Key challenges and emerging issues from the UK Marine Climate Change Impacts Partnership (MCCIP) community

Buckley, P.[1], Harrod, O[1], Howes, E.L.[2], Matear, L.[3], Robinson, K.[4], Stoker, B.[3], and Turrell, W.[5]

[1] MCCIP Secretariat, Cefas, Pakefield Road, Lowestoft, Suffolk, NR33 OHT
[2] Natural History Museum, Cromwell Road, London, SW7 5BD
[3] Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough, PE1 1JY
[4] Natural Resources Wales, Maes y Ffynnon, Penrhosgarnedd, Bangor, Gwynedd, LL57 2DW
[5] Marine Scotland Science, Marine Laboratory, 375 Victoria Rd, Aberdeen AB11

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Abstract

Identifying key challenges and emerging issues was a major part of MCCIP's 2020 marine climate change impacts report card. With contributions from over 150 leading researchers across 50 organisations, the report card provides a unique, quality assured overview of the evidence base in the UK. In the first instance, the 108 key challenges and emerging issues identified across the 26 topics reviews in the 2020 report card are summarised and collated in one, easily accessible space, for use by the UK marine climate change community. These issues are drawn together as a set of challenge area narratives, responses to which were explored with representatives from across the UK marine climate change community. Finally, a set of guiding principles are presented, supported by best practice examples, to act as a 'blueprint' for community action.

Keywords: Marine climate change; impacts; key challenges; emerging issues; community response

1. Overview

Since 2005, the Marine Climate Change Impacts Partnership (MCCIP) has worked with over 300 leading researchers to summarise the evidence for climate change impacts on UK coasts and seas. As a trusted, independent source of authoritative evidence, MCCIP is uniquely placed to provide an overview of the key challenges and emerging issues facing the UK marine climate change community, and support the UK marine science strategy, and requirements under the Climate Change Act.

Supporting delivery of the UK Marine Science Strategy and Climate Change Act

The UK Marine Strategy (2010-2025) provides a domestic framework for achieving good environmental status (GES) and delivering UK marine policy to promote clean, health, safe, productive and biologically diverse seas. It sets the general direction of travel for future marine science across the UK for the period 2010 to 2025, by identifying high-level priority areas for marine science; and by tackling cross-cutting barriers, to help deliver the science. Recent updates to the Strategy, notably Part 2 on UK monitoring programmes, serve to emphasise the need for collaboration, including internationally through the OSPAR Convention for the Protection of the of the Marine Environment of the North East Atlantic (OSPAR).

The UK Marine Strategy is overseen by the Marine Science Co-ordination Committee (MSCC), a cross-government committee that aims to coordinate scientific knowledge, resources and communications to support marine policy decisions. The MSCC roadmap has identified a number of priority areas, including a "better understanding of the impacts of climate change, including its multiple stressors and feedbacks, and the ocean's resistance and resilience to a changing climate". The MSCC's ocean in a changing climate statement expands on the climate change theme. It summarises key facts from the 2020 MCCIP report card and highlights the role that marine science and technology needs to play in building our understanding of marine climate change impacts and providing solutions. MCCIP leads on climate change for the MSCC, as well as contributing to the International and communication sub-groups. At a devolved

level, key documents including the Welsh marine evidence strategy and Climate ready Scotland: Second Scottish Adaptation Programme 2019-2024 have identified understanding the effects of climate change as a key challenge for the management of coasts and seas, with MCCIP highlighted as the principal evidence provider.

The UK Climate Change Act (2008) includes requirements to publish a UK climate change risk assessment (CCRA) every five years and identify responses through UK and devolved adaptation programmes. The challenges identified in the CCRA include the coastal and marine environment, with much of the evidence drawn from MCCIP topic review papers for both observed and future change. For future change, the MCCIP papers draw heavily on the marine outputs from the UK Climate Projections (UKCP), which themselves play a key role in underpinning the CCRA.

The formal 'response' to issues raised in the CCRA, the National Adaptation Programme (NAP) for England and Wales and Scotland's climate change adaptation programme include marine and coastal challenges that need to be addressed; and highlight the role MCCIP plays in collating and communicating the best available UK marine and coastal climate evidence to support action. This includes support for the adaptation reporting power (ARP), a further requirement of the UK Climate Change Act through which organisations report on the climate challenges they face, and how they are responding. Reporting organisations include public bodies with a marine remit (e.g. Marine Management Organisation, EA, Natural England and the Maritime and Coastguard Agency), critical infrastructure providers, including at the coast or in the sea (e.g. Harbours, Energy generators, road and rail, lighthouses), trade associations (e.g. Seafish) and the preservation of the historic environment (e.g. Historic England).

As MCCIP plays a key role in all these UK and Devolved initiatives, including the overall strategy for UK marine science, and the legal framework for reporting on, and responding to, climate change risks, this overview should provide a fair reflection of the key challenges and emerging issues facing the UK marine climate change community, and the responses required.

2. Approach

Aims

The principal aims of this MCCIP key challenges and emerging issues project are to:

1. Present a community view on key challenges and emerging issues based on the 26 topic review papers from the 2020 report card.
2. Engage widely across the MCCIP stakeholder community to update and validate the key challenge narratives and identify actions.
3. Develop a set of guiding principles for addressing the key challenges identified, illustrated through best practice examples.

The outputs generated will be of interest to all MCCIP stakeholders, including those engaged in commissioning, planning, and delivering marine and coastal climate change science programmes and national assessments (e.g. the UK CCRA).

Methods

In the 2020 MCCIP report card topic review papers, there is a section dedicated to key challenges and emerging issues. Authors for the 26 topic review papers were asked to identify, and provide detailed justification for, the top 3 key challenges and emerging issues for their topic.

Following publication of the 2020 MCCIP report card an MCCIP Working Group (WG) was established, comprising representatives from UK and Devolved Administrations (DA) research and policy communities, to review the 108 key challenges and emerging issues presented across the 26 topic papers, highlight common themes and identify potential responses.

Three 'challenge areas' were identified, representing a continuum from the 1) underlying evidence, 2) understanding pressures and impacts and 3) supporting decision making. All 108 key challenges and emerging issues were assigned to one of these challenge areas, based on their 'best fit'.

Stakeholder workshops, one for each challenge area, were convened to update and validate the challenge area 'narratives' and identify response options and priority actions. Around 20-30 stakeholders, representing both evidence providers and users from across the UK attended each workshop.

Interactive software was used to elicit individual response 'options' to the challenge areas presented. The long-lists produced were grouped, and priority areas explored further in breakout groups (i.e. what needs to happen, by who, how, and when). Evidence providers and users were 'mixed' together to ensure perspectives from both groups were captured.

The updated challenge area narratives and workshop outputs were used to develop a set of MCCIP guiding principles on how best to collectively address these issues, illustrated with case study examples.

The approach is summarised in figure 1.

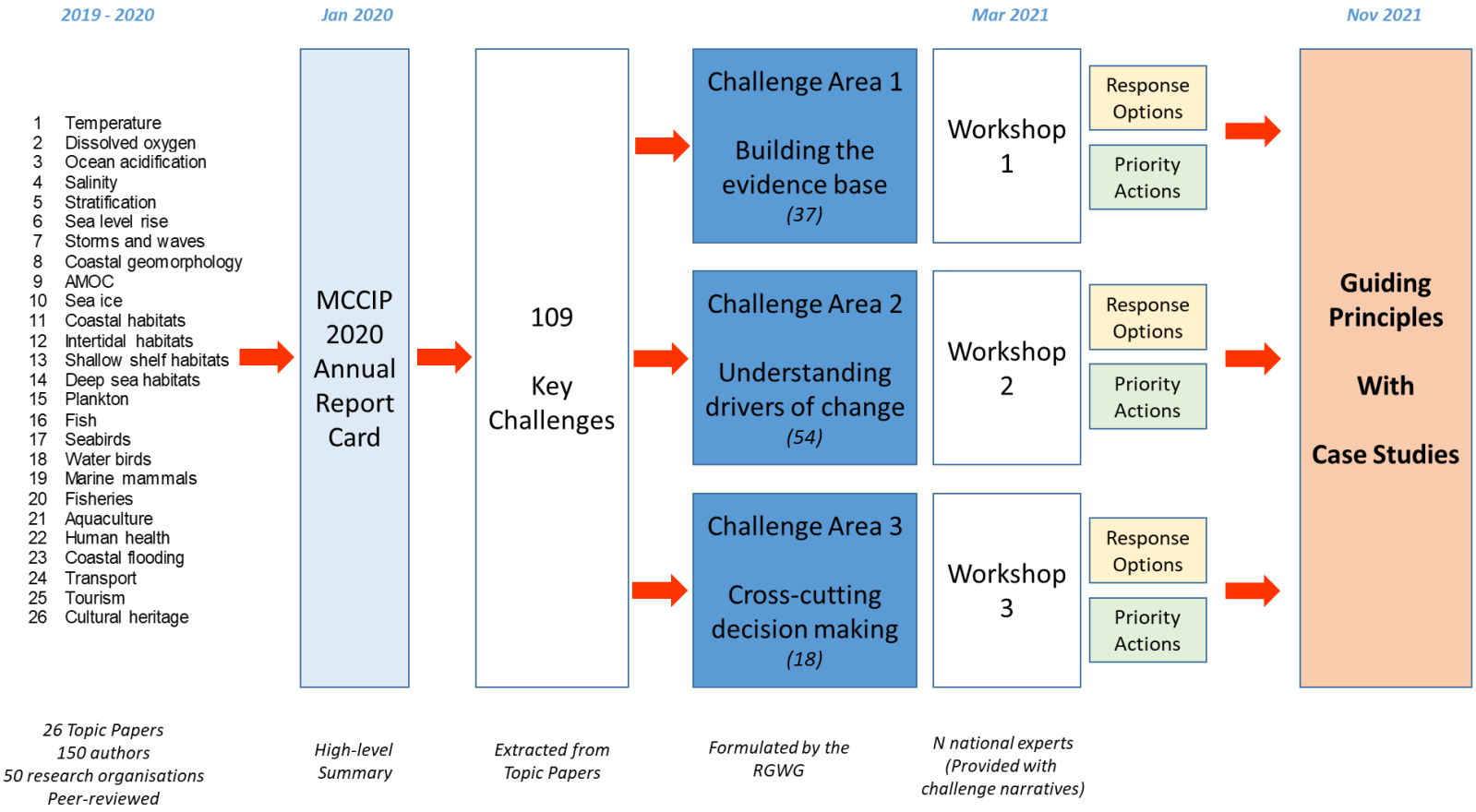

Figure 1. Schematic of the MCCIP research gaps process.

3. Results

The UK Consensus on key challenges and emerging Issues

In total, 108 key challenges and emerging issues were identified from across the 26 MCCIP 2020 report card review papers. These are presented here according to the themes used for the 2020 report card:

Climate of the Marine Environment: 36 challenges and emerging issues across 10 topic areas (Temperature; Salinity; Dissolved oxygen; Acidification; Stratification; Sea ice; Sea level rise; Storms and waves; Geomorphology; Atlantic Meridional Overturning Circulation (AMOC).

Impacts on Healthy and Biologically Diverse Marine Ecosystems: 44 challenges and emerging issues across 10 topic areas (Intertidal habitats; Coastal habitats; Shallow and shelf habitats; Deep-sea habitats; Plankton; Fish; Waterbirds; Seabirds; Marine mammals.

Impacts on Society: 29 challenges and emerging issues across 7 topic areas (Coastal flooding; Cultural heritage; Human health; Transport and infrastructure; Tourism and recreation; Aquaculture; Fisheries).

On the website, a link is provided under each topic to the relevant peer-reviewed backing paper, containing a much more detailed description of the key challenges and emerging issues listed.

3.1 Climate of the Marine Environment

Temperature	Conduct **further research** on the **near-shore experience of marine heat wave conditions**, and how these events could affect industry, society and ecosystems
	Improve understanding of the **ocean scale influence** on shelf-sea temperatures, including the causes and effects of change in the North Atlantic subpolar gyre
	Produce more accurate Sea Surface Temperature predictions (monthly-seasonal; sub-decadal) and near future **decadal and multi-decadal projections**
Salinity	**Develop key metrics describing salinity change for use in assessments**, supported by analysis (e.g. ODaT) and reanalysis (e.g. Copernicus) tools
	Build knowledge on the ocean-shelf exchange processes that drive multi-annual variability and long-term trends in the shelf seas
	Utilise more data from **sustained observations to identify multi-decadal salinity changes**
Dissolved Oxygen	**Identify when and where dissolved oxygen changes are being affected by human stressors** (e.g. ocean warming or nutrient enrichment) rather than just natural variability
	Establish long-term datasets (outside the North Sea) to record the occurrence, frequency and spatial extent of oxygen deficiency in UK coastal and shelf waters
	Improve the resolution of dissolved oxygen data to provide more confidence in testing coastal and shelf sea models
	Reduce model uncertainty in the individual and coupled processes that control dissolved oxygen dynamics (especially coastal and shelf sediments)
	Establish long-term time–series data to test coupled physical-ecosystem models, and variability in functioning between sites with different conditions
Acidification	**Develop accurate and stable autonomous observing technologies for pH and related variables**, deploying them in difficult-to-sample regions, and linking and analysing their measurements effectively with other data streams
	Improve the spatial and temporal resolution of models, along with their descriptions of bio-geochemical processes, to capture the relatively small-scale controls on the marine carbonate system in complex coastal and shelf sea environments
	Sustain time–series observations of the marine carbonate system at key point sites and transects, and improve high resolution monitoring of the near-coast marine environment
Stratification	**Increase coastal observing data** to assess stratification trends
	Address model limitations in simulating shelf edge processes and salinity
	Address model limitations in simulating river inflows and intermittent thermal stratification near the coast
	Conduct **more research into the key role stratification strength and duration plays in bottom water dissolved oxygen concentration**
	Address the fact that shelf sea biology and physics are very sensitive to water mixing across the pycnocline, but this **mixing is poorly resolved in models**

	Explore the role of rainfall and horizontal changes in salinity across the shelf sea in triggering spring stratification (and implications for model predictions of stratification)
	Improve modelling of regional changes in rainfall and winds over this century, and their impacts on stratification
Sea Ice	**Assess risks associated with Arctic Shipping** (e.g. increased radiative forcing from non CO_2 sources; contaminant spills; waves / floes / icing spray damage to ships)
	Assess climate change impacts on coastal erosion and permafrost decay (e.g. increased erosion releasing organic carbon to nearshore environments and rapid permafrost thawing affecting the discharge of carbon)
	Identify potential impacts from changes in sea ice and the ocean on Arctic marine ecosystem services (e.g. fisheries / industries / beneficial use for indigenous people)
Sea Level Rise	**Quantify and constrain high-end scenarios through a better understanding of dynamic ice processes** (and their controlling factors)
	Translate updated sea-level science into resilience planning (e.g. to ensure Shoreline Management Plans are realistic and sustainable in economic, social and environmental terms)
	Understand how the storm track (position, strength) and storm surges will change in the future, with coupling CMIP6 models to storm surge and wave models as a priority
Storms and Waves	**Improve the simulation of storms in climate models**
	Improve understanding of the role climate feedbacks play in **Arctic sea-ice retreat and consequences for storms and wave height**
	Improve understanding of how North Atlantic storms and blocks respond to external forcing
Geomorphology	Enhance monitoring and modelling of extreme storm response and recovery to **identify tipping points** (e.g. at wave dominated barrier coasts)
	Develop understanding of bio-physical interactions for model input, to include, for example extracellular polymeric substances (EPS) and vegetation effects on hydrological and sediment dynamics
	Develop models that predict long-term and large-scale **coastal system response to sea-level rise** (and that include management measures)
AMOC (Atlantic Meridional Overturning Circulation)	Resolve model bias issues to **improve decadal projections and identify the transition from multi-decadal variability to long term decline**
	Improve understanding of how individual processes (e.g. wind driven circulation, deep water formation) and the links between them affect **Atlantic gyres, and the potential effects of climate change**
	Determine whether the ongoing AMOC decline is part of a multidecadal cycle or part of a long-term decline due to climate change. Crucial to understanding this issue is **sustaining the direct observations of the AMOC**

3.2 Healthy and biologically diverse marine ecosystems

Coastal Habitats	Develop a multidisciplinary **catchment-to-coast approach** to understand the role of climate change in **transferring carbon from land to sea**
	Account for coastal habitats in national greenhouse gas inventories, and adopt a true multidisciplinary catchment-to-coast approach to determine their relative importance within the global carbon cycle
	Create more natural shorelines to help restore the natural function of coastal processes and increase resilience, and **promote cultural acceptance of the dynamic nature of these habitats**
	Conduct more **research on the potential social impacts of climate change on the UK coast**, which are wide ranging and include health, well-being and livelihoods
	Enhance collaboration between environmental economists and coastal and marine scientists to provide **robust natural capital valuations** for coastal habitats
	Integrate **nature-based approaches into coastal management** so ecosystems can self-regulate in response to climate change
Intertidal Habitats	**Improve detection of climate driven changes** to **soft sediment benthic biodiversity** by expanding monitoring sites
	Sustain time-series that are tracking climate-driven changes in intertidal biodiversity
	Provide more reliable information and scientific data to **support implementation of marine biodiversity legislation**
Shallow and Shelf Habitats	**Improve predictions of extreme events**, and the disproportionate effects they have on species range / abundance / local extinctions, to support cross-cutting decision making
	Identify potential impacts from changes in 'engineering' taxa on ecosystems and the goods and services they provide
	Establish baseline data for species and habitats to separate effects from different stressors
	Improve monitoring to better characterise year to year population variability
	Take difficult cross sectoral decisions to manage seas and **increase resilience to multiple stressors**
Deep Sea Habitats	Build knowledge of the **physical environment influencing UK deep-sea communities, including hydrography and Particulate Organic Carbon (POC) flux**, as well as collecting time-series data on community change
	Build knowledge of **deep-sea biological communities and ecosystem functioning,** which is still lacking for large areas of the UK deep-sea, including pelagic
	Develop more **regional**, rather than ocean-scale, **predictions to understand how UK deep-sea habitats will respond to future climate change.** Models must consider impacts of multiple stressors on both benthic and pelagic habitats
Plankton	Identify **vulnerable and resilient species and habitats**, and separate climate impacts from other human stressors (e.g. nutrients)
	Better **understand mechanistic links between climate warming, plankton and fisheries** (and other higher trophic levels such as seabirds) to develop a predictive capacity
	Better understand **risks and potential opportunities from new species colonisations**, including new pathogens and Harmful Algal Blooms

	Better understand the **rate of genetic adaptation to climate change impacts**
	Better understand the **risks caused by warming temperatures and acidification on native marine organisms**
	Better **understand the processes involved in the plankton drawdown of atmospheric CO_2 (biological pump**) and implications of climate change regarding its role in sequestering and storing carbon
Fish	Assess the **vulnerability of fisheries to changing storminess** to inform adaptation action
	Develop more **robust projections of climate change impacts on productivity and distribution at a species level**, through better integration of data on life trait characteristics
	Identify **climate sensitive life cycle 'bottlenecks'** (e.g. shallow nursery areas) to reduce pressure on struggling stocks
	Distinguish the contribution of climate drivers to changes in fish distribution, productivity and size **from other drivers**
	Better parameterise models through more validation and empirical studies, including habitat dependency, physiology and population dynamics
Waterbirds	Consider the potential role of climate related **disruptions in Arctic predator-prey dynamics**, such as lemming cycles, in reducing breeding success for species wintering in the UK
	Expand existing monitoring efforts to address current knowledge gaps on temperate non-breeding abundance, productivity and survival
	Better understand **potential relationships between anthropogenic pressures** and assess their likely interactions with future climate change
	Enhance demographic and environmental monitoring for input to population models that **identify drivers of waterbird populations and distributions**
	Address the challenge of monitoring non-breeding seasons, as distributions shift north and east of areas currently well-covered by volunteer-based schemes in Europe
Seabirds	**Consider how landing obligations** to halt the discard of fish from vessels will remove an important food source for seabird species, **compounding climate change impacts**
	T**est whether climate change (e.g. temperature, extreme weather) can cause selection and rapid 'evolutionary rescue',** enabling seabird populations to adapt to climate change
	Explore **interactions between climate change and anthropogenic drivers** affecting seabirds, such as fisheries, pollutants, disease and marine renewables
	Increase data collection on the **effects of climate change on principal prey species** of seabirds
	Understand **cumulative impacts of climate change and environmental pollution** on seabirds (e.g. legacy and emerging contaminants and plastics)
	Understand how policy driven **expansions in marine renewables may impact seabirds through collision and displacement**
Marine Mammals	Establish **long term monitoring** of distribution and abundance change for cetacean species to assess climate change impacts
	Distinguish climate effects from other drivers in recent observed changes in seal populations
	Quantify the synergistic effects between climate change and other human stressors on cetacean range shifts

	Understand how **direct impacts on lower trophic levels** affect top predators **through improved links to upper trophic levels** in ecosystem models

3.3 Impacts on society

Coastal Flooding	**Identify barriers to 'managed realignment' and 'no active intervention'** in Shoreline Management Plans (e.g. for historic landfill sites at the coast that have to be protected)
	Identify how to plan our future shoreline on the open coast and along estuaries and **deliver practical portfolios of adaptation options for our future shoreline** that are technically feasible, balance costs and benefits, can attract appropriate finance, and are socially acceptable
	Calculate annual coastal damages and event losses to inform national threat level
	Identify trends, and consequent impacts, from past storm events, and determine likely **impacts from future changes** in wave and surge climate
Cultural Heritage	**Gain 'acceptance' of managing loss of heritage assets** due to climate change, and the need for more robust systems of valuing and prioritising assets for action
	Develop long-term datasets to identify climate change impacts on cultural heritage assets (e.g. ocean acidification on ship decay; erosion rates)
	Quantify the impact of multiple climate threats (storms, surge, flooding, wind driven rain) which cumulatively cause major damage to cultural heritage assets
Human Health	**Improve regional salinity and temperature data** to help support modelling of the **location and timing of risks to human health** from marine pathogens
	Development of Harmful Algal Bloom models, for both short term (one to two week) forecasts and under future climate scenarios, to inform industry responses
	Improve understanding of how climatic factors affect the **fate and behaviour of Norovirus in the marine environment,** to facilitate the development of predictive models for human health protection
	Determine the potential **role of climate change in recent discoveries of the potent neurotoxin Tetrodotoxin (TTX) in European bivalves**, which present a new threat to shellfish food safety
	Measure actual human exposure and incidence of illness from Harmful Algal Bloom related toxins, Vibrios, Norovirus and Tetrodotoxin (TTX) and improve research into societal impacts
Transport and infrastructure	Establish how climate change affects **infrastructure performance, deterioration and threshold failure,** supported by long-term monitoring
	Improve **confidence regarding how climate change will impact on weather parameters**, notably wind and wave regimes, that determine infrastructure risk profiles
	Improve understanding of correlated flood risks (such as events affecting large sections of the coast, clustered in time or from multiple sources, i.e. coastal and riverine) to transport and infrastructure
Tourism and recreation	**Understand how UK tourism businesses currently manage for and respond to climate change.** Are there important spatial or sectoral variations, and how does climate change feature in appetites for risk?
	Explore how place-based 'product mixes', destination types, or the nature of coastal and/or marine environments **could be variously affected by climate change**

	Assess **how projected climate change impacts on tourism and recreation sectors may affect their value** (either beneficial or adverse, direct or indirect)
	Develop forecasting capabilities for climate change impacts on tourism, identifying the full range of potential physical and social impacts and their interactions (potentially compounding one another)
	Produce risk assessments across scales that connect the local (i.e. destination) level to transboundary impacts
Aquaculture	**Identify the effects** of climate change and ocean acidification **on pathogens and disease** development, and complex disease outcome
	Identify the potential effects of climate change and ocean acidification on **sustainable growth of offshore aquaculture**
	Assess the **capacity of aquaculture species** at individual and population level **to adapt to climate change and ocean acidification**
	Understand the s**ynergistic effects of climate change and ocean acidification** (and the effect of fluctuating, compared to continuous, exposure to these impacts) **on settlement (shellfish), growth and survival** of aquaculture species
	Identify the potential **impacts of climate change on environmental conditions at aquaculture sites** e.g. the assimilative capacity of receiving water bodies, including offshore
	Identify what impacts of climate change that could favour the **establishment and spread of non-native species** at sites
Fisheries	Evaluate climate change **impacts on the benefits derived from recreational fishing** (e.g. to coastal economies and wellbeing of participants)
	Apply more climate change research to **species of conservation importance** (e.g flapper skate, basking shark) to inform conservation measures
	Understand potential **barriers to sector and fleet adaptation** to climate change (e.g. market failures, information and policy barriers, inc. quotas and discards)

Three overarching Challenge Areas

Prior to the workshops, the working group took the 108 challenges and emerging issues that had been identified by the authors of the individual ARC topic papers as the starting point for this work. A review of these individual issues led to the identification of three overarching challenge areas:

- Building the evidence base (through improved data collection and utilisation, and enhanced modelling capability). 37 of the 108 challenges were assigned here.
- Understanding drivers of change (and their effects on ecosystems and society). 53 of the 108 challenges assigned were here.
- Applying knowledge to support cross-cutting decision making and fulfil obligations.18 of the 108 challenges were assigned here.

There is a broad continuum moving from the provision of underlying evidence (challenge 1), through to understanding drivers and effects (challenge 2) and then applying impacts evidence to support decision making (challenges 3).

Each of the challenge areas are further subdivided into 3-4 subcategories as described in the sections below. A summary of response options is also provided below, along with an overview of priority actions.

The one-page narratives, and full lists of response options and detailed discussions on priority actions are available here.

3.4 Challenge Area 1: Building the evidence base

Defining the Challenges

The challenge here is to build the evidence base through improved data collection and utilisation, and enhanced modelling capability. Four sub-challenges were identified:

Building the Evidence Base ***Defining the Challenges***			
a To develop existing monitoring	**b To establish new monitoring**	**c To improve process understanding and representation in models**	**d To refine model outputs**
Sustaining, and expanding monitoring efforts, to continue to track the effects of climate change.	Establishing new long-term datasets to start to identify climate-driven trends across physical, ecological and societal systems.	Improving representation of physical, chemical and biological processes, and their interactions, in models (including how data is assimilated).	Developing improved projections, with more predictive capability, across a range of spatial and temporal scales, under different scenarios.

Sub-challenge a) relates to both the physical environment (e.g. ocean circulation, salinity, temperature, oxygen, stratification, acidification and sea level) and habitat and species change. b) is focussed on improving data coverage, including sampling in remote sites and generating baseline data on marine species, c) on improving resolution and representation of physical (e.g. storms) and biological processes (e.g. life traits) and bio-physical links and d) predictive capability, constraining 'likely' upper limits, and system responses, that also factor in other stressors.

Response options and priority actions

Points raised focussed on better co-ordination (e.g. between the monitoring and modelling communities and across sectors), data collection technologies and methods, and the design and application of models, with the end user in mind.

Priority actions for these sub-challenges include need for better co-ordination across existing monitoring programmes and establishment of long-term datasets; improved process studies (observed and modelled, including feedbacks) and better use of observations to improve model outputs.

Building the Evidence Base ***Summary of Response Options***			
A **To develop existing monitoring**	**b** **To establish new monitoring**	**c** **To improve process understanding and representation in models**	**d** **To refine model outputs**
- Adopt novel monitoring methods and technology. - Improve existing coordination and governance. - Develop partnerships with industry. - Piggyback new monitoring on existing monitoring. - Improve the metrics used and ensure they are relevant. - Link programmes across discipline/spatial boundaries. - Lobby for funding more effectively.	- Build new and emerging monitoring and modelling technologies into programmes from the start. - Ensure coordination across programmes and good governance from the start.	- Improve model resolution (time/space) and consistency between models. - Co-design: Use models to design monitoring, and monitoring to improve models. - Improve model interfaces to increase access/uptake/sense checking by users. - Promote targeted process studies to improve models. - Improve representation of near-shore processes.	- Make model outputs more accessible and relevant to end users. - Improve observation assimilation in models. - Improve collaboration and comparisons between modellers and modelling disciplines.

3.5 Challenge Area 2: Understanding drivers of change and their effects

Defining the Challenges

Here the challenge is to understand drivers of change and their effects on ecosystems and society. Three sub-challenges were identified:

Understanding Drivers of Change ***Defining the Challenges***		
a **To understand physical effects of climate change**	**b** **To understand habitat and species response to climate change and human pressures**	**c** **To build knowledge of socio-economic effects of climate change**
Further our understanding of how coasts and seas are responding to climate change.	Better understand the combined effects of climate change and human activities on habitats and species, and their capacity to adapt.	Develop an understanding of the effects of climate change on human health, wellbeing and socio-economic activities.

Sub-challenge a) relates to large scale oceanographic change and coastal and near-shore change (inc. marine heatwaves, storm and wave climate and carbon exchanges), b) on primary productivity and harmful species, habitat and biological community change and resilience to combined stressors, and c) societal impacts including food security and supply chains, coastal and offshore transport and infrastructure (especially vulnerability to extremes) and human health, wellbeing and livelihoods.

Response options and priority actions

For the response options, collaboration was a prominent feature, as well as accounting for multiple stressors in habitat and species responses and end user engagement, including the development of narratives to guide adaptive management responses.

Priority actions for these sub-challenges included establishing better links from research to policy use, with better data and information flows; better monitoring of multiple stressors and improving engagement with stakeholders, including through increased ocean literacy, network mapping and co-design of projects.

Understanding Drivers of Change ***Summary of Response Options***		
A **To understand** **physical effects of climate change**	**b** **To understand** **habitat and species response to climate change and human pressures**	**c** **To build** **knowledge of socio-economic effects of climate change**
- Improve the flow of data from collection to use including research needs. - Use indicators and analogues that are appropriate and easily communicated. - Improve the understanding of influence of large spatial scale processes. - Fund model improvements. Increase available monitoring datasets. - Promote collaborations across discipline boundaries.	- Promote integration and collaboration between physics and biology. - Integrate monitoring across multiple stressors / drivers. - Use "big data" sources more (e.g. citizen science; remote sensing; eDNA).	- Use ocean literacy (Understand what people want and how they value marine systems (changes in space and time). - Harness citizen science, crowd sourcing and engage citizenry. - Improve stakeholder engagement from the beginning of projects. - Develop innovative methods to engage stakeholders (e.g., role play, story maps) - Address bias and discrimination in stakeholder communication (e.g., ethnic, equality, deprivation) - Work at local scales, community scales. - Promote flexible and adaptive solutions.

3.6 Challenge Area 3: Supporting Decision Making

Defining the Challenges

This challenge addresses the application of knowledge to support cross-cutting decision making and fulfil our societal obligations (e.g. to minimise adverse effects from climate change on people and the environment). The four sub-challenges identified are:

Supporting Decision Making ***Defining the Challenges***			
a **To value assets to support decision making**	**B** **To develop adaptive management responses in the coastal and marine environment**	**c** **To fulfil our climate and environmental commitments in a changing world**	**d** **To enable cross-cutting decision making**
Determine the value of natural and built assets to make informed decisions on their future use, in the context of a changing climate.	Enable flexible management options that can accommodate uncertainty in the nature and scale of climate change impacts.	Support the implementation of national and international obligations to conserve the environment (e.g., regulation, legislation and conventions).	Create effective mechanisms to deliver the breadth of evidence, and advice, needed to underpin decisions affecting multiple sectors and policy domains.

Sub-challenge a) relates to valuing frameworks, including ecosystem services and calculating damage and loss, b) adaptive management, including barriers, responses and application in marine spatial planning, c) meeting our obligations, including blue carbon inventories and conservation targets (against moving climate 'baselines') and d) applying 'best available' evidence and tools, better ocean literacy (to inform decisions), 'managing extremes' and effectively balancing conflicts across different policy and sectoral interests.

Response options and priority actions

For the response options, mechanisms for maximising the 'value' of funding (without an explicit increase in it) was highlighted, along with more effective valuation frameworks, and wider application of adaptive management approaches and toolboxes.

Priority actions for these sub-challenges included adapting valuation frameworks for the costal and marine environment, including taking account of value of 'blue' health'; optimising adaptive management approaches, including through participatory planning and better communication tools; and toolboxes for understanding coastal and marine biological community changes, incorporating a national planning perspective whilst enabling local action.

Supporting Decision Making *Summary of Responses*			
a **To value assets to support decision making**	**B** **To develop adaptive management responses in the coastal and marine environment**	**c** **To fulfil our climate and environmental commitments in a changing world**	**d** **To enable cross-cutting decision making**
- Ensure stakeholders are suitably identified and engaged to ensure the full value of assets is identified. - Develop more innovative funding and finance mechanisms for nature based solutions. - Adapt and develop the valuation frameworks to encompass more than financial value and find a standardised way to express it. - Use national curriculums to increase ocean literacy and value of nature.	- Use accurate communication to prepare and engage communities for long term change. - Develop national approaches to adaptive management. - Work with funders/investors to build in adaptation. - Develop optimum adaptive management with stakeholders. - Consider the role MPAs could play in adaptive management. - Ensure that legal and management infrastructure support flexibility.	- Understand better likely coastal and marine biological community changes and the adaptive management toolbox. - Make tools for understanding climate change risks more well known and accessible. e.g. UKCP, CCRA. - Support regional initiatives to quantify impacts and enable learning to be shared nationally.	- Improve collaboration at different geographic scales, different topics, and different sectors. - Use transparent decision support tools and processes. - Use universally agreed and understood language/definitions. - Improve governance and understand potential conflicts.

4. Guiding Principles

Given the role MCCIP plays in drawing the UK marine climate change community together, establishing best-practice 'principles' to collectively address these challenges identified is an important priority, and provides an opportunity for MCCIP to promote action.

The principles defined below draw on common themes from the three challenge areas, response options and priority actions identified at the workshops.

Many of the aspects covered will already be familiar to the wider marine climate change community, but barriers to their successful implementation have persisted over time and a more coordinated approach is needed.

The detailed guiding principles (and best practice case studies) can be accessed here.

A high-level list of the principles is provided below, with best practice examples in brackets:

1. *An integrated UK marine climate change community*
   - Better integration across boundaries (MSCC)
   - Achieving better outcomes (MERP)

2. *Evidence gathering and use*
   - Coordinated data gathering (OSPAR)
   - Collect once, use many times (MEDIN)
   - Baseline and standards (NMBAQC)

3. *Communication and engagement*
   - Planning communication and engagement activities (Marine Pioneer)
   - Building networks and finding a common voice (UK Marine Strategy)
   - Communicating outputs and outcomes (MCCIP)

4. *Decisions and outcomes*
   - Evidence based decision making and evaluation (CCRA / NAP)
   - Adaptive management approaches, enabling flexibility and responsive decision making (Historic Environment Scotland)
   - Effective governance and wider engagements for decision making, improving transparency (NRW)

5. Conclusions and next steps

The long list of key challenges and emerging issues represent a UK marine climate change community view from 150 scientists across 50 organisations. It is a unique repository, that has been tracked over the past 15 years.

MCCIP will continue to track key challenges and emerging issues as MCCIP evidence reporting moves from periodic reporting to 'rolling updates'. As contributing authors will have the opportunity to regularly keep their topic reviews up to date, this will help evidence providers and users understand how key challenges and emerging issues are evolving over time, how they are being addressed and what else needs to be done. This will be an invaluable resource for UK and devolved marine science and climate change strategies.

Many of the key challenges are familiar (e.g. 'better' integration of monitoring and modelling approaches) but they are persistent over time, highlighting an imperative for developing new approaches to mitigate existing and recurring issues. To improve integration requires evidence providers to find a common language and a more explicit expectation around demonstrating 'impact' from research...and the benefits this brings to all parties (e.g. how data 'flows' and is reused to have maximum impact, including what 'value' is added to maintain the flow from the point where evidence is generated through to its application by end users).

There are many good practice examples where these barriers have been overcome and the guiding principles can be used to provide a framework for integration, evidence gathering, communication and ensuring best outcomes for the UK Marine Climate Change research and end user communities, and ultimately support the successful implementation of the UK marine science strategy and delivery of requirements under the climate change act.

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