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Review

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

Matthew Frost[a,*], John Baxter[b], Paul Buckley[c], Stephen Dye[c,e], Bethany Stoker[d]

[a] Marine Biological Association of the United Kingdom, Plymouth PL1 2PB, UK
[b] Scottish Natural Heritage, Edinburgh, UK
[c] MCCIP Secretariat, Marine Climate Change Centre, Cefas, Lowestoft, UK
[d] Joint Nature Conservation Committee, Peterborough, UK
[e] COAS, School of Environmental Sciences, UEA, Norwich, UK

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ABSTRACT

Climate change science can trace its origins back to the early 19th Century although interest really took off in the 1980s, when public interest and research activity proliferated as the potential negative effects of global warming became clear. The impacts of climate change on the marine environment was receiving little attention at this time, but in recent years has started to "catch up" both in terms of research activity and public and policy interest. In the UK, the Marine Climate Change Impacts Partnership (MCCIP) has played a key role in transferring the emerging evidence base on marine climate change impacts to decision makers through the development of climate change report cards. Since publishing its first card back in 2006, the MCCIP cards have become established as the principal source of marine climate change impacts evidence for policy makers in the UK, and similar approaches have been adopted elsewhere. Here we broadly describe how the climate change evidence base has evolved over time, with a focus on the marine evidence base, and the approach adopted in the UK by MCCIP to rapidly transfer this evidence to end users. The SIIRMS model developed by MCCIP to ensure integrity and independence in the scientific translation process is explored, along with wider lessons learnt along the way (e.g. about communicating uncertainty) and the impact MCCIP has had on informing decision making.

1. Climate change science: a brief history

The first 150 years of climate change science was characterised by occasional but important reports and observations leading to a gradual development of knowledge over time. The earliest climate observation is often reported as that by the French physicist Joseph Fourier who demonstrated that the Earth would be colder if it lacked an atmosphere (Fourier, 1824). In 1859 John Tyndall first described the 'greenhouse effect' whereby changes in the concentration of gases in the atmosphere could lead to changes in climatic conditions (Tyndall, 1859) and in 1896 the Swedish chemist Svante Arrhenius used estimates of coal burning to calculate that emissions from human industry might someday cause a warming of the atmosphere (Arrhenius, 1896). Research linking CO_2 production to global temperatures continued in the 20th century (e.g. Revelle and Suess, 1956; Callendar, 1938) although it is interesting to note that scientists from Arrhenius through to Guy Callendar did not necessarily see an increase in global temperatures as a negative phenomenon and in fact tended to draw out positive benefits if anything (Bowen, 2006). From 1975 when the term "global warming" was coined by the US scientist Wallace Broecker (Broecker, 1975), the focus was shifting to the negative impacts of anthropogenically-induced climate change. This concern began to spread within and beyond the scientific community, with public perception of climate change as a problem increasing rapidly throughout the 1980′s and 1990′s (Capstick et al., 2015).

1.1. The challenge: a rapidly expanding evidence base

The need to collate and assess the rapidly growing body of evidence on climate change led to the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and since then the amount of research carried out into climate change has increased dramatically across countries and scientific disciplines (Haunschild et al., 2016; Jinfeng et al., 2011). The amount of specifically marine focused climate research has also increased dramatically although reporting marine environmental impacts was not initially given as high a priority as

* Corresponding author.
E-mail addresses: Mattfr@mba.ac.uk (M. Frost), john.baxter@snh.gov.uk (J. Baxter), paul.buckley@cefas.co.uk (P. Buckley), stephen.dye@cefas.co.uk (S. Dye), beth.stoker@jncc.gov.uk (B. Stoker).

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terrestrial studies: only 2 pages of the 414 page first IPCC report focused on impacts on marine ecosystems, and as recently as the 2007 IPCC 4th Assessment Report, 28,586 significant biological changes in terrestrial systems were highlighted, but only 85 were from marine and freshwater systems (Richardson and Poloczanska, 2008), a deficiency addressed by the establishment of an international symposium on the effects of climate change on the world's oceans (Barange et al., 2016). By the time the fifth assessment report was published during 2013 and 2014 (IPCC, 2014; IPCC 2013), it was clear efforts were being made to address these deficiencies in reporting on marine climate change, with dedicated chapters on oceans and marine and coastal ecosystem responses. A dedicated IPCC special report on oceans and cryosphere's is planned before the Sixth Assessment Report is published. Reporting on marine climate change impacts is therefore finally starting to 'catch up' with the proliferation of marine climate change research since the first IPCC report was published, given the number of papers on marine climate science has doubled every year since 1990 (Jex, 2016).

2. A new model for evidence transfer: the marine climate change impacts partnership

For the UK, a significant event in marine climate reporting was the publication of a major government report into the State of UK Seas (Defra, 2005). This report included an examination of the impacts of climate change but the information was disparate and far from comprehensive. The Marine Climate Change Impacts Partnership (MCCIP) was initiated as a direct response to recommendations in the report, to act as a 'neutral clearing house for marine climate change evidence relevant to the UK' (see Page 4, Defra, 2005). The MCCIP partnership necessarily includes participants working along the spectrum from pure science to policy and many individuals on its working groups, as well as contributing authors, have considerable experience operating in both science and policy contexts. Since 2006 MCCIP has reported on the physical drivers of marine climate change; and their impacts on marine biodiversity; cleanliness and safety; and commercial productivity of the coastal and marine environment around the UK (MCCIP 2017, 2015, 2013, 2012, 2010, 2009, 2008, 2006) with the aim to "transfer high quality evidence on marine climate change impacts, and guidance on adaptation and related advice, to policy advisors and decision-makers" (MCCIP, 2014). In doing so, MCCIP provides an independent translation of information from the scientific to the political and public arena, which is vital if policy and action related to climate change impacts is to be evidence-based, or at least 'evidence informed' (Kennel et al., 2016; Rose, 2014; Urwin and Jordan, 2008). The need for a mechanism for transferring this evidence to policy-makers led to the development by MCCIP of the world's first marine climate impacts report card. The MCCIP report card model has since been adapted for use in Australia (Poloczanska et al., 2012, 2009) and the Caribbean (CMEP, 2017) as well as for terrestrial and freshwater climate reporting in the UK (Morison and Matthews, 2016; Watts and Anderson, 2016; Kovats, 2015; Morecroft and Speakman, 2015) leading to them now being recognised as an important medium for communicating climate science in a way that can bridge the science policy interface (Fung et al., 2015). The more than 10 years' experience MCCIP has in working at the science-policy interface to report on marine climate change impacts, and the fact that the model is being more widely adopted, means an examination of the effectiveness of the MCCIP model of reporting is particularly apposite. Specific lessons learned on the effectiveness of the MCCIP model for use at the science-policy interface are therefore discussed with a focus on the issue of reporting uncertainty and on ensuring independence and integrity. The results of this review are used to draw some general conclusions and make recommendations for those working at the interface between science and policy.

2.1. The MCCIP process

Before looking at the lessons learned it is useful to note the process by which MCCIP produces its report cards − further information is then provided in Section 2.3.1. The MCCIP Report Card Working Group sets out proposals to the MCCIP Steering Group about the delivery of any report card, including information on timing and the subject matter to be covered. Once agreed by the steering group, the work group commissions lead authors to provide the underlying evidence for the report card (the number of lead authors invited depends on the number of topics being covered). Lead authors are provided with a template with specific terms of reference asking them to take responsibility to invite co-authors in their area so the submission reflects the view of experts in their field. Peer reviewers are also identified at an early stage by the working group. Once submissions have been submitted, peer-reviewed and finalised, the working group collates the evidence (based on the work group Terms of Reference and refines the key messages for the target audience (the final form of the key messages are agreed in liaison with the lead authors).

3. Lessons from the science-policy interface

The 'science-policy interface' is a simple and widely-used way of referring to the intersection between the worlds of science and policy, the assumption being that they operate in separate but overlapping spheres. The term can also refer to specific processes as in Van den Hove's definition of science–policy interfaces as social processes which encompass relations between scientists and other actors in the policy process (Van den Hove, 2007). There is a history of academic research into methods to improve the science-policy interface including climate science and policy specifically (Howarth and Painter, 2016; Jones et al., 1999) but for many scientists it is only experience of this interface that provides the insight required to identify and address the numerous challenges (Watson, 2005). MCCIP is no exception and the focus here is on what has been learned in terms of communicating uncertainty and maintaining scientific integrity and independence. There is an additional challenge in that scientific information needs to be conveyed in a way that is easy for the 'layman' to understand; a problem exacerbated by the fact that the audience for the information can range widely in expertise from those with scientific training to those with very little or no experience of interpreting and dealing with scientific outputs and knowledge, as well as wide differences in values and perspective (Grorud-Colverta et al., 2010; Nisbet and Scheufele, 2009). The translation, provision and interpretation of scientific information for a non-specialist audience i.e. making sure that technical information is conveyed in a way that makes it accessible to non-specialists, has however been dealt with in detail elsewhere (Brownell et al., 2016; Moser, 2016).

4. Lessons from the science-policy interface: dealing with uncertainty

Scientific information can be complex and one of the most challenging aspects of communicating complexity is working with, and conveying, the concept of uncertainty (Wardekker et al., 2008). Policy-makers and managers may want to use the evidence supplied to make decisions, take action and even develop or amend legislation (Frost et al., 2016), which is why it is vital that some indication of uncertainty is provided with scientific information. A well-established mechanism for communicating uncertainty is the use of a 'confidence rating' (e.g. Laffoley and Baxter, 2016; UKMMAS, 2010). The confidence rating adopted by MCCIP draws on the IPCC approach in addressing uncertainty by reflecting both the consensus (degree of agreement amongst the scientific community) and the amount of scientific data available on which findings are based (Mastrandrea et al., 2010). The MCCIP report cards display two confidence ratings for each topic, one for the statements on the current status of the topic and one in relation to statements on what could happen in the future. The authors provide a rationale for the confidence ratings in their detailed submissions. For example, a prediction of climate impacts on aquaculture (including on the economic development of the industry) may be low confidence due to a lack of data and consensus (Callaway et al., 2012) whereas coastal flooding predictions based on large amounts of high quality data and strong consensus in the scientific community are accorded a high confidence.

4.1. Using confidence as a measure of uncertainty: information resolution and applying the confidence rating

The use of a confidence rating, based on consensus and the amount of scientific data available, sounds attractively straightforward but is in practice is very difficult to implement in a clear objective manner. Firstly, there is the issue of what level of information or degree of detail you attach a confidence rating to. Do you attach confidence to every statement or just provide a general indication of uncertainty across a subject?

For certain parameters such as sea level rise and flooding, there is a good understanding of past trends in climate drivers, and a high degree of confidence that changes will continue in the same direction in the future. These projections are, however, still subject to high levels of uncertainly around the *magnitude* and *speed* of change. For example, when considering sea level rise in the UK, the most recent projections from UKCP09 (Lowe et al., 2009) show nine different curves representing different trajectories over the 21st Century depending on whether the future greenhouse gas emissions scenario is low medium or high, and within each of those, a mid-point estimate, plus the 5th and 95th percentiles. Not allowing for isostatic adjustment, these curves span a range of sea level rise over the 21st Century of between 12 and 76 cm in the UK. In addition, there is a low probability, high impact (H + +) scenario provided where sea level rise is up to 2m, for contingency planning purposes.

The difficulty of knowing what aspect of change to allocate uncertainty to (e.g. direction, magnitude *and* rates of change, plus the influence of non-climate factors) is perhaps one of the reasons MCCIP has found that over time the science submissions themselves can appear inconsistent in the way the confidence criteria are applied. MCCIP attempts to deal with this inconsistency in two ways. Firstly, the authors are required to give a rationale (with scores for amount of evidence and consensus applied to a 3 × 3 matrix) so that then at least the reason for changes in confidence can be tracked. Secondly the confidence assessment is included in the peer-review with authors challenged and checked on their judgement. This can be even more challenging where the impact of climate change is less well established (e.g. the impact of climate change on harmful algal blooms) or where the subject is making rapid advances through scientific investment (e.g. Ocean Acidification).

4.2. Using confidence as a measure of uncertainty: does more information always lead to a decrease in uncertainty?

Another issue in identifying uncertainty and attaching confidence ratings is that even where research on a specific topic has proliferated, more information may actually make the picture more rather than less complicated. An article on IPCC reporting for example states "*Is it not a reasonable expectation that as knowledge and understanding increase over time, uncertainty should decrease? But while our knowledge of certain factors does increase, so does our understanding of factors we previously did not account for or even recognize*" (Trenberth, 2010). The fact that more information may not provide clearer answers and may even invalidate or complicate an earlier simpler understanding of what is happening may seem counterintuitive and is therefore a difficult message to convey to stakeholders (especially those who are providing funding in the hope of getting clear answers to policy questions) even though it is a relatively well-known phenomenon (Trenberth, 2010).

4.3. Using confidence as a measure of uncertainty: the solution

The challenges noted here with communicating uncertainty, added to the fact that the parameters of the confidence rating (consensus, amount of information) are themselves subjective (in the sense that they are difficult to define in a quantitative way), is why MCCIP now recommends that for reporting purposes confidence ratings should 'provide an indication as to the degree of uncertainty'. Providing some kind of confidence rating will remain a key part in reporting to policy makers as well as a key requirement from them but MCCIP has learnt that the most important way to address these issues is to manage expectations from policy customers and to take time to explain what is meant by uncertainty. Uncertainty is a familiar and non-threatening concept for scientists (and a core component of 'doing science') but can cause disengagement from policy customers who don't understand the concept from a scientific perspective (Lorenzoni et al., 2007). It is not that the concept of uncertainty is not familiar to policy-makers, rather it is that terms such as 'uncertain' or 'low confidence' can mean something very different to someone working in the policy arena than to a scientist (Kinzig and Starrett, 2003). Making every effort to ensure policy-makers understand how uncertainty is being reported is as important as the information itself (Wardekker et al., 2008) making direct briefings and discussions with policy-makers crucial in supplementing report card information.

5. Lessons from the science policy interface: scientific integrity and independence in climate reporting

Ensuring that scientific information and advice is independent, i.e. free from bias or 'political interference', is a vital aspect of the science-policy interface (Sarkki et al., 2015). There has been a large growth in the study of many aspects of the science-policy interface including models for knowledge transfer (e.g. Holmes and Clark, 2008; Cash et al., 2003); science-policy communication (e.g. Robins, 2006); enhancing the policy impact of science (e.g. Koetz et al., 2011; Perrings et al., 2011; Lawton, 2007); and the misuse of science for policy purposes (e.g. Williamson, 2016; Chapron, 2014; Winner, 2004). There has however been comparatively little reported on processes to support scientific integrity and independence (although see Hoffman and Rottingen, 2014 and discussions on conservation biology and advocacy in Lackey, 2007; Scott et al., 2007; Jose, 2006). Climate change reporting in particular has been at the centre of a number of controversies related to the scientific independence (Williamson, 2016; Nerlich, 2010) and a robust, transparent process for advice provision is therefore required that can mitigate against accusations of a lack of integrity or of bias in climate reporting.

5.1. The solution: the 'Scientific Integrity and Independence Risk Management Scheme (SIIRMS)

MCCIP was established to provide independent advice for policy-makers (MCCIP, 2014) and has therefore developed a process for managing risks associated with scientific independence. The "Scientific Integrity and Independence Risk Management Scheme (SIIRMS)" summarised in Table 1 has evolved in its application over the years of the MCCIP but has essentially been in place since its inception. It would of course be naïve to believe that any scientific advice is totally free from any subjective interpretation or bias (Sarkki et al., 2015) so the process outlined here is designed to 'manage and mitigate risks' around the issue of scientific independence as much as is reasonably possible. Holmes and Clark (2008) summarise four key steps used for information provision at the science-policy interface 1) establishing research questions and agendas; 2) accessing information and expertise; 3) the role of interpreters; and 4) transparency and evaluation. Table 1 uses

Table 1
Scientific Integrity and Independence Risk Management Scheme (SIIRMS). The concept of 'independent scientific advice' is a vital aspect of the science-policy interface. This table provides suggestions on how risk to scientific integrity and independence can be managed. The process steps are those used in the MCCIP reporting process but are expected to apply more generally to reporting at the science-policy interface.

Process step	Risk to independent provision of information and/or advice	Risk Management
1. Information identification	Selection bias: 'cherry-picking' topics/research areas that support pre-held opinions e.g. only topics where dramatic climate impacts are chosen in order to support the opinion that climate change is a significant issue for scientists and policy makers.	a) Joint setting of 'information agenda': agree information reporting areas with scientists and end-users/stakeholders. b) Transparent decisions: be clear to end-users on reporting process including choice of overall theme and state reason for including/excluding specific information areas.
2. Expert identification	Expert bias: selecting expert or narrow group of experts known for promoting certain views/hypotheses. Not taking into account 'cognitive frailties' involved in use of expert advice (Sutherland and Burgman, 2015).	a) Comprehensive expert involvement: all individuals with relevant expertise are invited to contribute regardless of opinions/views. b) Expert representation guidance: lead authors are made to understand they are collating information to reflect consensus if it exists or the wide range of opinion in the subject area − they not gathering evidence to support their own research findings and/or opinions. They are asked for example to co-author their submission with as many scientists in the field as possible (co-authors can also be suggested by the work group overseeing the process). c) Independent peer review process: all scientific submissions should be subject to an independent review process by identified subject specialists, and not generalists.
3. Information translation	Interpretation bias: those responsible for translating the information for the policy community can introduce their own bias and opinion.	a) Clear ToRs and accountability: it must be made clear to those responsible that their role is to translate the information so it is clearer to understand for policy-makers and other end-users, not to introduce their own interpretation of the facts or data or to provide their own political opinions. Groups of individuals need to be vigilant in this and hold each other to account when it is suspected that personal opinion or bias has crept in. b) Scientists cross-check: any higher-level dissemination of the information supplied by the science community should be checked with the relevant scientists to ensure they are happy with how the information has been conveyed. c) Information and data audit: it is vital that end-users have access not just to high-level synthesis reports but to the more detailed information as supplied by the science community. This should include wherever possible access to the data and the experts who provide the analysis.
4) Information Communication	Evidence 'weighting' bias: evidence or advice may be given too much credence or credibility. This may involve the 'hype' or 'overplaying' certain statements in the media or elsewhere.	a) Confidence Assessment: a clearly understandable confidence assessment should be used alongside any evidence provision/communication. Communicating 'uncertainty' is as an essential element of communication.

these steps as a basis for identifying risks to scientific independence although 'transparency and evaluation' is included in our step 3 (information interpretation) and with our step 4 being focussed on communication.

5.1.1. SIIRMS step 1: information identification

The first step in the process is information identification, which immediately brings about risks associated with selection bias. A common accusation thrown at the climate science community is of 'cherry-picking' i.e. only choosing to report information that appears to demonstrate the effects of climate change whilst ignoring data that may reveal no effect. For MCCIP, the initial way to manage risk is to use appropriate means to set the 'information agenda' (Table 1 (1a)). Dilling and Lemos (2011) for example note that it is only when scientists and end-users agree the climate information agenda together that the science-policy interface functions in delivering 'usable science'. This process is also a useful step in terms of scientific independence as it helps prevent end-users or scientists selecting information to support a particular view. A core element of MCCIPs reporting process is agreeing the scope of future report cards with the project steering group, which includes representatives from government, NGOs, science and industry. More specific and focussed report themes are then agreed in liaison with stakeholders as illustrated specifically by considering the MCCIP report into climate change effects on fish, fisheries and aquaculture (Frost et al., 2012), where the decision to report on these areas was made as a result of extensive discussion with scientists and the policy community as well as direct discussion with government ministers (Frost et al., 2012). It is also important that decisions on what information is included are transparent (Table 1, (1b)). When for example MCCIP produced a broad topic overview update, new data relating to climate change impacts were only available for a small number of topics (MCCIP, 2013). When only these few topics were selected for reporting on it was made clear why this was the case, with the report focusing on why there was little new evidence to add (MCCIP, 2013). This means there is also transparency concerning reasons for the frequency of reporting against topics. At the topic level it is largely to do with monitoring, scientific analysis and identification of trends (MCCIP, 2013). At the practical level, reporting too frequently puts too much burden onto the scientific community (who are providing input voluntarily) including authors and reviewers, and the policy community (who do not have the resources to engage and respond on too regular a basis.

5.1.2. SIIRMS step 2: expert identification

The second step in the process is expert identification (Table 1, (2)). MCCIP is clear in its dealings with the scientific community that all experts in their field are invited to make a contribution in terms of supplying data and information for a topic (Table 1, (2a)), although guaranteeing comprehensive expert involvement is challenging with a process relying on voluntary contributors. There does of course need to be suitable individuals to lead on different topic areas and this is where strong guidance is required (Table 1 (2b)) to ensure that what is delivered represents the range of opinions in an area and the wide variety of evidence available. This may or may not point to a consensus view, which is ultimately reflected in the confidence assessment (see Section 2.2) but the information and evidence provided must broadly reflect the view of the scientific experts in the field, not an individual's own opinions or research.

Since the first report card was published in 2006, 253 different individuals have contributed as authors to MCCIP report cards, with a further 96 reviewers. Over time, the number of authors contributing to 'full' MCCIP report cards has increased greatly. For the 2013 'full' report card for example, 150 authors contributed, working out at an average of just under 5 authors per topic (compared to 37 authors in 2006, or just over one author per topic). Including reviewers, over 200 scientists contributed to the 2013 report card.

This risk of bias in information provision by experts for policy is a significant one: Sutherland and Burgman (2015) point out that methods seeking to address potential bias by combining independent opinions are well-known if little used. They also state that no method should rely on "the opinion of the best-regarded expert" or "unstructured group consensus" (Sutherland and Bergman, 2015). MCCIP seeks not just to provide useful information to policy-makers but also to provide it in a timely manner and therefore does not automatically go through a journal publication process before each 'report' is provided. This has led to the necessity of establishing a rigorous independent review process (Table 1, (2c)) that can be relied on to produce reviews to the appropriate rigour and time-scale. There is often a challenge in finding reviewers due to the strong steer to include as many of the science community as possible in initial evidence provision but this step is another key element in expert bias mitigation.

5.1.3. SIIRMS step 3: information translation

Step 3, the translation of information for policy makers and other end-users is a vital step as bias and/or errors in translation can result in inaccurate information being provided, which is therefore more likely to result in incorrect or inadequate policy decisions as well as miscommunication by the media. There needs to be mitigation therefore against those responsible for interpreting and disseminating the information also introducing bias associated with their pre-held opinions and values. The risk management steps for this part of the process begin with a clear understanding of the Terms of Reference (ToRs) by those leading on the collation and interpretation of information (Table 1 (3a)). If information is translated in such a way as to either stray into biased interpretation or to stray beyond evidence into making policy statements, then it is up to the group in the first instance to respond to this, which of course relies on the group having a high degree of awareness of subjective influences and theirs and others vulnerability to this (Sutherland and Bergman, 2015). For MCCIP these issues are addressed and formalised in a number of ways. Firstly, and embedded in the MCCIP business plan, the representatives of partner organisations at the Steering Group give responsibility for delivery of the report cards to working groups (Business Plan 2015–2020 (MCCIP, 2014) http://www.mccip.org.uk/media/1442/mccip-phase-iii-business-plan-2016-2020_final.pdf). The working group members are then mandated to contribute their individual expertise whether in science, communications or policy and not the positions of their organisation (MCCIP Steering Group 18/03/2015 − http://www.mccip.org.uk/archive/mccip-steering-group-meetings/march-2015/). The primary aim of working groups is to deliver MCCIP reports that are scientifically robust and balanced but also accessible to non-specialists. These requirements were first laid out as ToRs the Business plan published in 2008 (see Annex C in MCCIP Business Plan 2006–2010 http://www.mccip.org.uk/media/1448/mccip-business-plan-220908.pdf).

This accountability also extends to the scientists who have provided the information (Table 1, (3b)) who must be given sight of any information syntheses with the option to comment should they see any problems with interpretation, either personal bias or genuine error. In the age of open data and access to information, there is also no excuse for not keeping an audit trail (Table 1 (3c)). The original scientific submissions in the form of 'backing documents' are also made available online for anyone to access and MCCIP make it clear even on the report cards themselves exactly which institutes and individuals have been involved in submitting marine climate information. MCCIP even took a decision early on in the process that any submission to a scientific journal based on the MCCIP reporting would be published as fully open-access.

5.1.4. SIIRMS step 4: information communication

The final step in the process is an aspect of the science-policy interface that has received a great deal of attention, namely science communication (Table 1, (4a). The role of the 'confidence assessment' for MCCIP has already been described (see Section 'dealing with uncertainty') along with the need for dialogue between scientists and policy-makers to ensure his is properly understood. A confidence assessment is also important in terms of protecting the integrity of the process by preventing those responsible for communicating the information from going beyond the science to over-emphasise certain findings to support a particular position. It also prevents 'spin' or 'exaggeration' whereby weak or negative findings are portrayed in a more positive light (e.g. see recent discussion on 'spin' in clinical trial reporting by Mahtani, 2017). As public scepticism on climate change has been strongly linked to suspicions that scientists are exaggerating the issue (Whitmarsh, 2016) then the importance of this step cannot be overestimated. In practical terms, this is where the need for going on beyond straightforward provision of information to verbal communication becomes vital. Once MCCIP report cards are published a period of briefing and communication events are established (active engagement) and dialogue and discussion is offered to any individual or organisation that asks for this (responsive engagement). Examples of active engagement by MCCIP have included launch events with government ministers, policy-makers and scientist and talks given directly to government departments and agencies; and presentations at scientific conferences and meetings (national and international). Examples of responsive engagement have included invited presentations; lectures at universities and policy forums; and face to face meetings with policy-makers and advisors. It is also important to note that where discussion is required on specific scientific topics then the scientists who provided the initial technical information are asked to engage in the dialogue − it is not just left to MCCIP.

6. Conclusion and recommendations

Developing ways of communicating complex messages and implementing science-policy interface mechanisms, such as the SIIRMS model discussed here, are not ends in themselves: the idea in collating, interpreting and disseminating information on climate impacts on marine systems is to see uptake of information from the science community by policy and decision-makers so that management and forward-planning can be undertaken accordingly. MCCIP report cards and supporting evidence reviews have informed national and UK state assessments and adaptation frameworks, such the Scotland's climate change adaptation framework (Scottish Government, 2009), the Marine Planning for Wales Strategic Scoping Exercise (Welsh Government, 2015); The State of Natural Resources Report (SoNaRR) 2016 (NRW, 2016) and Charting Progress 2 (UKMMAS, 2010) and MCCIP has also been explicitly referenced in climate change legislation (Frost et al., 2016). The fact that scientific evidence on marine climate change is having such an effect on policy makes this assessment of its methodology crucial. MCCIP has achieved its goal of becoming a 'neutral clearing house for marine climate change evidence' with the MCCIP model now used worldwide and for other aspects of environmental reporting. It is therefore recommended that the findings from this review are considered for implementation by those working at the science-policy interface, namely that 1) confidence assessments are a useful way of communicating uncertainty but be clear on the limitations of this method and always supplement with direct briefings and meetings and 2) Maintaining integrity and independence is vital when operating at the science-policy interface and the SIIRMS model developed by MCCIP is recommended as a useful tool for this.

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Declaration of interest

The authors confirm that there are no known conflicts of interest associated with this publication.

References

Arrhenius, S., 1896. On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground, London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science (fifth series). April 1896, 41, 237–275.
Barange, M., King, J., Valdes, L., Turra, A., 2016. The evolving and increasing need for climate change research on the oceans. ICES J. Mar. Sci. 73 (5), 1267–1271. http://dx.doi.org/10.1093/icesjms/fsw052.
Bowen, M., 2006. Thin Ice. Henry Holt, New York ISBN 978-0-8050-6443-8.
Broecker, W., 1975. Climatic change: are we on the brink of a pronounced global warming? Science 189, 460–463.
Brownell, S.E., Price, J.V., Steinman, L., 2016. Science communication to the general public: why we need to teach undergraduate and graduate students this skill as part of their formal scientific training. J. Undergrad. Neurosci. Educ. 12 (1), E6–E10.
CMEP, 2017. Caribbean Marine Climate Change Report Card 2017. Eds. Buckley, P., Townhill, B., Trotz, U., Nichols, K., Murray, P. Clarke-Samuels, C., Gordon, A. & Taylor, M Commonwealth Marine Economies Programme, 12pp www.gov.uk/government/uploads/system/uploads/attachment_data/file/604876/Caribbean_Report_Card.pdf.
Callaway, R., Shinn, A.P., Grenfell, S.E., BURNELLG, Crumlish, M., Culloty, S., Davidson, K., Ellis, R.P., Flynn, K.J., Fox, C., Green, D.M., Hays, G.C., Hughes, A.D., Johnston, E., Lowe, C.D., Lupatsch, I., Malham, S., Mendzil, A.F., Nickell, T., Pickerell, T., Rowley, A.F., Stanley, M.S., Tocher, D.R., Turnbull, J.F., Web Wootton, G., Shields, R.J., 2012. Review of climate change impacts on marine aquaculture in the UK and Ireland. Aquat. Conserv. Mar. Freshwater Ecosyst. 22 (3), 389–421.
Callendar, G.S., 1938. The artificial production of carbon dioxide and its influence on temperature. Q. J. R. Meteorolog. Soc. 64, 223–240. http://dx.doi.org/10.1002/qj.49706427503.
Capstick, S., Whitmarsh, L., Poortinga, W., Pidgeon, N., Upham, P., 2015. International trends in public perceptions of climate change over the past quarter century. WIREs Clim. Change 6, 35–61. http://dx.doi.org/10.1002/wcc.321.
Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jager, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proc. Nat. Acad. Sci. 100 (14), 8091 July 8, 2003.
Chapron, G., 2014. Challenge the abuse of science in setting policy. Nature 516, 289.
Defra, 2005. Charting Progress An Integrated Assessment of the State of UK Seas. Defra, London.
Dilling, Lemos, 2011. Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Global Environ. Change 21, 680–689.
Fourier, J., 1824. Remarques Générales Sur Les Températures Du Globe Terrestre Et Des Espaces Planétaires. Annales de Chimie et de Physique 27, 136–167.
Frost, M., Baxter, J., Buckley, P., Cox, M., Dye, S., & Withers-Harvey, N., 2012. Impacts of climate change on fish, fisheries and aquaculture. Aquat. Conserv. Mar. Freshw. Ecosyst. 22 (3), 331–336.
Frost, M., Bayliss-Brown, G., Buckley, P., Cox, M., Dye, S., Sanderson, W., Stoker, B., Withers Harvey, N., 2016. A review of climate change and the implementation of marine biodiversity legislation in the United Kingdom. Aquat. Conserv. Mar. Freshw. Ecosyst. 26, 576–595. http://dx.doi.org/10.1002/aqc.2628.
Fung, F., Orr, H.G., Charlton, M.B., 2015. Climate change impacts report cards. Prog. Phys. Geogr. 39 (1), 130–134. http://dx.doi.org/10.1177/0309133314538894.
Grorud-Colverta, K., Lester, S.E., Airamé, S., Neeley, E., Gaines, S.D., 2010. Communicating marine reserve science to diverse audiences. Proc. Natl. Acad. Sci. 107 (43), 18306–18311.
Haunschild, R., Bornmann, L., Marx, W., 2016. Climate change research in view of bibliometrics. PLoS One 11 (7), e0160393. http://dx.doi.org/10.1371/journal.pone.0160393.
Hoffman, S., Rottingen, J.A., 2014. Split WHO in two: strengthening political decision-making and securing independent scientific Advice. Public Health 128 (2), 88–194.
Holmes, J., Clark, R., 2008. Enhancing the use of science in environmental policy-making and regulation. Environ. Sci. Policy 11, 702–711.
Howarth, C., Painter, J., 2016. Exploring the science–policy interface on climate change: the role of the IPCC in informing local decision-making in the UK. Palgrave Commun. http://dx.doi.org/10.1057/palcomms.2016.58.
IPCC (Intergovernmental Panel for Climate Change), 2013. Summary for policymakers. In: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, and New York.
IPCC (Intergovernmental Panel for Climate Change), 2014. Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA.
Jex, C., 2016. How Climate Change Changed the Face of Marine Science. (Accessed 30/6/17). http://sciencenordic.com/how-climate-change-changed-face-marine-science.
Jinfeng, L., Ming-Huang, W., Yuh-Shan, H., 2011. Trends in research on global climate change: a Science Citation Index Expanded-based analysis. Global Planet. Change 77, 13–20.
Jones, S.A., Fischhoff, B., Lach, D., 1999. Evaluating the science-policy interface for climate change research. Clim. Change 43, 581. http://dx.doi.org/10.1023/A:100549511947.
Jose, S., 2006. Should conservation biologists push policies? Nature 442 (6).
Kennel, C.F., Briggs, S., Victor, D.G., 2016. Making climate science more relevant. Science 354 (6311) 28 October 2016.
Kinzig, A., Starrett, D., 2003. Coping with uncertainty: a call for a new science-policy forum. AMBIO: J. Hum. Environ. 32 (5), 330–335.
Koetz, T., Farrell, K.N., Bridgewater, P., 2011. Building better science-policy interfaces for international environmental governance: assessing potential within the Intergovernmental Platform for Biodiversity and Ecosystem Services. Int. Environ. Agreements. http://dx.doi.org/10.1007/s10784-011-9152-z.
Kovats, S., (eds.) 2015. Health Climate Change Impacts Summary Report Card, Living with Environmental Change. ISBN 978-0-9928679-8-0.
Lackey, R., 2007. Science, scientists, and policy advocacy. Conserv. Biol. 21 (1).
Laffoley, D., Baxter, J.M., (editors). 2016. Explaining ocean warming: causes, scale, effects and consequences. Executive Summary. Gland, Switzerland: IUCN. 12 pp. https://portals.iucn.org/library/sites/library/files/documents/2016-046-Summ.pdf. Accessed 30/6/17.
Lawton, J., 2007. Ecology: politics and policy. J. Appl. Ecol. 44, 465–474.
Lorenzoni, I., Nicholson-Cole, S., Whitmarsh, L., 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. Global Environ. Change 17, 445–459.
Lowe, J.A., Howard, T., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., 2009. UK Climate Projections Science Report: Marine and Coastal Projections. Met Office Hadley Centre, Exeter, UK ISBN 978-1-906360-03-0.
MCCIP, 2006. Marine Climate Change Impacts Annual Report Card 2006. (Eds. Buckley, P.J., Dye, S.R. and Baxter, J.M.), Summary Report, MCCIP, Lowestoft, 8pp.
MCCIP, 2008. Marine Climate Change Impacts Annual Report Card 2007–2008. (Eds. Baxter, J.M., Buckley, P.J., Wallace, C.J.). Summary Report, MCCIP, Lowestoft, 8pp.
MCCIP, 2009. Marine Climate Change Ecosystem Linkages Report Card 2009. (Eds. Baxter, J.M., Buckley, P.J., Frost M.T.). Summary Report, MCCIP, Lowestoft, 16pp.
MCCIP, 2010. Marine Climate Change Impacts Annual Report Card 2010–2011. (Eds Baxter, J.M., Buckley, P.J., Wallace, C.J.). Summary Report, MCCIP, Lowestoft, 12pp.
MCCIP, 2012. Marine Climate Change Impacts on Fish, Fisheries and Aquaculture. (Eds. Frost, M., Baxter, J.M., Buckley, P.J., Cox, M., Dye, S.R., Withers Harvey, N.) Summary Report, MCCIP, Lowestoft, 12pp.
MCCIP, 2013. Marine Climate Change Impacts on Report Card 2013. (Eds. Frost, M., Baxter, J.M., Bayliss-Brown, G.A., Buckley, P.J., Cox, M., Withers Harvey, N.) Summary report, MCCIP, Lowestoft, 12pp.
MCCIP, 2014. MCCIP Business Plan 1st April 2015–31 st March 2020. http://www.mccip.org.uk/media/1442/mccip-phase-iii-business-plan-2016-2020_final.pdf. Accessed 30th June, 2017.
MCCIP, 2015. Marine climate change impacts: implications for the implementation of marine biodiversity legislation. (Eds. Frost, M., Bayliss-Brown, G., Buckley, P., Cox, M., Stoker, B., Withers Harvey, N.,) Summary Report. MCCIP, Lowestoft, 16pp.10.14465/2015. mbl00.001-016.
MCCIP, 2017. Marine Climate Change Impacts: 10 years' experience of science to policy reporting. (Eds. Frost, M., Baxter, J., Buckley, P., Dye, S., Stoker, B.,) Summary Report, MCCIP, Lowestoft, 12pp. 10.14465/2017. arc10.000-arc.
Mahtani, K.R., 2017. Beware Evidence Spin: an Important Source of Bias in the Reporting of Clinical Research. Centre for Evidence Based Reporting. (Accessed 02/06/17.). http://www.cebm.net/beware-evidence-spin-an-important-source-of-bias/.
Mastrandrea, M.D., Field, C.B., Stocker, T.F., Edenhofer, O., Ebi, K.L., Frame, D.J., Held, H., Kriegler, E., Mach, K.J., Matschoss, P.R., Plattner, G.K., Yohe, G.W., Zwiers, F.W., 2010. Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties. Intergovernmental Panel on Climate Change (IPCC). . Available at http://www.ipcc.ch (Accessed 17/7/17).
Morecroft, M.D., Speakman, L., 2015. Biodiversity Climate Change Impacts Summary Report. Living With Environmental Change. ISBN 978-0-9928679-6-6.
Morison, J.I.L., Matthews, R.B., (eds.) 2016. Agriculture and Forestry Climate Change Impacts Summary Report, Living With Environmental Change. ISBN 978-0-9934074-0-6.
Moser, S., 2016. Reflections on climate change communication research and practice in the second decade of the 21 st century: what more is there to say? WIREs Clim. Change 7, 345–369. http://dx.doi.org/10.1002/wcc.403.
NRW, 2016. The State of Natural Resources Report. https://naturalresources.wales/evidence-and-data/research-and-reports/the-state-of-natural-resources-report-assessment-of-the-sustainable-management-of-natural-resources/?lang=en.
Nerlich, B., 2010. 'Climategate': paradoxical metaphors and political paralysis. Environ. Values 19 (4), 419–442.
Nisbet, M.C., Scheufele, D.A., 2009. What's next for science communication? Promising directions and lingering distractions. Am. J. Bot. 96, 1767–1778.
Perrings, C., Duraiappah, A., Larigauderie, A., Mooney, H., 2011. The biodiversity and ecosystem services science-policy interface. Science 331. www.sciencemag.org.

Poloczanska, E.S., Hobday, A.J., Richardson, A.J., (Eds.), 2009. Report Card of Marine Climate Change for Australia (2009) NCCARF Publication 05/09, ISBN 978-1-921609-03-9.

Poloczanska, E.S., Hobday, A.J., Richardson, A.J., (Eds), 2012. Marine Climate Change in Australia, Impacts and Adaptation Responses. 2012 Report Card. ISBN 978-0-643-10927-8.

Revelle, R., Suess, H.E., 1956. Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO2 during the past decades. Tellus 9, 18–27. http://dx.doi.org/10.1111/j.2153-3490.1957. tb01849.x.

Richardson, A.J., Poloczanska, E.S., 2008. Under-resourced, under threat. Science 320, 1294–1295.

Robins, L., 2006. A model for knowledge transfer and adoption: a systemic approach to science communication. Environ. Sci. Policy 9, 1–9.

Rose, D., 2014. Five ways to enhance the impact of climate science. Nat. Clim. Change 4, 522–524.

Sarkki, S., Tinch, R., Niemela, J., Heink, U., Waylen, K., Timaeus, J., Young, J., Watt, A., Neßhover Van den Hove, C.S., 2015. Adding ßiterativity' to the credibility, relevance, legitimacy: a novel scheme to highlight dynamic aspects of science–policy interface. Environ. Sci. Policy 54, 505–512.

Scott, J.M., Rachlow, J.L., Lackey, R.T., Pidgorna, A.B., Aycrigg, J.L., Feldman, G.R., Svancara, L.K., Rupp, D.A., Stanish, D.I., Steinhorst, R.K., 2007. Policy advocacy in science: prevalence, perspectives, and implications for conservation biologists. Conserv. Biol. 21 (1).

Scottish Government, 2009. Scotland's Climate Change Adaptation Framework. http://www.gov.scot/Resource/Doc/295110/0091310.pdf.

Sutherland, W.J., Burgman, M.A., 2015. Comment: use experts wisely. Nature 526, 317–318.

Trenberth, K., 2010. More knowledge, less certainty. Nat. Rep. Clim. Change 4. http://dx.doi.org/10.1038/climate.2010.06.

Tyndall, J., 1859. On the transmission of heat of different qualities through gases of different kinds. Proc. R. Inst. 3, 155–158.

UKMMAS, 2010. Charting Progress 2: The State of UK Seas. (194pp). http://chartingprogress.defra.gov.uk.

Urwin, K., Jordan, A., 2008. Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. Global Environ. Change 18, 180–191.

Van den Hove, S., 2007. A rationale for science–policy interfaces. Futures 39, 807–826.

Wardekker, J.A., van der Sluijs, J.P., Janssen, P.H.M., Kloprogge, P., Petersen, A.C., 2008. Uncertainty communication in environmental assessments: views from the Dutch science-policy interface. Environ. Sci. Policy 11, 627–641.

Watson, R.T., 2005. Turning science into policy: challenges and experiences from the science–policy interface. Philos. Trans. R. Soc. B 360, 471–477. http://dx.doi.org/10.1098/rstb.2004.1601.

Watts, G., Anderson, M., (Eds.) 2016. Water climate change impacts report card 2016 edition. Living With Environmental Change. ISBN 978-0-9934074-1-3. Copyright (Living With Environmental Change).

Welsh Government, 2015. Marine Planning for Wales Strategic Scoping Exercise. http://gov.wales/docs/drah/publications/150521-marine-strategic-scoping-exercise-master-phase-3.pdf.

Whitmarsh, L., 2016. Scepticism and uncertainty about climate change: dimensions, determinants and change over time. Global Environ. Change 21 (2), 690–700.

Williamson, P., 2016. Take the time and effort to correct misinformation. Nature 8 (540), 171.

Winner, L., 2004. Science policy for true believers. Conserv. Biol. 18 (4), 866.