

Supplementary note on source material

Introduction

The source material for the two-page MCCIP 'Marine Climate Change Research Priorities 2014' summary document is principally drawn from MCCIP report cards. Over 150 scientists from more than 50 leading science organisations contributed to the 2013 report card, which covers 33 marine and coastal topics. The 33 topic reports were peer-reviewed by specialists in each topic area, helping to ensure that the evidence presented provides a fair and accurate representation of current scientific understanding.

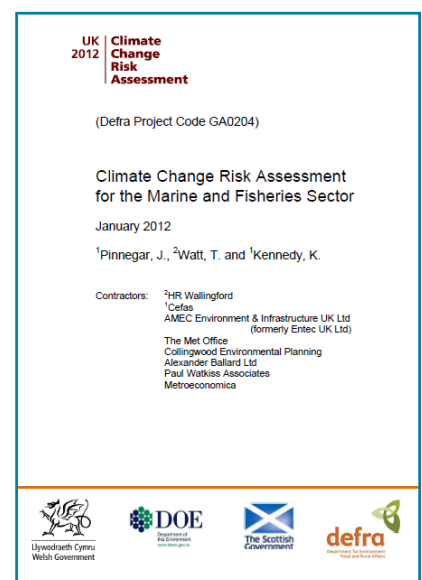
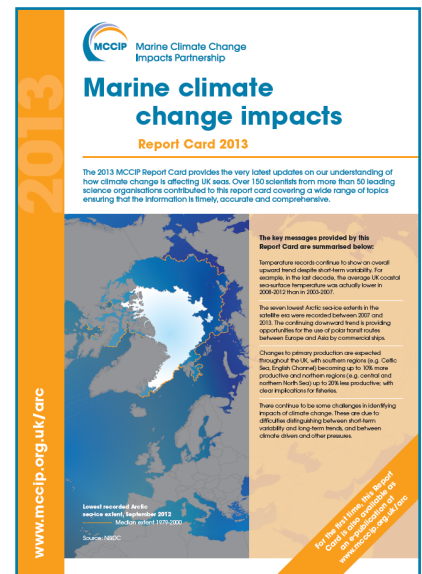
A key part of each topic report is the knowledge gaps section. Authors were asked to identify the top three knowledge gaps for their topics, which were subsequently challenged or validated, by the specialist peer reviewers. MCCIP collated, and summarised, the knowledge gaps from the 33 topic reports for use in this research prioritisation exercise. Relevant knowledge gaps from the Charting Progress 2: State of the UK Seas report, as well as the marine and fisheries sector report for the UK Climate Change Risk Assessment (CCRA), were added to help complete the overall picture of UK marine climate change knowledge gaps.

Accessing source material

The full list of knowledge gaps used for this exercise is provided as an annex to this paper. In compiling this list it was necessary to summarise the information into a consistent, and manageable, format. To achieve this, MCCIP initially screened all gaps from the 33 topic reports to ensure they were actually knowledge gaps (i.e. not just a funding request for a specific research project) and condensed others that were clearly part of the same issue. The gaps, as listed in this paper, include a 'bold' headline description, followed by 2-3 lines of more detailed information.

Some of the individual knowledge gaps in their original form (i.e. in the 33 MCCIP topic reports) run to half a page of text. Anyone requiring this level of detail on individual gaps can access the full 2013 topic reports at www.mccip.org.uk/arc. All of the topic reports are listed at the bottom of this webpage under the broad headings of Climate of the Marine Environment; Healthy and Biologically Diverse Marine Ecosystem; Clean and Safe Seas and Commercially Productive Seas. These groups, and the order of the topics, are the same as in annex 1 of this paper.

The vast majority of gaps highlighted in Charting Progress 2 and the CCRA are broadly covered in MCCIP report cards. However, there are a couple of topics not directly covered in MCCIP reports (e.g. microbes and jellyfish), which provide a valuable additional source of information. To access the source material from Charting Progress 2, go to the evidence groups parts of the climate change chapter¹. The gaps are embedded within the text of this short chapter. The CCRA marine and fisheries sector report has a specific knowledge gaps section (7.2) in the technical report².



¹ <http://chartingprogress.defra.gov.uk/chapter-6-climate-change-0>
² <http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=15747>

Air-sea exchanges of CO₂

How physical and biological processes interact to transfer carbon between surface and deeper waters A better understanding of how physical processes (e.g. near-surface vertical mixing by ocean eddies) and biological organisms interact (on scales of a few kilometres) is needed to determine the flux of carbon between surface, intermediate and deep waters.

How the ocean sink for CO₂ will change and feedback on climate change The ocean takes up a large amount of CO₂ from the atmosphere. This uptake may change in the future, affecting the rate of global climate change and ocean acidification. The processes governing CO₂ uptake are not well understood and requires more intensive monitoring in the open ocean and shelf waters.

Air-sea exchanges of heat and water

How does climate change affect exchange between the ocean and atmosphere? We know very little about the exchange of heat and water between the ocean and atmosphere in relation to climate change. Equally we do not know what impacts any future changes will have on ocean circulation or UK climate.

Arctic sea ice

Improved physical understanding of the Arctic system and links to other regions To better predict change we need an improved understanding of physical and biogeochemical processes in the Arctic system and sustained observations of its state as input to model projections. We also need to know more about how the Arctic system links to other regions (via teleconnections) through process studies combining modelling and observations.

Atlantic heat conveyor

The link between climate and the Atlantic heat conveyor The accuracy of seasonal to decadal predictions of North Atlantic climate, and of the Atlantic heat conveyor itself, are limited by a lack of observations and a full understanding of the physical processes that link the Atlantic heat conveyor to the wider climate.

Coastal erosion

How coastal systems, particularly at local scales, respond to changes in sea level, extreme storms and waves Coastal responses to changes in sea level, extreme storms and waves are complex and localised. Understanding the responses is made more difficult as our knowledge of how coastal systems function remains largely conceptual and this issue needs to be addressed through further research.

Noise

How might noise transmission change? How will changing pH and temperature of sea-water affect noise transmission in the marine environment?

Ocean acidification

How acidification will affect marine life Although the processes of acidification are relatively well understood, knowledge of the impacts on marine species and their ability to adapt to increased acidity is limited.

How pH will change at local and regional scales Biogeochemical feedbacks between ocean acidification and climate change and the impact of these global scale changes to local and regional scales.

Salinity

How the salinity of the ocean varies Salinity is a key parameter affecting biology and the circulation of our seas. The interpretation of long-term change is limited by sampling, particularly the seasonal cycle in the open ocean.

The link between the global hydrological cycle and ocean circulation The way salinity is expected to change in the future is difficult to predict. It is unclear how changes in the hydrological cycle relate to changes in ocean circulation and what the impact on salinity might be.

Sea level

The contribution of ice melting on Greenland and in the Western Antarctic to sea-level rise Better quantification of the contribution of land ice to sea level rise is needed to understand recent and future changes, particularly whether the contribution from the Greenland and Western Antarctic ice sheet is likely to continue increasing.

How sea levels at our coasts will change locally The planning and adaptation community require sea level change information at the regional level. This information cannot be obtained with any confidence from current climate models.

Shelf sea stratification

Changes to regional patterns of rainfall and wind Improved knowledge of how regional patterns in rainfall and winds will change over the next century is needed to understand potential changes to stratification in the shelf seas.

Modelling freshwater and salt supply to the shelf seas from the oceans and rivers Shelf sea salinity is not modelled with as much confidence as temperature. Projections of change in shelf sea stratification would benefit from improved predictions of salinity at the continental shelf edge where oceanic water crosses onto the shelf, at coasts where rivers supply freshwater and where stratification is not primarily driven by temperature (e.g. coastal regions influenced by river inflows).

Storms and waves

How the strength, pathway and frequency of Atlantic storms will change Changes in the strength, path frequency and seasonality of Atlantic storms are highly uncertain with different models providing different predictions.

Modelling waves at the coast Waves at the coast cannot be accurately predicted in models. This is due to the limited knowledge of very fine-scale bathymetry and small-scale physical processes known to influence coastal wave characteristics.

Having appropriate climate change information for coastal management Coastal managers need information at the local scale. There are two ways of doing this, one based on statistics, the other is based on running high resolution models (e.g. 5km by 5km as in UKCP09) but we need to clarify which is most appropriate.

Temperature (air and sea)

Detection and attribution of change due to climate change Knowledge and understanding of air temperature variability over the ocean is low, making detection and attribution of changes difficult.

Variability of sub-surface sea temperatures Beneath the ocean surface knowledge of variability in temperature is also low, particularly with respect to shorter time scales e.g. the annual cycle.

How should different types of observation be compared? A better understanding of how changing observing techniques can affect the consistency of records is needed, for example satellite measurements of sea surface temperature versus measurements physically taken in the ocean itself.

Lack of regional scale sea temperature projections Very few 'downscaling' regional scenarios have been applied to UK and Irish waters. Because of large uncertainties in regional marine climate projections, more ensembles are required to improve confidence in future projections of marine climate.

Coastal habitats

Coordination of coastal margin habitat surveys Whilst there is a slowly emerging baseline understanding of habitat area and condition, major knowledge gaps remain, particularly for cliffs, and of the extent of habitats outside designated (SAC, SSSI, etc.) sites. There is a need for either consistency of methodology between surveys, or inter-comparison exercises, in order to separate genuine change in extent or condition over time from differences due solely to methodology, which may be considerable.

Impacts of sea-level rise on sediment transport More information is needed on how sea-level rise will affect both sediment supply, and sediment transport on UK coasts, and the implications for coastal margin habitats.

Impacts of sea-level rise on coastal water tables How sea-level rise will affect groundwater, land drainage and aquifer recharge in coastal locations, and the implications for coastal margin habitats, has received little consideration to date.

Deep sea habitats

Distribution, structure and variability of deep-sea biological communities There is a lack of baseline data on the distribution and structure of deep-sea biological communities in UK waters and how they vary in time. Understanding the responses of these systems to climate change requires good baseline information.

Fish

Integrating observational and modelling work to make more robust predictions More work is needed to combine individual-based laboratory experiments, long-term survey data and statistical and process-based models to make robust predictions that take account of both direct and indirect climate change impacts on fish.

What is the adaptive capacity of fish to temperature and pH change over multiple generations? We don't know the adaptive capacity of individuals, populations and species over the next century (5 to 50 generations) to impacts from temperature and / or acidification. Multiple-generation studies of European temperate water species are needed to assess the response of fish to realistic changing conditions (warming and/or falling pH).

Need for better understanding of local impacts of climate change on fish More strategic collaboration is needed to combine expertise and resources at the regional and local scale, to fully explore the fine scale complexity of climate change impacts on fish within the seas surrounding the UK and Ireland.

Intertidal habitats

Impacts of climate drivers on intertidal mudflats, seagrass beds and chalk substrate These habitats are known to be sensitive habitats with respect to erosion, bait digging, coastal development and climate change, but there is insufficient information to be able to currently determine what impacts climate drivers such as increased temperature, decreasing pH, increased wave fetch, altered precipitation and salinity will have on these ecosystems.

Interactions between climate change and other human impacts affecting intertidal habitats There have been few experimental and monitoring programmes with the ability to separate out effects of individual human impacts or determine whether impacts are additive or synergistic. For intertidal systems, especially those in or near estuaries and semi-enclosed water bodies, climate change is likely to be affecting species and communities in combination with eutrophication, heavy metal and synthetic contaminant exposure, marine litter and reduction in extent and condition of natural habitat due to coastal development and construction of sea defences.

Jellyfish

Is climate change affecting the frequency of jellyfish blooms? Mass blooms of jellyfish may, very occasionally, cause serious economic damage to tourism and aquaculture. While there are some suggestions that jellyfish abundances may be increasing, we do not understand when and why blooms occur. Efforts to improve the monitoring of jellyfish should be supported.

Marine mammals

The response of marine mammals on different spatial scales We need better assessments of climate change impacts on marine mammals at the population level in order to discriminate between regional population responses and those occurring on a wider geographical scale. Long-term monitoring at a sufficient spatial scale is a component of this requirement.

The effect of all climate drivers on marine mammals A better understanding is required of how climate projections relate to changes most likely to impact upon marine mammals.

Microbes

Can we assess the role of microbes in the climate system? 75% of CO₂ fixation is by microbes, which are not plankton, and are not necessarily assessed in plankton surveys.

How will climate change affect the types of microbe in UK seas? Temperature induced habitat change may favour certain microbial populations over others resulting in altered assemblages with unknown impacts on oceanic food webs.

Non-natives

Baseline information on distribution, biology and regional scale distribution of non-native species A lack of long-term data collection for non-native species and in-depth biological information means that the influence of climate change on non-native species is difficult to determine and future predictions are based on often conflicting data.

Information on links between wider climate changes (other than sea temperature) and invasion success Very little information is available on the impacts of increased rainfall, heat waves, frequency of storm events and ocean acidification on the invasion success of non-native species.

Plankton

What are the links between warming, plankton and fisheries? Mechanistic links (and responses) between climate warming, plankton and fisheries (and other higher trophic levels such as seabirds) to form a predictive capacity. This includes understanding and predicting rapid and abrupt ecosystem shifts relating to climate change.

Improving coverage of pelagic ecosystem observations There are major gaps in the coverage of physical, chemical and biological measurements in pelagic ecosystems in the global oceans (in particular the Arctic Oceans and Nordic Seas).

Seabirds

Understanding interactions between climate, plankton and seabird prey species A better understanding of what influences key prey species (sandeel, sprat and herring) populations around the UK and Ireland would improve assessments of what climate change impacts are currently affecting seabirds. Seabirds require not only prey of sufficient abundance and quality, but that it is available at the right time to coincide with their peak energy demands, an understanding of climate-mediated effects on this trophic mismatch effect is important to our understanding of these food web linkages.

Impact of climate effects beyond UK and Irish waters As many species migrate across a vast area, climate effects on a global scale and across seasons need to be understood.

Interactions between climate change and other human impacts affecting seabirds We need to better understand how potential drivers such as marine renewables, pollutants and disease, impact on seabirds and the rest of the marine ecosystem in a changing climate.

Shallow and shelf subtidal habitats

Large scale changes in benthic species Knowledge of large scale benthic (bottom living) species distribution within UK waters is required, in order to detect changes over large areas of the seabed and patterns of benthic response to climate change.

Interactions between climate change and other human impacts affecting shallow and shelf subtidal habitats How do other factors affecting links between the seabed and water column, or food web dynamics, strengthen, weaken or confound climate effects (for example, in combination effects of climate and fishing effects on the sea bed).

Clean and Safe Seas (CSSEG)	Coastal flooding
	Changes to coastal defences and natural flood management measures <i>A better understanding is needed of climate change impacts on coastal defence deterioration rates, fragility and failure, as well as flood management contribution from natural systems such as inter-tidal habitats.</i>
	Integrated assessments of future coastal development and flood losses <i>Reliable predictions of new coastal development, siting of new infrastructure and protection measures are needed to undertake integrated assessments of future flood losses.</i>
	HABs
	How coastal blooms are 'seeded' <i>As there is little monitoring of HABs in offshore areas, the role of transport from these areas in seeding coastal blooms is poorly understood. The wind and density driven transport at the boundary between the coastal and offshore regions are likely to be affected by climate change resulting in more rapid coupling leading to a greater frequency of coastal blooms.</i>
	Response of different types of HABs to climate change <i>It is difficult to predict the response of different HAB groups and genera to the influences of climate change.</i>
	Human health
	Environmental monitoring and linking clinical cases to the marine environment <i>Understanding human health impacts from pathogens occurring in, or released into, the marine environment is hampered by a lack of monitoring and joined up epidemiological reporting systems. This makes it difficult to definitively link clinical cases back to climatic events in the UK marine environment.</i>
	Modelling of future extreme weather events and human health impacts <i>Short lived or localised extreme weather events (especially heat waves and episodic downpours) are not captured well by climate models. This limits our ability to predict the future impacts of climate change on important pathogens and algal toxins in coastal and marine environments. For example, the outputs from climate models are at too large a scale to predict how combined sewer overflow discharges, and their related pathogens, may respond to localised rainfall events.</i>
	Nutrient enrichment
	The nitrogen cycle and its temperature dependence <i>Understanding the role and temperature dependence of processes that are the key sinks for nitrogen – denitrification and anammox – which currently have large uncertainties.</i>
	Transport of nutrients from river systems to the marine environment <i>Un-monitored parts of catchments and ground water seepage are important but poorly constrained components of the transport of nutrients from river systems to the marine environment.</i>
	The consequences of changing climate for nutrient discharge to the sea <i>Prediction of the consequences of changing rainfall and temperature for nutrient discharge to the sea would improve with more use of catchment models and a better understanding of nutrient cycling.</i>
	Pollution
Climate effects on key processes <i>Some of the potential changes within key processes are poorly understood. Changes to mixing and circulation of discharges from outfalls; the potential for hypoxic episodes in coastal waters causing fish kills; changes in the distribution of contaminants through sediment disturbance; microbial pollutants in coastal catchments and near-shore receiving waters.</i>	
The relationship between climate change and major pollution events <i>The joint probability of intense rainfall during or after a long period of dry weather and low river flow is required to better predict major pollutant transport events.</i>	
Effects of salinity, temperature and pH change on chemical contaminants <i>Understanding the effects of salinity, temperature and pH change upon chemical contaminants affecting marine organisms.</i>	
Will climate change alter the frequency or impact of oil or chemical spills? <i>We know very little about how climate change could affect the frequency or impact of oil and chemical spills through changes to either accidents for oil-bearing vessels, or to the routes and cargo taken by ships.</i>	

What is Research Prioritisation?

In December 2013, The UK Marine Climate Change Impacts Partnership (MCCIP) published its latest report card with over 150 leading UK scientists providing contributions across 33 marine and coastal topics.

A key part of the 33 peer-reviewed topic reports is a knowledge gap section that MCCIP has used as the basis for this research prioritisation exercise. Additional gaps from the UK Climate Change Risk Assessment (CCRA) and Charting Progress 2 were also used. These gaps are presented in this document.

With assistance from the UKMMAS evidence groups, these knowledge gaps were prioritised.

The resulting list primarily prioritises those knowledge gaps where immediate attention is required for a policy, science or sustainability need, and secondly those that require attention across all of the fields, as considered by the relevant UKMMAS evidence group.

This list and research prioritisation methodology are provided on the MCCIP website, www.mccip.org.uk/arc



**MCCIP Marine Climate Change
Impacts Partnership**

**MCCIP Marine Climate Change
Research Priorities 2014**

Climate change is impacting on the marine environment in many ways. These impacts have been reported in the latest UK Marine Climate Change Impacts Partnership (MCCIP) report card, published in November 2013. Over 150 leading UK scientists provided contributions to the report card, across 33 marine and coastal topics.

These 33 reports, along with the UK Climate Change Risk Assessment (CCRA) and Charting Progress 2, have identified significant gaps in our knowledge that must be addressed to help respond to marine climate change.

Here we present the most urgent research priorities which should be of significant interest to funders of scientific research, as well as policy makers, marine managers and industry.

Our approach

All members of the four UK Marine Monitoring and Assessment (UKMMAS) evidence groups (Ocean Processes (OPEG); Healthy and Biologically Diverse Seas (HBDSG); Clean and Safe Seas (CSSEG) and Productive Seas (PSEG) were invited to undertake a research priorities assessment exercise. Some groups chose to provide a collective response, whereas others nominated individuals to undertake the assessment on behalf of their group. Following analysis by MCCIP, the top priorities were identified and sent to the UKMMAS evidence group leads for final agreement.

Whilst this assessment considered the four UKMMAS groups separately, there are strong inter-dependencies across the four evidence groups. For example, the fishing industry, a PSEG topic, is vulnerable to the impacts to sea surface temperature change (OPEG) on marine ecosystem health (HBDSG and CSSEG; see Figure). These inter-dependencies need to be recognised as part of taking an ecosystem approach to marine management.

The top research priorities identified for each evidence group area are summarised on the following page, and are presented alphabetically by evidence group. The top priorities represent the highest ranked knowledge gaps for each evidence group, based on their importance to marine policy, scientific research and UK growth and sustainability.



How is it relevant to policy?

Understanding marine climate change research priorities is important for a range of policy needs, including:

- The UK Marine Science Strategy which identifies "Responding to climate change and its interaction with the marine environment" as one of three key priority areas.
- The Climate Change Act. Identifying evidence needs is a key part of reporting under the five-year cycle of Climate Change Risk Assessment (CCRA) and National Adaptation Programme (NAP). Organisations responding to the Adaptation Reporting Power (ARP) also need to identify their evidence needs.

At a broader level, improving climate change information for marine spatial planning and EU directives, such as the Marine Strategy Framework Directive (MSFD), will be critical to their successful implementation. MCCIP is producing a new report card on the implications of climate change for marine protected areas and achieving good environmental status under the MSFD.

For complete transparency, and to help aid others wishing to undertake further analysis, short supplementary papers on source material and methodology are provided on the MCCIP website:

Commercially Productive Seas (PSEG)	Aquaculture
	Resilience of aquaculture habitats <i>What is the capacity of water bodies to receive waste waters or toxic materials without damage to aquatic life under climate change?</i>
	Will climate change affect aquaculture pathogens? <i>Update epidemiological risk assessments to include climate change impacts on aquaculture pathogens.</i>
	Changing storms effect on of fish farm escapes <i>More research is needed on the potential relationship between fish farm escapes and changing frequency of storm events.</i>
	Impacts of ocean acidification on shellfish aquaculture <i>We need to know more about the likely effects of ocean acidification on early life stages of bivalves and the implications for shellfish farm spat-fall.</i>
	Built structures (coastal)
	The rate of 21st century sea-level rise and erosion and impacts on coastal structures <i>Improved estimates of future SLR are required to understand socio-economic effects associated with increased flooding and erosion (particularly in relation to extreme events and trigger points), and resultant implications for coastal structures.</i>
	Interactions between future climate change impacts and other coastal flood system variables for planning <i>A better understanding of how climate change will interact with other flood system variables is needed for future assessments of coastal flood impacts (e.g. sediment transport processes and coastal morphology, drainage, interactions between groundwater, fluvial and surface water flooding and cliff stability and morphology).</i>
	Built structures (offshore)
	Better understanding of historical changes in offshore winds and significant wave heights <i>There is scope for careful collation and analysis of datasets to provide a more robust historical record of wind and significant wave height for offshore industries.</i>
	Future climate change projections and weather windows <i>As 'weather windowing' is routinely undertaken by many offshore industries for a huge range of activities, work is required to look at how different climate change scenarios could impact thresholds for operations.</i>
	Fisheries
	Response of fishing fleets and dependent economies <i>A UK-wide assessment of social and economic implications of climate change for fishing fleets and dependent economies is needed as there have been very few studies which have quantified these.</i>
	Vulnerability of the fishing industry to ocean acidification <i>The threat posed by ocean acidification is not well constrained, particularly for the UK shellfish industry.</i>
	The effect of low oxygen levels on fish and fisheries <i>The incidence of low oxygen zones have been predicted to increase in the future in response to climate warming. The scale of impacts of low oxygen zones on fish and fisheries is not well understood.</i>
	Safety and access for fishing boats <i>Better wind and storm projections to predict impacts on maritime safety and access to fisheries areas for boats.</i>
	Marine renewables
	Optimal siting for marine renewables given changing conditions <i>Improvements in the modelling of future patterns of wind, wave and currents would give additional evidence on the long term prospects for marine renewable sites (e.g. tidal stream energy sector). This could be either in terms of available energy resource or in terms of safety of the installations.</i>
	Ports and shipping
	Economic impacts of opening arctic trade routes with melting sea ice <i>The economics of potential new arctic trade routes and trading patterns associated with new routes.</i>
Impacts of new Arctic trade routes on UK ports and shipping development <i>The impact of new trade routes and trading patterns on port development and shipping activities about the UK.</i>	
Tourism	
Will more tourists visit UK coasts as a result of increasing temperatures? <i>Social research is required to understand how visitors make choices and whether this will be affected by climate change in the future (e.g. in reality, will more tourists visit cooler, Northern European coasts as a result of increasing temperatures?).</i>	
What would be the consequences of increased visitor numbers to coastal regions? <i>Warmer temperatures are predicted to increase visitor numbers to certain coastal regions. Therefore we need to determine adaptive and carrying capacity of these regions, and the potential degradation or development of their sites and attractions. This information would also highlight any potential economic opportunities that may arise from increased visitor numbers.</i>	
How vulnerable is coastal tourism to flooding, erosion and extreme weather events? <i>To assess the likely impacts of increased flooding, erosion and extreme weather, there is a need for detailed vulnerability mapping of coastal tourist operations and infrastructure. The findings could then be used to inform targeted adaptation strategies.</i>	

What is MCCIP?

The Marine Climate Change Impacts Partnership (MCCIP) is a partnership between scientists, government, its agencies, non-governmental organisations (NGOs) and industry. The principal aim is to provide a coordinating framework for the UK, so as to be able to transfer high quality evidence on marine climate change impacts, and guidance on adaptation and related advice, to policy advisers and decision makers.

Acknowledgements

We would like to thank the UK Marine Science Co-ordination Committee (MSCC) for help with scoping this work, and the UK Marine Monitoring and Assessment (UKMMAS) evidence groups for undertaking the assessment exercise.

For complete transparency, and to help aid others wishing to undertake further analysis, the research priority methodology and list of research priorities are provided on the MCCIP website:

<http://www.mccip.org.uk/arc>