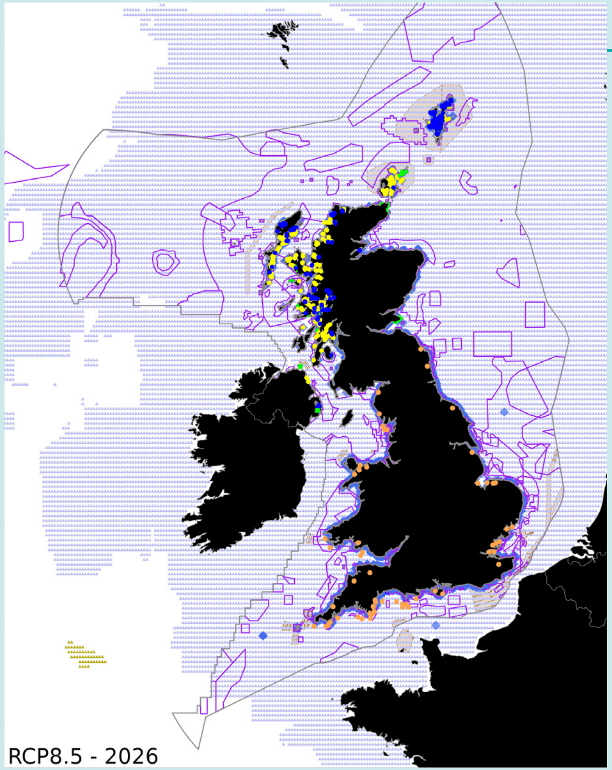
Figure 12

KEY

- Conservation site*
- High density shipping
- Waste water discarge
- Mussel (suspended culture)
- Salmon culture
- Seaweed culture
- Unspecified shellfish culture
- Climate change hotspot
- Climate change brightspot

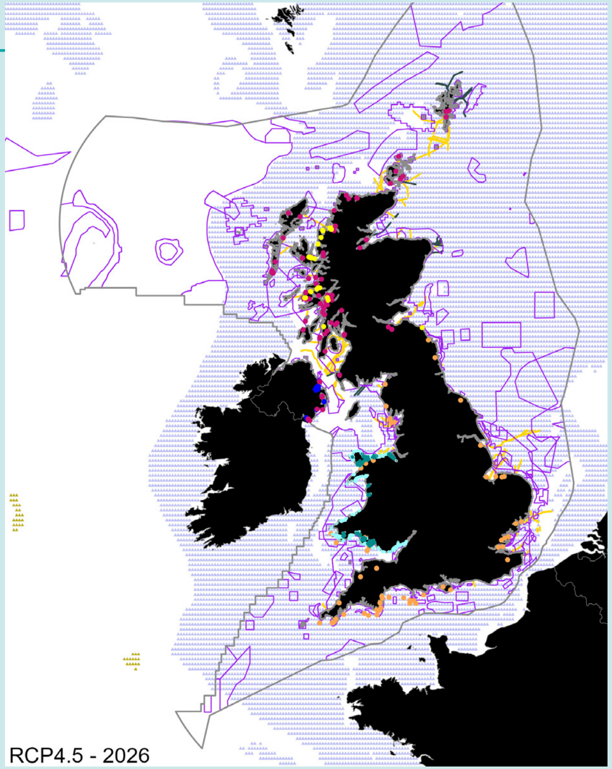
* MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

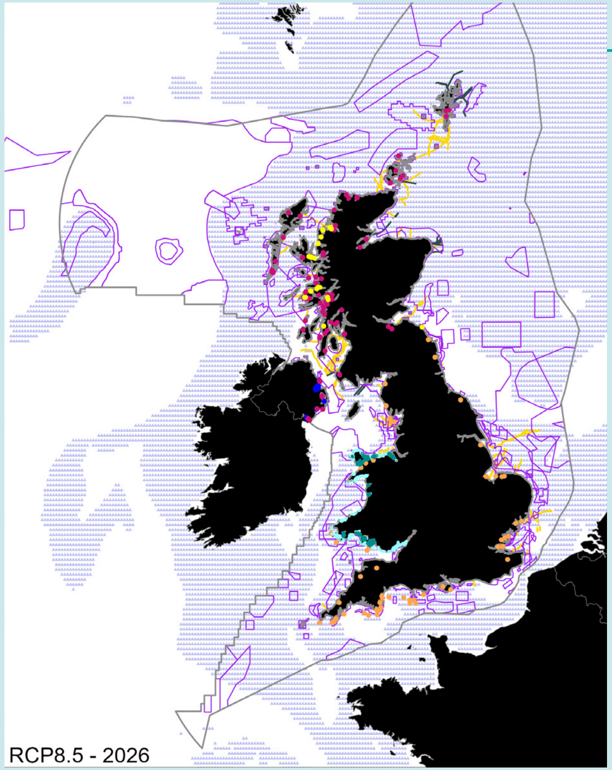




Climate driven changes in species and habitats of interest to UK pelagic aquaculture sector (SI Table S3) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles and hotspots are purple triangles.GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses to these species (top) or those that represent additional sources of impacts (bottom), beyond climate change. Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that “2040” refers to the period 2040 – 2059.

Figure 13





KEY

- Cables
- Pipes
- Conservation site*
- Shelfish trestle culture potential
- Shelfish protected waters
- Mussel (suspended culture)
- Oyster (bottom/trestle culture)
- King scallop culture
- Unspecified shellfish culture
- Climate change hotspot
- Climate change brightspot

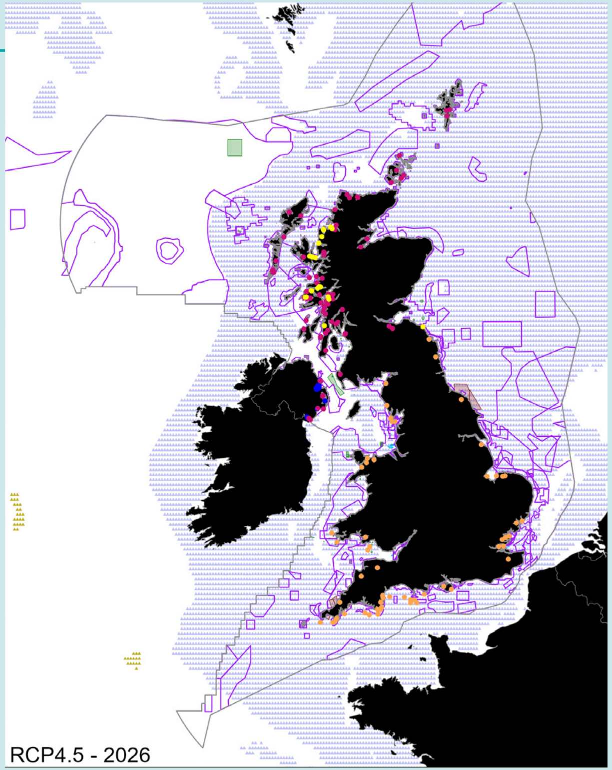
* MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar

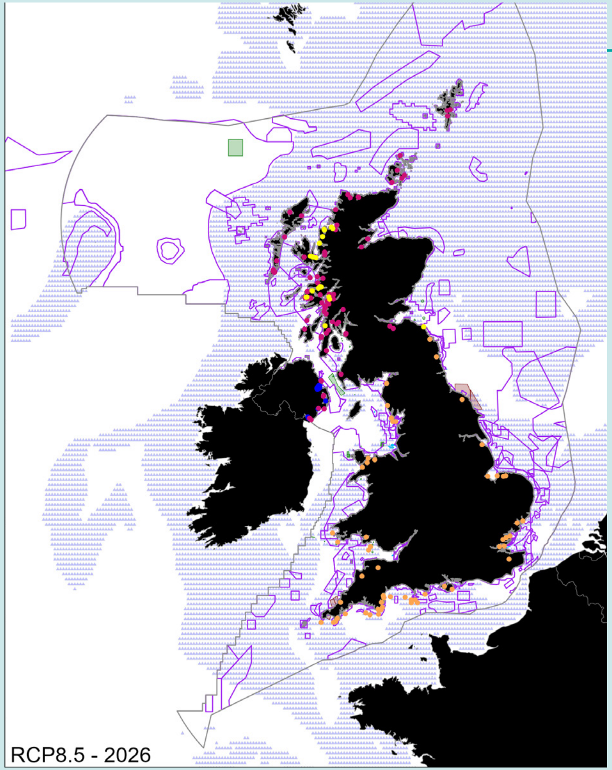
Figure 13

KEY

- Dredging
- Mining lease
- Spoil dumping
- Mussel (botom culture)
- Oyster (bottom/trestle culture)
- King scallop culture
- Unspecified shellfish culture
- Conservation site*
- Climate change hotspot
- Climate change brightspot

* MPA, MCZ, SPA, SAC, NNR, SSSI, Ramsar





Climate driven changes in habitats of interest to UK seabed aquaculture sector activities (SI Table S3) throughout the 21st century, relative to the reference period (2006 – 2025), under RCP4.5 (left) and RCP8.5 (right). Climate change refugia exist where there are no coloured triangles. Bright spots are yellow triangles and hotspots are purple triangles. GIS data representing maritime sectors overlaid (keys in figures), including those that provide some degree of protection from extractive uses to these species (top) or those that represent additional sources of impacts (bottom), beyond climate change. Grey line is the boundary of the UK EEZ. Each year highlighted is the first year of each 20 year time-slice which was contrasted with the reference period (2006 – 2025) in the meta-analysis calculations, such that “2040” refers to the period 2040 – 2059.

3.3.2

Seabed Aquaculture

In this section, we focused on aquaculture sector activities that take place on the seafloor, such as oyster trestle, and gigas/Pacific oyster and mussel farmed on the seabed (3.2.2). As no species distribution modelling for species of interest to UK seabed based aquaculture was available to this report that could be used in our statistical framework (2.1.1 and SI Table S5), we based our analysis on the assessment of benthic habitats presented in 3.1.3 (Fig.13). As observed before, the key areas exhibiting climate-resilience in both scenarios considered include the Irish Sea, the coast of Northern Ireland, the south west coast of Scotland and, more dynamically, some areas in the south east of England. All of these areas host extensive aquaculture infrastructure (Fig.13, top). Assessing individual layers used in this analysis, it emerges that climate-resilience in these areas is likely due to the absence of increased stratification and a consequential decline in bottom water oxygen (expected to progress as a result of climate change), as well as an increase in the saturation state of aragonite (contrary to the expected trend, Fig.14, though no observational data could be used to validate these modelling projections, Annex 1). These trends are less consistent under RCP 8.5 (Fig.14, bottom). No additional pressures could be quantified in these analyses that should prevent the growth of the sector in these areas (Fig.14, bottom).

Other areas exhibit some resilience at least in one scenario and for some time, and those areas are located in the outer Severn estuary, west of Orkney, and the east and south east of England, where oyster and other shellfish farming take place at present (Fig.13 top). All other seabed habitats, many harboring important aquaculture infrastructure at present, host climate change hotspots during the majority of the time period assessed, in both scenarios, and may require management measures to remain sustainable in the coming decades.

Shellfish Farm ©Alexey Komissarov

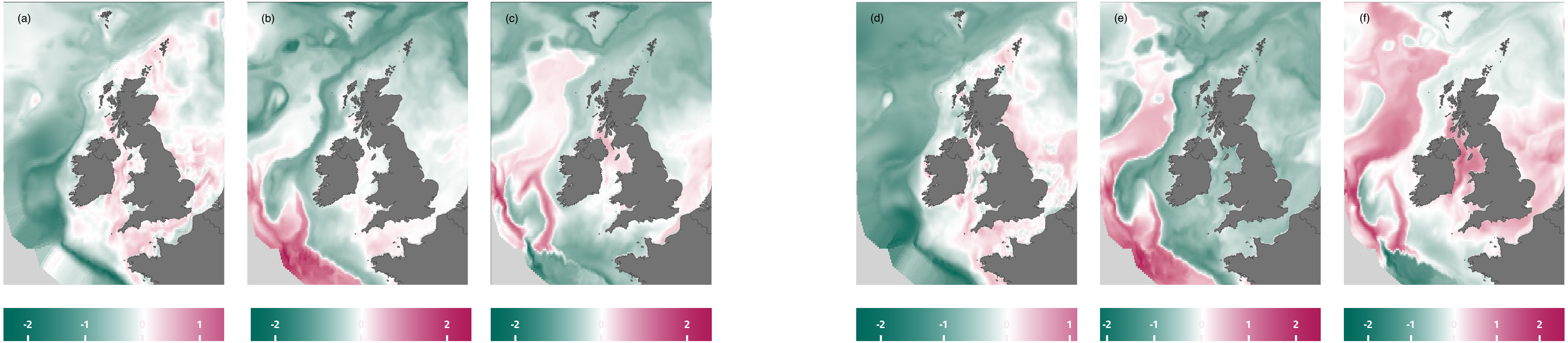


Figure 14

Projected changes in potential growth conditions for key species farmed by the aquaculture sector on the seabed in UK marine waters, between the period of 2026 – 2045 relative to the reference period (2006 – 2025), under RCP4.5 (top) and RCP8.5 (bottom). Colour provides the value of the estimated normalised mean different estimator (Hedge's g), with green indicating a- decline and pink an improvement of conditions. A & D: Water column stratification (i.e. potential energy anomaly, with green indicating more stratification.) B & E: Dissolved oxygen in water layer near the seafloor (green is a decline in dissolved oxygen concentration). C & F: The saturation state of aragonite (green is a decline between time periods). Datasets detailed in SI Table S3.

4
Discussion

With this report, we sought to address three identified capability gaps in the ability of the UK's marine policy and industry communities to address climate change:

1
Designing a marine protected area network (including the designation of Highly Protected Marine Areas) that effectively supports species and habitats of conservation value into the future, as their distributions change in response to climate change.

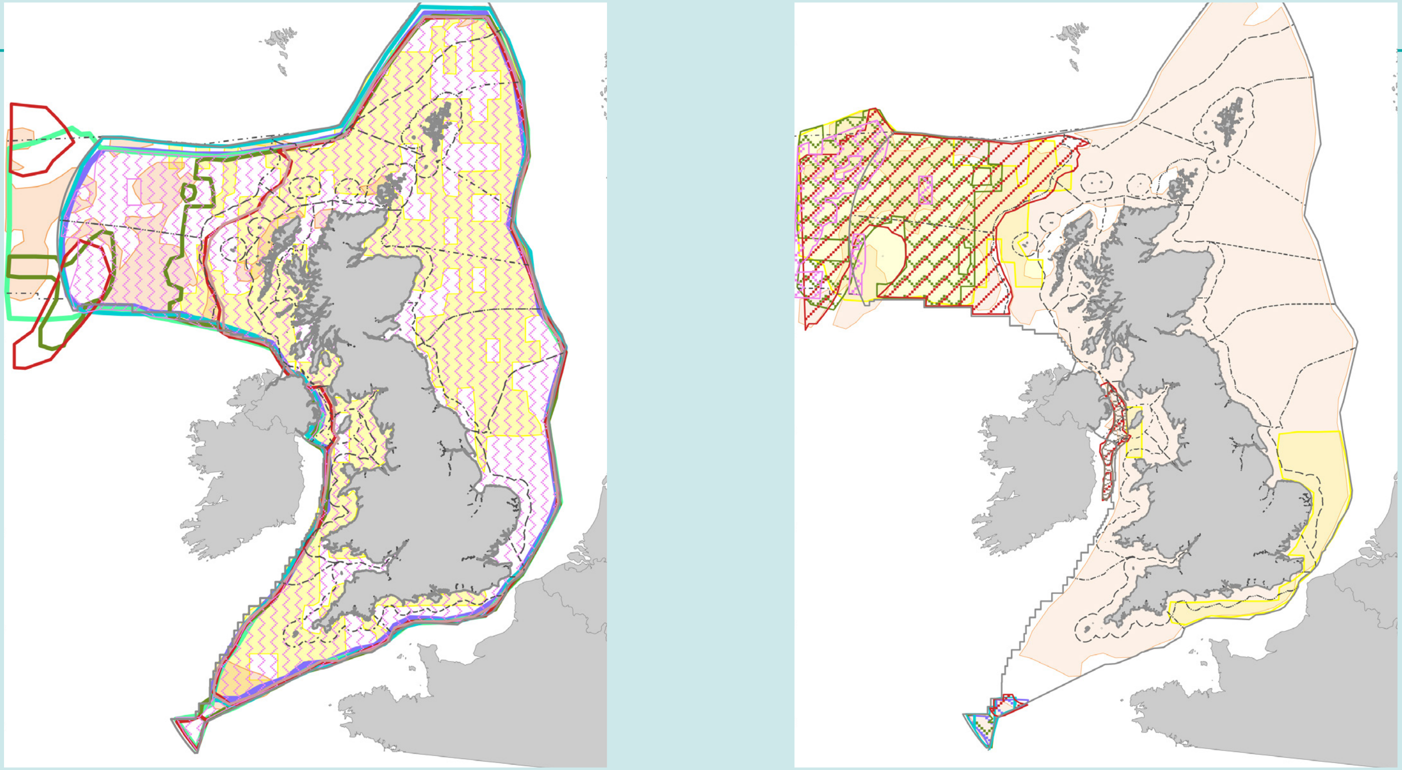
2
Spatially managing and delivering fisheries and aquaculture in a manner that is resilient to changes in target species and habitats distributions as they are modified by climate change.

3
Considering climate change evidence during marine planning and licensing, through guidance that can enable the spatial management of marine sectors, without reducing the ability of species and habitats to redistribute in response to climate change.

Figure 15

KEY

- Climate Services
- Pelagic fish
- Demersal fish
- Pelagic megafauna
- Benthic megafauna
- Benthic habitats
- Pelagic habitats
- Pelagic aquaculture
- Benthic aquaculture
- Marine plan areas
- EEZ



KEY

- Climate Services
- Pelagic fish
- Demersal fish
- Pelagic megafauna
- Benthic megafauna
- Benthic habitats
- Pelagic aquaculture
- Benthic aquaculture
- Marine plan areas
- EEZ

Location of long-term climate change hotspots (left) and climate change refugia (right) for species and habitats underpinning the conservation, fisheries and aquaculture sectors within the UK EEZ. Outlined areas include sites identified with high agreement between emissions scenarios. For detail please see Section 2.3. Data underpinning these maps can be accessed at http://doi.org/10.17031/64e8b1409baf0.

4.1 Climate-smart recommendations

We now make spatially explicit recommendations that could be used to inform climate-resilient strategies for the UK's conservation, fisheries and aquaculture sectors, by harnessing benefits delivered by the distribution of natural climate change resilience within the UK marine species and habitats. Because marine planning requires the consideration of large numbers of spatial datasets, we chose to focus recommendations on the location of identified long-term climate change refugia only, where these were found with high agreement between emissions scenarios considered (Fig. 15, right). We also provide information on the location of long-term climate change hotspots (Fig.15, left), and those could also be the focus of other, complementary, climate-smart strategies for the management of the three core sectors of this report. All data (i.e. shapefiles) illustrated in figure 15 can be accessed at http://doi.org/10.17031/64e8b1409baf0.

4.1.1

Spatial management of the fishing sector

4.1.1.a — Pelagic Fisheries

The following areas could harbour climate-resilient pelagic fisheries in the long-term (high agreement between emissions scenarios, Fig. 15)

It is important to note that some species targeted by this fleet may have early life-stages dependent on seabed habitats (e.g. herring) and such considerations will be required when considering the particular set of species targeted by fleets operating within a given management area.

REFUGIA LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
Offshore areas in the West of Scotland, including the George Bligh and Rockall Banks, and the Rockall trough	Scotland's National Marine Plan	The area is partially exploited, by some sections of the pelagic fleet. Conservation areas in the region have not been designated to protect such pelagic species (SI Table S2), but they harbour sensitive seabed habitats. The area also hosts climate change refugia for megafauna, and other benthic and pelagic species (section 4.1.3) possibly requiring the consideration of potential synergies and trade-offs between fishing and conservation goals.
The Northwest coast of Anglesey	Welsh Marine Plan	The area is already exploited by pelagic fishers. It also includes designated sites that may protect some of those species further – those sites target the protection of puffin and tern populations, and that of harbour porpoise, all of which seek prey species that are also targeted by the pelagic fleet (such as sprat, herring and mackerel). The area also hosts climate refugia for megafauna, and other benthic and pelagic species (Section 4.1.3) possibly requiring the consideration of potential synergies and trade-offs between fishing and conservation goals.
Inshore and offshore areas from Sheringham to Brixham	English East, South East and South Marine Plans	Pelagic fishing activity is already widespread in this region. This region also hosts important conservation sites, some of them designated to support target pelagic species or species depend on them (birds, seals) though fishing is widespread in many of these. Other uses that may need to be considered include high intensity shipping; and waste water discharge.

4.1.1.b — Benthic and Demersal Fisheries

The sensitivity of the benthic target assemblage to climate change was identified as being extensive across the UK EEZ. The following area is the only one identified as harbouring climate change refugia for this assemblage, and thus the potential to host climate-resilient benthic fisheries (for the species we considered, Supplementary Information) in the long term (high agreement between emissions scenarios, Fig. 15)

REFUGIA LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
The south west tip of the UK EEZ	English South West Marine Plan	Fishing is currently limited in this (deep) region. The area also hosts three marine conservation zones, targeting fragile benthic species including fan mussel and several species of coral. This suggests that delicate trade-offs would need to be considered to support both sectors under climate change.

4.1.2

Spatial management of the aquaculture sector

4.1.2.a — Pelagic Aquaculture

Species targeted by pelagic aquaculture in the UK and associated habitats were found to be vulnerable to climate change in all areas except the very offshore western edges of the EEZ, off the coast of South-west England (high agreement between emissions scenarios, Fig.15). These analyses thus suggest that climate change vulnerabilities for the sector may be widespread, requiring technological deployment of counter-measures where possible, to support activities into the future.

Two key environmental drivers challenging the sector under climate-change are the projected increased frequency of heatwaves and changes to the carbonate system leading to ocean acidification. Key areas where both drivers were found to progress more mildly or to remain near current conditions, under RCP4.5 only, include:

FAVOURABLE LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
The mull of Kintyre and the Clyde, the Welsh coast and the Severn estuary	Clyde Regional Marine Plan, the Welsh Marine Plan, the English North West and South West Marine Plans	Whilst these areas harboured climate change hotspots, they may present milder conditions in key environmental drivers that may support the sector into the future. Parts of these areas already host extensive pelagic shellfish aquaculture as well as salmon culture.

Pelagic Aquaculture continued

Focusing specifically on salmon, all areas were found to host declining growth conditions. With salmon being the key farmed species across the UK, technological interventions may be needed to support the sector.

Focusing specifically on seaweed, the fastest growing sector in the UK and Europe, conditions were also found to be declining for the main farmed species, sugar kelp. Areas where sugar kelp farming may decline less or remain viable into the middle of the 21st century (high agreement between emissions scenarios) include:

FAVOURABLE LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
Southern Orkney, the Outer Hebrides, the Moray Firth and the Firth of Forth, and offshore areas from here, to the East	Scottish Orkney, Outer Hebrides, Argyll, Moray Firth and Forth and Tay Marine Plans, and Scotland's National Marine Plan	From these areas, seaweed is (to the best of our knowledge) only currently farmed in the Firth of Forth and so there may be potential for expansion. Waste water discharge in these inshore areas may be an important consideration. Other types of aquaculture already exist in many of these areas.

4.1.2.b — Seabed Aquaculture

The following areas offer opportunities for long-term, climate-resilient seabed based aquaculture (high agreement between emissions scenarios, Fig. 15):

FAVOURABLE LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
The western Irish Sea, including the coast of Northern Ireland and the coast of Dumfries and Galloway in Scotland	Marine Plan for Northern Ireland and the Scottish Argyll and Clyde and Solway Marine Regional Plans	These areas already harbour extensive aquaculture infrastructure, including: oyster bottom and trestle culture (south west of Scotland and Northern Irish coast); mussel bottom culture in the Northern Irish coast; king scallop culture in the south west Scottish coast; and other, non-specified shellfish farms in the north west of England. Potential for expansion may be considered in support of the sector, affected elsewhere. The region also hosts climate change refugia of interest to the conservation of benthic and pelagic habitats (sections 4.1.3b-c) such that synergies and trade-offs may need to be assessed between the two sectors.

4.1.3

Spatial management of protected areas

4.1.3.a — Megafauna

The following areas could be prioritised for climate-resilient conservation of megafauna reliant on benthic prey and habitats in the long term (high agreement between scenarios, Fig. 15):

REFUGIA LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
Offshore areas to the West of Scotland off the George Bligh and Rockall Banks	Scotland's National Marine Plan	Some sites already part of MPA network. Trade-offs regarding the activity of bottom contact gears should be considered. There is moderate activity of bottom trawling here, as well as data deficiency in data records, both from trawling and habitat condition (Annex 2).
The south west tip of the UK EEZ	English South West Marine Plan	There is limited fishing in this (deep) region, and most of the area has no impact of bottom trawling recorded. There is insufficient data from the region to make an assessment of habitat condition (Annex 2)

The following sites were identified that could be prioritised for long-term climate-resilient conservation of megafauna reliant on pelagic prey and habitats, with high agreement between scenarios (Fig. 15).

Offshore areas in the George Bligh and Rockall Banks	Scotland's National Marine Plan	This area is already protected and we could not identify clear pressures from other marine sectors, at present.

4.1.3.b — Pelagic Habitats

No sites were identified that could be prioritised for long-term, climate-resilient conservation of pelagic habitats, with high agreement between scenarios. The following areas may offer that potential, but with higher uncertainty (RCP4.5 only):

REFUGIA LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
Offshore areas in the George Bligh and Rockall Banks	Scotland's National Marine Plan	Some of this area already is already designated but some is exploited by pelagic fishing.
The Irish Sea, coast of Northern Ireland and the inner Hebrides south of, and including, Jura	Welsh Marine Plan, the English North West Marine Plan, the Marine Plan for Northern Ireland and the Scottish Argyll and Clyde Marine Regional Plans	This area already includes several designated sites. Trade-offs with high intensity shipping, pelagic fishing and light pollution generating activities may need to be considered.
Inshore areas in the South West of England	South West Marine Plan	This area already includes several designated sites (such as the Marine Conservation Zone South of the Isles of Scilly which appears as particularly resilient). High intensity shipping, pelagic fisheries and wastewater discharges are sectoral considerations in this area.

4.1.3.c — Benthic Habitats

Three sites have been recently identified for designation as Highly Protected Marine Areas in England, with a particular interest in the delivery of carbon sequestration and as feeding grounds for demersal species of conservation value. From these sites, Allonby Bay (Southwest Marine Plan) exhibits the greatest potential to be climate resilient in the long term (high agreement between scenarios), with Dolphin Head (South Marine Plan) and North East Farnes Deep (North East Marine Plan) overlapping with climate change hotspots (high agreement between scenarios, Fig. 15).

The following additional areas offer opportunities for long-term climate-resilient conservation of benthic habitats (high agreement between scenarios, Fig. 15):

REFUGIA LOCATION	RELEVANT MARINE PLAN	OTHER USES IN THE REGION
The George Bligh and Rockall Banks, and the Rockall trough	Scotland's National Marine Plan	Some sites are already part of the MPA network, with poor condition OSPAR Threatened and Declining habitats also present. Trade-offs regarding the activity of bottom contact gears should be considered. There is moderate activity of bottom trawling here, as well as a deficiency in data records, for both trawling and habitat condition (Annex 2).
The Irish Sea, coast of Northern Ireland and the West Coast of Scotland up to Islay	Welsh Marine Plan, the English North West Marine Plan, the Marine Plan for Northern Ireland and the Scottish Argyll and Clyde Marine Regional Plans	This area already includes several designated sites, as well as the presence of OSPAR Threatened and/or Declining habitats in poor condition, and broader benthic communities varying between poor status to moderate and good. (Annex 2). Seabed extractive activities vary between low to moderate and high. Bottom trawling is prevalent throughout, including key overlap with the location of identified climate refugia off the coast of Northern Ireland (Figure 6, Annex 2). Spoil dumping also occurs in this region. Light pollution is prevalent in coastal areas. Trade-offs against such activities could thus be considered. Several areas in this region already host restriction of bottom gears (e.g. in the south of Arran), and other harbour cables (Mull of Kintyre, south of Arran) and pipelines (Scottish border). De facto gear restrictions in those sites could thus offer some protection for these habitats, in the absence of new site designation, and present a win-win option for the conservation of these climate change refugia.
The far south west of the UK EEZ	English South West Marine Plan	The demersal fishing fleet currently exploits the area, which also hosts three marine conservation zones, targeting fragile benthic species including fan mussel and several species of coral. This suggests that delicate trade-offs would need to be considered to support both sectors under climate change.

4.1.3.d — Climate Services

Based on the analyses undertaken here, with few exceptions, habitat conditions promoting carbon sequestration were seen to be climate resilient in most of the UK EEZ (high agreement between scenarios, Fig. 15). Those areas include sites already identified as having high carbon sequestration potential and many others, providing a positive outlook for the expansion of HPMA sites.

However, results from Section 3.1.3 suggest that benthic biota that have high impacts on seabed carbon sequestration (Snelgrove, Soetaert et al. 2018) may be sensitive to climate change in many areas of the UK EEZ (see also Section 3.1.4). Furthermore, analyses in Annex 2 confirm the suggestions made by others (Black, Smeaton et al. 2022, Epstein, Middelburg et al. 2022) that the wide distribution of extractive seabed uses across the UK EEZ represent a challenge to the effective protection of carbon sequestering sites. It is therefore possible that the results of our analysis of the effects of climate change on climate services delivered by benthic habitats may be overly optimistic at this stage. Lastly, results shown in Annex 1 suggest that the current UK capability for the modelling and projection of carbon sequestration potential in our marine waters remains limited, and is exacerbated by substantial observation sparsity. An improved investment in dedicated observation across the four nations, and subsequent uptake of that data into our modelling capability, is thus likely still needed before recommendations can be made about potential sites for climate resilient carbon sequestration in the UK.

4.2 Concluding remarks

The recommendations made in this report may be used to inform how we develop spatial management of the UK marine environment in the near future. As highlighted in each instance, decisions about the future use of identified climate change refugia may require careful consideration of synergies and trade-offs between those of each explored sector, and other ecological, social and economic goals. Those decisions will likely be made within the umbrella of planning and licensing mechanisms within which each identified site falls.

The evidence presented clearly suggests that in order to be preparing our blue economy for the ocean of tomorrow, as well as supporting the sustainable management of UK marine resources, it is essential to consider climate change effects in marine species and habitats, under marine planning, sites for conservation, and for the management of fisheries and aquaculture. In some cases explored here, climate change refuges are widely distributed, providing broad scope for some of the climate-smart spatial management recommendations we make. However, regrettably, strong agreement between scenarios suggests that changes will likely be observable in many other habitats (both benthic and pelagic) of conservation and commercial value. What's more, these changes are not in a distant future, but rather likely in our immediate future. Preparing for these changes now will thus be supporting our marine biodiversity, our species and habitats, as they move and respond to the pressures of climate change. The review of the East Marine Plan, the current design of some of Scotland's regional marine plans, the ongoing drafting of the Marine Plan for Northern Ireland, and future reviews of other planning mechanisms across the UK provide opportunities to deliver on these ambitions; the same ambitions set out in the UK National Adaptation Plan, and the Second Climate Change Adaptation Programme 2019 – 2024. Focusing the delivery of our marine planning policy mechanisms in this way may thus lead to important environmental, social and economic consequences at the UK level, and within our Nations.

A key point that emerges from evidence presented here, is that the degree of climate change we come to experience will very much determine how much we can do to support identified climate refuges through spatial management. Both emissions trajectories we explored here (Fig. 16) exceed the Paris agreement, leading to ~2.4°C and 4.3°C of mean global warming by the end of the 21st century (RCP4.5, RCP8.5). This corresponds to an increase in mean UK sea surface temperature of ~1°C and ~2°C, respectively (based on climate modelling data used in this report). Between scenario comparisons presented here highlighted that climate-resilient spatial management of our marine species and habitats has greater scope under the lower emissions scenario we explored, with climate refugia often having greater extension under those conditions (e.g. for species targeted by pelagic fishing fleets; for habitats potentially delivering climate services). In several other cases, however, the degree of climate change estimated even under the lower emission trajectory we considered may already be a step too far (e.g. for habitats of interest for the conservation of pelagic species). Notably, it is striking how few bright spots areas we were able to identify with our analyses. The climate modelling methodology analysis employed allows for the detection of such sites, areas where habitat and species trends counter those expected under climate change in the mid-term, presenting opportunities to deliver on (and grow) our ambitions for sectors reliant on marine species and habitats (Queirós, Talbot et al. 2021). The almost complete absence of bright spots, and in some instances, the limited extent of climate refuges identified, provide strong evidence that supports stronger action on curbing emissions. Reinforcing international commitments to the Paris Agreement would thus also likely provide a more sustainable future for the UK's marine biodiversity, our blue economy, and the wellbeing of those whose livelihoods depend on them. That future makes it more likely that the UK will deliver effectively on our "30by30" target; and that we support our communities dependent on our marine environment.

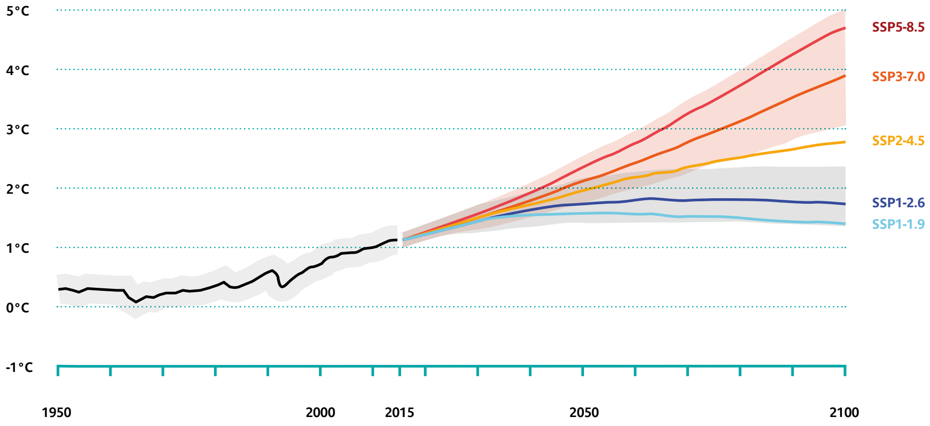


Figure 16

The correspondence between the emissions trajectories scenarios employed by modelling used in this report (corresponding to SSP2-4.5 and SSP5-8.5, Section 1), and the expected mean global warming (air temperature) at the end of the 21st century. In: Figure SPM.8a (the IPCC 2021): Selected indicators of global climate change under the five illustrative scenarios used in (the IPCC 2021) Report. Reprinted with permission from IPCC (2021).

A key aspect that emerges from our analyses also, is the need for integrated spatial management of our territorial waters, across our nations. Marine planning is by and large a devolved responsibility across the UK. It requires careful consideration of UK goals within the specific ambitions and priorities of each Nation, its policy landscape, its people, its industries, which are diverse and not necessarily reciprocal.

And yet, driven by global processes, climate change affects our marine species and habitats in a holistic manner. Supporting them, and the sectors reliant on them, will thus require careful coordination of efforts in spatial management across our nations, and with our international partners. A key example of this is represented by the waters centred around the Irish Sea, extending from the inner Hebrides to the south west of England, including the Welsh and Northern Ireland coasts, and the Irish coast. This area emerged most frequently as the area harbouring climate change refugia for all sectoral analyses. It may thus be worthwhile considering the transboundary implications that effectively managing such a key set of climate-resilient habitats, falling under a number of different, adjacent plans, may bring to the UK, to ensure the best ecological, social and economic outcomes. With our national waters ever more busy with our activities, supporting our marine climate change refugia, these potential marine seedbanks for our future generations becomes ever more complex. Great national level coordination will thus be needed.

5
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6
Supplementary information

SI Table 1

GIS datasets used in this report.

SPATIAL DATASET	DATA PROVIDER	AVAILABLE AT
Marine protected Areas England	Natural England	https://environment.data.gov.uk/DefraDataDownload/?mapService=NE/MarineConservationZonesEngland&Mode=spatial
Marine Protected Areas Wales	Natural Resources Wales	http://lle.gov.wales/catalogue/item/ProtectedSitesMarineNatureReserves/?lang=en
Marine Protected Areas Scotland	Marine Scotland	https://cagmap.snh.gov.uk/natural-spaces/dataset.jsp?code=MPA
Special Protected Areas England	Natural England	https://environment.data.gov.uk/DefraDataDownload/?mapService=NE/SpecialProtectionAreasEngland&Mode=spatial
Special Protected Areas Scotland	Marine Scotland	https://cagmap.snh.gov.uk/natural-spaces/dataset.jsp?code=SPA
Special Protected Areas Northern Ireland	DAERA	https://www.daera-ni.gov.uk/publications/special-protection-areas-digital-datasets
Special Areas of Conservation Wales	Natural Resources Wales	http://lle.gov.wales/catalogue/item/ProtectedSitesSpecialAreasOfConservation/?lang=en
Special Areas of Conservation Scotland	Marine Scotland	https://cagmap.snh.gov.uk/natural-spaces/dataset.jsp?code=SAC
Special Areas of Conservation Northern Ireland	DAERA	https://www.daera-ni.gov.uk/publications/special-areas-conservation-digital-datasets
Special Areas of Conservation England	Natural England	https://environment.data.gov.uk/DefraDataDownload/?mapService=NE/SpecialAreasOfConservationEngland&Mode=spatial

SPATIAL DATASET	DATA PROVIDER	AVAILABLE AT
National Nature Reserve Northern Ireland	DAERA	https://www.daera-ni.gov.uk/publications/national-nature-reserves-digital-datasets
RAMSAR Site England	Natural England	https://environment.data.gov.uk/DefraDataDownload/?mapService=NE/RAMSAREngland&Mode=spatial
RAMSAR Site Wales	Natural Resources Wales	http://lle.gov.wales/catalogue/item/ProtectedSitesRamsarWetlandsOfInternationalImportance/?lang=en
RAMSAR Site Northern Ireland	DAERA	https://www.daera-ni.gov.uk/publications/ramsar-sites-digital-datasets
Relative Benthic Status	JNCC	Embargoed until publication
Benthic Habitat Assessment	JNCC	By request
Offshore fishing effort distribution – pelagic gears	Global Fishing Watch	https://globalfishingwatch.org/data-download/datasets/public-fishing-effort
Offshore fishing effort distribution – benthic/demersal gears	ICES for OSPAR	https://ices-library.figshare.com/articles/report/OSPAR_request_on_the_production_of_spatial_data_layers_of_fishing_intensity_pressure/18639182
Inshore fishing effort distribution	Marine Management Organisation	By request to MMO
Area management fishing restrictions Scotland	NatureScot	https://spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/Marine_Scotland_FishDAC_1306

SPATIAL DATASET	DATA PROVIDER	AVAILABLE AT
Marine artificial light at night pollution	PML	By request
(Statistically estimated) carbon sequestration	Diesing et al. 2021	By request to Cefas
Offshore oil and gas infrastructure	North Sea Transition Authority	https://opendata-nstauthority.hub.arcgis.com/datasets/NSTAUTHORITY::surface-points-wgs84/explore?location=55.460493%2C-2.660275%2C6.62
Offshore wind cables	Crown Estate	https://opendata-thecrownestate.opendata.arcgis.com/datasets/thecrownestate::wind-cable-agreements-england-wales-ni-the-crown-estate/explore?location=52.646134%2C-1.244512%2C8.06
Offshore wind infrastructure	Crown Estate	https://opendata-thecrownestate.opendata.arcgis.com/datasets/thecrownestate::wind-site-agreements-england-wales-ni-the-crown-estate/explore
Offshore fixed wind key resource area	Crown Estate	https://opendata-thecrownestate.opendata.arcgis.com/datasets/fixed-wind-kra-england-wales-ni-the-crown-estate/explore?location=53.002868%2C-2.279659%2C7.62
Offshore floating wind key resource area	Crown Estate	https://opendata-thecrownestate.opendata.arcgis.com/datasets/thecrownestate::floating-wind-kra-england-wales-ni-the-crown-estate/about
Tidal stream key resource area	Marine Management Organisation	https://environment.data.gov.uk/DefraDataDownload/?mapService=MMO/AreasOfIdentifiedTidalStreamResourceTIDE1&Mode=spatial
Offshore pipelines	Crown Estate Scotland	https://crown-estate-scotland-spatial-hub-coregis.hub.arcgis.com/datasets/coregis::pipelines-crown-estate-scotland/explore?location=57.746008%2C-2.937197%2C7.84
High density navigation routes	Marine Management Organisation	https://environment.data.gov.uk/DefraDataDownload/?mapService=MMO/HighDensityNavigationRoutes&Mode=spatial

SPATIAL DATASET	DATA PROVIDER	AVAILABLE AT
Dredging sites England	Marine Management Organisation	https://environment.data.gov.uk/DefraDataDownload/?mapService=MMO/ExistingDredgeSitePolygonsMMO1190&Mode=spatial
Dredge spoil disposal sites Wales	Natural Resources Wales	http://lle.gov.wales/catalogue/item/MarineLicences/?lang=en
Waste water outfalls England and Wales	Environment Agency/Rivers Trust	https://data.catchmentbasedapproach.org/datasets/2cf731d1782f4a899c317be83f221226_11/explore?location=52.788754%2C-3.144202%2C7.74
Waste water outfalls Scotland	Scottish Environment Protection Agency	http://map.sepa.org.uk/atom/SEPA_SPRI_Waste_Water_releases.atom
Mining site agreements England	Crown Estate	https://opendata-thecrownestate.opendata.arcgis.com/datasets/thecrownestate::mining-site-agreements-england-wales-ni-the-crown-estate/about
Seaweed aquaculture agreements Scotland	Marine Scotland	https://spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/Marine_Scotland_FishDAC_1249
Finfish aquaculture agreements Scotland	Aquaculture Scotland	http://aquaculture.scotland.gov.uk/data/site_details.aspx
Shellfish aquaculture agreements Scotland	Aquaculture Scotland	http://aquaculture.scotland.gov.uk/data/site_details.aspx
Aquaculture agreements Northern Ireland	DAERA	https://gis.daera-ni.gov.uk/arcgis/apps/webappviewer/index.html?id=e44a8e27333241bfa2faf4a387fd99d7
Aquaculture agreements England and Wales	ICES	ICES Aquaculture Overviews Celtic Seas ecoregion, 2022

SPATIAL DATASET	DATA PROVIDER	AVAILABLE AT
Offshore shellfish aquaculture lease sites	Marine Management Organisation	https://environment.data.gov.uk/DefraDataDownload/?mapService=MMO/OffshoreShellfishMusselFarmLeaseSitesMMO1051&Mode=spatial
Shellfish protected waters – Wales	Welsh govt	https://datamap.gov.wales/layers/geonode:shellfish_waters_protected_area#download-metadata-section
Potential seaweed culture area Wales	ABPmer/Welsh govt	http://lle.gov.wales/catalogue/item/PotentialAquaculture?lang=en
Potential caged salmon culture area Wales	ABPmer/Welsh govt	http://lle.gov.wales/catalogue/item/PotentialAquaculture?lang=en
Potential mussel culture area Wales	ABPmer/Welsh govt	http://lle.gov.wales/catalogue/item/PotentialAquaculture?lang=en
Potential native oyster restoration area	Marine Management Organisation	https://environment.data.gov.uk/DefraDataDownload/?mapService=MMO/MMO1135PotentialNativeOysterRestoration&Mode=spatial
Potential seagrass restoration area	Marine Management Organisation	https://environment.data.gov.uk/DefraDataDownload/?mapService=MMO/MMO1135PotentialSeagrassCreationRestoration&Mode=spatial

SI Table S2

Species list, maps each marine conservation site across the UK Nations to its corresponding marine planning area, provides a list of designation features.

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	East Inshore	Alde–Ore Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus fuscus*
England	East Inshore	Alde–Ore Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna sandvicensis*
England	East Inshore	Alde–Ore Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	East Inshore	Alde–Ore Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	East Inshore	Cromer Shoal Chalk Beds	MCZ	*Parablennius gattorugine*
England	East Inshore	Cromer Shoal Chalk Beds	MCZ	*Scyliorhinus canicula*
England	East Inshore	Gibraltar Point	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	East Inshore	Holderness Inshore	MCZ	*Anguilla anguilla*
England	East Inshore	Holderness Inshore	MCZ	*Limanda limanda*
England	East Inshore	Holderness Inshore	MCZ	*Labridae*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	East Inshore	Holderness Inshore	MCZ	*Cancer pagurus*
England	East Inshore	Holderness Inshore	MCZ	*Necora puber*
England	East Inshore	Holderness Inshore	MCZ	*Homarus gammarus*
England	East Inshore	Holderness Inshore	MCZ	*Cerastoderma edule*
England	East Inshore	Holderness Inshore	MCZ	*Peringua ulvae*
England	East Inshore	Holderness Offshore	MCZ	*Arctica islandica*
England	East Inshore	Humber Estuary	SPA, SAC, SSSI, National Nature Reserve	*Bucephala clangula*
England	East Inshore	Humber Estuary	SPA, SAC, SSSI, National Nature Reserve	*Sterna albifrons*
England	East inshore	Humber Estuary	SPA, SAC, SSSI, National Nature Reserve	*Halichoerus grypus*
England	East inshore	Humber Estuary	SPA, SAC, SSSI, National Nature Reserve	*Petromyzon marinus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	East Inshore	Minsmere-Walberswick	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	East Inshore	Minsmere–Walberswick	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	East Inshore	North Norfolk Coast	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna sandvicensis*
England	East Inshore	North Norfolk Coast	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna hirundo*
England	East Inshore	North Norfolk Coast	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	East Inshore	North Norfolk Coast	SPA, SSSI, RAMSAR, National Nature Reserve	*Melanitta fusca*
England	East Inshore	North Norfolk Coast	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	East Inshore	The Wash	SPA, SSSI, National Nature Reserve	*Melanitta nigra*
England	East Inshore	The Wash	SPA, SSSI, National Nature Reserve	*Bucephala clangula*
England	East Inshore	The Wash	SPA, SSSI, National Nature Reserve	*Sterna hirundo*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	East Inshore	The Wash	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	East inshore	The Wash and North Norfolk Coast	SAC	*Lutra lutra*
England	East inshore	The Wash and North Norfolk Coast	SAC	*Phoca vitulina*
England	East Inshore & East Offshore	Greater Wash	SPA, SSSI, National Nature Reserve	*Gavia stellata*
England	East Inshore & East Offshore	Greater Wash	SPA, SSSI, National Nature Reserve	*Melanitta nigra*
England	East Inshore & East Offshore	Greater Wash	SPA, SSSI, National Nature Reserve	*Larus minutus*
England	East Inshore & East Offshore	Greater Wash	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
England	East Inshore & East Offshore	Greater Wash	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	East Inshore & East Offshore	Greater Wash	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	East Inshore & East Offshore	Orford Inshore	MCZ	*Scyliorhinus canicula*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	East Inshore, East Offshore & South East Inshore	Outer Thames Estuary	SPA, SSSI, National Nature Reserve	*Gavia stellata*
England	East Inshore, East Offshore & South East Inshore	Outer Thames Estuary	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	East Inshore, East Offshore & South East Inshore	Outer Thames Estuary	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	East Offshore	Breydon Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna hirundo*
England	North East Inshore	Coquet Island	SPA	*Sterna sandvicensis*
England	North East Inshore	Coquet Island	SPA	*Sterna dougallii*
England	North East Inshore	Coquet Island	SPA	*Sterna hirundo*
England	North East Inshore	Coquet Island	SPA	*Sterna paradisaea*
England	North East Inshore	Coquet to St Mary	MCZ	*Ceramaster arcticus*
England	North East Inshore	Farne Islands	SPA	*Sterna sandvicensis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North East Inshore	Farne Islands	SPA	*Sterna dougallii*
England	North East Inshore	Farne Islands	SPA	*Sterna hirundo*
England	North East Inshore	Farne Islands	SPA	*Sterna paradisaea*
England	North East Inshore	Farne Islands	SPA	*Uria aalge*
England	North East Inshore	Farnes East	MCZ	*Sea-pen and burrowing megafauna*
England	North East Inshore	Farnes East	MCZ	*Arctica Islandica*
England	North East Inshore	Flamborough and Filey Coast	SPA, SSSI, National Nature Reserve	*Morus bassanus*
England	North East Inshore	Flamborough and Filey Coast	SPA, SSSI, National Nature Reserve	*Rissa tridactyla*
England	North East Inshore	Flamborough and Filey Coast	SPA, SSSI, National Nature Reserve	*Uria aalge*
England	North East Inshore	Flamborough and Filey Coast	SPA, SSSI, National Nature Reserve	*Alca torda*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North East Inshore	Lindisfarne	SPA, SSSI, RAMSAR, National Nature Reserve	*Somateria mollissima*
England	North East Inshore	Lindisfarne	SPA, SSSI, RAMSAR, National Nature Reserve	*Melanitta nigra*
England	North East Inshore	Lindisfarne	SPA, SSSI, RAMSAR, National Nature Reserve	*Mergus serrator*
England	North East Inshore	Lindisfarne	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna dougallii*
England	North East Inshore	Lindisfarne	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	North East Inshore	Northumberland Marine	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
England	North East Inshore	Northumberland Marine	SPA, SSSI, National Nature Reserve	*Sterna dougallii*
England	North East Inshore	Northumberland Marine	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	North East Inshore	Northumberland Marine	SPA, SSSI, National Nature Reserve	*Sterna paradisaea*
England	North East Inshore	Northumberland Marine	SPA, SSSI, National Nature Reserve	*Sterna albifrons*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North East Inshore	Northumberland Marine	SPA, SSSI, National Nature Reserve	*Uria aalge*
England	North East Inshore	Northumberland Marine	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
England	North East Inshore	Northumbria Coast	SPA, SSSI, National Nature Reserve	*Sterna paradisaea*
England	North East Inshore	Northumbria Coast	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	North East Inshore	Runswick Bay	MCZ	*Arctica islandica*
England	North East Inshore	Teesmouth and Cleveland Coast	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
England	North East Inshore	Teesmouth and Cleveland Coast	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	North East inshore	Tweed Estuary	SAC	*Petromyzon marinus*
England	North East Offshore	Fulmar	MCZ	*Arctica Islandica*
England	North East offshore	North East of Farnes Deep	MCZ	*Arctica islandica*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North East offshore	Swallow Sand	MCZ	*Ditrupa arietina*
England	North East offshore	Swallow Sand	MCZ	*Pisione remota*
England	North East offshore	Swallow Sand	MCZ	*Glycera lapidum*
England	North East offshore	Swallow Sand	MCZ	*Spisula elliptica*
England	North East offshore	Swallow Sand	MCZ	*Echinocyamus pusillus*
England	North East offshore	Swallow Sand	MCZ	*Fabulina fabula*
England	North East offshore	Swallow Sand	MCZ	*Aricidea minuta*
England	North East offshore	Swallow Sand	MCZ	*Ophelia borealis*
England	North East offshore	Swallow Sand	MCZ	*Bathyporeia elegans*
England	North East offshore	Swallow Sand	MCZ	*Ophiuroidea*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North East offshore	Swallow Sand	MCZ	*Spatangoida*
England	North East offshore	Swallow Sand	MCZ	*Amphiuridae*
England	North East Offshore, East Inshore & East Offshore	Southern North Sea	SAC	*Phocoena phocoena*
England	North West Inshore	Allonby Bay	MCZ	*Subtidal biogenic reefs*
England	North West Inshore	Allonby Bay	MCZ	*Mytilus edulis*
England	North West Inshore	Allonby Bay	MCZ	*Sabellaria alveolata*
England	North West Inshore	Cumbria Coast	MCZ	*Intertidal biogenic reefs*
England	North West Inshore	Cumbria Coast	MCZ	*Sabellaria alveolata reefs*
England	North West Inshore	Cumbria Coast	MCZ	*Alca torda*
England	North West Inshore	Fylde	MCZ	*Nucula nitidosa*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North West Inshore	Fylde	MCZ	*Pharus legumen*
England	North West Inshore	Fylde	MCZ	*Abra alba*
England	North West Inshore	Fylde	MCZ	*Solea solea*
England	North West Inshore	Fylde	MCZ	*Pleuronectes platessa*
England	North West Inshore	Mersey Narrows and North Wirral Foreshore	SPA, SSSI, National Nature Reserve	*Phalacrocorax carbo*
England	North West Inshore	Mersey Narrows and North Wirral Foreshore	SPA, SSSI, National Nature Reserve	*Larus minutus*
England	North West Inshore	Mersey Narrows and North Wirral Foreshore	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	North West Inshore	Mersey Narrows and North Wirral Foreshore	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	North West Inshore	Morecambe Bay and Duddon Estuary	SPA, SSSI, National Nature Reserve	*Larus melanocephalus*
England	North West Inshore	Morecambe Bay and Duddon Estuary	SPA, SSSI, National Nature Reserve	*Larus fuscus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North West Inshore	Morecambe Bay and Duddon Estuary	SPA, SSSI, National Nature Reserve	*Larus argentatus*
England	North West Inshore	Morecambe Bay and Duddon Estuary	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
England	North West Inshore	Morecambe Bay and Duddon Estuary	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	North West Inshore	Morecambe Bay and Duddon Estuary	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	North West Inshore	Ribble and Alt Estuaries	SPA, SSSI, National Nature Reserve	*Phalacrocorax carbo*
England	North West Inshore	Ribble and Alt Estuaries	SPA, SSSI, National Nature Reserve	*Melanitta nigra*
England	North West Inshore	Ribble and Alt Estuaries	SPA, SSSI, National Nature Reserve	*Larus ridibundus*
England	North West Inshore	Ribble and Alt Estuaries	SPA, SSSI, National Nature Reserve	*Larus fuscus*
England	North West Inshore	Ribble and Alt Estuaries	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	North West Inshore	Ribble Estuary	MCZ	*Osmerus eperlanus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	North West Inshore	The Dee Estuary	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
England	North West Inshore	The Dee Estuary	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	North West Inshore	The Dee Estuary	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	North West Inshore	Wyre-Lune	MCZ	*Osmerus eperlanus*
England	North West Inshore & North West Offshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Gavia stellata*
England	North West Inshore & North West Offshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Melanitta nigra*
England	North West Inshore & North West Offshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Larus minutus*
England	North West Inshore & North West Offshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Sterna hirundo*
England	North West Inshore & North West Offshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Sterna albifrons*
England	North West Inshore & North West Offshore	West of Walney	MCZ	*Sea-pen and burrowing megafauna*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South East Inshore	Blackwater Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South East Inshore	Blackwater Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	South East Inshore	Blackwater, Crouch, Roach and Culne Estuaries	MCZ	*Ostrea edulis*
England	South East Inshore	Colne Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South East Inshore	Colne Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	South East Inshore	Dover to Deal	MCZ	*Ostrea edulis*
England	South East Inshore	Dover to Deal	MCZ	*Mytilus edulis*
England	South East Inshore	Dover to Deal	MCZ	*Sabellaria reefs*
England	South East Inshore	Dover to Folkestone	MCZ	*Ostrea edulis*
England	South East Inshore	Foulness	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna sandvicensis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South East Inshore	Foulness	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna hirundo*
England	South East Inshore	Foulness	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South East Inshore	Goodwin Sands	MCZ	*Sabellaria spinulosa reefs*
England	South East Inshore	Goodwin Sands	MCZ	*Eunicella verrucosa*
England	South East Inshore	Goodwin Sands	MCZ	*cup corals*
England	South East Inshore	Hamford Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South East Inshore	Hamford Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	South East inshore	Medway Estuary	MCZ	*Alkmaria romijni*
England	South East inshore	Medway Estuary	MCZ	*Osmerus eperlanus*
England	South East inshore	Medway Estuary	MCZ	*Dicentrarchus labrax*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South East inshore	Medway Estuary	MCZ	*Clupea harengus*
England	South East inshore	Medway Estuary	MCZ	*Gadus morhua*
England	South East inshore	Medway Estuary	MCZ	*Pleuronectidae*
England	South East inshore	Medway Estuary	MCZ	*Soleidae*
England	South East inshore	Medway Estuary	MCZ	*Pholas dactylus*
England	South East inshore	Medway Estuary	MCZ	*Sterna sandvicensis*
England	South East Inshore	Medway Estuary and Marshes	SPA, SSSI, National Nature Reserve	*Gavia stellata*
England	South East Inshore	Medway Estuary and Marshes	SPA, SSSI, National Nature Reserve	*Phalacrocorax carbo*
England	South East Inshore	Medway Estuary and Marshes	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
England	South East Inshore	Medway Estuary and Marshes	SPA, SSSI, National Nature Reserve	*Sterna albifrons*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South East Inshore	Stour and Orwell Estuaries	SPA, SSSI, National Nature Reserve	*Phalacrocorax carbo*
England	South East Inshore	Stour and Orwell Estuaries	SPA, SSSI, National Nature Reserve	*Bucephala clangula*
England	South East Inshore	Swanscombe	MCZ	*Alkmaria romijni*
England	South East inshore	Thanet Coast	MCZ	*Mytilus edulis*
England	South East inshore	Thanet Coast	MCZ	*Haliclystus sp.*
England	South East inshore	Thanet Coast	MCZ	*Calvadosia cruxmelitensis*
England	South East inshore	Thanet Coast	MCZ	*Saballeria spinulosa*
England	South East inshore	Thanet Coast	MCZ	*Seagrass beds*
England	South East Inshore	Thanet Coast and Sandwich Bay	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
England	South East Inshore	The Swale	RAMSAR	*Larus melanocephalus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore	Axe Estuary	MCZ	*Anguilla anguilla*
England	South Inshore	Beachy Head East	MCZ	*Hippocampus hippocampus*
England	South Inshore	Beachy Head East	MCZ	*Saballeria spinulosa*
England	South Inshore	Beachy Head West	MCZ	*Mytilus edulis*
England	South Inshore	Beachy Head West	MCZ	*Ostrea edulis*
England	South Inshore	Beachy Head West	MCZ	*Hippocampus hippocampus*
England	South Inshore	Bembridge	MCZ	*Maerl Beds*
England	South Inshore	Bembridge	MCZ	*Sea-pen and burrowing megafauna*
England	South Inshore	Bembridge	MCZ	*Hippocampus hippocampus*
England	South Inshore	Bembridge	MCZ	*Calvadosia campanulata*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore	Bembridge	MCZ	*Haliclystus sp.*
England	South Inshore	Bembridge	MCZ	*Ostrea edulis*
England	South Inshore	Bembridge	MCZ	*Padina pavonica*
England	South Inshore	Bembridge	MCZ	*Seagrass beds*
England	South Inshore	Chesil Beach and Stannis Ledges	MCZ	*Eunicella verrucosa*
England	South Inshore	Chesil Beach and Stannis Ledges	MCZ	*Ostrea edulis*
England	South Inshore	Chesil Beach and The Fleet	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South Inshore	Chichester and Langstone Harbours	SPA, SSSI, RAMSAR, National Nature Reserve	*Mergus serrator*
England	South Inshore	Chichester and Langstone Harbours	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna sandvicensis*
England	South Inshore	Chichester and Langstone Harbours	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna hirundo*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore	Chichester and Langstone Harbours	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South Inshore	Chichester and Langstone Harbours	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	South Inshore	Dungeness, Romney Marsh and Rye Bay	SPA	*Larus melanocephalus*
England	South Inshore	Dungeness, Romney Marsh and Rye Bay	SPA	*Sterna sandvicensis*
England	South Inshore	Dungeness, Romney Marsh and Rye Bay	SPA	*Sterna hirundo*
England	South Inshore	Dungeness, Romney Marsh and Rye Bay	SPA	*Sterna albifrons*
England	South Inshore	Exe Estuary	SPA, SSSI, RAMSAR, National Nature Reserve	*Podiceps auritus*
England	South Inshore	Folkestone Pomerania	MCZ	*Fragile sponge & anthozoan communities on subtidal rocky habitats*
England	South Inshore	Folkestone Pomerania	MCZ	*Sabellaria alveolata reefs*
England	South Inshore	Folkestone Pomerania	MCZ	*Sabellaria spinulosa reefs*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South inshore	Kingmere	MCZ	*Spondyliosoma cantharus*
England	South Inshore	Otter Estuary	MCZ	*Anguilla anguilla*
England	South Inshore	Otter Estuary	MCZ	*Salmo salar*
England	South Inshore	Otter Estuary	MCZ	*Salmo trutta*
England	South Inshore	Otter Estuary	MCZ	*Alosa fallax*
England	South Inshore	Pagham Harbour	SPA, MCZ, SSSI, RAMSAR, National Nature Reserve	*Sterna hirundo*
England	South Inshore	Pagham Harbour	SPA, MCZ, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South inshore	Pagham Harbour	SPA, MCZ, SSSI, RAMSAR, National Nature Reserve	*Seagrass beds*
England	South inshore	Pagham Harbour	SPA, MCZ, SSSI, RAMSAR, National Nature Reserve	*Caecum armoricum*
England	South inshore	Pagham Harbour	SPA, MCZ, SSSI, RAMSAR, National Nature Reserve	*Gammarus insensibilis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore	Poole Harbour	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	South Inshore	Poole Harbour	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna sandvicensis*
England	South Inshore	Poole Harbour	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna hirundo*
England	South Inshore	Poole Harbour	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	South inshore	Poole Rocks	MCZ	*Cnidaria*
England	South inshore	Poole Rocks	MCZ	*Spondyliosoma cantharus*
England	South inshore	Poole Rocks	MCZ	*Gobius couchi*
England	South inshore	Poole Rocks	MCZ	*Ostrea edulis*
England	South Inshore	Portsmouth Harbour	SPA, SSSI, National Nature Reserve	*Mergus serrator*
England	South Inshore	Purbeck Coast	MCZ	*Maerl beds*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore	Purbeck Coast	MCZ	*Padina pavonica*
England	South Inshore	Purbeck Coast	MCZ	*Haliclystus sp.*
England	South Inshore	Purbeck Coast	MCZ	*Spondyliosoma cantharus*
England	South Inshore	Selsey Bill and the Hounds	MCZ	*Hippocampus hippocampus*
England	South Inshore	Solent and Southampton Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*
England	South Inshore	Solent and Southampton Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna sandvicensis*
England	South Inshore	Solent and Southampton Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna dougallii*
England	South Inshore	Solent and Southampton Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna hirundo*
England	South Inshore	Solent and Southampton Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna albifrons*
England	South Inshore	Solent and Southampton Water	SPA, SSSI, RAMSAR, National Nature Reserve	*Larus melanocephalus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore	Southbourne Rough	MCZ	*Spondyliosoma cantharus*
England	South Inshore	Studland Bay	MCZ	*Hippocampus guttulatus*
England	South Inshore	Studland Bay	MCZ	*Seagrass beds*
England	South Inshore	Studland Bay	MCZ	*Syngnathidae*
England	South Inshore	Studland Bay	MCZ	*Labridae*
England	South Inshore	Studland Bay	MCZ	*Serranidae*
England	South Inshore	Studland Bay	MCZ	*Cyprinidae*
England	South Inshore	Studland Bay	MCZ	*Solea solea*
England	South Inshore	Studland Bay	MCZ	*Pleuronectidae*
England	South Inshore	The Needles	MCZ	*Seagrass beds*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore	The Needles	MCZ	*Lucernariopsis campanulata*
England	South Inshore	The Needles	MCZ	*Padina pavonica*
England	South Inshore	The Needles	MCZ	*Ostrea edulis*
England	South inshore	Torbay	MCZ	*Hippocampus guttulatus*
England	South inshore	Torbay	MCZ	*Ostrea edulis*
England	South inshore	Torbay	MCZ	*Padina pavonica*
England	South inshore	Torbay	MCZ	*Seagrass beds*
England	South inshore	Torbay	MCZ	*Spatangoida*
England	South inshore	Torbay	MCZ	*Ensis spp.*
England	South inshore	Torbay	MCZ	*Hippocampus spp.*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South inshore	Torbay	MCZ	*Syngnathidae*
England	South inshore	Torbay	MCZ	*Dicentrarchus labrax*
England	South inshore	Torbay	MCZ	*Sepiida*
England	South inshore	Torbay	MCZ	*Mergus serrator*
England	South inshore	Torbay	MCZ	*Gavia immer*
England	South Inshore	Yarmouth to Cowes	MCZ	*Pholadidae*
England	South Inshore	Yarmouth to Cowes	MCZ	*Ostrea edulis*
England	South Inshore & South Offshore	Inner Bank	MCZ	*Ostrea edulis*
England	South Inshore & South Offshore	South Dorset	MCZ	*Pholas dactylus*
England	South Inshore & South Offshore	South Dorset	MCZ	*Hydrozoa*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Inshore & South Offshore	South Dorset	MCZ	*Dicentrarchus labrax*
England	South Inshore & South Offshore	South Dorset	MCZ	*Pleuronectiformes*
England	South Inshore & South Offshore	South Dorset	MCZ	*Ammodytidae*
England	South Offshore	Offshore Brighton	MCZ	*Alcyonium digitatum*
England	South Offshore	Offshore Overfalls	MCZ	*Scophthalmus maximus*
England	South Offshore	Offshore Overfalls	MCZ	*Scophthalmus rhombus*
England	South Offshore	Offshore Overfalls	MCZ	*Micropterus salmoides*
England	South Offshore	Offshore Overfalls	MCZ	*Gadus morhua*
England	South Offshore	Offshore Overfalls	MCZ	*Raja brachyura*
England	South Offshore	Offshore Overfalls	MCZ	*Galeorhinus galeus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South Offshore	Offshore Overfalls	MCZ	*Cancer pagurus*
England	South Offshore	Offshore Overfalls	MCZ	*Ammodytidae*
England	South West Inshore	Bideford to Foreland Point	MCZ	*Fragile sponge & anthozoan communities on subtidal rocky habitats*
England	South West Inshore	Bideford to Foreland Point	MCZ	*Sabellaria alveolata reefs*
England	South West Inshore	Bideford to Foreland Point	MCZ	*Eunicella verrucosa*
England	South West Inshore	Bideford to Foreland Point	MCZ	*Palinurus elephas*
England	South West Inshore	Bideford to Foreland Point	MCZ	*Squalidae*
England	South West Inshore	Dart Estuary	MCZ	*Alkmaria romijni*
England	South West Inshore	Devon Estuary	MCZ	*Alkmaria romijni*
England	South West Inshore	East of Start Point	MCZ	*Scomber scombrus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West Inshore	Erme Estuary	MCZ	*Alkmaria romijni*
England	South West Inshore	Falmouth Bay to St Austell Bay	SPA, SSSI, National Nature Reserve	*Gavia arctica*
England	South West Inshore	Falmouth Bay to St Austell Bay	SPA, SSSI, National Nature Reserve	*Gavia immer*
England	South West Inshore	Falmouth Bay to St Austell Bay	SPA, SSSI, National Nature Reserve	*Podiceps auritus*
England	South West Inshore	Hartland point to Tintagel	MCZ	*Fragile sponge & anthozoan communities on subtidal rocky habitats*
England	South West Inshore	Hartland point to Tintagel	MCZ	*Sabellaria alveolata reefs*
England	South West Inshore	Hartland point to Tintagel	MCZ	*Eunicella verrucosa*
England	South West Inshore	Helford Estuary	MCZ	*Ostrea edulis*
England	South West inshore	Isles of Scilly	MCZ	*Sponge and Anthozoan communities*
England	South West inshore	Isles of Scilly	MCZ	*Gobius cobitis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West inshore	Isles of Scilly	MCZ	*Eunicella verrucosa*
England	South West inshore	Isles of Scilly	MCZ	*Palinurus elephas*
England	South West inshore	Isles of Scilly	MCZ	*Calvadosia campanulata*
England	South West inshore	Isles of Scilly	MCZ	*Calvadosia cruxmelitensis*
England	South West inshore	Isles of Scilly	MCZ	*Haliclystus sp.*
England	South West inshore	Isles of Scilly	MCZ	*Brachyura*
England	South West inshore	Isles of Scilly	MCZ	*Alcyonacea*
England	South West inshore	Isles of Scilly Complex	SAC	*Halichoerus grypus*
England	South West inshore	Lundy	SAC, MCZ	*Halichoerus grypus*
England	South West inshore	Lundy	SAC, MCZ	*Palinurus elephas*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West Inshore	Morte Platform	MCZ	*Sabellaria spinulosa reefs*
England	South West Inshore	Morte Platform	MCZ	*Ammodytidae*
England	South West Inshore	Mounts Bay	MCZ	*Seagrass beds*
England	South West Inshore	Mounts Bay	MCZ	*Gobius cobitis*
England	South West Inshore	Mounts Bay	MCZ	*Haliclystus spp*
England	South West Inshore	Mounts Bay	MCZ	*Lucernariopsis campanulata*
England	South West Inshore	Mounts Bay	MCZ	*Lucernariopsis cruxmelitensis*
England	South West Inshore	Newquay and the Gannel	MCZ	*Gobius cobitis*
England	South West inshore	Padstow Bay and Surrounds	MCZ	*Eunicella verrucosa*
England	South West inshore	Padstow Bay and Surrounds	MCZ	*Palinurus elephas*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West inshore	Padstow Bay and Surrounds	MCZ	*Phaeophyceae*
England	South West inshore	Padstow Bay and Surrounds	MCZ	*Rhodophyta*
England	South West inshore	Plymouth Sound and Estuaries	SAC	*Alosa alosa*
England	South West Inshore	Runnel Stone	MCZ	*Eunicella verrucosa*
England	South West inshore	Skerries Bank and Surrounds	MCZ	*Eunicella verrucosa*
England	South West inshore	Skerries Bank and Surrounds	MCZ	*Palinurus elephas*
England	South West inshore	Skerries Bank and Surrounds	MCZ	*Echinoidea*
England	South West inshore	Skerries Bank and Surrounds	MCZ	*Homarus gammarus*
England	South West inshore	Skerries Bank and Surrounds	MCZ	*Brachyura*
England	South West inshore	Tamar Estuary	MCZ	*Biogenic reef*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West inshore	Tamar Estuary	MCZ	*Mytilus edulis*
England	South West inshore	Tamar Estuary	MCZ	*Ostrea edulis*
England	South West inshore	Tamar Estuary	MCZ	*Osmerus eperlanus*
England	South West inshore	The Manacles	MCZ	*Maerl beds*
England	South West inshore	The Manacles	MCZ	*Amphianthus dohrnii*
England	South West inshore	The Manacles	MCZ	*Palinurus elephas*
England	South West inshore	The Manacles	MCZ	*Haliclystus auricula*
England	South West inshore	The Manacles	MCZ	*Eunicella verrucosa*
England	South West inshore	The Manacles	MCZ	*Homarus gammarus*
England	South West inshore	The Manacles	MCZ	*Brachyura*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West inshore	The Manacles	MCZ	*Echinoidea*
England	South West inshore	The Manacles	MCZ	*Echinozoa*
England	South West inshore	Upper Fowey and Pont Pill	MCZ	*Phaeophyceae*
England	South West inshore	Upper Fowey and Pont Pill	MCZ	*Salmo trutta*
England	South West inshore	Upper Fowey and Pont Pill	MCZ	*Dicentrarchus labrax*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Amphianthus dohrnii*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Arctica islandica*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Calvadosia campanulata*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Calvadosia cruxmelitensis*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Eunicella verrucosa*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West inshore	Whitsand and Looe Bay	MCZ	*Gobius cobitis*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Haliclystus sp.*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Seagrass beds*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Homarus gammarus*
England	South West inshore	Whitsand and Looe Bay	MCZ	*Brachyura*
England	South West Inshore & South West Offshore	South of the Isles of Scilly	MCZ	*Atrina fragilis*
England	South West Inshore & South West Offshore	South of the Isles of Scilly	MCZ	*Bean Mussel*
England	South West Inshore & South West Offshore	South of the Isles of Scilly	MCZ	*Pecten Maximus*
England	South West Inshore & South West Offshore	South of the Isles of Scilly	MCZ	*Dogfish*
England	South West Inshore & South West Offshore	South of the Isles of Scilly	MCZ	*Solea solea*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West Inshore & South West Offshore	South of the Isles of Scilly	MCZ	*Lepidorhombus whiffiagonis*
England	South West Inshore & South West Offshore	South of the Isles of Scilly	MCZ	*Gaidropsarus vulgaris*
England	South West Offshore	East of Haig Fras	MCZ	*Sea-pen and burrowing megafauna*
England	South West Offshore	East of Haig Fras	MCZ	*Atrina fragilis*
England	South West Offshore	East of Haig Fras	MCZ	*Arnoglossus laterna*
England	South West Offshore	East of Haig Fras	MCZ	*Lepidorhombus whiffiagonis*
England	South West Offshore	East of Haig Fras	MCZ	*Chelidonichthys cuculus*
England	South West Offshore	Greater Haig Fras	MCZ	*Sea-pen and burrowing megafauna*
England	South West Offshore	North-West of Jones Bank	MCZ	*Sea-pen and burrowing megafauna*
England	South West Offshore	South of Celtic Deep	MCZ	*Zeus faber*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England	South West Offshore	South of Celtic Deep	MCZ	*Melanogrammus auglefinus*
England	South West Offshore	South of Celtic Deep	MCZ	*Angler Fish*
England	South West offshore	South-West Deeps (West)	MCZ	*Atrina fragilis*
England	South West Offshore	The Canyons	MCZ	*Sea-pen and burrowing megafauna*
England	South West Offshore	The Canyons	MCZ	*Coral Gardens*
England	South West Offshore	The Canyons	MCZ	*Cold-water coral reefs*
England	South West Offshore	Western Channel	MCZ	*Ammodytidae*
England & Scotland	North East Inshore & Forth and Tay	Berwickshire and North Northumberland Coast	SAC	*Halichoerus grypus*
England & Scotland	North West Inshore & Solway	Solway Firth	SPA, SAC, MCZ, SSSI, National Nature Reserve	*Bucephala clangula*
England & Scotland	North West Inshore & Solway	Solway Firth	SPA, SAC, MCZ, SSSI, National Nature Reserve	*Osmerus eperlanus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
England & Scotland	North West Inshore & Solway	Solway Firth	SPA, SAC, MCZ, SSSI, National Nature Reserve	*Petromyzon marinus*
England & Wales	North West Inshore & Wales Inshore	Dee Estuary/ Aber Dyfrdwy	SAC	*Petromyzon marinus*
England & Wales	South West Inshore & Wales Inshore	Bristol Channel Approaches / Dynesfeydd Môr Hafren	SAC	*Phocoena phocoena*
England & Wales	South West Inshore & Wales Inshore	Severn Estuary/ Môr Hafren	SAC	*Alosa fallax*
England & Wales	South West Inshore & Wales Inshore	Severn Estuary/ Môr Hafren	SAC	*Petromyzon marinus*
Northern Ireland	Northern Ireland inshore	Belfast Lough	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
Northern Ireland	Northern Ireland inshore	Belfast Lough	SPA, SSSI, National Nature Reserve	*Sterna paradisaea*
Northern Ireland	Northern Ireland inshore	Carlingford Lough	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
Northern Ireland	Northern Ireland inshore	Carlingford Lough	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
Northern Ireland	Northern Ireland inshore	Larne Lough	SPA, SSSI, National Nature Reserve	*Larus melanocephalus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Northern Ireland	Northern Ireland inshore	Larne Lough	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
Northern Ireland	Northern Ireland inshore	Larne Lough	SPA, SSSI, National Nature Reserve	*Sterna dougallii*
Northern Ireland	Northern Ireland inshore	Larne Lough	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
Northern Ireland	Northern Ireland inshore	Murlough	SAC	*Phoca vitulina*
Northern Ireland	Northern Ireland inshore	Outer Ards	SPA, SSSI, National Nature Reserve	*Sterna paradisaea*
Northern Ireland	Northern Ireland inshore	Rathlin Island	SPA, SSSI, National Nature Reserve	*Rissa tridactyla*
Northern Ireland	Northern Ireland inshore	Rathlin Island	SPA, SSSI, National Nature Reserve	*Uria aalge*
Northern Ireland	Northern Ireland inshore	Rathlin Island	SPA, SSSI, National Nature Reserve	*Alca torda*
Northern Ireland	Northern Ireland Inshore	Skerries and Causeway	SAC	*Phocoena phocoena*
Northern Ireland	Northern Ireland inshore	Strangford Lough	SPA, SAC, SSSI, Marine Nature Reserve, National Nature Reserve	*Sterna sandvicensis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Northern Ireland	Northern Ireland inshore	Strangford Lough	SPA, SAC, SSSI, Marine Nature Reserve, National Nature Reserve	*Sterna hirundo*
Northern Ireland	Northern Ireland inshore	Strangford Lough	SPA, SAC, SSSI, Marine Nature Reserve, National Nature Reserve	*Sterna paradisaea*
Northern Ireland	Northern Ireland inshore	Strangford Lough	SPA, SAC, SSSI, Marine Nature Reserve, National Nature Reserve	*Phoca vitulina*
Northern Ireland	Northern Ireland inshore	The Maidens	SAC	*Halichoerus grypus*
Northern Ireland	Northern Ireland Inshore & Northern Ireland Offshore	North Channel	SAC	*Phocoena phocoena*
Northern Ireland	Northern Ireland offshore	Queenie Corner	MCZ	*Sea-pen and burrowing megafauna*
Northern Ireland	Northern Ireland offshore	Queenie Corner	MCZ	*Nephrops norvegicus*
Northern Ireland	Northern Ireland offshore	South Rigg	MCZ	*Sea-pen and burrowing megafauna*
Northern Ireland	Northern Ireland offshore	South Rigg	MCZ	*Alcyonium digitatum*
Northern Ireland	Northern Ireland offshore	South Rigg	MCZ	*Nephrops norvegicus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Argyll	Eileanan agus Sgeiran Lios mor	SAC	*Phoca vitulina*
Scotland	Argyll	Moine Mhor	SAC	*Lutra lutra*
Scotland	Argyll	North Colonsay and Western Cliffs	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Argyll	Rinns of Islay	RAMSAR	*Alca torda*
Scotland	Argyll	South-East Islay Skerries	SAC	*Phoca vitulina*
Scotland	Argyll	Treshnish Isles	SAC	*Halichoerus grypus*
Scotland	Clyde	Ailsa Craig	SPA, SSSI, RAMSAR, National Nature Reserve	*Morus bassanus*
Scotland	Clyde	Ailsa Craig	SPA, SSSI, RAMSAR, National Nature Reserve	*Uria aalge*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Gavia stellata*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Podiceps auritus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Phalacrocorax carbo*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Somateria mollissima*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Melanitta nigra*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Melanitta fusca*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Bucephala clangula*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Mergus serrator*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Sterna sandvicensis*
Scotland	Forth and Tay	Firth of Forth	SPA, SSSI, RAMSAR, National Nature Reserve	*Melanitta fusca*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Phalacrocorax carbo*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Somateria mollissima*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Melanitta nigra*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Melanitta fusca*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Bucephala clangula*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Mergus serrator*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Mergus merganser*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Sterna albifrons*
Scotland	Forth and Tay	Firth of Tay and Eden Estuary	SPA, SAC, SSSI, National Nature Reserve	*Phoca vitulina*
Scotland	Forth and Tay	Forth Islands	SPA	*Morus bassanus*
Scotland	Forth and Tay	Forth Islands	SPA	*Phalacrocorax carbo*
Scotland	Forth and Tay	Forth Islands	SPA	*Phalacrocorax aristotelis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Forth and Tay	Forth Islands	SPA	*Larus fuscus*
Scotland	Forth and Tay	Forth Islands	SPA	*Larus argentatus*
Scotland	Forth and Tay	Forth Islands	SPA	*Rissa tridactyla*
Scotland	Forth and Tay	Forth Islands	SPA	*Sterna sandvicensis*
Scotland	Forth and Tay	Forth Islands	SPA	*Sterna dougallii*
Scotland	Forth and Tay	Forth Islands	SPA	*Sterna hirundo*
Scotland	Forth and Tay	Forth Islands	SPA	*Sterna paradisaea*
Scotland	Forth and Tay	Forth Islands	SPA	*Uria aalge*
Scotland	Forth and Tay	Forth Islands	SPA	*Alca torda*
Scotland	Forth and Tay	Forth Islands	SPA	*Fratercula arctica*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Forth and Tay	Isle of May	SAC	*Halichoerus grypus*
Scotland	Forth and Tay	St Abb's Head to Fast Castle	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Forth and Tay	St Abb's Head to Fast Castle	SPA, SSSI, National Nature Reserve	*Alca torda*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Sterna paradisaea*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Fratercula arctica*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Melanitta nigra*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Larus ridibundus*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Rissa tridactyla*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Somateria mollissima*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Bucephala clangula*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Uria aalge*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Larus canus*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Sterna hirundo*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Phalacrocorax aristotelis*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Larus argentatus*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Larus minutus*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Clangula hyemalis*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Puffinus puffinus*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Morus bassanus*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Alca torda*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Mergus serrator*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Gavia stellata*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Podiceps auritus*
Scotland	Forth and Tay & Scottish National Marine Plan	Outer Firth of Forth and St Andrews Bay Complex	SPA	*Melanitta fusca*
Scotland	Moray Firth	Cromarty Firth	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
Scotland	Moray Firth	Dornoch Firth and Morrich More	SAC	*Lutra lutra*
Scotland	Moray Firth	Dornoch Firth and Morrich More	SAC	*Phoca vitulina*
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Phalacrocorax carbo*
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Phalacrocorax aristotelis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Larus argentatus*
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Larus marinus*
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Rissa tridactyla*
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Moray Firth	East Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Alca torda*
Scotland	Moray Firth	Fowlsheugh	SPA	*Fulmarus glacialis*
Scotland	Moray Firth	Fowlsheugh	SPA	*Uria aalge*
Scotland	Moray Firth	Fowlsheugh	SPA	*Alca torda*
Scotland	Moray Firth	Inner Moray Firth	SPA, SSSI, National Nature Reserve	*Sterna hirundo*
Scotland	Moray Firth	Moray Firth	SAC	*Tursiops truncatus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Orkney Islands	Calf of Eday	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Orkney Islands	Calf of Eday	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Orkney Islands	Copinsay	SPA	*Fulmarus glacialis*
Scotland	Orkney Islands	Copinsay	SPA	*Uria aalge*
Scotland	Orkney Islands	Faray and Holm of Faray	SAC	*Halichoerus grypus*
Scotland	Orkney Islands	Hoy	SPA	*Fulmarus glacialis*
Scotland	Orkney Islands	Hoy	SPA	*Uria aalge*
Scotland	Orkney Islands	Hoy	SPA	*Fratercula arctica*
Scotland	Orkney Islands	Marwick Head	SPA	*Uria aalge*
Scotland	Orkney Islands	Rousay	SPA	*Fulmarus glacialis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Orkney Islands	Rousay	SPA	*Uria aalge*
Scotland	Orkney Islands	Sanday	SAC	*Phoca vitulina*
Scotland	Orkney Islands	Sule Skerry and Sule Stack	SPA, SSSI, National Nature Reserve	*Morus bassanus*
Scotland	Orkney Islands	Sule Skerry and Sule Stack	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Orkney Islands	Sule Skerry and Sule Stack	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Scotland	Orkney Islands	West Westray	SPA	*Fulmarus glacialis*
Scotland	Orkney Islands	West Westray	SPA	*Uria aalge*
Scotland	Orkney Islands	West Westray	SPA	*Alca torda*
Scotland	Orkney Islands & Scottish Natinal Marine Plan	North-west Orkney	NCMPA	*Ammodytes spp.*
Scotland	Outer Hebrides	Flannan Isles	SPA	*Fulmarus glacialis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Outer Hebrides	Flannan Isles	SPA	*Uria aalge*
Scotland	Outer Hebrides	Flannan Isles	SPA	*Alca torda*
Scotland	Outer Hebrides	Flannan Isles	SPA	*Fratercula arctica*
Scotland	Outer Hebrides	Loch nam Madadh	SAC	*Lutra lutra*
Scotland	Outer Hebrides	Mingulay and Berneray	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Outer Hebrides	Mingulay and Berneray	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Outer Hebrides	Mingulay and Berneray	SPA, SSSI, National Nature Reserve	*Alca torda*
Scotland	Outer Hebrides	Mingulay and Berneray	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Scotland	Outer Hebrides	Monach Islands	SAC	*Halichoerus grypus*
Scotland	Outer Hebrides	North Rona	SAC	*Halichoerus grypus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Outer Hebrides	North Rona and Sula Sgeir	SPA	*Fulmarus glacialis*
Scotland	Outer Hebrides	North Rona and Sula Sgeir	SPA	*Morus bassanus*
Scotland	Outer Hebrides	North Rona and Sula Sgeir	SPA	*Uria aalge*
Scotland	Outer Hebrides	North Rona and Sula Sgeir	SPA	*Alca torda*
Scotland	Outer Hebrides	North Rona and Sula Sgeir	SPA	*Fratercula arctica*
Scotland	Outer Hebrides	Seas off St Kilda	SPA	*Fratercula arctica*
Scotland	Outer Hebrides	Seas off St Kilda	SPA	*Uria aalge*
Scotland	Outer Hebrides	Seas off St Kilda	SPA	*Hydrobates pelagicus*
Scotland	Outer Hebrides	Seas off St Kilda	SPA	*Fulmarus glacialis*
Scotland	Outer Hebrides	Seas off St Kilda	SPA	*Morus bassanus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Outer Hebrides	Shiant Isles	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Outer Hebrides	Shiant Isles	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Outer Hebrides	Shiant Isles	SPA, SSSI, National Nature Reserve	*Alca torda*
Scotland	Outer Hebrides	Shiant Isles	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Scotland	Outer Hebrides	Sound of Barra	cSAC/SCI	*Phoca vitulina*
Scotland	Outer Hebrides	South Uist Machair	SAC	*Lutra lutra*
Scotland	Outer Hebrides	South Uist Machair and Lochs	SPA, SSSI, National Nature Reserve	*Sterna albifrons*
Scotland	Outer Hebrides	St Kilda	SPA	*Fulmarus glacialis*
Scotland	Outer Hebrides	St Kilda	SPA	*Puffinus puffinus*
Scotland	Outer Hebrides	St Kilda	SPA	*Morus bassanus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Outer Hebrides	St Kilda	SPA	*Uria aalge*
Scotland	Outer Hebrides	St Kilda	SPA	*Alca torda*
Scotland	Outer Hebrides	St Kilda	SPA	*Fratercula arctica*
Scotland	Outer Hebrides, Scottish North Coast and Moray Firth	North Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Outer Hebrides, Scottish North Coast and Moray Firth	North Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Rissa tridactyla*
Scotland	Outer Hebrides, Scottish North Coast and Moray Firth	North Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Outer Hebrides, Scottish North Coast and Moray Firth	North Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Alca torda*
Scotland	Outer Hebrides, Scottish North Coast and Moray Firth	North Caithness Cliffs	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Scotland	Scottish National Marine Plan	East of Gannet and Montrose Fields	NCMPA	*Arctica islandica*
Scotland	Scottish National Marine Plan	Faroe-Shetland Sponge Belt	NCMPA	*Deep sea sponge aggregations*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Scottish National Marine Plan	Faroe-Shetland Sponge Belt	NCMPA	*Arctica islandica*
Scotland	Scottish National Marine Plan	Firth of Forth Banks Complex	NCMPA	*Arctica islandica*
Scotland	Scottish National Marine Plan	Hatton-Rockall Basin	NCMPA	*Deep sea sponge aggregations*
Scotland	Scottish National Marine Plan	North-East Faroe-Shetland Channel	NCMPA	*Deep sea sponge aggregations*
Scotland	Scottish National Marine Plan	Norwegian Boundary Sediment Plain	NCMPA	*Arctica islandica*
Scotland	Scottish National Marine Plan	The Barra Fan and Hebrides Terrace Seamount	NCMPA	*Seamount communities*
Scotland	Scottish National Marine Plan	The Barra Fan and Hebrides Terrace Seamount	NCMPA	*Hoplostethus atlanticus*
Scotland	Scottish National Marine Plan	Turbot Bank	NCMPA	*Ammodytes spp.*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Coral gardens*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Deep sea sponge aggregations*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Seamount communities*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Molva dypterygia*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Centrophorus squamosus*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Centrophorus granulosus*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Hoplostethus atlanticus*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Centroscymnus coelolepis*
Scotland	Scottish National Marine Plan	West of Scotland	MPA	*Coryphaenoides rupestris*
Scotland	Scottish North coast	Durness	SAC	*Lutra lutra*
Scotland	Shetland Isles	Buchan Ness to Collieston Coast	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Shetland Isles	Buchan Ness to Collieston Coast	SPA, SSSI, National Nature Reserve	*Uria aalge*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Shetland Isles	Fair Isle	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Shetland Isles	Fair Isle	SPA, SSSI, National Nature Reserve	*Morus bassanus*
Scotland	Shetland Isles	Fair Isle	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Shetland Isles	Fair Isle	SPA, SSSI, National Nature Reserve	*Alca torda*
Scotland	Shetland Isles	Fair Isle	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Scotland	Shetland Isles	Fetlar	SPA	*Fulmarus glacialis*
Scotland	Shetland Isles	Foula	SPA	*Fulmarus glacialis*
Scotland	Shetland Isles	Foula	SPA	*Uria aalge*
Scotland	Shetland Isles	Foula	SPA	*Alca torda*
Scotland	Shetland Isles	Foula	SPA	*Fratercula arctica*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Shetland Isles	Hascosay	SAC	*Lutra lutra*
Scotland	Shetland Isles	Mousa	SAC	*Phoca vitulina*
Scotland	Shetland Isles	Noss	SPA	*Fulmarus glacialis*
Scotland	Shetland Isles	Noss	SPA	*Morus bassanus*
Scotland	Shetland Isles	Noss	SPA	*Uria aalge*
Scotland	Shetland Isles	Noss	SPA	*Fratercula arctica*
Scotland	Shetland Isles	Ronas Hill – North Roe and Tingon	RAMSAR	*Cepphus grylle*
Scotland	Shetland Isles	Ronas Hill – North Roe and Tingon	RAMSAR	*Catharacta skua*
Scotland	Shetland Isles	Seas off Foula	SPA	*Stercorarius parasiticus*
Scotland	Shetland Isles	Seas off Foula	SPA	*Fratercula arctica*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	Shetland Isles	Seas off Foula	SPA	*Uria aalge*
Scotland	Shetland Isles	Seas off Foula	SPA	*Stercorarius skua*
Scotland	Shetland Isles	Seas off Foula	SPA	*Fulmarus glacialis*
Scotland	Shetland Isles	Sumburgh Head	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	Shetland Isles	Sumburgh Head	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	Shetland Isles	Yell Sound Coast	SAC	*Lutra lutra*
Scotland	Shetland Isles	Yell Sound Coast	SAC	*Phoca vitulina*
Scotland	West Highlands	Ascrib, Isay and Dunvegan	SAC	*Phoca vitulina*
Scotland	West Highlands	Canna and Sanday	SPA	*Uria aalge*
Scotland	West Highlands	Canna and Sanday	SPA	*Fratercula arctica*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	West Highlands	Handa	SPA	*Fulmarus glacialis*
Scotland	West Highlands	Handa	SPA	*Uria aalge*
Scotland	West Highlands	Handa	SPA	*Alca torda*
Scotland	West Highlands	Inner Hebrides and the Minches	SAC	*Phocoena phocoena*
Scotland	West Highlands	Inverpolly	SAC	*Lutra lutra*
Scotland	West Highlands	Rum	SPA, SAC, SSSI, National Nature Reserve	*Puffinus puffinus*
Scotland	West Highlands	Rum	SPA, SAC, SSSI, National Nature Reserve	*Uria aalge*
Scotland	West Highlands	Rum	SPA, SAC, SSSI, National Nature Reserve	*Lutra lutra*
Scotland	West Highlands	Sunart	SAC	*Lutra lutra*
Scotland	West Highlands & Scottish North Coast	Cape Wrath	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Scotland	West Highlands & Scottish North Coast	Cape Wrath	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	West Highlands & Scottish North Coast	Cape Wrath	SPA, SSSI, National Nature Reserve	*Alca torda*
Scotland	West Highlands & Scottish North Coast	Cape Wrath	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Scotland	West Highlands & Shetland Isles	Hermaness, Saxa Vord and Valla Field	SPA, SSSI, National Nature Reserve	*Fulmarus glacialis*
Scotland	West Highlands & Shetland Isles	Hermaness, Saxa Vord and Valla Field	SPA, SSSI, National Nature Reserve	*Morus bassanus*
Scotland	West Highlands & Shetland Isles	Hermaness, Saxa Vord and Valla Field	SPA, SSSI, National Nature Reserve	*Uria aalge*
Scotland	West Highlands & Shetland Isles	Hermaness, Saxa Vord and Valla Field	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Wales	Wales Inshore	Anglesey Terns / Morwenoliaid Ynys Môn	SPA, SSSI, National Nature Reserve	*Sterna sandvicensis*
Wales	Wales Inshore	Anglesey Terns / Morwenoliaid Ynys Môn	SPA, SSSI, National Nature Reserve	*Sterna dougallii*
Wales	Wales Inshore	Anglesey Terns / Morwenoliaid Ynys Môn	SPA, SSSI, National Nature Reserve	*Sterna hirundo*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Wales	Wales Inshore	Anglesey Terns / Morwenoliaid Ynys Môn	SPA, SSSI, National Nature Reserve	*Sterna paradisaea*
Wales	Wales inshore	Bae Caerfyrddin/ Carmarthen Bay	SPA, SSSI	*Melanitta nigra*
Wales	Wales inshore	Burry Inlet	SPA, SSSI, RAMSAR, National Nature Reserve	*Anas clypeata*
Wales	Wales inshore	Cardigan Bay/ Bae Ceredigion	SAC	*Halichoerus grypus*
Wales	Wales inshore	Cardigan Bay/ Bae Ceredigion	SAC	*Lampetra fluviatilis*
Wales	Wales inshore	Cardigan Bay/ Bae Ceredigion	SAC	*Petromyzon marinus*
Wales	Wales inshore	Cardigan Bay/ Bae Ceredigion	SAC	*Tursiops truncatus*
Wales	Wales inshore	Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd	SAC	*Alosa alosa*
Wales	Wales inshore	Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd	SAC	*Alosa fallax*
Wales	Wales inshore	Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd	SAC	*Lampetra fluviatilis*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Wales	Wales inshore	Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd	SAC	*Lutra lutra*
Wales	Wales inshore	Carmarthen Bay and Estuaries/ Bae Caerfyrddin ac Aberoedd	SAC	*Petromyzon marinus*
Wales	Wales inshore	Glannau Aberdaron ac Ynys Enlli/ Aberdaron Coast and Bardsey Island	SPA, SSSI, National Nature Reserve	*Puffinus puffinus*
Wales	Wales inshore	Grassholm	SPA, SSSI, National Nature Reserve	*Morus bassanus*
Wales	Wales Inshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Melanitta nigra*
Wales	Wales Inshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Larus minutus*
Wales	Wales Inshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Sterna hirundo*
Wales	Wales Inshore	Liverpool Bay / Bae Lerpwl	SPA, SSSI, Marine Nature Reserve, National Nature Reserve	*Sterna albifrons*
Wales	Wales inshore	Northern Cardigan Bay / Gogledd Bae Ceredigion	SPA, SSSI, National Nature Reserve	*Gavia stellata*
Wales	Wales inshore	Pembrokeshire Marine/ Sir Benfro Forol	SAC	*Alosa alosa*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Wales	Wales inshore	Pembrokeshire Marine/ Sir Benfro Forol	SAC	*Alosa fallax*
Wales	Wales inshore	Pembrokeshire Marine/ Sir Benfro Forol	SAC	*Halichoerus grypus*
Wales	Wales inshore	Pembrokeshire Marine/ Sir Benfro Forol	SAC	*Lampetra fluviatilis*
Wales	Wales inshore	Pembrokeshire Marine/ Sir Benfro Forol	SAC	*Lutra lutra*
Wales	Wales inshore	Pembrokeshire Marine/ Sir Benfro Forol	SAC	*Petromyzon marinus*
Wales	Wales inshore	Pen Llyn a`r Sarnau/ Lleyn Peninsula and the Sarnau	SAC	*Halichoerus grypus*
Wales	Wales inshore	Pen Llyn a`r Sarnau/ Lleyn Peninsula and the Sarnau	SAC	*Lutra lutra*
Wales	Wales inshore	Pen Llyn a`r Sarnau/ Lleyn Peninsula and the Sarnau	SAC	*Tursiops truncatus*
Wales	Wales Inshore & Wales Offshore	Skomer, Skokholm and the Seas off Pembrokeshire / Sgomer, Sgogwm a Moroedd Penfro	SPA, SSSI, National Nature Reserve	*Puffinus puffinus*
Wales	Wales Inshore & Wales Offshore	Skomer, Skokholm and the Seas off Pembrokeshire / Sgomer, Sgogwm a Moroedd Penfro	SPA, SSSI, National Nature Reserve	*Hydrobates pelagicus*

NATION	MARINE PLAN	SITE NAME	SITE DESIGNATIONS	QUALIFYING CRITERION
Wales	Wales Inshore & Wales Offshore	Skomer, Skokholm and the Seas off Pembrokeshire / Sgomer, Sgogwm a Moroedd Penfro	SPA, SSSI, National Nature Reserve	*Larus fuscus*
Wales	Wales Inshore & Wales Offshore	Skomer, Skokholm and the Seas off Pembrokeshire / Sgomer, Sgogwm a Moroedd Penfro	SPA, SSSI, National Nature Reserve	*Fratercula arctica*
Wales	Wales Inshore & Wales Offshore	West Wales Marine / Gorllewin Cymru Forol	SAC	*Phocoena phocoena*
Wales	Wales Offshore	Irish Sea Front	SPA	*Puffinus puffinus*
Wales & Northern Ireland	Wales Inshore, Wales Offshore & Northern Ireland Offshore	North Anglesey Marine / Gogledd Môn Forol	SAC	*Phocoena phocoena*

SI Table S3

Modelling datasets used in the conservation sector meta-analyses. Species shown are preferred prey of key megafauna species of interest to the UK, as listed in SI Table S6, below.

MODEL TYPE	MODELLED VARIABLE	UNITS	SECTORAL ANALYSIS	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Physical-biogeochemical	Available refractory carbon	Kg C m-3	Climate services	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Increased	IPCC (2019)
Physical-biogeochemical	Buried refractory carbon	Kg C m-3	Climate services	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Increased	IPCC (2019)
Physical-biogeochemical	Depth of oxygen horizon	cm	Climate services	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Decreased, decreased productivity	IPCC (2019)
Physical-biogeochemical	Slowly degradable carbon	Kg C m-3	Climate services	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Increased	IPCC (2019)
Physical-biogeochemical	Net primary production	Kg C m-3 s-1	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Potential energy anomaly (stratification)	J m-3	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Increased	IPCC (2019)
Physical-biogeochemical	Water column sum of phytoplankton carbon	Kg C m-3	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased, decreased productivity	IPCC (2019)
Physical-biogeochemical	Bottom dissolved oxygen	mmol m-3	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Bottom non-living organic carbon	Kg C m-3	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased, decreased productivity	IPCC (2019)
Physical-biogeochemical	Bottom saturation state of aragonite	scalar	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)

MODEL TYPE	MODELLED VARIABLE	UNITS	SECTORAL ANALYSIS	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Physical-biogeochemical	Bottom sea water pH	scalar	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Bottom sea water potential temperature	°C	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Increased	IPCC (2019)
Physical-biogeochemical	Bottom sea water salinity	PSU	Benthic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2021)
Physical-biogeochemical	Net primary production	Kg C m-3 s-1	Pelagic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Potential energy anomaly (stratification)	J m-3	Pelagic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Increased	IPCC (2019)
Physical-biogeochemical	Water column sum of phytoplankton carbon	Kg C m-3	Pelagic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased, decreased productivity	IPCC (2019)
Physical-biogeochemical	Surface dissolved oxygen	mmol m-3	Pelagic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Surface sea water pH	scalar	Pelagic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Surface sea water potential temperature	°C	Pelagic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Increased	IPCC (2019)
Physical-biogeochemical	Surface sea water salinity	PSU	Pelagic habitats	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)

MODEL TYPE	MODELLED VARIABLE	UNITS	SECTORAL ANALYSIS	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Physical	Summer surface thermal front strength	scalar	Pelagic habitats	POLCOMS-ERSEM	Miller - C3S MCF	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Increased	IPCC (2019)
Physical	Winter surface thermal front strength	scalar	Pelagic habitats	POLCOMS-ERSEM	Miller - C3S MCF	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Increased	IPCC (2019)
Physical	Heatwave duration	days	Pelagic habitats	POLCOMS-ERSEM	Wilson - MSPACE	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Increased	IPCC (2019)
Physical-biogeochemical	Surface dissolved oxygen	mmol m-3	Pelagic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Surface sea water potential temperature	°C	Pelagic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Increased	IPCC (2019)
Physical-biogeochemical	Surface sea water salinity	PSU	Pelagic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Net primary production	Kg C m-3 s-1	Pelagic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical	Summer thermal front strength	scalar	Pelagic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Increased	IPCC (2019)
Physical	Winter thermal front strength	scalar	Pelagic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Increased	IPCC (2019)
Species distribution	Clupea harengus	Abundance	Pelagic megafauna	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2099	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Townhill et al. (2023)

MODEL TYPE	MODELLED VARIABLE	UNITS	SECTORAL ANALYSIS	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Species distribution	Merlangius merlangus	Abundance	Pelagic megafauna	SS-DBEM	Fernandes - DEVOTES	PML/AZTI	AR5	RCP2.6; RCP8.5	2006-2098	Decreased	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Micromesistius poutassou	Abundance	Pelagic megafauna	SS-DBEM	Fernandes - DEVOTES	PML/AZTI	AR5	RCP2.6; RCP8.5	2006-2098	Decreased	IPCC (2022); Townhill et al. (2023)
Species distribution	Scomber scombrus	Abundance	Pelagic megafauna	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6;	2006-2098	Decreased	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Sprattus sprattus	Abundance	Pelagic megafauna	SS-DBEM	Sailley - CERES	PML	AR6	RCP8.5 MSY 8	2006-2098	Decreased	IPCC (2022); Pinnegar et al. (2020)
Physical-biogeochemical	Bottom dissolved oxygen	mmol m-3	Benthic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Bottom non-living organic carbon	Kg C m-3	Benthic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased, decreased productivity	IPCC (2019)
Physical-biogeochemical	Bottom sea water potential temperature	scalar	Benthic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	increased	IPCC (2019)
Physical-biogeochemical	Bottom sea water salinity	PSU	Benthic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Physical-biogeochemical	Net primary production	Kg C m-3 s-1	Benthic megafauna	POLCOMS-ERSEM	Kay - CERES	PML	AR5	RCP4.5; RCP 8.5	2006-2099	Decreased	IPCC (2019)
Habitat suitability	Cancer pagurus	habitat suitability	Benthic megafauna	DEB	Talbot - MSPACE	PML	AR5	RCP4.5; RCP 8.5	2006-2098	Decreased	Pinnegar et al. (2020)

MODEL TYPE	MODELLED VARIABLE	UNITS	SECTORAL ANALYSIS	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Species distribution	Crangon crangon	habitat suitability	Benthic megafauna	SS-DBEM	Sailley - CERES	PML	AR5	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decreased	Pinnegar et al. (2020)
Species distribution	Gadus morhua	abundance	Benthic megafauna	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decreased	Pinnegar et al. (2020)
Species distribution	Loligo forbesii	abundance	Benthic megafauna	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Mytilus edulis	abundance	Benthic megafauna	SS-DBEM	Fernandes - DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006-2098	Decreased	Pinnegar et al. (2020)
Species distribution	Pleuronectes platessa	abundance	Benthic megafauna	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decreased	Pinnegar et al. (2020)
Species distribution	Pollachius virens	abundance	Benthic megafauna	SS-DBEM	Fernandes - DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006-2098	Decreased	Pinnegar et al. (2020)
Species distribution	Solea Solea	abundance	Benthic megafauna	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decreased	Pinnegar et al. (2020)

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Modelling datasets used in the fishing sector meta-analyses.

MODEL TYPE	MODELLED SPECIES	UNITS	HABITAT TYPE	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Species distribution	Clupea harengus	abundance	Pelagic	SS-DBEM	Sailley - CERES	PML	AR6	"RCP 4.5 MSY 6;	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Townhill et al. (2023)
RCP8.5 MSY 8"	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Townhill et al. (2023)	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Dicentrachurs labrax	abundance	Pelagic	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Loligo forbesii	abundance	Pelagic	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Merlangius merlangus	abundance	Pelagic	SS-DBEM	Fernandes - DEVOTES	PML/AZTI	AR5	RCP2.6; RCP8.5	2006-2098	Decrease	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Micromesistius poutassou	abundance	Pelagic	SS-DBEM	Fernandes - DEVOTES	PML/AZTI	AR5	RCP2.6; RCP8.5	2006-2098	Decrease	IPCC (2022); Townhill et al. (2023)
Species distribution	Sardina pilchardus	abundance	Pelagic	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Townhill et al. (2023)
Species distribution	Scomber scombrus	abundance	Pelagic	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Sprattus sprattus	abundance	Pelagic	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease	IPCC (2022); Pinnegar et al. (2020)
Species distribution	Trachurus trachurus	abundance	Pelagic	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY 6; RCP8.5 MSY 8	2006-2098	Decrease due to decreased productivity. Though proportional increase in catch.	IPCC (2022); Pinnegar et al. (2020)

MODEL TYPE	MODELLED SPECIES	UNITS	HABITAT TYPE	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Species distribution	Crangon crangon	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Gadus morhua	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Hippoglossus hippoglossus	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Lophius piscatorius	abundance	Benthic & demersal	SS-DBEM	Fernandes - DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Melanogrammus aeglefinus	abundance	Benthic & demersal	SS-DBEM	Fernandes - DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Merluccius merluccius	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Mytilus edulis	abundance	Benthic & demersal	SS-DBEM	Fernandes - DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Nephrops norvegicus	abundance	Benthic & demersal	SS-DBEM	Fernandes - DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Pleuronectes platessa	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Pollachius pollachius	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)

MODEL TYPE	MODELLED SPECIES	UNITS	HABITAT TYPE	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Species distribution	Pollachius virens	abundance	Benthic & demersal	SS-DBEM	Fernandes - DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Scophthalmus maximus	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)
Species distribution	Solea Solea	abundance	Benthic & demersal	SS-DBEM	Sailley - CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006-2098	Decrease	Pinnegar et al. (2020)
Habitat suitability	Cancer pagurus	scalar	Benthic & demersal	DEB	Talbot - MSPACE	PML	AR5	RCP 4.5; RCP8.5	2006-2098	Decrease	Pinnegar et al. (2020)

SI Table S5

Modelling datasets used in the aquaculture sector meta-analyses.

MODEL TYPE	MODELLED VARIABLE	UNITS	SECTORAL ANALYSIS	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Physical-biogeochemical	Net primary production	Kg C m-3 s-1	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)
Physical-biogeochemical	Potential energy anomaly (stratification)	J m-3	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Increased	IPCC (2019)
Physical-biogeochemical	Water column sum of phytoplankton carbon	Kg C m-3	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased, decreased productivity	IPCC (2019)
Physical-biogeochemical	Bottom dissolved oxygen	mmol m-3	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)
Physical-biogeochemical	Bottom non-living organic carbon	Kg C m-3	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased, decreased productivity	IPCC (2019)
Physical-biogeochemical	Bottom saturation state of aragonite	scalar	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)
Physical-biogeochemical	Bottom sea water pH	scalar	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)
Physical-biogeochemical	Bottom sea water potential temperature	scalar	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Increased	IPCC (2019)
Physical-biogeochemical	Bottom sea water salinity	PSU	Benthic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2021)
Species growth	*Sacharina latissima*	Frond area dm-2	Pelagic aquaculture	DEB	Wilson – MSPACE	PML	AR5	RCP4.5; RCP 8.5	2000 – 2099	Decreased	IPCC (2021)

MODEL TYPE	MODELLED VARIABLE	UNITS	SECTORAL ANALYSIS	MODEL	SOURCE	INSTITUTE	SCENARIO TYPE	SCENARIO	TIME PERIOD	PREDICTED OUTCOME	SOURCE
Species distribution	*Salmo salar*	abundance	Pelagic aquaculture	SS-DBEM	Kay – CERES	PML	AR6	RCP 4.5 MSY6; RCP 8.5 MSY8	2006 – 2098	RCP 4.5 MSY6; RCP 8.5 MSY8	Pinnegar et al. (2020)
Species distribution	*Mytilus edulis*	abundance	Pelagic aquaculture	SS-DBEM	Fernandes – DEVOTES	AZTI	AR5	RCP 2.6; RCP8.5	2006 – 2098	Decreased	Pinnegar et al. (2020)
Physical-biogeochemical	Surface sea water potential temperature	°C	Pelagic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Increased	IPCC (2019)
Physical	Heatwave duration	days	Pelagic aquaculture	POLCOMS-ERSEM	Wilson – MSPACE	PML	AR5	RCP4.5; RCP 8.5	2006 – 2098	Increased	IPCC (2019)
Physical-biogeochemical	Surface dissolved oxygen	mmol m-3	Pelagic habitats	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)
Physical-biogeochemical	Surface sea water pH	scalar	Pelagic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)
Physical-biogeochemical	Surface saturation state of aragonite	scalar	Pelagic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)
Physical-biogeochemical	Net primary production	Kg C m-3 s-1	Pelagic aquaculture	POLCOMS-ERSEM	Kay – CERES	PML	AR5	RCP4.5; RCP 8.5	2006 – 2099	Decreased	IPCC (2019)

SI Table S6

Modelling datasets used in the aquaculture sector meta-analyses.

TYPE	SPECIES	IUCN POPULATION STATUS	PREY SPECIES	THERMAL FRONT ASSOCIATION	MODELLING DATASETS ANALYSED AS DISTRIBUTION DRIVERS	SOURCE
Bird	Arctic Skua – Stercorarius parasiticus	Endangered (Europe); Least Concern (Global)	Sandeel (Ammodytes spp.), crustaceans	No	SST, surface salinity, surface dissolved oxygen, integrated NPP	Andersson and Götmark (1980); Phillips et al. (1996)
Bird	Arctic tern – Sterna paradisaea	Least Concern (Europe); Least Concern (Global)	Sandeel (Ammodytes spp.) clupeids	Unknown.	"SST, surface salinity, surface dissolved oxygen,	AZTI
Bird	Atlantic puffin – Fratercula arctica)	Endangered (Europe); Vulnerable (Global)	Small pelagics – capelin (Mallotus villosus), sandeel (Ammodytes spp.), herring (Clupea harengus)	Unknown.	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Merlangius merlangus	Durant et al. (2003)
Bird	Black guillemot – Cepphus grylle	Least Concern (Europe); Least Concern (Global)	Sandeel (Ammodytes spp.), butterfish Pholis gunnellus, benthic invertebrates	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP	Ewins (1990)
Bird	Black throated diver – Gavia arctica	Least Concern (Europe); Least Concern (Global)	Predominantly fish, although aquatic insects, molluscs, crustaceans and some plant matter may also be taken	Unknown.	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Merlangius merlangus, Sprattus sprattus	del Hoyo et al. (1992)
Bird	Black-headed gull – Larus ridibundus	Least Concern (Europe); Least Concern (Global)	Fish, molluscs and crustaceans. Fisheries discards – often associated with trawlers in the N. Sea	Possibly. Can be associated with floating seaweed patches, which themselves often converge at fronts	SST, surface salinity, surface dissolved oxygen, integrated NPP	Vandendriessche et al. (2007), Götmark (1984), Kubetzki et al. (1999)
Bird	Common (Mew) gull – Larus canus	Least Concern (Europe); Least Concern (Global)	Fish, crustaceans, polychaetes	Possibly. Can be associated with floating seaweed patches, which themselves often converge at fronts	SST, surface salinity, surface dissolved oxygen, integrated NPP, surface thermal fronts, Clupea harengus, Scomber scombrus, Sprattus sprattus	Vandendriessche et al. (2007), Götmark (1984), Kubetzki et al. (1999)
Bird	Common guillemot – Uria aalge,	Least Concern (Europe); Least Concern (Global)	Small schooling forage fish e.g. capelin (Mallotus villosus), sprats (Sprattus sprattus), Sandeel (Ammodytes spp.), Atlantic cod (Gadus morhua) and Atlantic herring (Clupea harengus).	Yes	SST, surface salinity, surface dissolved oxygen, integrated NPP, Scomber scombrus, Sprattus sprattus, Gadus morhua	Begg and Reid (1997), Lilliendahl et al. (2003)
Bird	Common Scoter – Melanitta nigra	Least Concern (Europe); Least Concern (Global)	Bivalve molluscs, crustaceans, worms, echinoderms, isopods, amphipods	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP	Kaiser (2002), Kear (2005)
Bird	Common tern – Sterna hirundo	Least Concern (Europe); Least Concern (Global)	Sandeel (Ammodytes spp.), anchovy (Anchoa spp.), herring (Clupea harengus)	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus	Goyert (2014)

TYPE	SPECIES	IUCN POPULATION STATUS	PREY SPECIES	THERMAL FRONT ASSOCIATION	MODELLING DATASETS ANALYSED AS DISTRIBUTION DRIVERS	SOURCE
Bird	European shag – Phalocrocorax aristotelis	Least Concern (Europe); Least Concern (Global)	Cod (Gadus morhua) and saithe (Pollachius virens). Also small pelagics e.g capelin (Mallotus villosus) and clupeids (Clupea harengus)	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP, Gadus morhua, Pollachius virens, Clupea harengus	Hillersøy and Lorentsen (2012), Bustnes et al. (2013)
Bird	European storm petrel – Hydrobates pelagicus	Least Concern (Europe); Least Concern (Global)	Surface organisms e.g. small fish, squid, crustaceans and jellyfish	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP, Loligo forbesii	d'Elbée and Hémery (1998), Flood et al. (2009)
Bird	Northern fulmar – Fulmaris glacialis	Least Concern (Global); Vulnerable (Europe)	Norway pout (Trisopterus esmarckii), cod (Gadus morhua), blue whiting (Micromesistius poutassou), clupeid spp. e.g. herring (Clupea harengus)	Yes	SST, surface salinity, surface dissolved oxygen, integrated NPP, Gadus morhua, Micromesistius poutassou, Clupea harengus	Ojowski et al. (2001), Camphuysen (1997)
Bird	Great black backed gull – Larus marinus	Least Concern (Europe); Least Concern (Global)	Intertidal/shallow subtidal crustaceans and molluscs, nesting seabirds (shearwaters/puffins), wide range of fish species	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP, Micromesistius poutassou, Clupea harengus, Sprattus sprattus	Buckley (1990), Rome and Ellis (2004), Farmer and Leonard (2011)
Bird	Great cormorant – Phalacrocorax arbo	Least Concern (Europe); Least Concern (Global)	Cod (Gadus morhua) and saithe (Pollachius virens)	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP, Gadus morhua, Pollachius virens	Lorentsen et al. (2004)
Bird	Great northern diver – Gavia immer	Least Concern (Europe); Least Concern (Global)	Fish, crustaceans, molluscs	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP	del Hoyo et al. (1992)
Bird	Great Skua – Catharacta skua	Least Concern (Europe); Least Concern (Global)	Opportunistic predator/scavenger with a wide dietary range. Whitefish, and bird (auks, petrels) and mammalian (rabbits, sheep) prey. Also herring (Clupea harengus) and mackerel (Scomber scombrus). Fishery discards can also form a large part of the diet.	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Scomber scombrus	Votier et al. (2003)
Bird	Herring gull – Larus argentatus	Least Concern (Europe); Least Concern (Global)	Intertidal/shallow subtidal crustaceans and molluscs, fisheries discards	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP	Garthe et al. (1999), Rome and Ellis (2004)
Bird	Kittiwake – Rissa tridactyla	Vulnerable (Europe); Vulnerable (Global)	Mainly fish. Sandeel (Ammodytes spp.) is very important in the NE Atlantic	Yes	SST, surface salinity, surface dissolved oxygen, integrated NPP, surface thermal fronts.	Heubeck (2019), Durazo et al. (1998)

TYPE	SPECIES	IUCN POPULATION STATUS	PREY SPECIES	THERMAL FRONT ASSOCIATION	MODELLING DATASETS ANALYSED AS DISTRIBUTION DRIVERS	SOURCE
Bird	Leach's storm petrel – *Oceanodroma leucorhoa*	Near Threatened (Europe); Vulnerable (Global)	Mainly plankton, e.g. euphausiids, copepods, and hyperiid amphipods that live in jellyfish. They feed to a large extent on mesopelagic lantern fish, which only occur at the surface at night in water over the continental slope.	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP	Boertmann (2011)
Bird	Lesser black backed gull – *Larus graellsii*	Least Concern (Europe); Least Concern (Global)	Subtidal crustaceans and molluscs. Liocarcinus spp. often taken in the North Sea. Fish/fisheries discards	Unknown.	SST, surface salinity, surface dissolved oxygen, integrated NPP	Rome and Ellis (2004), Schwemmer and Garthe (2005)
Bird	Little gull – *Larus minutus*	Least Concern (Europe); Least Concern (Global)	Fish and decapod crustacean larvae during migrations	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP	Schwemmer and Garthe (2006)
Bird	Little tern – *Sterna albifrons*	Least Concern (Europe); Least Concern (Global)	Herring (*Clupea harengus*), sand smelts (Atherina spp.), sardines (*Sardina pilchardus*)		SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus	Perrow et al. (2011), Correia et al. (2016)
Bird	Long-tailed duck – *Clangula hyemalis*	Least Concern (Europe); Vulnerable (Global)	Bivalves (esp. Mytilus spp), Sandeel (Ammodytes spp.), crustaceans, polychaetes, gastropods	Yes	SST, surface salinity, surface dissolved oxygen, integrated NPP, surface thermal fronts, Mytilus edulis	Stempniewicz (1995), Žydelis and Ruškytė (2005)
Bird	Manx Shearwater – *Puffinus puffinus*	Least Concern (Europe); Least Concern (Global)	Sardines *(Sardina pilchardus*)	Yes	SST, surface salinity, surface dissolved oxygen, integrated NPP, surface thermal fronts	Gray and Hamer (2001), Shoji et al. (2015)
Bird	Mediterranean gull – *Larus melanocephalus*	Least Concern (Europe); Least Concern (Global)	Will take fisheries discards and small pelagics from near surface waters	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Scomber scombrus, Sprattus sprats, Merlangius merlangus, Micromesistius poutassou	Poot (2003), Cama et al. (2011)
Bird	Northern gannet – *Morus bassanus*	Least Concern (Europe); Least Concern (Global)	Mackerel (Scomber scombrus), herring (Clupea harengus), sandeel (Ammodytes spp.)	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP, Scomber scombrus, Clupea harengus	Skov et al. (2008), Scales et al. (2014)
Bird	Osprey – *Pandion haliaetus*	Least Concern (Europe); Least Concern (Global)	Fish – no particular preference for species	No	SST, surface salinity, surface dissolved oxygen, integrated NPP	Poole et al. (2002), Melia (2014)
Bird	Razorbill – *Alca toda*	Least Concern (Europe); Least Concern (Global)	Mid water schooling fish e.g. capelin (Mallotus villosus), Sandeel (Ammodytes spp.), sprats (Sprattus sprattus) and herring (Clupea harengus).	Yes	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Sprattus sprattus	Lavers and Jones (2007), Begg and Reid (1997)

TYPE	SPECIES	IUCN POPULATION STATUS	PREY SPECIES	THERMAL FRONT ASSOCIATION	MODELLING DATASETS ANALYSED AS DISTRIBUTION DRIVERS	SOURCE
Bird	Red throated diver – *Gavia stellata*	Least Concern (Europe); Least Concern (Global)	Will take a broad range of fish	Unknown.	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Sprattus sprattus	Guse et al. (2009)
Bird	Red-breasted merganser – *Mergus serrator*	Near Threatened (Europe); Least Concern (Global)	Generally take salmonid smolt on the seaward migration	Possibly. Can be associated with floating seaweed patches, which themselves often converge art fronts	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP	Alexander (1995), Kålås et al. (1993), Vandendriessche et al. (2007)
Bird	Roseate tern – *Sterna dougalii*	Least Concern (Europe); Least Concern (Global)	Sandeel (Ammodytes spp.), anchovy (Anchoa spp.), herring (Clupea harengus)	Unknown.	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus	Goyert (2014)
Bird	Sandwich tern – *Sterna sandvicensis*	Least Concern (Europe); Least Concern (Global)	Sandeel (Ammodytes spp.), herring (Clupea harengus)	Unknown.	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus	Fijn et al. (2017)
Bird	Velvet scoter – *Melanitta fusca*	Vulnerabel (Europ); Vulnerabel (Global)	Echinoderms bivalves, crustaceans	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP	Byrkjedal et al. (1997); Morkūnė et al. (2018),
Bird	Common goldeneye – *Bucephala clangula*	Least Concern (Europe); Least Concern (Global)	Unknown	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP	https://www.iucnredlist.org/
Bird	Common eider – *Somateria mollissima*	Endangered (Europe); Near Threatened (Global)	Unknown	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP	https://www.iucnredlist.org/
Bird	Slavonian grebe – *Podiceps auritus*	Near Threatened (Europe); Vulnerable (Global)	Unknown	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP	https://www.iucnredlist.org/
Mammal	Bottlenose dolphin – *Tursiops truncatus*	Data deficient (Europe); Least Concern (Global)	Wide variety of prey species, mostly fish and squid. Also shrimp and other crustaceans.	Yes	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Scomber scombrus, Sprattus sprats, Merlangius merlangus, Micromesistius poutassou, Loligo forbesii, Crangon crangon	Santos et al. (2001)
Mammal	Eurasian Otter – *Lutra lutra*	Near Threatened (Europe); Near Threatened (Global)	Small demersal fish and crustaceans (particularly Carcinus spp.)	No	SST, surface salinity, surface dissolved oxygen, integrated NPP	Watt (1991), Parry et al. (2011)

TYPE	SPECIES	IUCN POPULATION STATUS	PREY SPECIES	THERMAL FRONT ASSOCIATION	MODELLING DATASETS ANALYSED AS DISTRIBUTION DRIVERS	SOURCE
Mammal	Grey seal – *Halichoerus grypus*	Least Concern (Europe); Least Concern (Global)	Sandeel (Ammodytes spp.),, cod (Gadus morhua), sole (Solea solea), dab (Limanda limanda), flounder (Platichthys plessus), plaice (Pleuronectes platessa) and saithe (Polachius virens)	No	SST, surface salinity, surface dissolved oxygen, integrated NPP, Pleuronectes platessa, Gadus morhua, Polachius virens, Solea solea	Prime and Hammond (1990), Nowak (2019)
Mammal	Harbour porpoise – *Phocoena phocoena*	Vulnerable (Europe); Least Concern (Global)	Trisopterus spp. whiting (Merlangius merlangus), herring (Clupea harengus) and sprat (Sprattus sprattus)	No	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Merlangius merlangus, Sprattus sprattus	Rogan and Berrow (1996), Cox et al. (2018)
Mammal	Harbour seal – *Phoca vitulina*	Least Concern (Europe); Least Concern (Global)	Small groundfish e.g. whiting (Merlangius merlangus), flatfish e.g. plaice (Pleuronectes platessa), sandeel (Ammodytes spp.), herring (Clupea harengus) and sprat (Sprattus sprattus).	Unknown	SST, surface salinity, surface dissolved oxygen, integrated NPP, Clupea harengus, Merlangius merlangus, Pleuronectes platessa, Sprattus sprattus	Hall et al. (1998)
Mammal	Risso's dolphin – *Grampus griseus*	Data deficient (Europe); Least Concern (Global)	Mesopelagic and benthic cephalopods, including squid, cuttlefish and octopus	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP, Loligo forbesii	Cockcroft et al. (1993), LaBrecque et al. (2016)
Mammal	Minke whale – *Balaenoptera acutorostrata*	Least Concern (Europe); Least Concern (Global)	Variety of prey species taken according to availability. Sandeel (Ammodytes spp.), and Mackerel (Scomber scombrus)	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP, Scomber scombrus, Clupea harengus	Doniol-Valcroze et al. (2007), Windsland et al. (2007)
Ray	Blonde ray – *Raja brachyura*	Near Threatened (Europe); Near Threatened (Global)	Shrimps and mysids are especially important for smaller individuals. Brachyuran crabs for larger animals	No	Bottom temperature, bottom salinity, bottom dissolved oxygen, integrated NPP, bottom layer organic carbon, Crangon crangon	Dedman et al. (2017); (Holden & Tucker, 1974)
Shark	Basking shark – *Cetorhinus maximus*	Endangered (Europe); Endangered (Global)	Aggregations of zooplankton.	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP	Sims et al. (2000)
Shark	Leafscale gulper shark – *Centrophorus squamosus*	Endangered (Europe); Endangered (Global)	Fish and cephalopods.	No	Bottom temperature, bottom salinity, bottom dissolved oxygen, integrated NPP	Dunn et al. (2010)
Shark	Longnose velvet dogfish – *Centroselachus crepidater*	Least Concern (Europe); Near Threatened (Global)	Fish and cephalopods. Squid and micronektonic fish in the Rockall Trough. This species would appear to feed clear of the seabed on benthopelagic organisms	No	Bottom temperature, bottom salinity, bottom dissolved oxygen, integrated NPP	Mauchline and Gordon (1983)
Shark	Porbeagle shark – *Lamna nasus*	Critically Endangered (Europe); Vulnerable (Global)	Whiting (Merlangus merlangius), blue whiting (Micromesistius poutassou), mackerel (Scomber scombrus), herring (Clupea harengus), and squid (Loligo forbesii).	Yes	Surface thermal fronts, SST, surface salinity, surface dissolved oxygen, integrated NPP, Merlangus merlangius, Micromesistius poutassou, Scomber scombrus, Clupea harengus and Loligo forbesii.	Pade et al. (2009)

TYPE	SPECIES	IUCN POPULATION STATUS	PREY SPECIES	THERMAL FRONT ASSOCIATION	MODELLING DATASETS ANALYSED AS DISTRIBUTION DRIVERS	SOURCE
Shark	Portuguese dogfish – *Centroscymnus coelolepis*	Endangered (Europe); Near Threatened (Global)	Mainly fish (including sharks) and cephalopods. Also benthic invertebrates and cetaceans.	No	Bottom temperature, bottom salinity, bottom dissolved oxygen, integrated NPP, Cancer pagurus	Mauchline and Gordon (1983)
Shark	Spurdog/spiny dogfish – *Squalus acanthias*	Endangered (Europe); Vulnerable (Global)	Opportunistically prey on a variety of small fish and invertebrates	No	Bottom temperature, bottom salinity, bottom dissolved oxygen, integrated NPP	Dunn et al. (2013)
Shark	Tope – *Galeorhinus galeus*	Vulnerable (Europe); Critically Endangered (Global)	Teleost fish, most often bottom-associated species although pelagic fish are also taken. Cephalopods, mostly squid and octopus. Crustaceans and other prey such as annelids and gastropods taken by small juveniles.	No	Bottom temperature, bottom salinity, bottom dissolved oxygen, integrated NPP, Loligo forbesii	Walker (1999), Klippel et al. (2016)
Skate	Common skate complex – *Dipturus flossada & Dipturus intermedia*	Critically Endangered (Global) – no European assessment available	Mostly crustaceans and teleost fish, although reported several species of elasmobranch, including other species of rajid, in the stomach contents of fish landed in Devon and Cornwall.	No	Bottom temperature, bottom salinity, bottom dissolved oxygen, integrated NPP, bottom layer organic carbon, Cancer pagurus	Iglésias et al. (2010), Guisande et al. (2013)

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Annexes

Annex 1. Model Validation
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Annex 2. Seabed Habitats
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