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Developing the evidence-base to support climate-smart decision making on MPAs

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Summary

Finding solutions to tackle climate change is a key priority for the UK and international community. One emerging area of focus is ‘nature-based solutions’; utilising our knowledge of ecosystems and the services they provide to increase resilience to the impacts of climate change. Nature based solutions have a crucial role to play in taking action on climate adaptation, resilience, mitigation and biodiversity loss. This is why ‘Nature’ will be a key theme at the UN Framework for the 26th Convention of Climate Change (UNFCCC) Conference of the Parties (COP).

This project has been undertaken by JNCC for the Department of Environment, Food and Rural Affairs (DEFRA). It is focussed on building the evidence base to support climate smart decision-making for Marine Protected Areas (MPAs) in Secretary of State waters. It improves the evidence base underpinning which MPA protected features may be at most risk from the effects of climate change, and their functional role in building resilience to the impacts of it. Working with the Marine Biological Association (MBA), the sensitivity of high priority MPA protected features to climate related pressures has been assessed and presented on the Marine Life Information Network (MarLIN) website. As part of this project, sensitivity assessments were undertaken for 36 high priority biotopes related to specific MPA features, to four climate change pressures: ocean acidification, ocean warming, marine heatwaves and sea-level rise, and against medium and high emmission scenario benchmarks. The development of an approach to undertake sensitivity assessments for climate change pressures is the first of its kind and provides a methodology for assessment of additional MPA protected features based on their component biotopes in the future.

The project also reviewed the role of MPA protected features in climate regulation. Analysis undertaken as part of this project has shown that MPA features provide climate related ecosystem services for carbon sequestration and coastal protection. In Secretary of State waters, 52% of the total number of MPAs provide these services by virtue of the features they are intended to protect.

Improvements to the evidence base developed through this project was used to develop example climate profiles for two case study MPAs; The Canyons and Studland Bay Marine Conservation Zones (MCZs). The profiles were developed to communicate the impacts and the role of MPAs in climate change mitigation and adaptation, in an accessible manner.

This study has shown that MPAs in Secretary of State waters are important to enable protection of marine habitats that provide climate mitigation and adaptation services. However, these features via their associated species communities (biotopes) are often sensitive to pressures associated with climate change, which may result in a reduction in capacity to provide these services in the future. Any management of MPAs in the context of climate change will be complex, and, flexibility in line with ecological needs and changes will be important. Taking steps to address gaps in understanding the role that marine habitats and species play in climate related ecosystems, and their sensitivity to climate change pressures, will help inform climate smart decision making in the future.

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Glossary

Adapted from IPCC Special Report on the Ocean and Cryosphere in a Changing Climate; Annex I - Glossary (IPCC 2019)

Blue carbon
All biologically-driven carbon fluxes and storage in marine systems that are amenable to management can be considered as blue carbon. Coastal blue carbon focuses on rooted vegetation in the coastal zone, such as tidal marshes, mangroves and seagrasses. These ecosystems have high carbon burial rates on a per unit area basis and accumulate carbon in their soils and sediments. They provide many non-climatic benefits and can contribute to ecosystem-based adaptation. If degraded or lost, coastal blue carbon ecosystems are likely to release most of their carbon back to the atmosphere.

Carbon sequestration
The long-term removal of carbon dioxide (CO_2) or other forms of carbon from the atmosphere, with secure storage on climatically significant time scales (decadal to century). The period of storage needs to be known for climate modelling and carbon accounting purposes.

Carbon sink
Any process, activity or mechanism which removes a greenhouse gas (GHG), an aerosol or a precursor of a GHG from the atmosphere (United Nations Framework Convention on Climate Change, UNFCCC, Article 1.8).

Climate resilience
The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation.

Climate change adaptation
In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.

Climate change mitigation
A human intervention to reduce emissions or enhance the sinks of greenhouse gases (GHG).

Climate related ecosystem services
Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or biodiversity maintenance, (2) provisioning services such as food or fibre, (3) regulating services such as climate regulation or carbon sequestration and (4) cultural services such as tourism or spiritual and aesthetic appreciation.

Nature based solutions
Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN 2016).

1 Introduction

1.1 Background

The UK is a committed leader in tackling climate change; originally demonstrated through the Climate Change Act (2008) and further supported by the UK signing the Paris Agreement in 2015 and subsequently Government commitments to net zero emissions by 2050. Nature based solutions have a crucial role to play in taking action on climate adaptation, resilience, mitigation and biodiversity loss. This is why 'Nature' is a key theme at the UN Framework for the 26th Convention of Climate Change (UNFCCC) Conference of the Parties (COP), as well as being an area of focus at COP 25, at which the initial outputs from this project were presented. The importance of improving the evidence base to inform climate smart decision-making is well documented in relevant UK and international policy.

A network of Marine Protected Areas (MPAs) has been put in place across the UK to help safeguard marine biodiversity and the services it provides to society. The MPA network is a key component of a wider overall vision for clean, healthy, safe, productive and biologically diverse oceans and seas. The MPA network has been established to represent the range of marine biodiversity within our waters where appropriate and this includes many habitat types that could play an important role in offering 'nature-based solutions' to mitigating the impacts of climate change such as the sequestration or 'locking up' of atmospheric carbon.

If managed in an effective and equitable way, MPAs can help marine ecosystems adapt and enhance resilience to climate change by virtue of the fact that wider damaging activities are controlled (IUCN, 2017). Expanding our understanding of the sensitivity of MPA features to the pressures associated with climate change and the role of MPA features themselves in supporting resilience to climate change is vital to ensure informed decision-making around adaptive management of MPAs in the context of the wider marine environment.

JNCC have applied knowledge gained through the Defra-funded project 'Climate-smart MPAs' to illustrate using two MPAs as case studies how this critical information can be brought together at a site level to help inform longer-term decision making on MPA management and policy intervention in the face of a changing climate. This report provides a summary of the methodology and results from the project.

1.2 Objectives

The project had four main objectives:

1. Prioritise a set of MPA protected features in Secretary of State waters (English inshore and offshore and Northern Irish offshore waters) at highest risk from climate change pressures and identify their associated biotopes;
2. Create an inventory and high-level statistics on MPA protected features in Secretary of State waters with a role in supporting climate change resilience;
3. Devise pressure definitions and benchmarks for climate change pressures, and complete sensitivity assessments for the biotopes associated with prioritised protected features of MPAs found in Secretary of State waters, under the MarLIN project. This part of the project has been delivered through a sub-contract undertaken by the Marine Biological Association; and
4. Create example MPA climate profiles as a visual communications tool to communicate the impacts of climate change and the role of MPAs in enhancing resilience to climate change.

2 Objective 1: Prioritising MPA features at highest risk from climate change and associated biotopes

2.1 Methods

2.1.1 Literature search

To create a prioritised list of MPA features considered most at risk to climate change, JNCC undertook a rapid literature review to identify marine habitats and species likely to be impacted by climate change pressures. Outputs were correlated with the associated MPA features and biotopes. To inform and provide focus to the literature review, JNCC selected a set of climate-relevant pressures (Table 1), based on a draft list developed through Scottish Natural Heritage MPA climate change project (SNH, in prep), and a list of human-induced pressures from OSPAR Agreement 2014-02 (OSPAR Commission 2014).

Table 1. Climate change pressures selected by JNCC for the literature review.

Climate change pressures	Source
Sea level rise	SNH, in prep
Sea temperature;	SNH, in prep
Water column stratification	SNH, in prep
Freshwater input and salinity and pollution due to run off;	SNH, in prep
Storms and waves	SNH, in prep
Hydrography and circulation	SNH, in prep
Ocean acidification	SNH, in prep
Irradiance	SNH, in prep
Air temperature	SNH, in prep
Deoxygenation	OSPAR Agreement 2014-02
Emergence regime changes.	OSPAR Agreement 2014-02

Literature was searched via Google, Google Scholar and Science Direct using a series of primary and secondary search terms (Table 2). Each primary term was used to perform an initial search as a standalone word, and subsequently searched again as a unique pairing between primary and secondary terms to identify relevant literature. Additional search terms specifying geography (North-East Atlantic or UK) were added to all search results, and searches were repeated to identify potential literature of greater relevance. When identifying literature, expert judgement was used to select a temporal cut-off filter for the publications which were reviewed. All searches were filtered using conditional parameters via each search site used to return findings published from 2010 onwards to ensure temporal representativity.

Returned publications were selected via visual inspection, identifying literature which best matched the chosen search criteria. Furthermore, literature search results which detailed specific marine feature types of interest (habitats, invertebrates and other low mobility species) within the title, keywords or abstract were specifically targeted due to the higher level of relevance. Where publications cited or referred to other literature, which was deemed to be of relevance, the cited literature was also reviewed using the same filters for relevance.

Literature was filtered based on the following parameters:

- Geography: North-East Atlantic or UK
- Type of literature: peer reviewed papers; grey literature and other reports

- Feature type: Habitats, invertebrates and other low mobility species
- Date: 2010 onwards

Through this search, a wide range of receptors were identified comprising species, biotopes and habitat types. Information on level/intensity of effect was not available in most of the literature searched, and therefore receptors were recorded wherever literature indicated that climate pressures would have some effect. In total, 87 receptors were identified, ranging from individual species such as the seaweed, *Alaria esculenta* and the maerl species, *Lithothamnion corallioides,* to broad habitat types such as coastal saltmarsh.

Table 2. Search terms used to review literature on climate change effects on marine habitats and species.

Primary search term	Secondary search term
Marine vulnerability climate change	Sea temperature
Marine sensitivity climate change	Air temperature
Marine impact climate change	Salinity
Marine effect climate change	Sea level rise
Ocean vulnerability climate change	Emergence
Ocean sensitivity climate change	Stratification
Ocean impact climate change	Deoxygenation
Ocean effect climate change	Storms
	Waves
	Hydrography
	Circulation
	Current
	Acidification

2.1.2 Selection of pressures for sensitivity assessment

To streamline the number of sensitivity assessments to be undertaken under Objective 3, the climate change pressures used for the literature search were further prioritised. Drawing on expert knowledge, individual statutory nature conservation bodies (SNCBs) were asked to identify five of the pressures from Table 1 considered most likely to have an effect on habitats within UK waters. Pressures were scored by each SNCB (including JNCC), and a final prioritisation rank was developed using the mean value. The top five pressures were:

1. Sea surface temperature
2. Ocean acidification
3. Sea level rise
4. Storms and waves
5. Air temperature AND freshwater input and salinity changes (due to runoff).

2.1.3 Identification of MPA features and biotopes at-risk to climate pressures

To finalise a list of MPA features and their associated biotopes at highest risk to climate change pressures, the outputs from the literature search were refined to consider receptors affected by only the five prioritised pressures. Receptors were then correlated to MPA features (based on Habitats Directive Annex I; MCZ Features of Conservation Importance and Broadscale Habitats, and; Scottish Priority Marine Features) and biotopes based on whether they were habitats or species:

- Receptors listed as habitats were correlated to MPA features for all UK MPA types (e.g. littoral seagrass beds correlate directly to the MCZ FOCI ‘Seagrass beds’), and the MPA feature’s associated biotopes were identified using the JNCC marine habitat correlation table version 201801 (JNCC 2018).

- Receptors listed as invertebrate species were linked to JNCC biotopes using characterising species lists, and the correlating MPA features were identified using the JNCC marine habitat correlation table version 201801 (e.g. *Antipatharia* spp. are a characteristic species of three JNCC biotopes, which correlate with the MCZ FOCI habitats: 'Cold-water coral reefs' and 'Coral gardens').

2.2 Results

The results of this work found that between 85-95% of MPA features on each list had some level of risk to climate pressures, with the majority of the receptors correlating to more than one MPA feature type. In addition, 281 biotopes correlated with the 'at risk' receptors and/or MPA features. During the literature search, no filter was made for 'level' or intensity of risk to climate change pressures, as most literature either did not include this information or the terminology used for risk was not comparable between papers. As such, these outputs could potentially be refined in future work through a more detailed literature review, accounting for level/intensity of risk.

Since the majority of MPA features were considered to be 'at risk', it was not possible to use the outputs of this process to inform which MPAs to develop MPA climate profiles for under Objective 4. Instead, two sites were selected using expert judgement, Studland Bay MCZ and The Canyons MCZ. These sites include MPA features known to have some sensitivity to climate pressures, namely seagrass beds, and cold-water coral reefs and deep-sea coral gardens respectively. The sites were also selected to include representation of an inshore and an offshore MPA to use as examples for the profiles. The associated biotopes for these sites were therefore prioritised for sensitivity assessments (see Section 4.2). Specific biotope data from MPA surveys for these sites was limited, therefore in addition to known biotopes, biotopes were prioritised that a) correlated with the MPA features and b) were known to occur within the regional seas these sites were located in.

Additional sensitivity assessments were undertaken for a second set of 'at-risk' biotopes, prioritised through consultation with the SNCBs (including JNCC). The outputs of these additional assessments are available on the MarLIN website (https://www.marlin.ac.uk/habitats/az) to inform future work related to assessing the effects of climate change pressures on marine habitats.

3 Objective 2: Identifying MPA features with a role in climate change adaptation/mitigation

3.1 Methods

3.1.1 Literature assessment

To identify which MPA features have a role in climate change adaptation or mitigation, JNCC undertook a rapid literature assessment to investigate the provision of climate change related ecosystem services by MPA protected features. This was undertaken in 2 stages. Firstly, by drawing on existing products such as the JNCC marine natural capital asset register (in development), and literature reviews on this topic, such as the Joint Research Centre (JRC) report on the spatial distribution of ecosystem service capacity in European seas (Costa Tempera *et al.* 2016). This was supported by further targeted web-based searches for any more recent literature using agreed search terms to collate more detailed information about service provision.

- Stage 1 - The JRC report, the review papers used to underpin the JRC report and literature reviews on ecosystem services commissioned by JNCC not directly related to this project (supporting the development of other tools), informed the initial assessment. Information specific to the MPA features in SoS waters was directly extracted from these reports.

- Stage 2 - The JRC report converts the ecosystem service provision evidence from the underpinning review papers into the Common International Classification of Ecosystem Services (CICES) (version 4.3). The two main climate related ecosystem services identified were coastal protection and carbon sequestration/climate regulation which are equivalent to services C2.2.1 and C2.2.6.1[1] (version 5.1) respectively. These CICES services identified from the JRC report, and associated terms used in the underpinning review papers were used to identify the secondary search terms to be used alongside the UK MPA network features list (Table 3). Primary and secondary search terms were used in combination to undertake a supplementary review to identify more recent literature not considered within the JRC report. The broader secondary search terms ‘climate change’ and ‘climate regulation’ were also used to search for any potential additional services, but this resulted predominantly in literature on the impacts of climate change on the feature.

Table 3. Search terms used to review literature on climate change related ecosystem services provision by marine habitats and species.

Primary Search Term	Secondary search term
Feature name. Taken from the UK MPA features list (JNCC 2019)	Climate change
	Climate regulation
	Carbon storage
	Carbon sequestration
	Flood defence
	Flood protection
	Coastal protection
	Storm defence
	Storm protection
	Greenhouse gas reduction
	Formation of barriers
	Hazard regulation
	Sea defence
	Resilience

The evidence compiled through steps 1 and 2 was used in combination to assess the service provision by each of the protected features. Where evidence was lacking, some expert judgement was used to help infer likely service provision based on what we know about similar habitat types.

3.1.2 Assigning provision and confidence scores

Based on the literature assessment outputs, each feature was assigned a provision and confidence score of low/moderate/high, alongside an assessment of whether they could provide climate change related services. The scale of contribution was taken from the JRC review papers and was relative to other feature provisions, but it is likely that the level of contribution they make will vary depending on the extent, location and communities within an area. When evidence about the ecosystem service provision of an MPA network feature was contradictory, these were assigned a low confidence score and were not included in the list

[1] C2.2.1.1 – control of coastal erosion, C2.2.6.1 - Regulation of chemical composition of atmosphere and oceans.

of MPA features deemed to be providing the services. A list of these features can be found in table 4.

3.1.3 Combining with MPA data

The outputs of the literature assessment were used to develop statistics on the climate related ecosystem services provided by the UK MPA Network within Secretary of State (SoS) waters[2]. The UK MPA stocktake[3] data for SoS waters was used to determine the representation of MPA protected features. This was used to assess whether the MPA provided one of the climate change related services. Assessment was undertaken on a feature-level rather than on a site-by-site basis due to the short timeframe of the project. This data did not include ASSIs/SSSIs and Ramsar sites due to incomplete data on these sites across the UK. In addition, SPA bird features were not assessed as these were considered outside the scope of this project.

3.1.4 Approach to calculating the statistics

Statistics on the role of the UK MPA network in SoS waters in providing climate related ecosystem services were calculated by totalling the MPAs that protect features known to provide coastal protection or carbon sequestration services. Duplicate records, where sites protected multiple features that provide climate related services, and duplicates for the Isles of Scilly sites were removed. Totals were used to produce percentage figures of the 180 MPAs in SoS waters were provided.

3.2 Results

The information gathered through the review detailed in Section 3.1 was used to create a list of MPA features identified as having the potential to provide ecosystem services related to carbon sequestration and/or coastal protection (see Table 4). This list was then used in combination with UK MPA stocktake data to create statistics on MPAs in SoS waters with a role in climate mitigation and adaptation. The features assessed as providing a low contribution to these services were not included in the final list of features in Table 4, nor the statistics. This includes those cases where evidence about the ecosystem service provision was contradictory and a low confidence score was assigned as default. Therefore, only the features which were assessed as having a high or moderate service provision with high or medium confidence were included in the final statistics produced.

Table 4. MPA features identified as providing climate related ecosystem services related to carbon sequestration and/or coastal protection.

Carbon sequestration	**Coastal protection**
Coastal saltmarshes and saline reedbeds	
Littoral sediments dominated by aquatic angiosperms	
Sublittoral macrophyte dominated sediments	
Seagrass beds	
Subtidal mud	High energy littoral rock
Deep-sea mud	Moderate energy littoral rock
Littoral mud	Low energy littoral rock
Sea-pen and burrowing megafauna	Littoral coarse sediment
Mud habitats in deep water	Littoral sand and muddy sand
	Littoral mixed sediments
	Coastal saltmarshes and saline reedbeds

[2] Secretary of State waters refers to English territorial waters and UK offshore waters around England and Northern Ireland.
[3] UK MPA stocktake v2 - aimed to provide a standardised catalogue of features protected in UK MPAs. Further information available at: https://hub.jncc.gov.uk/assets/bc513d94-6ec2-4965-8486-83570ed93473

	Atlantic and Mediterranean high energy infralittoral rock
	Atlantic and Mediterranean moderate energy infralittoral rock
	Atlantic and Mediterranean low energy infralittoral rock
	Sublittoral biogenic reefs
	Blue mussel beds
	Estuarine rocky habitat
	Intertidal *Mytilus edulis* beds on mixed and sandy sediments
	Maerl beds
	Modiolus modiolus beds
	Musculus discors beds
	Ostrea edulis beds

The climate related ecosystem services provided by the MPAs in SoS waters are presented in Table 5. The statistics were summarised in a public facing infographic, see Figure 1.

Table 5. Climate related ecosystem services provided by the UK MPA Network in SoS waters.

Climate related ecosystem service	% of UK MPA network in SoS waters
Coastal protection	43%
Carbon sequestration	29%
Either coastal protection and/or carbon sequestration	52%

There are some caveats which apply to the method followed, and therefore to the figures calculated for service provision by MPAs. Statistics produced were calculated on a feature level rather than on a site-specific basis, therefore these may be further refined in future to take a more detailed approach to reflect individual sites and service provision at a local level. Additionally, the features with conflicting information or assessed with low confidence or contribution are not included within the figures. As more information becomes available in the future, the statistics could be reviewed/ updated accordingly.

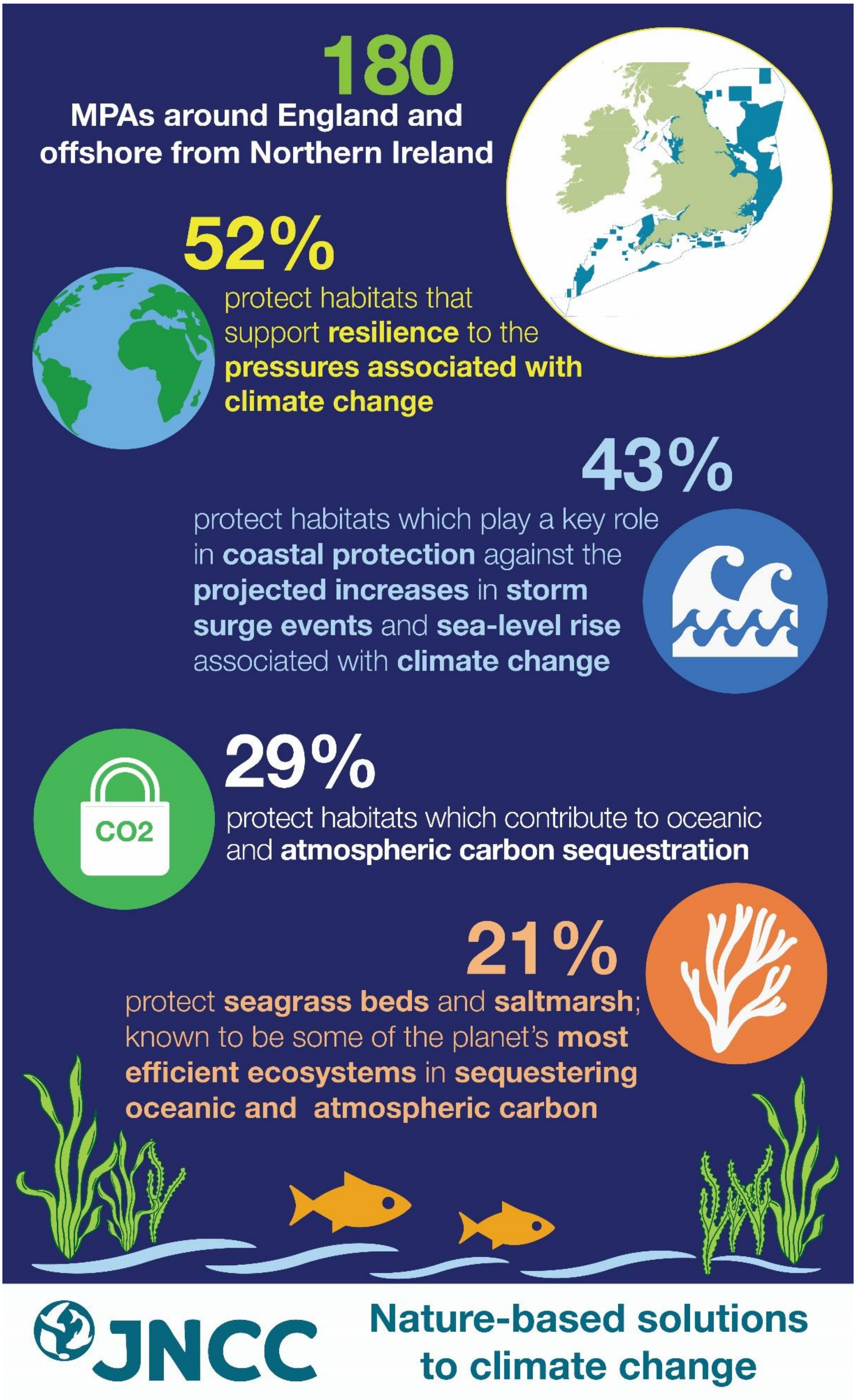

Figure 1. Infographic displaying statistics of the number of MPAs that provide climate change related ecosystem services.

4 Objective 3: Devising definitions and benchmarks for climate change pressures and complete sensitivity assessments for priority biotopes

4.1 Developing pressures and benchmarks

As noted in Section 2.1.2, five pressures were selected to undertake sensitivity assessments against. Through a sub-contract for the project, the MBA undertook a review of literature for these pressures, in order to propose a set of benchmarks based on best available evidence. These proposals were sent out for expert consultation to a range of academic and research institutions, and updates were made following this consultation. A multiple benchmark approach was agreed, with each pressure benchmark set at mean projected values for both middle and high greenhouse gas emission scenarios, and an additional extreme scenario for ocean warming and sea level rise. The full method for the development of benchmarks, including the outputs of the literature review, the expert consultation process, choice of emission scenarios, and full explanation of decisions made, are detailed in Garrard and Tyler-Walters (2020). The resultant benchmarks are summarised in Table 6.

Benchmarks were developed to be relevant at a UK-level, rather than just focusing on SoS waters since MarLIN is a UK-wide project, and any information published on the MarLIN website needs to be useful at a UK-level.

Table 6. Climate change pressures and their associated benchmarks developed following literature review and expert consultation.

Climate change pressures	**Benchmarks**		
	Middle emission scenario	**High emission scenario**	**Extreme emission scenario**
Ocean warming	3°C rise in SST, NBT (coastal & shelf seas) & surface air temp (in eulittoral & supralittoral habitats) by the end of this century 2081-2100	4°C rise in SST, NBT (coastal & shelf seas) & surface air temp (in eulittoral & supralittoral habitats) by the end of this century 2081-2100	5°C rise in SST and NBT (coastal to the shelf seas) **or** a 6°C rise in SAT (in eulittoral and supralittoral habitats) by the end of this century 2081-2100
	2°C rise in SAT in Scottish intertidal by the end of this century 2081-2100	3°C rise in SAT in Scottish intertidal by the end of this century 2081-2100	5°C rise in SAT in Scottish intertidal by the end of this century 2081-2100
	1°C rise in deep-sea habitats by the end of this century 2081-2100	1°C rise in deep-sea habitats by the end of this century 2081-2100	1°C rise in deep-sea habitats by the end of this century 2081-2100
Marine heatwaves	Occurring every 3 years, duration of 8 days, max intensity 2°C	Occurring every 2 years, duration of 120 days, max intensity 3.5°C	-
Ocean acidification	Further decrease in pH of 0.15 (annual mean) and corresponding 35% increase in H+ ions (extent of aragonite under-saturation unknown) by the end of this century 2081-2100	Further decrease in pH of 0.35 (annual mean) and corresponding 120% increase in H+ ions, with associated seasonal aragonite saturation by the end of this century 2081-2100	-
Sea level rise	50cm rise in average UK sea level by the end of this century (2081-2100)	70cm rise in average UK sea level by the end of this century (2081-2100)	107cm rise in average UK sea level by the end of this century (2081-2100)

4.2 Sensitivity assessments

Following the Marine Evidence-based Sensitivity Assessment (MarESA) method (Tyler-Walters 2018), a literature review was undertaken on the resistance (tolerance) and resilience (recovery rates) for the key functional, structural and characterising species of the biotopes identified through Objective 1. The resulting evidence base was used to assess and score resistance, resilience and hence, sensitivity, of each biotope to the climate change pressures at the different emission scenario benchmarks (see Garrard & Tyler-Walters 2020). As climate change pressures are by definition, 'ongoing', and unlikely to be reversed in any manageable timescale, the assessment of resilience was scored to reflect this, defaulting to a score of 'Very Low' (e.g. at least 25 years to recover), unless evidence for specific species suggested otherwise (e.g. potential for adaptation).

36 high priority biotopes were assessed against four climate change pressures for the MES and HES benchmarks, plus the extreme emission scenario benchmark for sea level rise and ocean warming. Biotopes were initially prioritised for features present in the two-case study MPAs, and additional biotopes were identified through consultation with the Statutory Nature Conservation Bodies (including JNCC). Full sensitivity assessments for each biotope, with the full supporting evidence base, associated references and confidence scores, are available on the MarLIN website[4].

A three-part confidence score was also assigned for each climate change sensitivity assessment. For more information on the sensitivity assessment method, including the confidence assessment, please refer to Tyler-Walters *et al.* (2018). The sensitivity assessments and associated evidence for the prioritised biotopes are published on the MarLIN website.

The sensitivity assessment outputs for the designated MPA features within Studland Bay and The Canyons MCZs are summarised in Table 7 and Table 9 below. These tables show the feature-level sensitivity scores for each climate change pressure at the HES benchmarks, alongside a short summary of the supporting evidence. The feature-level sensitivity scores are comprised of the most precautionary sensitivity score from the associated biotope sensitivity assessments. The associated biotopes, and the direct URLS for these sensitivity assessments, for the MPA features within Studland Bay and The Canyons MCZs are listed in Table 8 and Table 10.

It should be noted that there are likely to be other pressures related to climate change which may impact the protected features of Studland Bay and The Canyons MCZs. Some of these were not included within this initial piece of work due to difficulties in identifying inter-relationships between benchmarks or pressures. As such, the evidence presented here will not provide a complete picture.

[4] https://www.marlin.ac.uk/habitats/az.

Table 7. Summary sensitivity assessment outputs for Studland Bay MCZ, at the high emission scenario (HES) benchmark.

MPA protected feature	**Climate change pressure & sensitivity score**			
	Ocean warming (HES)	***Marine heatwaves (HES)***	***Ocean acidification (HES)***	***Sea level rise (HES)***
Intertidal coarse sediment	**Not sensitive** Few associated macrofauna.	**Medium** Few associated macrofauna.	**Medium** Few associated macrofauna.	**High** Habitat components may become eroded or submerged.
Subtidal sand	**Medium** Mean summer temperatures likely to increase beyond the current biogeographical limits of some species, for example *Arenicola marina* and *Bathyporeia* spp, may experience reduced reproduction. For others, such as *Hydrallmania falcata* and *Sertularia cupressina,* this could result in mortality.	**Low** Two of the associated species, *Arenicola marina* and *Bathyporeia* spp., are likely to have some population loss. However, due to the duration of a summer marine heatwave, this is unlikely to affect their overall population.	**Medium** Likely reduction in settlement and growth of some chitinous hydroid species, e.g. *Sertularia cupressina* and *Hydrallmania falcata,* but other species are not sensitive.	**Not sensitive** Limited effect on associated species due to depth range exceeding the assumed sea-level rise.
Seagrass beds	**Medium** UK species can withstand temperatures of up to and over 25°C and may be able to adapt to cope with a gradual rise in ocean temperatures.	**High** An increasing length of high summer temperatures is likely to cause early die-offs. It may also reduce population resilience through an inability to fully recover before further marine heatwaves occur.	**Not sensitive** Where there is sufficient light available, there will be a net beneficial impact for UK species due to increased photosynthesis, growth and sugar levels in response to increasing CO_2.	**Medium** Where landward environmental conditions are not suitable for migration of seagrass beds, declines will occur without recovery.

Table 8. List of the biotopes associated with MPA protected features in Studland Bay MCZ, with hyperlinks to their full sensitivity assessments on the MarLIN website.

MPA feature	Biotope & URL to sensitivity assessment
Intertidal coarse sediment	Barren littoral shingle
Subtidal sand	Infralittoral mobile clean sand with sparse fauna
	Sertularia cupressina and *Hydrallmania falcata* on tide-swept sublittoral sand with cobbles or pebbles
	Nephtys cirrosa and *Bathyporeia* spp. in infralittoral sand
	Arenicola marina in infralittoral fine sand or muddy sand
Seagrass beds	*Zostera marina/angustifolia* beds on lower shore or infralittoral clean or muddy sand

Table 9. Summary sensitivity assessment outputs for The Canyons MCZ, at the high emission scenario (HES) benchmark.

MPA protected feature	Climate change pressure & sensitivity score	
	Ocean warming (HES)	***Ocean acidification (HES)***
Deep-sea bed	**Medium** A number of associated organisms naturally occur within a range of temperatures. However, under increased temperatures, hydrozoans may experience inhibited metabolic function and impaired polyp production, whilst reproduction may be affected in sabellids.	**Medium** Some species naturally occur in areas with low aragonite saturation states and are tolerant to wide pH ranges, exhibiting physiological adaptations. However, hydrocorals may experience a reduction in calcification and hydrozoans may show inhibited metabolic function. Any coral rubble present is likely to be impacted by dissolution under a reduced aragonite saturation state, reducing the habitat provision.
Sea-pen and burrowing megafauna communities	**Not sensitive** The characterising sea-pen species naturally occurs within a range of bottom water temperatures.	**Not sensitive** The characterising sea-pen species naturally occurs in acidic waters and below the aragonite and calcite saturation horizon. Dissolution is unlikely; however, some stress responses and up-regulated genes may occur.
Cold-water coral reefs	**Not sensitive** The main reef-building coral species are naturally exposed to short-term and high-frequency temperature fluctuations. It also may show increases in growth rates under increased temperatures.	**High** The main reef-building coral species may experience a reduction in calcification rates, respiration and prey capture under ocean acidification. Furthermore, dissolution may occur leading to a weakening of the coral structure and loss of structural complexity.

Coral gardens	**Medium** A number of species associated with coral gardens naturally occur within a range of temperatures, with *Leiopathes glabberima* accustomed to natural short-term and high-frequency temperature variations. However, cup corals (*Caryophylliidae* spp.) may experience significant reductions in calcification rates under increased temperatures.	**Medium** The pH decrease would be outside the natural range of some species associated with coral gardens (e.g. *Leiopathes* spp and *Acanthogorgia armata*). Others naturally occur in areas with low pH and low aragonite saturation levels, with some exhibiting physiological adaptations. However, aragonite undersaturation may cause a reduction in calcification rates, respiration and prey capture for *Lophelia pertusa.* Evidence of dissolution and weakening of the coral structure is also expected for both *Lophelia pertusa* and *Madrepora oculata*.

Table 10. List of the biotopes associated with MPA protected features in The Canyons MCZ, with hyperlinks to their full sensitivity assessments on the MarLIN website.

MPA feature	Biotope & URL to sensitivity assessment
Deep-sea bed	Atlantic mid-bathyal mud*
	Cerianthid anemones and burrowing megafauna in Atlantic mid bathyal mud
	Leptometra celtica assemblage on Atlantic upper bathyal coarse sediment
	Squat lobster assemblage on Atlantic upper bathyal rock and other hard substrata
	Burrowing ophiuroid communities on Atlantic upper bathyal sand**
Sea-pen and burrowing megafauna communities	*Kophobelemnon* fields on Atlantic upper bathyal mud
	Kophobelemnon fields on Atlantic mid bathyal mud
Cold-water coral reefs	Atlantic upper bathyal live *Lophelia pertusa* reef (biogenic structure)
Coral gardens	Mixed coral assemblage on Atlantic mid bathyal *Lophelia pertusa* reef framework (biogenic structure)
	Mixed coral assemblage on Atlantic upper bathyal *Lophelia pertusa* reef framework (biogenic structure)
	Discrete *Lophelia pertusa* colonies on Atlantic upper bathyal rock and other hard substrata
	Discrete *Lophelia pertusa* colonies on Atlantic mid bathyal rock and other hard substrata

* Sensitivity assessments were not possible for this biotope due to the lack of species level information for the biotope.
** Sensitivity assessments were not undertaken for this biotope due to limited evidence availability.

4.3 Sensitivity maps

To display the sensitivity assessment scores in a more visual way, sensitivity maps were created for the two-case study MPAs. Maps were created for each climate change pressure, displaying the HES benchmark sensitivity scores.

Using ESRI ArcMap 10.1 software, sensitivity scores were assigned to MPA habitat maps and coloured accordingly. Habitats were mainly mapped as MPA features, and therefore the most precautionary (highest) sensitivity score of each feature's component biotopes was applied as the overall MPA feature sensitivity score. Although alternative approaches could be taken, such as mapping the mean or modal sensitivity value based on the component biotopes, this could result in the most 'at risk' (e.g. high sensitivity) biotopes being de-valued. Therefore, a more precautionary approach was taken. However, for The Canyons MCZ, the 'deep-sea bed' feature was comprised of multiple mapped biotopes, and therefore biotope sensitivity scores were assigned for this feature to show any distinguishing areas of higher or lower sensitivity.

When assigning sensitivity scores to the habitat map polygons, the value was mapped across the entire area in which the MPA feature or biotope occurred. In instances where multiple features or biotopes were recorded in a single location (i.e. mosaic habitats), data were aggregated together using automated processes in Python 3.6, to identify the most sensitive habitat within the mosaic, which was then displayed. This did create some differences in which habitat was mapped for each climate pressure assessment for The Canyons MCZ.

Following the development of these maps, it was decided that the illustration of information was not an effective method of communication for MPA sensitivity to climate change, since sensitivity to different pressures could not be shown in one map. As such, summary tables were developed instead, as detailed in Section 5.

Sensitivity maps for Studland Bay MCZ showing MPA feature sensitivity to climate change pressures are shown in Figure 2. Sensitivity maps for The Canyons MCZ, showing feature sensitivity to climate change pressures are shown in Figure 3 and Figure 4.

5 MPA climate profiles

Climate profiles were created for the two-case study MPAs; Studland Bay MCZ and The Canyons MCZ, as examples of how information on MPAs and climate change could be communicated at a site level. The climate profiles provided summary information about the MPA, information on its provision of climate change related ecosystem services as a result of literature assessment (section 3.1.1); the potential response of these features to climate change as a result of sensitivity assessments (section 4.2); and conclusions from this evidence and knowledge gaps to be addressed by further research. The sensitivity assessment section summarised the sensitivity scores (based on the high emissions scenario benchmark) for each protected feature in each site and was represented in a summary table to highlight each sensitivity and confidence score.

Studland Bay MCZ is an inshore site protecting intertidal coarse sediment, subtidal sand, seagrass beds and long-snouted seahorse. The Canyons MCZ is an offshore MPA protecting deep-sea bed, coral gardens, cold-water coral and sea-pen and burrowing megafauna. Only protected features identified as playing a role in providing climate related ecosystem services were included in the profiles and therefore the protected feature long-snouted seahorse (*Hippocampus guttulatus*) was not included in the Studland Bay MCZ climate profile.

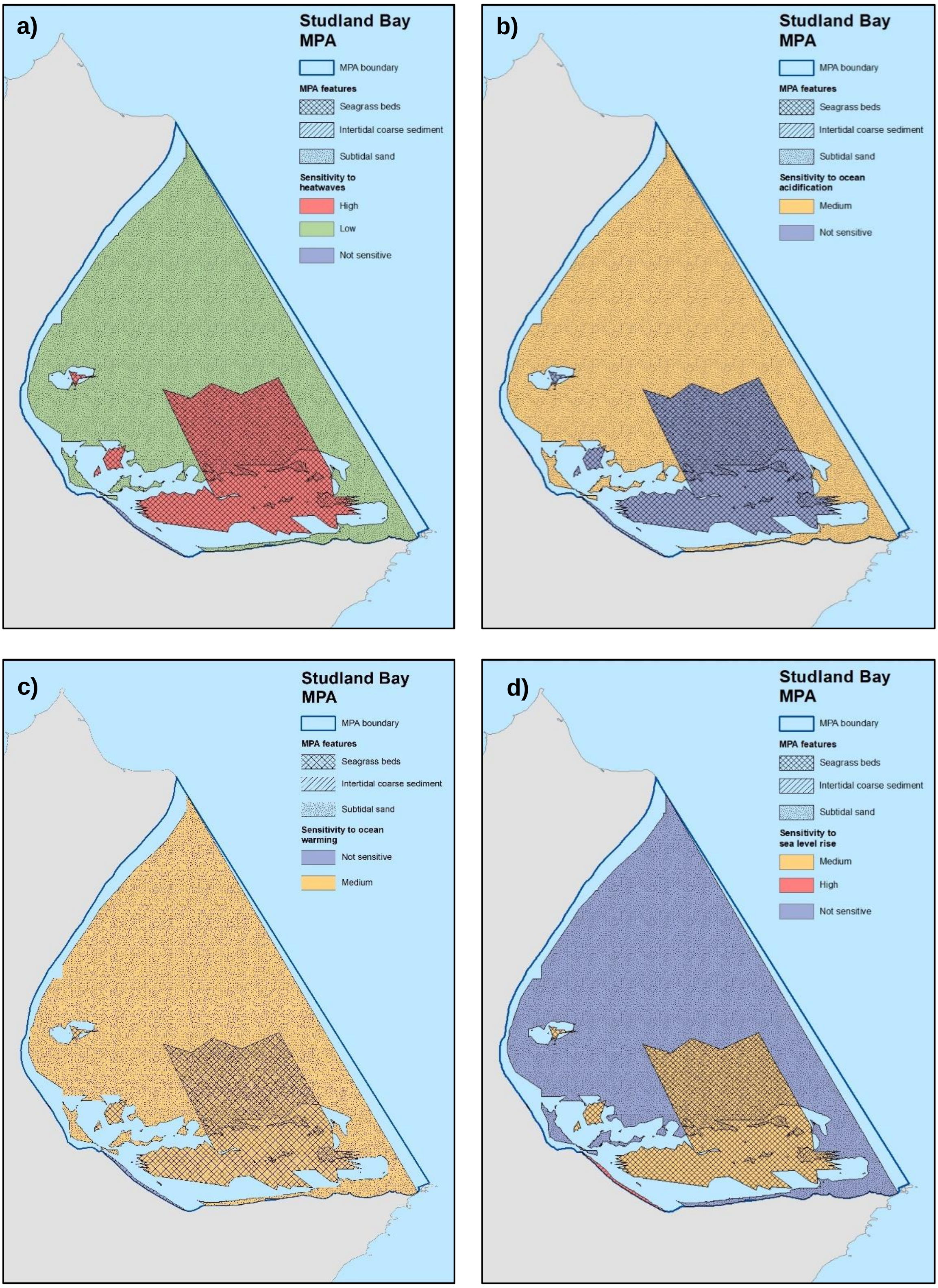

Figure 2 Studland Bay MCZ – sensitivity to a) heatwaves, b) ocean acidification, c) ocean warming and d) sea level rise.

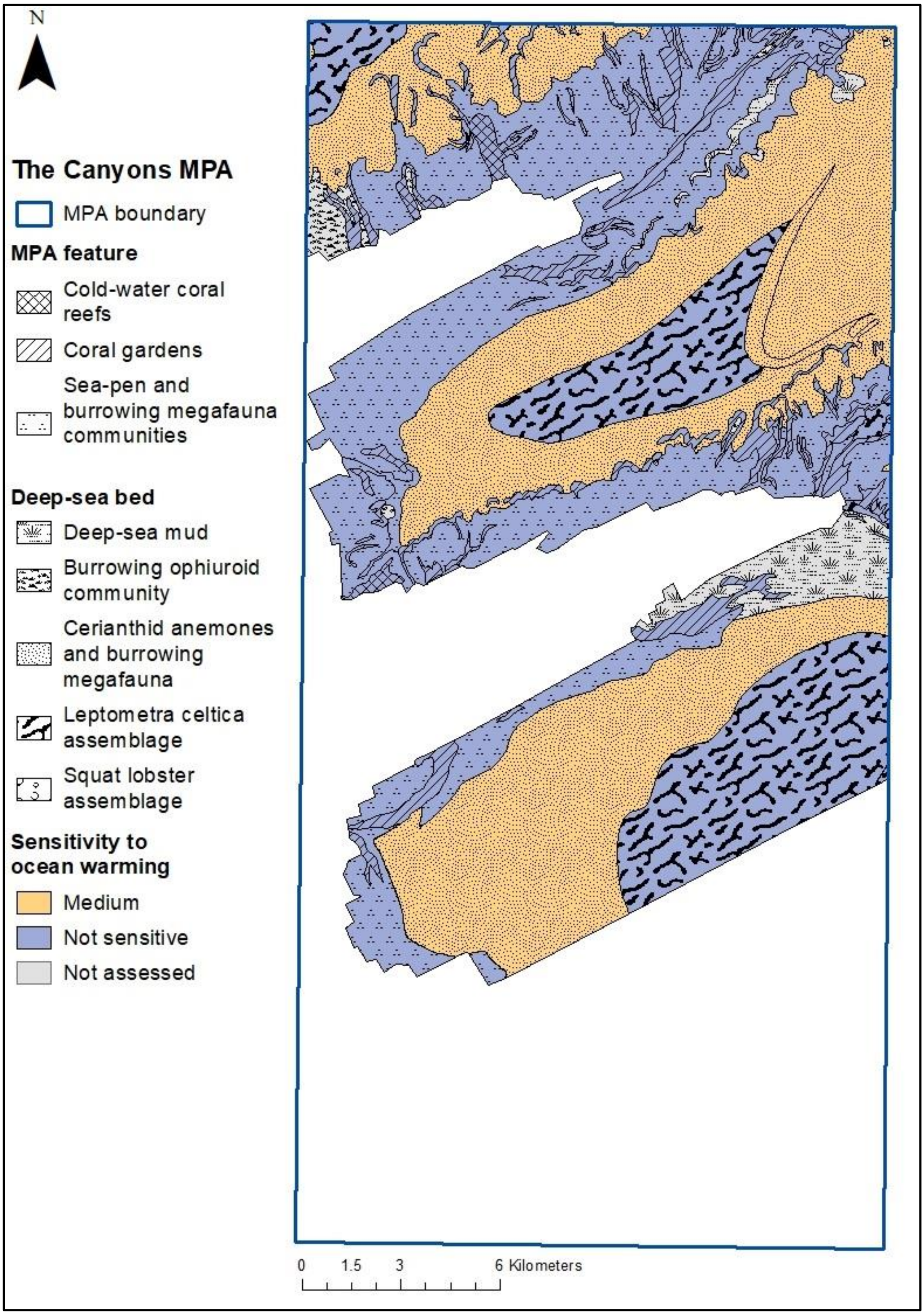

Figure 3 The Canyons MCZ - sensitivity to ocean warming.

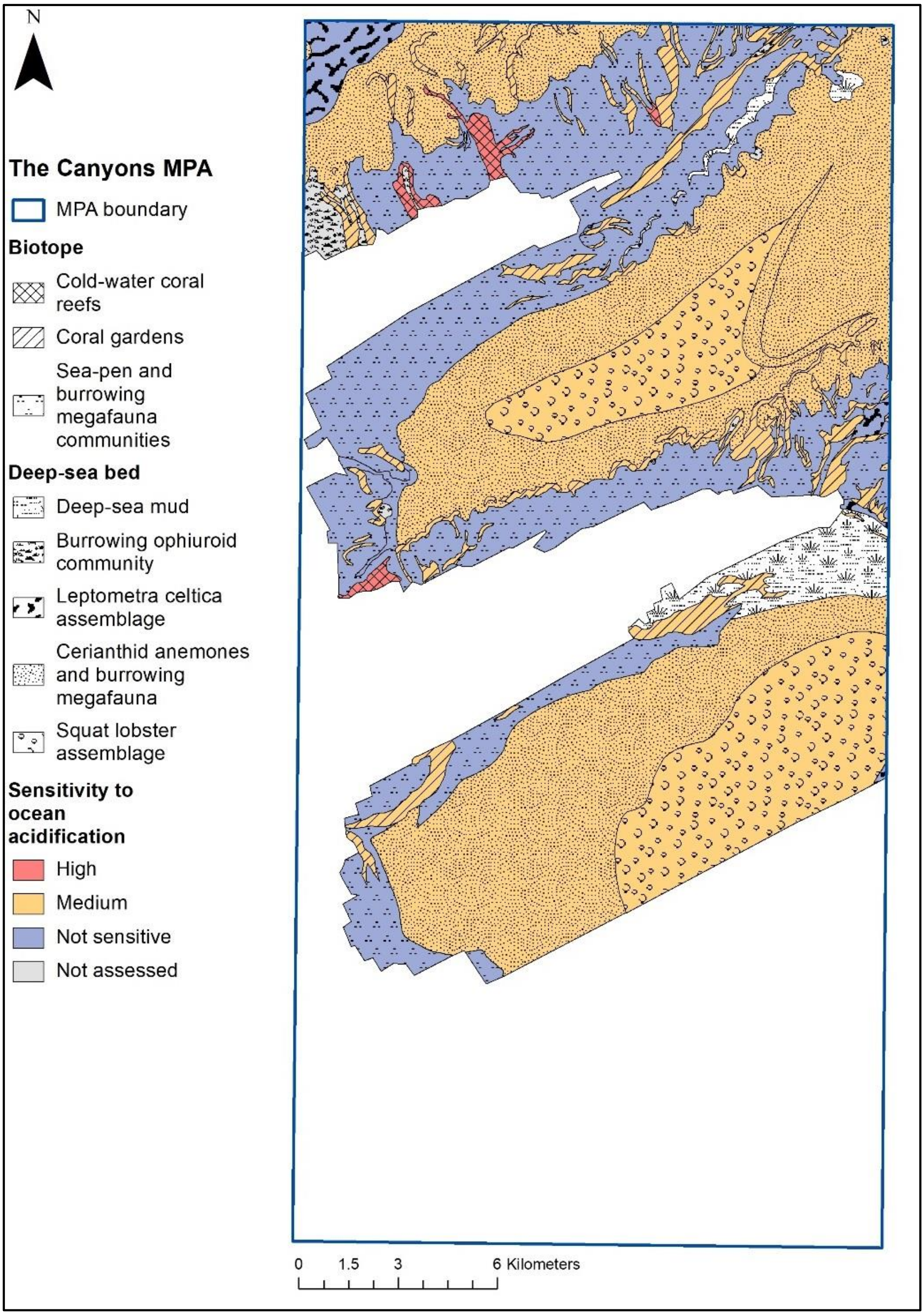

Figure 4 The Canyons MCZ - sensitivity to ocean acidification.

6 Discussion

6.1 Understanding the role of MPA protected features in climate mitigation and adaptation

This project has provided a first analysis of the contribution of the MPA network in Secretary of State waters to climate related ecosystem services, providing some initial statistics on the number of MPAs that contribute to climate change resilience. The project has identified that a considerable proportion of MPAs in Secretary of State waters have a role to play in climate mitigation and adaptation and provide climate related ecosystem services. The project has developed a methodology for undertaking climate related sensitivity assessments and has provides these for 36 high priority biotopes. Using two case study MPAs, it has trialled an approach for developing and presenting site specific information on climate mitigation and adaption.

However, it should be noted that multiple features in the MPA network in Secretary of State waters assessed as part of the project were not included in the final statistics due to low confidence in their service provision or low scale of contribution (see section 3.2). This suggests that further research is required to understand climate service provision and UK MPA features; preferably in a quantifiable way (e.g. using carbon stock calculations and assessments).

The scale of contribution to climate related services from UK MPA features will likely be dependent on the specific location, extent and communities making up the features. For example, both cold-water coral reefs and coral gardens (protected features of The Canyons MCZ) could contribute towards carbon sequestration through trapping sediment and formation of carbonate-rich deposits. Some evidence suggests that slow growth rates of cold-water corals can result in a small amount of annual carbon sequestration, but over geological time scales (Burrows *et al*. 2014). Conversely, other evidence suggests that the calcium carbonate production of cold-water corals and other biogenic reefs is a source of atmospheric CO_2 (Macreadie *et al.* 2017). As mentioned above, the balance between net carbon sequestration and production may vary in different localities, over different timescales and may depend upon the communities present. Therefore, it is currently unknown whether cold-water coral reefs and coral gardens in The Canyons MCZ provide this service, and as such, cold-water corals were not included within the MPA network statistics. However, this assessment was undertaken at a feature-level and therefore to gain a better understanding of MPA service provision, a site-specific approach could improve this work in the future.

Similarly, it has been reported that carbon sequestration by seagrass beds, such as those protected in Studland Bay MCZ, may depend on their specific properties and location (Mazarrasa *et al*. 2015). Sequestration capacity is also likely to be underestimated, as some of this captured carbon ends up in deep-sea sediments (Duarte & Krause-Jensen 2017). There is also limited research into sedimentary habitats and their contribution to carbon sequestration (Burrows *et al.* 2014) and physical properties relating to coastal protection such as wave attenuation (Tillin *et al.* 2019). This is also dependent on specific topographic features and community composition and may depend on distance from the coastline. Future work would be useful to focus on some of the other variables that determine service provision within sedimentary habitats.

6.2 Understanding climate change pressures and MPA feature sensitivities to these pressures

There is a range of evidence available on the effects of climate change pressures on marine habitats and species. This project was able to assess the sensitivity of all prioritised biotopes against each of the MES and HES benchmarks for the four pressures selected. Specific studies in the field or laboratory were used to inform the assessments where possible, however in many cases more general understanding of species ecology was used. For example, for the ocean warming pressure, assessments were commonly based on understanding of characterising species' distributions, thermal tolerances and adaptation potential. Evidence for specific species was not always available, and in these cases proxy species information was used. For example, for the biotope '*Nephtys cirrosa* and *Bathyporeia* spp. in infralittoral sand', information on the impact of ocean acidification on *Nephtys cirrosa* and *Bathyporeia* spp. was lacking, and therefore evidence on the effects on non-calcifying polychaetes and amphipods was used as a proxy (Tillin & Garrard 2019). In general, less evidence was available for deep-sea species for The Canyons MCZ biotopes than littoral and sublittoral species present in Studland Bay MCZ.

Sensitivity assessments were based on best-available evidence at the time of publication for a limited number of pressures. However, the MPA features may have higher sensitivity to other climate change related pressures. For example, storms and waves are likely to significantly affect seagrass beds, but there is currently no consensus on projected future storm frequency and wave energy levels associated with climate change and therefore, it was not possible to develop a benchmark for this pressure.

It is also recognised that new data to support understanding of MPA feature sensitivity will become available in time, including sensitivity evidence and biological data on the specific biotopes present within the MPA. It is therefore recommended that biotope sensitivity assessments should be undertaken for any newly identified biotopes in the MPA, and sensitivity assessments should be kept up to date with new literature over time. Precautionary feature-level sensitivity scores should then be updated with this new information to ensure the most accurate picture is provided.

7 Conclusions

This project has developed an up to date review of the MPA network in Secretary of State waters in the context of climate change, examining the climate change related ecosystem services provided by protected features, undertaking sensitivity assessments of UK MPA features to climate change related pressures, and exploring how to present this information in a public-facing manner. MPAs play an important role in climate mitigation and adaptation. The results of this work found that between 85-95% of MPA features on each list had some level of risk to climate pressures, with the majority of the receptors correlating to more than one MPA feature type. Although they are not able to solve climate change, nor are they immune to the potential impacts associated with it, with effective management they could provide nature-based solutions that can help build ecosystem resilience and mitigate associated impacts. A case could therefore be made to consider such factors in the wider context of MPA management.

UK marine habitats such as seagrass beds, saltmarsh and sandbanks, provide both coastal protection and carbon sequestration services. The MPA network is therefore important to enable protection of these associated services. However, these features, via their associated species communities, are often sensitive to pressures associated with climate change, which may result in a reduction in capacity to provide these services. For example, seagrass beds are likely to be highly sensitive to marine heatwaves at the high emission scenario benchmark (D'Avack *et al.* 2019), with diebacks likely to reduce their ability to provide coastal protection and carbon sequestration. It is therefore vital to understand how and why MPA features are sensitive to climate change pressures, and thus what type of management would be best suited to protect these habitats from impacts if/where possible.

Cumulative effects of pressures from climate change and anthropogenic activities may also act to impact MPA features. As well as climate change pressures, seagrass beds are subject to pressures from activities such as fishing, aquaculture and recreational boating (Unsworth *et al.* 2015). This can result in reduced recruitment, fragmented habitats or loss of habitat altogether and the seagrass ecosystems are then less resilient to impacts of climate change as they have reduced capacity to adapt or withstand them. Continued regulation of potentially damaging activities in the marine environment is therefore important, which can in turn support the resilience of ecosystems to the impacts associated with climate change.

Managing protected sites in the context of climate change is complex, however, flexibility in line with ecological needs and changes will be important. Furthermore, taking steps to address gaps in understanding the role that habitats and species in the marine environment play in climate related ecosystems, and their sensitivity to climate change pressures, will help inform climate smart decision making in the future.

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