



Marine Climate Change
Impacts Partnership

Marine climate change impacts

10 years' experience of science to policy reporting

This report card summarises how our understanding of marine climate change impacts has developed since the first MCCIP report card and lessons for science to policy reporting.



“Concern about the state of our seas has caused them to be studied more intensively - and extensively - than ever before. Here is a summary of the findings. They have never been more important.”

Sir David Attenborough

Key headlines

Short term variations in key parameters, such as temperature, over the last decade highlight the need to communicate observed change in the context of long-term trends.

There is evidence of some marine species responding to climate change but not necessarily in the ways anticipated 10 years ago.

Some areas, such as human health, remain poorly understood but there are early signs that climate change will have an impact.

Marine climate change impacts on society have been identified and understanding for some topics, such as fisheries and coastal flooding, is more advanced than for others.

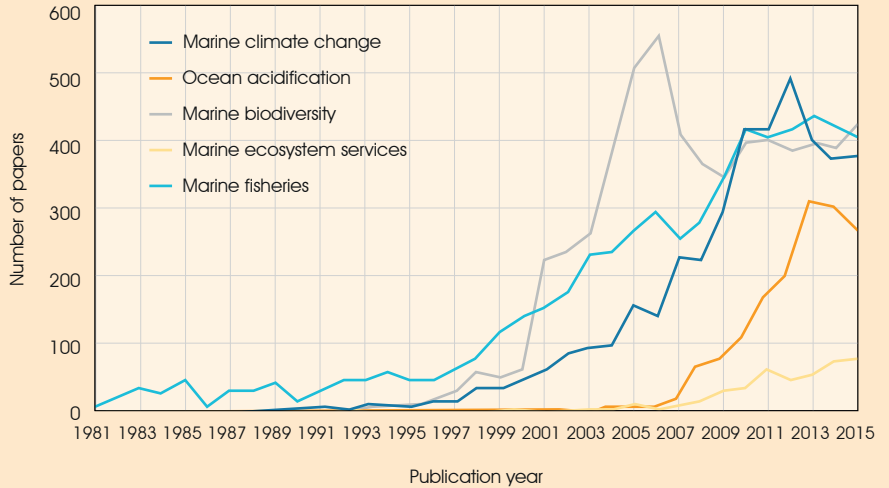
In general, marine climate change impacts have been better studied than ever before and ensuring integrity and independence when translating evidence is vital to inform considered decision making.

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Introduction

Climate science has come a long way since the observation by the French physicist Joseph Fourier in 1824 that the Earth would be colder if it lacked an atmosphere. There is now a large body of evidence on climate change, including impacts on the marine environment, with implications for policy and management. Thus the need to collate, synthesise and interpret evidence on climate change for policy-makers is greater than ever.



Growth in peer-reviewed journal publications for marine climate change and ocean acidification as well as other topical subjects in the marine environment (as derived from keyword searches of the Scopus database).

This report card summarises over 10 years of reporting on marine climate change impacts in the UK, examining how understanding has evolved since the first MCCIP report card was published in 2006.

It reports on key lessons learned working at the science-policy interface, ensuring marine climate science continues to be provided to end-users to inform policy and management.

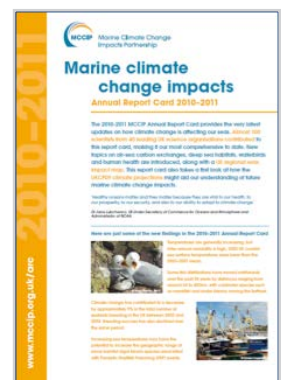
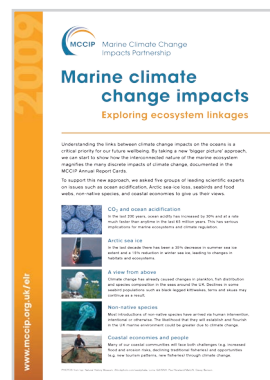
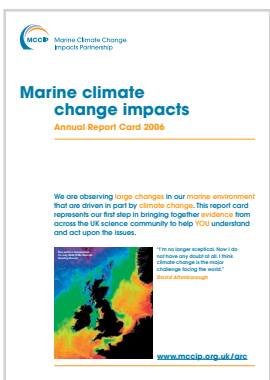


What is MCCIP?

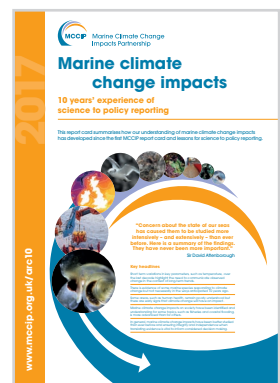
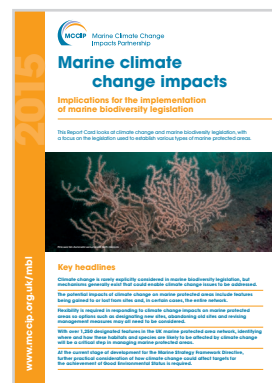
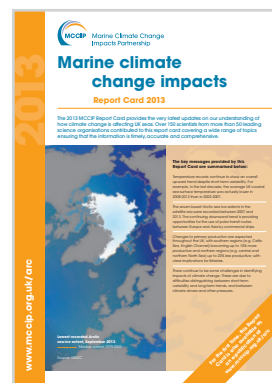
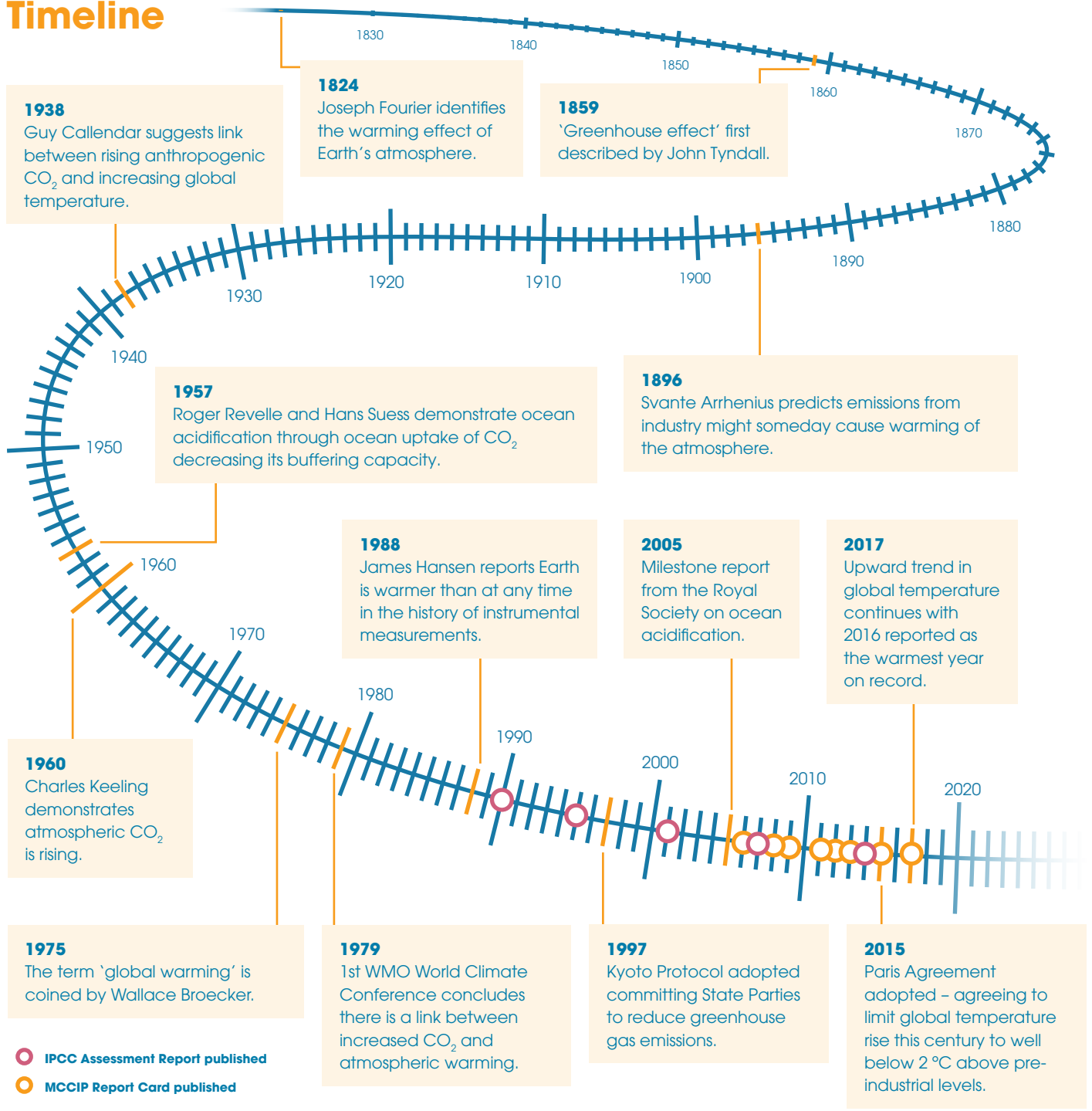
The Marine Climate Change Impacts Partnership (MCCIP) was created in 2005 to act as a coordinating framework for the UK, providing marine climate change impacts evidence to decision makers. MCCIP report cards provide regular updates on the current state of scientific understanding in a clear and concise manner. Over the past 10 years many leading marine scientists have contributed to MCCIP report cards, covering a wide range of topics related to changes in the climate of the marine environment and impacts of these changes on marine biodiversity and society.

Underlying evidence for this report card

This report card is based on a series of peer-reviewed papers produced by more than 50 authors, as well as drawing on previous report cards and a review by the MCCIP Report Card Working Group entitled "Reporting marine climate change impacts: lessons from the science – policy interface". The papers and this report card are accessible through www.mccip.org.uk/arc10



Timeline



Development in understanding of marine climate change impacts

This report card examines what was reported in 2006, and how this has changed for nine key topic areas, under the broad headings of climate of the marine environment (i.e. ocean acidification, Atlantic Meridional Overturning Circulation and temperature), impacts on biodiversity (i.e. seabirds, non-native species, and intertidal species and habitats) and impacts on society (i.e. fisheries, human health and coastal flooding).

For each topic the following structure is used:

- **MCCIP reported in 2006 that:** headline messages from the first report card.
- **And in 2017 that:** what the headline messages are now.
- **And also that:** new information not reported in 2006.
- **What we have learned.**

Climate of the marine environment

Since 2006 the marine climate theme has covered topics related to the prevailing physical characteristics of the marine and coastal environment (temperature, salinity, fluxes of heat and water, sea level, stratification, storms and waves), as well as changes in ocean chemistry (ocean acidification, CO₂ fluxes), and large scale components of the oceanic climate system (Arctic sea-ice and the Atlantic ocean circulation).

Key highlights are presented for ocean acidification, Atlantic Meridional Overturning Circulation and temperature, for which the evidence base is relatively well developed and scientific and public interest remains high.

Ocean Acidification

MCCIP reported in 2006 that:

- there is high confidence that ocean pH is decreasing, and will continue to do so for as long as atmospheric CO₂ continues to increase;
- the impacts of ocean acidification on marine ecosystems and foodwebs are largely unknown.

And in 2017 that:

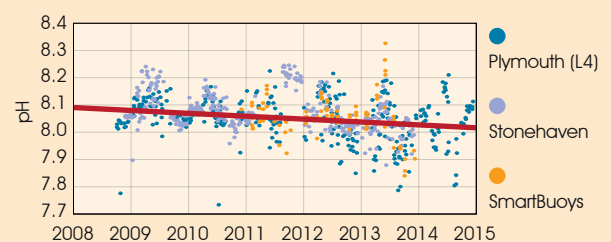
- global ocean pH continues to decrease. The evidence base is more robust, with longer time-series, and with a wider range of physico-chemical measurements and greater geographic coverage;
- there is evidence the overall effect of ocean acidification on marine ecosystems will be deleterious, e.g. a risk of substantive reductions in shellfish growth (and harvest) within 50 years, although some algae and seagrasses may benefit from increased availability of CO₂.

And also that:

- ocean acidification in UK seas over the last 30 years has been happening at a faster rate than for the wider North Atlantic;
- interactions with other stressors (e.g. temperature, toxic metals, oxygen and food supply) and species-specific responses need to be considered to better understand impacts on ecosystems.

What we have learned:

Long-term ocean measurements are essential to understand how ocean pH varies over months to decades. The biological impacts of ocean acidification (for ecosystems, fisheries and aquaculture) not only depend on site-specific physical and chemical conditions, but also species physiology, adaptive capacity, food availability and occurrence of other stressors.



UK pH data 2008 – 2015 for time series at L4 (off Plymouth), Stonehaven (near Aberdeen) and for SmartBuoys in the North Sea and Irish Sea, the red line illustrates the trend. Modified from Ostle *et al.*, 2016, Carbon dioxide and ocean acidification observations in UK waters: Synthesis report with a focus on 2010 – 2015. doi:10.13140/RG.2.1.4819.4164

Atlantic Meridional Overturning Circulation (AMOC)

MCCIP reported in 2006 that:

- a 30% decline in the AMOC has been observed since the early 1990s based on a limited number of observations. There is a lack of certainty and consensus concerning the trend;
- most climate models anticipate some reduction in strength of the AMOC over the 21st century due to increased freshwater influence in high latitudes. The IPCC project a slowdown in the overturning circulation rather than a dramatic collapse.

And in 2017 that:

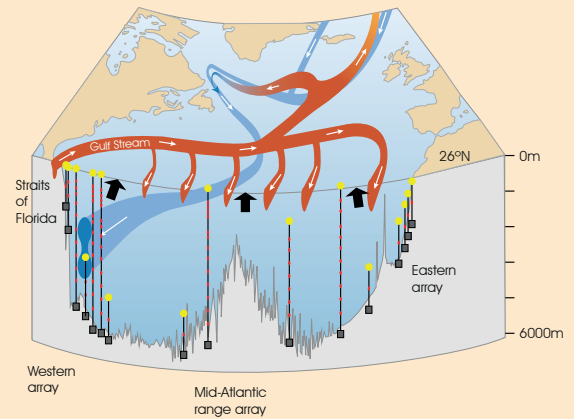
- a substantial increase in the observations available to estimate the strength of the AMOC indicate, with greater certainty, a decline since the mid 2000s;
- the AMOC is still expected to decline throughout the 21st century in response to a changing climate. If and when a collapse in the AMOC is possible is still open to debate, but it is not thought likely to happen this century.

And also that:

- a high level of variability in the AMOC strength has been observed, and short term fluctuations have had unexpected impacts, including severe winters and abrupt sea-level rise;
- recent changes in the AMOC may be driving the cooling of Atlantic ocean surface waters which could lead to drier summers in the UK.

What we have learned:

Measuring variability of the AMOC is key to understanding any trends and wider implications for the UK such as extreme winters or the seasonal-to-decadal variations in the climate.



Atlantic Meridional Overturning Circulation (AMOC). Red colours indicate warm, shallow currents and blue colours indicate cold, deep return flows. Modified from Church, 2007, A change in circulation? *Science*, 317(5840), 908-909. doi:10.1126/science.1147796

Temperature

MCCIP reported in 2006 that:

- the last 3 decades have seen sea surface temperature (SST) warming trends of 0.2 - 0.6 °C per decade around the UK;
- climate change models project that SST will continue to rise in all waters around the UK, with strongest warming in the south-east (1.5 - 4.0 °C over the 21st century in the southern North Sea) and weakest in the north-west (0.5 - 2.0 °C at Rockall).

And in 2017 that:

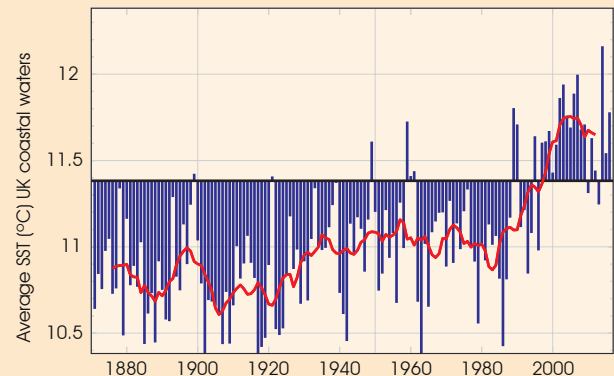
- against the backdrop of a general warming trend, there is variability at regional scales and between years and decades; e.g. between 2003 and 2013 UK coastal waters show a decreasing trend in SST;
- projections over the 21st century continue to show SST increases as reported in 2006, e.g. over 3 °C for most of the North Sea, and closer to 2 °C off the north-west.

And also that:

- projections are available at a much higher spatial resolution i.e. 12km versus 50km squares;
- decision makers need forecasts for the next 10 years (as opposed to projections over a century) and our ability to provide forecasts on these shorter timescales for SST is improving.

What we have learned:

Any short-term trends in SST, as a result of year-to-year fluctuations, have to be understood in the context of the underlying long-term warming trend.



Time series of average annual SST in °C for UK coastal waters 1870-2016. The blue bars show the annual values relative to the 1981-2010 average, shown as the black line, and the smoothed red line shows the 10-year running mean. Data are from the HadISST data set.

Marine climate change impacts on biodiversity

Since 2006 the healthy and diverse marine ecosystem theme has covered a range of topics: species groups (fish, waterbirds, seabirds, plankton, and marine mammals), habitats (from the intertidal zone to the deepest parts of our seas) and biological pressures (non-native species).

Key highlights are presented for seabirds, non-native species, and intertidal species and habitats, for which scientific and policy interest remains high.

Seabirds

MCCIP reported in 2006 that:

- poor breeding success, reduced survival and population declines in black-legged kittiwakes are strongly linked to warmer winters and changes in fish prey populations (e.g. sandeels). Other species have been similarly affected;
- further declines in some seabird populations are expected in the future;
- shoreline and cliff nesting birds may be affected by sea-level rise and increased storminess, respectively.

And in 2017 that:

- productivity of fulmars, Atlantic puffins, and common, Arctic and little terns, as well as black-legged kittiwakes decreases as temperature rises;
- short-term weather events such as severe summer storms are having strong negative effects on breeding performance of some species, especially razorbills.

And also that:

- there will be a continuing shift northwards in habitat suitability and prey availability for many species over the coming century and some species such as Leach's storm petrel, great skua and Arctic skua could become extremely rare or even extinct in the UK;
- seabirds in the UK face an uncertain future because of climate change and its potential interaction with other factors.

What we have learned:

It is critically important to consider multiple drivers simultaneously, not in isolation, because the complex way in which they interact with climate may play a key role in determining the long term well-being of seabirds in the UK.



Non-native species

MCCIP reported in 2006 that:

- warmer UK waters over the last three decades are facilitating the establishment of some non-native species in the marine environment.

And in 2017 that:

- some established non-native species have expanded their range in the UK which may be in response to warming sea surface temperatures (e.g. Pacific oyster *Crassostrea gigas*, the alga *Pilayella littorale* and the clubbed tunicate *Styela clava*).

And also that:

- despite a significant amount of research activity related to non-native species, there is no direct evidence that their introduction has been a consequence of climate change.

What we have learned:

Climate change, via warmer seas, may have contributed to the spread of some established non-native species in the UK, but human vectors (e.g. ballast water, ship hulls) are primarily responsible for their initial introduction and local conditions determine whether they will become established.



Pacific oyster (*Crassostrea gigas*) © Nova Mieskowska

Intertidal species and habitats

MCCIP reported in 2006 that:

- southern, warm-water species on rocky shores in the UK have increased in abundance and range with rising sea surface temperatures (SST) since the mid-1980s, whilst northern, cold-water species have decreased in abundance;
- these changes are predicted to continue into the future as SST continues to rise.

And in 2017 that:

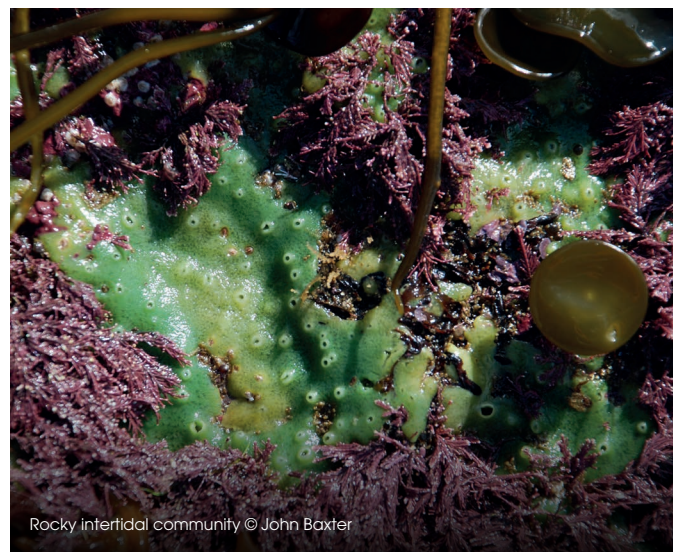
- most major shifts in intertidal rocky shore species distributions over the last 50 years occurred before 2000;
- annual surveys since 2000 show there have been no changes in the distribution ranges of intertidal animals and plants on rocky shores, which is consistent with the lack of increase in UK SST over the same time period.

And also that:

- the Community Temperature Index (CTI) that measures the overall status of the community of animals and plants on rocky shores, in terms of its composition of cold- and warm-water species is likely to be a valuable indicator of SST changes.

What we have learned:

Care needs to be taken when attributing cause and effect to shifts in distribution of intertidal species, without a comprehensive understanding of long and short term trends in SST and information on species lifestyles, life histories and their thermal affinities.



Rocky intertidal community © John Baxter

Marine climate change impacts on society

Since 2006 the society theme has covered topics related to both cleanliness and safety of the marine and coastal environment (flooding, nutrient enrichment, harmful algal blooms (HABs), pollution and human health), as well as commercial productivity (coastal and offshore built structures, tourism, fisheries, aquaculture, and ports and shipping).

Key highlights are presented for fisheries, human health and coastal flooding. Coastal flooding and fisheries have been selected because of the continuing high level of political interest. Human health is an emerging area of concern but has received less attention to date. In 2006 human health was not specifically considered in its own right; HABs were reported in 2006 while marine pathogens were added in 2010-11.

Fisheries

MCCIP reported in 2006 that:

- warm water commercial species such as sea bass, red mullet and tuna are becoming more common place in our seas;
- cold water species, such as cod have declined, with a possible link suggested between warmer sea temperatures and reduced populations of fish at the southern limit of their distribution range;
- continued declines in abundance and northward retreat in distribution of commercial cold water species;
- new species might become available for commercial exploitation.

And in 2017 that:

- warm water species have continued to become more commonplace, for example large numbers of bluefin tuna have been sighted off south-west UK in recent years;
- for the past 10 years, the number of juvenile cod entering the population has remained very low despite dramatic decreases in fishing mortality and this sustained reduction is thought to be a result of climate change;
- it is not simply a case of species moving northwards in response to warming, they may also move deeper. Patterns of distribution are also influenced by fishing pressure;
- cephalopod (squid, cuttlefish and octopus) populations around the UK are expanding in response to warming. Squid numbers have increased dramatically, allowing an important summer trawl fishery to be developed.

And also that:

- changes in mackerel distribution have been linked to a combination of factors, including warmer seas, changes in food availability and a range expansion of the stock into Faroese and Icelandic waters with consequences for fisheries quota allocation and governance;
- in the early 2000s, European seabass had expanded dramatically, especially in the English Channel, and was moving northward as a result of warming and was expected to continue. Seabass have been observed further north than was previously the case, although, because of overfishing, not in the numbers originally anticipated in 2006;
- despite many studies it is still unclear which ports and fleet segments will be most impacted by future climate change.

What we have learned:

There is now a substantial body of evidence supporting links between climate change and the distribution of commercial fish stocks. Predictions made 10 years ago about changes in stocks of cold-water species, such as cod, have largely been borne out. How changes in commercial species distributions are impacting on the industry is less clear, and little is known about the social and economic effects on fleets and fisheries.

Human health

MCCIP reported in 2006 that:

- harmful algal blooms (HABs) have increased in some areas of the north-east Atlantic over the past 50 years, as the seas around the British Isles have become warmer, especially since the mid-1980s. Around the UK, there is some regional variability in this trend with a reduced incidence of HABs off the east coast;
- there could be a higher incidence of HABs in the future linked to higher river discharges and an increase in stratification could also favour many HAB-causing species.

And in 2017 that:

- the relationship between climate change and HABs is complex, with bloom events found to be influenced by factors such as wind and current mediated transport;
- no evidence has been found to support a higher incidence of HABs linked to higher river discharges and increased stratification.

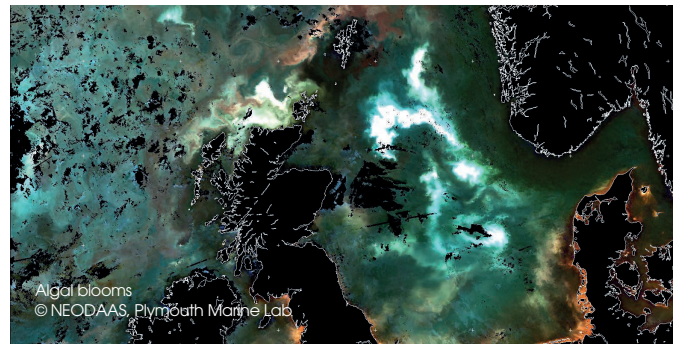
And also that:

- toxin producing HABs have continued to close shellfish harvesting areas in UK and Irish waters, but a direct relationship between these species and climate change has yet to be thoroughly investigated;
- heatwave events have been associated with the emergence of vibrio-associated infections in northern Europe, with factors such as warmer weather and human exposure (e.g. recreational swimming) driving infections;

- increased levels of human norovirus in shellfish have been associated with the number of storm overflow events (e.g. in a UK estuary, levels of human noroviruses in shellfish were ten times higher during high-flow and storm tank discharge conditions, than during low-flow and no storm tank discharge conditions).

What we have learned:

There is uncertainty about the effects that climate change will have on HABs, marine pathogenic vibrios and viruses in the UK and their possible effect on human health.



Enhanced ocean colour view 12-18 July 2015, showing a reddish bloom of the harmful *Karenia* algae near Shetland, and several bright/turquoise blooms of a harmless coccolithophore.

Coastal flooding

MCCIP reported in 2006 that:

- the incidence of extreme sea levels is increasing, as a result of relative sea-level rise;
- future extreme flood events may become more common due to relative sea-level rise and increased storminess.

And in 2017 that:

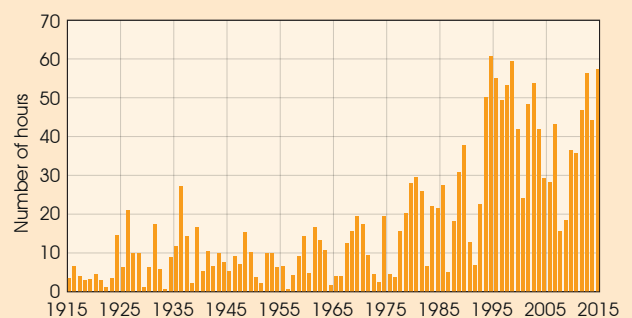
- there is more evidence that the increased incidence of extreme sea level events has been driven by the rise in relative sea level over the last 150 years;
- relative sea-level rise will continue and its rate will likely accelerate. This will further increase the incidence of extreme sea level events.

And also that:

- increased incidence of extreme sea level events has not led to a corresponding increase in coastal flooding due to continued improvements in flood defences, emergency planning, forecasting and warning.

What we have learned:

Appropriate and ongoing adaptation measures can help avoid significant impacts on the UK's coastal population, economy and infrastructure. Considerable uncertainty remains in regard to future climate driven changes to storms and thus there is low confidence about how the wave and storm surge climate around the UK may alter over time.



Example of the changing incidence of extreme water levels: Number of hours per year that water levels exceeded 5.75m Chart Datum at Newlyn, Cornwall.

Reporting marine climate change impacts: lessons from the science-policy interface

Dealing with uncertainty

Policy-makers and managers use evidence for a range of purposes including making decisions, taking action, developing policy and drafting legislation. It is vital that an indication of the degree of certainty and uncertainty in the evidence is provided.

Past MCCIP report cards have drawn on the IPCC approach for communicating the degree of certainty in key findings by using a qualitative expression of uncertainty that reflects: (1) the degree of agreement amongst the scientific community; and (2) the amount and nature of the evidence available on which findings are based.

The confidence ratings in MCCIP report cards are assigned by the scientists who provide the evidence for each topic. Although a straightforward process, it has raised challenges when changes in confidence over time are considered. For example, a deeper understanding of a topic (e.g. due to more information being available) can counter-intuitively lead to greater uncertainty and a lower confidence rating.

One way to address such challenges is to manage the expectations of those using the evidence by taking the time to explain what is meant by uncertainty for each topic. This is done by following up any MCCIP reporting with face-to-face briefings and discussions and by encouraging the use of the more detailed peer-reviewed papers provided for each topic.

Keeping pace with the science-policy interface

There have been numerous changes at the science-policy interface over the decade that MCCIP has been reporting on marine climate change impacts.

For example, the implementation of marine spatial planning at different scales has highlighted the need for improved spatial and temporal resolution of climate change driven impacts on the marine environment.

2006

Why we changed

2017



Scientific integrity and independence

A robust and transparent process can mitigate against accusations of a lack of integrity or of bias in reporting. MCCIP is an independent provider of evidence for policy-makers and has developed a four-step process to ensure scientific integrity and independence in its products.

Step 1: Information identification

Risk	Mitigation	MCCIP approach
Selection bias: 'cherry-picking' topics or research areas that support pre-held opinions	<ul style="list-style-type: none"> Joint setting of 'information agenda' Transparent decisions 	<ul style="list-style-type: none"> The MCCIP Steering Group, comprising 26 partners, identify the information need Scope of information need is then refined through audited discussions with policy customers and science community

Step 2: Expert identification

Risk	Mitigation	MCCIP approach
Expert bias: selecting a narrow group of experts known for promoting certain views or hypotheses	<ul style="list-style-type: none"> Comprehensive expert involvement Clear instruction to authors to include representative range of opinion Independent peer review process 	<ul style="list-style-type: none"> Provisional lead authors identified and approached Lead authors are required to represent and work with community of experts in their field regardless of individuals' opinions Materials produced by authors are anonymously and independently peer reviewed and revised accordingly

Step 3: Information translation

Risk	Mitigation	MCCIP approach
Interpretation bias: those responsible for translating the information can introduce their own bias and opinion	<ul style="list-style-type: none"> Clear terms of reference and accountability Scientists cross-check Information and data audit 	<ul style="list-style-type: none"> Report Card Working Group established - individuals mandated as experts, not representatives of their organisations All summary information to be published shared with lead authors for cross-checking All information and data made publically available (online) and any publications provided as open access in journals

Step 4: Information communication

Risk	Mitigation	MCCIP approach
Evidence 'weighting' bias: evidence or advice may be given too much credence or credibility	<ul style="list-style-type: none"> Confidence assessment 	<ul style="list-style-type: none"> Lead authors provide confidence rating as indication of uncertainty around topic Simple language used to avoid ambiguity

Modified from Frost *et al.*, "Reporting marine climate change impacts: lessons from the science – policy interface."

Looking forward

The challenges posed by climate change impacts on the marine environment remain as relevant in 2017 as they were when MCCIP was launched in 2005. MCCIP has proven to be a successful partnership, communicating peer-reviewed evidence on marine climate change impacts to policy advisers and decision-makers.

The needs of partners and stakeholders have changed over the last decade, as has the broader landscape within which MCCIP operates. Looking forward MCCIP intends to:

- provide a locus for discussions between scientists and policy-makers to form a consensus view;
- continue to work with the scientific community to provide evidence on marine climate change impacts for non-specialists;
- facilitate discussions around adaptation;
- continue to evolve in response to changing customer requirements and new policy drivers.



MCCIP partners are:

Adaptation Scotland; Agri-Food and Biosciences Institute, Northern Ireland; Centre for Environment, Fisheries and Aquaculture Science; Climate UK; Department for Business, Energy & Industrial Strategy; Department for Environment, Food and Rural Affairs; Department of the Environment, Northern Ireland; Environment Agency; International Union for Conservation of Nature; Isle of Man Government; Joint Nature Conservation Committee; Marine Biological Association; Marine Conservation Society; Marine Management Organisation; Marine Scotland; Natural England; Natural Resources Wales; Royal Society for the Protection of Birds; Scottish Environment Protection Agency; Scottish Government; Scottish Natural Heritage; Sir Alister Hardy Foundation for Ocean Science; States of Guernsey; States of Jersey; UK Met Office; Welsh Government.

Further details and contacts

The delivery of this report card was overseen by the MCCIP Report Card Working Group. The members of this group are: M. Frost (MBA); J. Baxter (SNH); P. Buckley (Cefas); S. Dye (Cefas/UEA) and B. Stoker (JNCC).

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For further details about the work of MCCIP, go to

www.mccip.org.uk

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Legend

(1) Ocean acidification

(2) Atlantic Meridional Overturning Circulation

(3) Temperature

(4) Seabirds

(5) Non-native species

(6) Intertidal species and habitats

(7) Fisheries

(8) Human health

(9) Coastal flooding

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