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Inter-disciplinary, multi-scale science to support society to adapt under global change

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Abstract. Factualised storytelling narratives may assist scientists to communicate inter-disciplinary, multi-scale climate change research with stakeholders and non-expert members of the community. Scientists are increasingly required to balance scientific rigour with storytelling narratives that can facilitate climate change mitigation and adaptation as new communication technologies evolve. In this editorial to the research front, 'Climate impacts on marine system structure and function: molecules to ecosystems', a review of climate change coverage in the media since 1980 showed that climate change science had a substantial voice globally and, in particular, in countries with carbon-dependent economies. However, the effective communication of multi-scale climate change research in the media can be complicated by the complex messages, the lack of training scientists receive in communication, and the traditionally distant relationship that the scientific community has with the media and, more so, with the broader community. Considerable scientific effort is being made to overcome these challenges as additional responsibility is placed on the scientific community to produce newsworthy scientific outputs. However, the integration of inter-disciplinary, multi-scale information, such as outlined in this research front, can result in more holistic climate change stories that scientists can effectively communicate with stakeholders and the broader community.

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Anthropogenic climate change is having unprecedented implications for marine ecosystems and the socio-economic values they support at regional and global scales (Harley *et al.* 2006; Pecl *et al.* 2017; Hughes *et al.* 2018). Addressing the complex and diverse impacts of anthropogenic global change requires scientists to communicate with an equally diverse and complex audience (Kerski 2015). Factualised narrative storytelling can be an important tool for communicating multi-scale and inter-disciplinary science to the stakeholders and members of the non-expert community (Dahlstrom 2014). A challenge for scientists in communicating climate change is to balance technical rigour with policy needs, while not diminishing scientific narratives that can inform climate change mitigation and adaptation (Rose 2015).

As science embraces social media, citizen science and crowd-funding, there is a concomitant need for scientists to provide information directly to the broader community, particularly about climate change (Martinez-Conde and Macknik 2017). Funding schemes, such as administered by the Australian Research Council, now require specific attention to the general communication of results. Scientific communication of climate change has previously been criticised as broad, informal and undirected (Corner and Groves 2014; Howarth and Black 2015). There have been several explanations for the failure in communication by the scientific community, most notably the information-deficit model whereby scientists have failed to provide sufficient information (Corner and Groves 2014), uncertainty of the science and the absence of consensus (Brüggemann and Engesser 2017), and the lack of engagement with the community, particularly on local levels that could facilitate change (Howarth and Black 2015).

Climate change science in the media

Lack of output is not a likely failing. A search for climate change articles in the print media (search terms are described in Appendix 1) showed that climate change science has a substantial voice globally (Fig. 1*a*). Between 1980 and 2009, the number of newspaper and magazine articles covering climate change increased (7.3%, 1.8% per decade); however, since 2010, coverage has reached a plateau at 7.34%. The greatest increase in the number of newspaper and magazine articles on climate change occurred in 2007 (3.3%; Fig. 1*a*). This followed the release of 'An Inconvenient Truth' in 2006 (Arlt *et al.* 2011) and the release of the 4th Intergovernmental Panel on Climate Change (IPCC) Assessment Report (Ford and King, 2015), which, together, brought widespread attention to climate

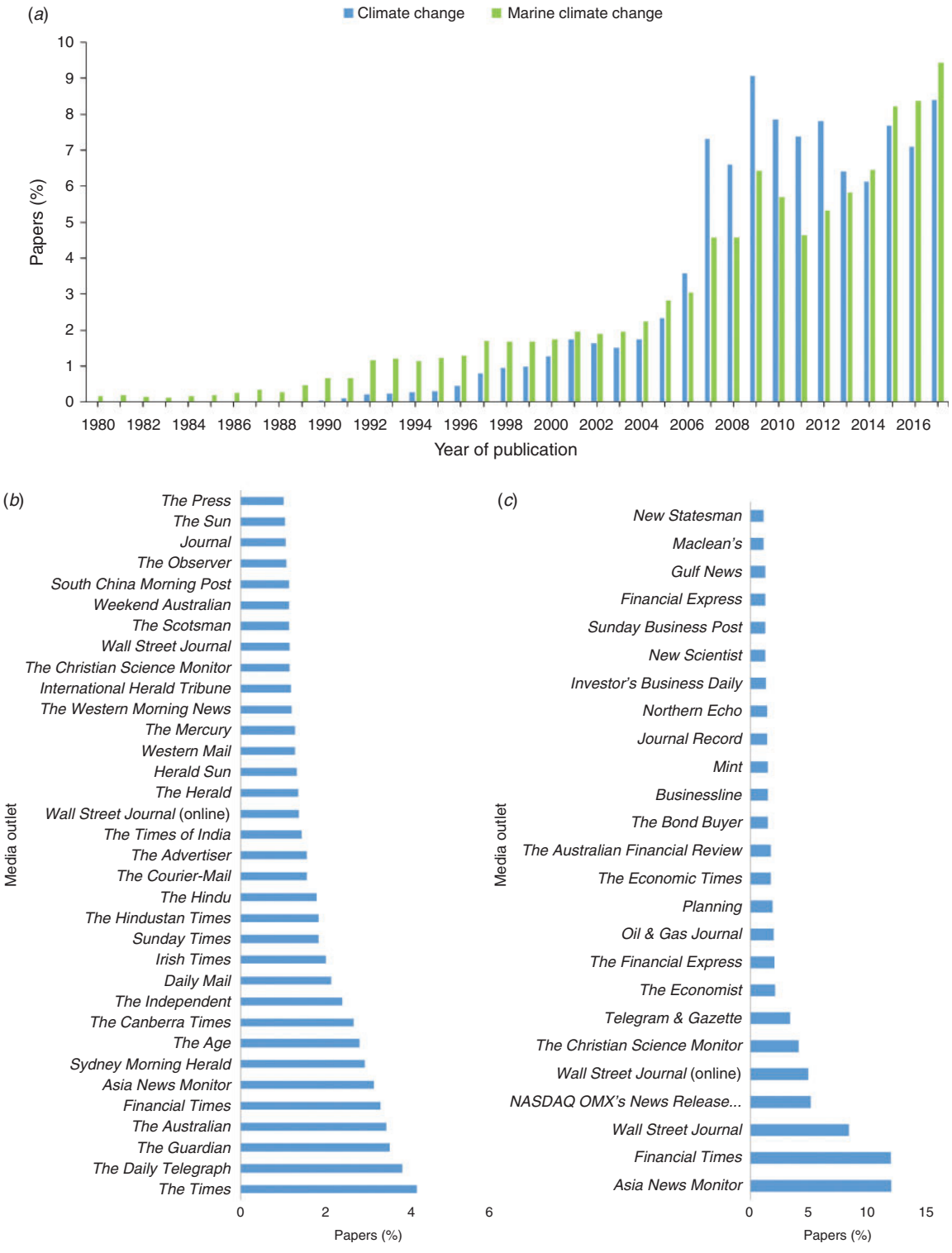

Fig. 1. News and magazine print media for climate change (1 159 725 articles) and marine climate change (229 252 articles) between 1980 and 2017: (*a*) percentage of all articles by year, (*b*) top media outlets for climate change articles, and (*c*) top media outlets for marine climate change articles.

Table 1. Newspaper and magazine coverage of climate change and marine climate change by country or region (up to 1%)
Note that Asia, Europe and Africa are included as regions

Climate change		Marine climate change	
Country or region	Percentage of articles	Country or region	Percentage of articles
United States	16	United States	38
United Kingdom	14	United Kingdom	9
Australia	12	India	5
China	7	China	5
India	5	Europe	7
Europe	4	Vietnam	3
New Zealand	3	Canada	3
Pakistan	2	Australia	2
Germany	2	Asia	2
Asia	1	Japan	2
Japan	1	Bangladesh	1
France	1	Philippines	1
Russia	1	Russia	1
Vietnam	1	Germany	1
Africa	1		

change. The majority of newspaper and magazine coverage of climate change since 1980 has been in mass-media outlets, such as *The Times* (Fig. 1*b*).

Coverage of marine climate research has also increased in newspaper and magazine media since 1980 (6.5%, 1.6% per decade; Fig. 1*a*), paralleling trends in scientific publishing (Hobday and Cvitanovic 2017). Media outlets reporting on marine climate change are focused primarily on industry and trade such as the *Wall Street Journal* and *Financial Times* (Fig. 1*c*). The prominence of these media outlets for marine climate change articles indicates the socio-economic importance of marine resources and industries and the need for interdisciplinary approaches in marine climate change research. Developments in digital media channels now allow even wider and more direct communication with the non-scientific community; many scientists are now directly accessing such channels for wide dissemination of results (e.g. Côté and Darling 2018).

Citizens of countries that have carbon-dependent economies, such as the USA, China and regions of the Middle East and Europe, have less concern for climate change than do those of countries that are not reliant on carbon resources (Stokes *et al.* 2015). However, these countries have media that devote substantial reporting effort to climate change (Table 1). Schäfer *et al.* (2014) showed that media interest in climate change in India, Australia and Germany increased with activities of political and environmental non-governmental organisations (ENGOs) such as conference of the parties (COP) meetings and Greenpeace events. A challenge for scientists is to take traditional scientific reporting methods (peer-reviewed papers and discipline-specific conference proceedings) and transfer that information into popular communications. This requires a shift from the communication of impersonal and technical climate science facts to styles that provide a broad picture of system change to which a range of audiences can relate. Digital channels now directly provide that opportunity for scientists (e.g. *The Conversation*, *OceansDeeply*, TED talks).

Both print and digital media provide an important forum for climate change impacts and adaptation and mitigation options to be presented and discussed with the community because media is the primary information source for the majority of people (Ford and King 2015). Effective utilisation of media coverage by scientists may also encourage policy makers to act on climate change (Schmidt *et al.* 2013). However, most traditional media outlets and a range of digital platforms are profit-seeking businesses, and are not watchdogs or advocates for social wellbeing and reform (Corbett 2015; Bolsen and Shapiro 2018). For example, Hulme (2007) investigated the reporting of the 4th IPCC Assessment Report and showed that 9 in 10 UK newspapers that ran stories on the report contained emotive adjectives that elicited fear responses and made unsubstantiated claims (O'Neill and Nicholson-Cole 2009). Additional responsibility, thus, lies with scientists when translating scientific output into newsworthy stories for print and digital media. Scientific organisations are increasingly communicating climate science directly to public; however, these public-relations opportunities are not yet being fully utilised by the scientific community (Lee *et al.* 2018). Digital media now provides wide opportunity to reach audiences via websites, blogs and tweets (Côté and Darling 2018), with many scientists being active in this forum.

Multi-scale climate change communication

However, communication can be difficult because scientists are not generally trained in general communication. Climate-related research also covers multiple scales (McDonald *et al.* 2018), further complicating public engagement as messages can be complex or appear inconsistent, depending on the scale being discussed. As described in McDonald *et al.* (2018), scientific disciplines conduct climate change research on multiple spatial, temporal and biological scales that often can result in difficulties with exchange of knowledge across these scales. For example,

Hauser *et al.* (2016) reported that physical and chemical oceanographers conducted research at much larger scales than did biologists. These differences in focal scales impede not only the scientific understanding of marine ecosystem implications, but also the uptake of information into climate change policy (Baker and Hollowed 2014), particularly if temporal scales of information and decision making are not aligned. It is, therefore, an essential first step that the scientific community find methods of overcoming these differences and exchange knowledge on climate change impacts across scales (McDonald *et al.* 2018).

Papers in this research front show how climate change-related disciplines can be integrated for a better understanding of the multi-scale impacts and mechanisms of climate change. They illustrate inter-disciplinary climate change research in marine systems across spatial, temporal and biological scales and each provides novel insights from 'omics' to systems ecology. At the smallest scale, molecular analysis can reveal a range of previously hidden patterns, including dietary linkages. The first paper (Devloo-Delva *et al.* 2019) used molecular analysis of socio-economically important large tropical fish and their diet to provide information on the trophic status of the ecosystem. This paper includes the first comparison of genetic markers used to study diets, and noted that the substantial variability in the accuracy of the markers is important to consider when designing research experiments. Their approach can be applied to other genetic research, including biomonitoring of ecological shifts with climate change and analyses of the changes in diets in a range of species.

Diets can also be disrupted if a changing climate leads to spatial or temporal mismatches between predators and their prey. A multi-scale approach was used by Owen *et al.* (2019) to explore the foraging behaviour of large marine mammals that feed on microscopic plankton. These authors used a novel mixed modelling approach conducted on both a medium scale (tens of kilometres) and a fine scale ($<$1 km). Sea-surface temperature (SST) was identified as a driving mechanism for changes in the foraging behaviour of baleen whales, which may have important implications as SST increases with climate change. Their findings also support the theory that whales may be able to track preferred environmental conditions to seek prey, which could assist them to adapt and find suitable habitat under altered environmental conditions.

Altered habitat-suitability and climate-driven shifts in kingfish distribution were investigated by Champion *et al.* (2019). Their analyses were conducted on near-future management-relevant scales (up until 2040) and predicted a poleward increase in habitat suitability and a decline in habitat suitability in the equatorial limits of six bioregions in south-eastern Australia. The forecast of habitat suitability under global change will be important for the management of valuable fisheries resources under climate change, and links both present and future time scales that are relevant to decision-makers.

Climate change can modify habitats and ecosystems; however, without baseline information, the degree of change cannot be assessed. Linklater *et al.* (2019) used a novel technology to map and characterise mesophotic corals on the subtropical shelves of Lord Howe Island and Balls Pyramid in the south-eastern Pacific Ocean. High-resolution video data were analysed to characterise the habitat cover in these locations, so as to assist management of the Marine Park and World Heritage Area. The characterisation of these reefs provides a critical baseline to the future management of these areas that may provide refugia for coral ecosystems under climate change.

Given widespread and diverse impacts of climate change across marine regions, research activity that is coordinated and focused is desirable. A recent program that supported research on climate change impacts and adaptation strategies for Australian marine systems was assessed by Ling and Hobday (2019). Their evaluation of the National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources found that structured, well conducted research programs could achieve the delivery of rapid and direct scientific information that is required for addressing climate change challenges. This effective implementation of a climate change research strategy is a crucial consideration in the allocation of funding and resources to climate change research and the capacity for marine socio-economic sectors to adapt to rapid climate change.

The research front concludes with a scientific perspective of the inter-disciplinary climate change science that is required to address multi-scale climate change impacts that will challenge sustainability and societal wellbeing (Alexander *et al.* 2019). The barriers and incentives for applying ecosystem-based management research are discussed from the shared perspective of experienced researchers and early career scientists. The area where most effort is needed was in 'understanding the ecosystem' where system dynamics, system boundaries, spatial and temporal distributions of resources, economic values, histories of resource use, property-rights systems, and collective-choice rules all require improved inter-disciplinary literacy and knowledge exchange. Through improving the inter-disciplinary research that underpins ecosystem-based management, decision making in socio-ecological systems may be better prepared to address the impacts of climate change.

Discussion

The papers contained in this research front clearly span disciplinary and scale boundaries, illustrating wide-ranging impacts of climate change from dietary shifts to altered ecosystem structure. Novel techniques, including genetics and biotelemetry, can reduce the time required to understand and characterise these impacts. The integration of inter-disciplinary, multi-scale information can similarly speed up the pace of scientific studies. Collaborations that further facilitate knowledge exchange were evident in these papers, such as the use of fisheries forecasts to guide ecosystem-based management. These opportunities for further collaboration and knowledge exchange across more distant disciplines should improve the inter-disciplinary approaches to climate change by scientific communities and result in more holistic climate change stories that scientists can effectively communicate with stakeholders and the broader community. An important focus of several papers was to provide information for supporting socio-economic values of marine systems under climate change. Although the implementation of scientific research into climate change decision making may not be happening to the extent that some scientists would like (Munck af Rosenschöld *et al.* 2014), it is clear that many scientists are making extensive efforts to communicate (or even co-produce) scientific

information with stakeholders, including policy makers (e.g. Cvitanovic *et al.* 2015).

Scientists, policy makers and the media all play a role in the preparation and implementation of climate change responses; therefore, it is important that the relationships among them are effective (Cvitanovic *et al.* 2015; Legagneux *et al.* 2018). Although bridging disciplinary and scale boundaries in marine climate change research brings additional complexity, such studies must also be communicated to the media and policy makers. Although challenging, engaging in, and communicating multi-scale, inter-disciplinary research is critical to addressing the climate change problems now facing marine environments, and society in general.

Conflicts of interest

The authors, acting as guest editors for this research front, declare that they have no conflicts of interest.

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Appendix 1. Data were collected from the ABI/INFORM collection on 28 August 2018

The following search parameters were used as indicative of climate change articles

	Search parameter	Source
Climate change	'Climate change' or 'environmental change' or 'global warming'	Newspapers or magazines
Marine climate change	'Climate change' or 'environmental change' or 'global warming' and 'marine'	Newspapers or magazines