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# Stakeholder perceptions on actions for marine fisheries adaptation to climate change

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**Abstract.** Fisheries are under threat from climate change, with observed impacts greater in faster-warming regions. This research investigated current and future potential for climate adaptation to be integrated into fisheries management strategies using Tasmanian commercial wild-catch fisheries as a case study, and then identified obstacles and recommendations for fisheries management to better adapt to future climate changes. We conducted qualitative interviews with fisheries stakeholders and experts to identify their perceptions of the effects of climate change on commercial wild-catch fisheries and local marine ecosystems, as well as opportunities for enhanced management in the future. The results show that climate adaptation in Tasmania fisheries management has largely been passive or incidental to date, and suggested future improvements may incorporate: (1) more or different scientific information and better application; (2) government reviews, reforms and stronger action; (3) industry changes and taking responsibility for the issue; (4) gaining more funding and resources; and (5) increasing education, extension and interaction among stakeholder groups. Implementation of the recommendations suggested in this study would help create a more forward-thinking and proactive response to climate change for Tasmanian fisheries, as well as a more flexible and resilient fishing industry that is better able to absorb shocks related to climate change.

**Keywords:** climate adaptation, fisheries management, planning, recommendations, Tasmanian fisheries.

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## Introduction

Climate change is already having significant effects on oceans around the world (Intergovernmental Panel on Climate Change 2014). Marine systems are affected by climate-driven physical and chemical changes, including changes in water temperature, salinity, acidity and upwelling and current strength and direction (Brierley and Kingsford 2009; Pörtner *et al.* 2014; Weatherdon *et al.* 2016). Climate change is also known to affect changes in species characteristics and dynamics, leading to changes in species distributions, abundance and phenology (Brierley and Kingsford 2009; Johnson *et al.* 2011; Pecl *et al.* 2014*a*). These effects have considerable impacts on fisheries, requiring changes in jurisdictional management processes, and fishing location or duration (Brander 2010; Barange *et al.* 2018; Hobday *et al.* 2018*a*; Townhill *et al.* 2019; Pinsky *et al.* 2021).

Adaptation, a broad term (Adger *et al.* 2007) that has been used to describe both biological and human adaptation, is used here in reference to adaptation relevant to socioecological systems. Adaptation and improving adaptive capacity are crucial to ensuring an adequate response to the risks posed to fisheries by climate change (Barnett and Campbell 2010). Adaptation can take many forms and can be identified through a range of mechanisms; however, it is argued that those adaptations derived from multiple stakeholder perspectives (as opposed to using singular perspectives) may be most effective because they can help mitigate maladaptation (e.g. implementing inefficient strategies or increasing the vulnerability of other areas or groups; Barnett and O'Neill 2010; Radhakrishnan *et al.* 2017). For example, the risk of implementing adaptations derived from the perspectives of only policy makers or experts may result in the responsibility for adaptation being placed on local adjustments and technomanagerial measures, perhaps overlooking social struggles (Reid *et al.* 2009; Eriksen *et al.* 2015). It is therefore important to consult with all relevant stakeholders when developing adaptation strategies, including industries and communities, so as not to delegitimise local knowledge or exacerbate marginalisation (Grafton 2010; Eriksen *et al.* 2015). Additional benefits of the consultation process to develop adaptation strategies may include improved relationships and mutual understanding and trust between stakeholders (e.g. managers, fishers, researchers and communities), as well as better buy-in and support from fishers and broader industry about why particular changes are needed (Grafton 2005; Pecl *et al.* 2009).

With this in mind, the discussion of possible fisheries management adaptation options to address climate change with diverse stakeholders has become more widespread in recent years, with favoured options including conducting vulnerability assessments, managing and protecting important habitats, assisted migration, comanagement, marine protected areas and adapting to benefit from migrating or redistributing species (Furgal and Prowse 2008; Daw *et al.* 2009; Johnson 2012; Kovats *et al.* 2014; Magrin *et al.* 2014; Niang *et al.* 2014; Romero-Lankao *et al.* 2014). Actors that have taken action to address climate impacts around the world include managers, scientists and industry (Bell *et al.* 2020). Currently, there are limited examples of implemented adaptation actions and an evaluation of outcomes (Lindegren and Brander 2018; Bell *et al.* 2020; Sumby *et al.* 2021), with studies mainly focusing on frameworks and principles of adaptation planning in marine systems (Lindegren and Brander 2018; Miller *et al.* 2018), and planned adaptation actions within human systems discussed within the literature at low rates (Berrang-Ford *et al.* 2011). Adaptation by local governments in coastal communities is largely lacking, or in the early stages, and is narrowly focused (Bradley *et al.* 2015). Implemented autonomous adaptations to climate change are also rarely discussed, but this non-government form of adaptation is occurring in the marine space because many find it a more rapid approach to adaptation (Ojea *et al.* 2017; Pecl *et al.* 2019*a*). Failing to facilitate autonomous adaptation as part of management and policy responses may leave fishers vulnerable to climate change (Pecl *et al.* 2009, 2019*a*). In light of these gaps, the aim of this study was to investigate what strategies are currently in place, how effective they are, what is not currently working and what changes would make fisheries adaptation to climate change better and more effective.

The aims of this study were addressed through qualitative interviews of fisheries stakeholder groups (i.e. managers, researchers and industry representatives) in the region of Tasmania, Australia. Tasmanian waters are some of the fastest-warming waters in the world (Hobday and Pecl 2014) and thus fisheries within this region represent some of the most at-risk from the effects of climate change. Further, Tasmania is recognised as an adaptation hotspot, where autonomous climate-related adaptation in the marine sector is actively occurring (Frusher *et al.* 2014; Pecl *et al.* 2019*a*); thus, key stakeholders within this region are uniquely placed to provide perspectives on adaptation of fisheries based on existing activities and efforts. Although this research is based on Tasmanian fisheries, the results may be relevant to other Australian fisheries and fisheries internationally, particularly where rapid environmental change is occurring.

## Materials and methods

This study investigated current and future adaptations of fisheries and fisheries management to climate change using Tasmanian commercial wild-catch fisheries. Qualitative interviews were conducted with Tasmanian fisheries managers, academics and industry representatives using an interview guide and were designed following the methods described in Cvitanovic *et al.* (2016, 2018) to develop an in-depth understanding of these stakeholders' perceptions regarding the obstacles and changes necessary to current management strategies and practices. Evaluations of the objectives of fisheries adaptation to climate change have been assessed previously (Jennings *et al.* 2016). However, this study is the first time this approach has been used to investigate fisheries management adaptation and to provide stakeholder-derived recommendations for improving fisheries adaptation to long-term environmental changes like climate change.

### *Study region*

Tasmania is the most southern Australian state; it is an island separated from mainland Australia by Bass Strait and has distinctive and diverse temperate rocky reef marine ecosystems (Cresswell 2000; Edgar *et al.* 2004; Barrett *et al.* 2007; Oliver *et al.* 2016). The climate-driven poleward extension of the warm-water East Australian Current (EAC) over recent decades (Ridgway 2007; Ridgway and Hill 2012), amplified by recent marine heatwave events (Oliver *et al.* 2017; Perkins-Kirkpatrick *et al.* 2019), has led to environmental and ecosystem changes along the Tasmanian coastline (Johnson *et al.* 2011; Last *et al.* 2011; Gervais *et al.* 2021) and recognition of Tasmania as a 'climate hotspot'. Tasmanian commercial fisheries (Box 1) are affected by these changes and are exposed to risks relating to future climate-related impacts. Investigating the climate-driven changes and impacts observed in Tasmania provides other similar regions with an early warning for what to expect from climate change and what management strategies may be useful (Hobday and Pecl 2014; Pecl *et al.* 2014*b*).

### *Data collection*

To address the objectives of this study we used a qualitative research approach, conducting semistructured interviews with participants between August 2019 and August 2020. These methods allowed us to generate a set of stakeholder-derived recommendations and to identify key obstacles to overcome in order to enhance commercial fisheries management in Tasmania. The interview guide addressed nine themes over three research objectives. The three research objectives addressed were: (1) current and future expected climate change impacts on fisheries and local marine environments; (2) management responses to observed climate change impacts; and (3) costs, obstacles and future improvements for fisheries management adaptation to climate change. The nine themes were: (1) examples of climate change impacts; (2) expected environmental changes and impacts; (3) how climate change is broadly addressed by organisation or research; (4) management

**Box 1. Description of the commercial wild-catch fisheries in the case study area, Tasmania**

**Case study: Tasmanian commercial wild-catch fisheries**

Tasmania has a wild-catch fisheries seascape composed of six main commercial fisheries: abalone, rock lobster, giant crab, scallop, scalefish and commercial dive (urchins, periwinkles, clams and seaweed), the largest and most valuable of which are the commercial rock lobster and abalone fisheries. Tasmanian commercial wild-catch fisheries held a total production value of A$194.3 million (US$142 million; 5314 tonnes) in 2017–18, accounting for 18% of Tasmania's seafood gross value production (GVP), the largest seafood GVP of any Australian state (Steven *et al.* 2020). Tasmanian state fisheries employed 778 people (full-time equivalent) directly and 564 people indirectly in 2017–18 (Fisheries Research and Development Corporation 2019). In addition, Tasmania has various recreational and Indigenous fisheries, with 22% of Tasmanian residents (98 000 people) participating in recreational fishing activity at least once a year (Lyle *et al.* 2014). Tasmanian commercial wild-catch fisheries are managed by the Wild Fisheries Management Branch of the Tasmanian Government Department of Primary Industries, Parks, Water and Environment, through overarching legislation (the *Living Marine Resources Management Act* 1995), as well as individual management plans for each fishery set as legislation and harvest strategies that are issued and updated by the Wild Fisheries Management Branch. Tasmanian fisheries management documents currently do not prominently discuss the effects of climate change on the industry or associated environments; however, this may be included in stock assessments for individual fisheries (Fogarty *et al.* 2020). Decisions on important issues around commercial wild-catch fisheries management in Tasmania are issued by the Fisheries Minister (local member of parliament), and may or may not be based on recommendations and advice provided by a fishery advisory committee (FAC), the peak advisory group for each major Tasmanian fishery (Department of Primary Industries, Parks, Water and Environment 2020). The Fisheries Minister must seek consultation over key arrangements, such as size limits, seasonal closures, gear restrictions and total allowable catches (TACs). FAC meetings are generally held two to four times per year for each fishery, with membership made up of a diverse range of fishery stakeholders (Department of Primary Industries, Parks, Water and Environment 2020). Management methods in place for many of these fisheries include gear restrictions, limited entry, quotas, size limits, spatial closures, temporal closures and TAC limits (Fisheries Research and Development Corporation 2020). For further information on the target species, production values, management and environmental drivers of these major commercial wild-catch fisheries in Tasmania, see the 'Case study: Tasmanian commercial wild-catch fisheries' section in the Supplementary material.

responses to current climate impacts; (5) the effectiveness of responses; (6) the assessment of the effectiveness of responses; (7) costs of management changes; (8) obstacles or barriers; and (9) necessary changes and future improvements.

In all, 28 stakeholders were identified as relevant to the aims of this study and were contacted and invited to take part in the interviews. Of these 28 fisheries stakeholders, interviews were completed with 16 (57% response rate): 7 fisheries managers, 7 academics and 2 industry representatives who agreed to take part in the study. Analysis of the interview transcripts revealed that the cumulative number of new concepts (i.e. themes derived from the raw data) encountered during interviews started to plateau after approximately 8 interviews, and theoretical saturation of concepts was reached after analysis of the 13th interview (Fig. S1 of the Supplementary material). However, to ensure that new concepts would not emerge, an additional three interview were undertaken.

Although there is no universally accepted appropriate sample size for the analysis of qualitative interviews as used in this study, the evidence suggests that theoretical saturation often occurs after ~12 interviews (see Guest *et al.* 2006; Baker and Edwards 2012). Further, of the interview participants, 14 had been with their organisation for over 10 years, and 11 of the participants are members of, or sit on councils, committees or associations related to, Tasmanian commercial wild-catch fisheries and so have extensive knowledge of the topics covered in this study. Because Tasmanian commercial wild-catch fisheries are managed by only a relatively small government department and the University of Tasmania is a small institution relative to other Australian universities, seven participants from each of these groups provided substantial coverage of fisheries leaders in Tasmania. After numerous attempts to establish contact for interviews with industry representatives, we were able to conduct two interviews within this group. Therefore, due to the uneven sample size between stakeholder groups, we analysed our data as one large group unless there were contrasts in answers, where individual stakeholder groups were analysed.

The fisheries managers who participated in interviews were employees of the Tasmanian Government Department of Primary Industries, Parks, Water and Environment. Potential industry representative participants were invited to take part in the study based on their affiliation with leading representative organisations and activity on fishery advisory committees. Potential academic interview participants were approached initially based on the search results for lead researchers in Tasmanian fisheries and climate change using Scopus (www.scopus.com). The first search included three search terms, 'Tasmania*' AND 'Fisher*' AND 'Climat*', and the second search included the same three terms plus 'Manage*'. Both searches returned mostly the same author names, but with minor differences in the order of names based on the number of articles published. Academics were contacted in order based on the number of publications in these searches. Two of the authors of this paper were identified in this search as leaders in Tasmanian fisheries and climate science and were selected for interview. At the end of each interview, participants were asked whether they were aware of anyone who could provide an interesting insight or perspective, and subsequently two academics were interviewed due to this 'snowball sampling' method (Sadler *et al.* 2010).

All interviews were undertaken by a single member of the research team (HF) to ensure a consistent approach, and were guided by a set of questions (i.e. an interview guide) designed to explore the perceptions of participants around how Tasmanian commercial wild-catch fisheries can better prepare for, and adapt to, long-term environmental changes like climate change. The interview guide was developed with the intention of the questions addressing the aims of this study, and was then tested with research associates of the authors. This test resulted in some refinements in the wording of some questions for clarity, but no major changes to the interview guide were required. Interview participants were all asked the same questions, with minor terminology changes depending on stakeholder group (e.g. one question asked about the stakeholders' organisation when directed to managers and industry representatives, but asked about the stakeholders' research when directed to academics). The interview guide is available in the 'Interview Guide' section in the Supplementary material.

Prior to commencing each interview, the purpose of the research was explained to the participant and formal written consent was obtained (in accordance with human research ethics requirements). Thirteen interviews were conducted face to face, and another three were conducted remotely during the COVID-19 lockdown and restrictions. Interview recordings lasted between 20 and 49 min, with a mean duration of 33 min. All interviews were audio recorded and were transcribed by either the lead author (HF) or by a professional transcription service.

This study was approved by the Tasmanian Social Sciences Human Research Ethics Committee (Approval reference: H0018116).

### *Data analysis*

All interview transcripts were analysed using NVivo R1 qualitative data analysis software (QSR International, see www.qsrinternational.com). The analysis consisted of broad thematic coding against research objectives following established methods (Charmaz and Belgrave 2012; Saldaña 2015; King *et al.* 2018; Blythe and Cvitanovic 2020). Interview questions were designed to: (1) understand Tasmanian commercial wild-catch stakeholder perceptions of how climate change has, and is expected to, affect Tasmanian commercial wild-catch fisheries; (2) explore the extent to which existing fisheries management strategies and practices address long-term environmental changes, like climate change, and how effective those responses have been; and (3) identify the obstacles and barriers that prevent fisheries adaptation to climate change, and what changes are deemed necessary for future improvement in Tasmanian commercial fisheries management to ensure the longevity and sustainability of Tasmanian fisheries in the face of future climate change. The interview questions and research objectives formed the basis of the coding structure, with analysis of the raw data following an inductive approach based on grounded theory analysis (Glaser and Strauss 1967) so that the research findings could emerge from the interviews without restrictions imposed by structured methodologies (Hay 2010). Therefore, each individual response was identified and then secondarily categorised into themes, and evolving interpretations were frequently verified against the raw data from which they originated. Finally, the main recommendations on improving climate adaptation within fisheries were divided into four categories to be more easily applied to relevant sectors, namely scientific-, government- and industry-led opportunities, as well as cross-cutting opportunities.

## Results

The analysis produced 59 main themes encountered across the 16 interviews, spread over the nine research subobjectives of the interview guide, that could be grouped into three categories (Table 1) as detailed below.

### *Current and expected future effects of climate change on fisheries and local marine environments*

This section outlines the results of two research subobjectives of the interview guide: (1) examples of observed climate change impacts; and (2) expected environmental changes and impacts on local marine environments, ecosystems and fisheries related to climate change and other long-term environmental changes.

When asked to provide current examples of likely climate change impacts on Tasmanian commercial wild-catch fisheries

**Table 1. Outline of the research objectives and subobjectives explored through the interview guide, and the number of main themes encountered during the interviews**

| Research objectives | Research subobjectives of the interview guide | Number of main themes encountered |
|---|---|---|
| Current and future expected climate change impacts on fisheries and local marine environments | Examples of observed climate change impact | 4 |
| | Expected environmental changes and impacts | 12 |
| Management responses to observed climate change impacts | How climate change is broadly addressed by organisation or research | 9 |
| | Management responses to current climate change impacts and long-term environmental changes | 7 |
| | Effectiveness of the response | 4 |
| | Assessment of the effectiveness of the responses | 3 |
| Costs, obstacles and future improvements for fisheries management adaptation to climate change | Costs of management changes | 7 |
| | Obstacles or barriers to effective climate adaptations | 7 |
| | Necessary changes and future improvements | 6 |

or local marine environments, participants identified four changes (Table 2). 'Warming water effect on nutrient levels and species' was mentioned most frequently and by all 16 participants (Table 2). The warming of water having negative effects on species was spoken about by 15 participants (e.g. declining abalone productivity; loss of kelp forests affecting rock lobster and abalone populations), with only three participants mentioning positive biological effects on local species of warming water. The occurrence of climate-driven range extensions linked to warming water was also mentioned by 15 participants (Table 2), of whom 10 specifically referenced the climate-driven range extension of *Centrostephanus rodgersii*, the long-spined sea urchin, and its devastating effects on local ecosystems, rock lobster and abalone stocks, as well as the potential benefits of having a new viable ongoing fishery and economy as a control method for the species. Other examples of climate-driven extensions in species range were mentioned by 10 participants and potential beneficial effects for the state were highlighted, because these changes are seen as positive for recreational fishers and some species may become commercially viable if their abundance increases.

When asked about the expected changes to Australian fisheries, participants identified seven main themes (Table 2). Of these, 'oceanographic changes' were mentioned most frequently when considering a longer-term (10- to 50-year) timescale (mentioned by 13 participants), followed by references to 'regime shifts' (mentioned by 12 participants). For longer-term oceanographic changes, participants primarily spoke about increased water temperature, marine heatwave events, lower productivity, changes to the strength of currents such as the EAC and direct effects of ocean acidification on commercially important crustaceans and molluscs (Table 2). Changes in species biomass and abundance, climate-driven species redistributions and ecosystem or species collapse or local extinction were the most mentioned longer-term regime shifts (Table 2). Similarly, when asked to consider the effects of climate change on Australian fisheries over shorter time scales (over the next 5 years), participants most often identified effects relating to regime shifts (mentioned by five participants) and oceanographic changes (mentioned by four participants; Table 2). More specifically, participants mentioned an increased prevalence of diseases, viruses and toxins, an increased prevalence of climate-driven range extensions for some species, changes in species biomass and abundance, increasing water temperature with potential marine heatwaves and warm-water events and increasing ocean acidification.

### Management responses to observed climate change impacts

This section outlines the results of the first four research subobjectives of the interview guide: (1) how climate change is broadly addressed by organisation or research; (2) management responses to current climate change impacts and long-term environmental changes; (3) the effectiveness of these responses; and (4) assessment of the effectiveness of responses.

When asked to identify how their organisation (for managers and industry representatives) or research (for academics) addresses climate change in relation to fisheries, participants identified nine main themes (Table 3). Eight participants identified that organisational climate change adaptation is minimal, and that climate change is largely addressed indirectly through normal fisheries management and activities (e.g. through traditional management levers that are adjusted in response to changes in stock biomass, recruitment or environment; and that climate is an underpinning driver of the social issues and pressures that relate to fisheries management; Table 3). Six participants mentioned that climate change is being addressed by fisheries stakeholders through collaboration, communication

**Table 2. Main themes mentioned by interview participants relating to current observed and future expected changes and impacts to local marine environments, ecosystems and fisheries, related to climate change and other long-term environmental changes**

Sources, the number of participants who mentioned each 'main theme' (maximum $n = 16$); frequency, the number of new mentions of a 'main theme' by participants

| Research subobjective of interview guide | Main themes encountered in the interview | Sources | Frequency |
|---|---|---|---|
| 1. Observed climate change impact examples | Effects of warming water on nutrient levels and species | 16 | 75 |
| | • Local biological changes due to warming waters | 15 | 38 |
| | • Climate-driven range extensions due to warming water | 15 | 34 |
| | • East coast of Tasmania has been worst affected by climate change impacts (compared to the rest of the Tasmanian coastline) | 3 | 3 |
| | Ocean acidification has negative effects on local species | 2 | 2 |
| | Positive changes and effects modest compared with negative changes and effects | 1 | 2 |
| | Higher rainfall and increased freshwater run-off lead to species shifting into deeper waters | 1 | 1 |
| 2. Expected environmental changes and impacts | Regime shifts | 15 | 37 |
| | Oceanographic changes | 13 | 36 |
| | More of the same changes and impacts we see today | 7 | 9 |
| | Temporal changes and biological impacts | 3 | 4 |
| | Possible recovery, improvements and increased resilience | 2 | 5 |
| | Increased variability across everything (e.g. weather, species abundance, fishing seasons) | 2 | 2 |
| | Unsure (hard to predict and anticipate what the effects will be) | 2 | 2 |

**Table 3. Main themes mentioned by interview participants relating to current and previous Tasmanian fisheries management responses to climate change and long-term environmental changes, and the effectiveness of those management responses**

Sources, the number of participants who mentioned each 'main theme' (maximum $n = 16$); frequency, the number of new mentions of a 'main theme' by participants

| Research subobjective of interview guide | Main themes encountered in the interview | Sources | Frequency |
|---|---|---|---|
| How climate change is broadly addressed by organisation or research | Climate change adaptation is minimally or indirectly addressed through normal fisheries management and activities | 8 | 16 |
| | Through government, industry and science collaboration, communication and engagement to develop projects to help fisheries prepare | 6 | 9 |
| | Not yet taking a long-term strategic view or approach | 4 | 7 |
| | Undertaking research to understand and predict the effects of climate change | 2 | 4 |
| | Industry encouraged to be conscientious and environmentally friendly | 2 | 2 |
| | Industry tries to be flexible and keep up to date with new fishing methods and gear | 1 | 2 |
| | Outreach and communication with the public to reach a wider audience | 1 | 1 |
| | Climate change is a scapegoat for stock dynamics changing from fishing pressure (i.e. climate change is used as an excuse to cover or explain away changes caused by humans) | 1 | 1 |
| | Climate change is talked about a lot, but not specifically addressed | 1 | 1 |
| Management response to current climate impacts[A] | Traditional management levers implemented by government | 13 | 26 |
| | Government, industry and science collaborations | 8 | 16 |
| | A passive response to climate change | 5 | 5 |
| | No climate change management response or strategic approach to climate adaptation | 4 | 5 |
| | Industry intervention methods | 2 | 3 |
| | Long-term view and precautionary approach | 2 | 3 |
| | Modelling changes | 1 | 1 |
| Effectiveness of response | Positive outcome or positive early signs | 8 | 14 |
| | Not applicable or difficult to differentiate (no management changes were identified as directly responding to climate change) | 7 | 7 |
| | Hopeful, but too soon to tell how effective responses have been | 2 | 3 |
| | Inadequate response | 1 | 2 |
| Assessment of effectiveness | Stock assessments and monitoring | 10 | 15 |
| | We do not assess the effectiveness | 10 | 13 |
| | Industry and government communication and engagement | 1 | 1 |

[A]Impacts as identified by participants in the Research Subobjective 1 in Table 2.

and engagement between government, industry and science (e.g. government engages with scientists and industry on projects to address climate change; and using communication and engagement to increase awareness of climate change and increase scientific understanding and literacy). However, by contrast, four participants mentioned that some organisations and research efforts are not yet taking a long-term strategic view or approach to fisheries climate change adaptation (Table 3).

When asked their opinions of how the management agency or industry has responded to the changes and impacts on certain fisheries (identified by participants in an earlier question: Table 2, Research Subobjective 1), participants identified seven main themes (Table 3). Thirteen participants identified that changes and impacts are addressed through traditional management levers implemented by government (Table 3). Eight participants mentioned that government, industry and science collaborations were taking place to respond to long-term changes and impacts (Table 3), such as the Abalone Industry Reinvestment Fund, which was developed to invest industry fees and additional funding into research, recovery of the abalone fishery and subsidising the harvest of long-spined sea urchin *C. rodgersii*. Five participants mentioned that government and industry responses to climate change were passive because it is difficult to differentiate and separate the effects of climate change from other influences (Table 3). Furthermore, four participants mentioned there is currently no climate change management response or strategic approach to climate change adaptation being undertaken (Table 3).

When asked about the effectiveness of the responses they reported to long-term environmental changes and impacts, participants identified four main themes (Table 3). Eight participants mentioned a positive biological response or early signs of a positive response from management or industry to long-term environmental changes and impacts (Table 3), such as improving southern rock lobster biomass, reducing the abundance of the long-spined sea urchin *C. rodgersii* and improving abalone stocks. By contrast, seven participants mentioned that the effectiveness of a response was either not applicable (because management changes have not been a direct result of climate change) or difficult to differentiate (because it is hard to separate the effects of fishing and the effects of climate; Table 3). Ten participants further identified that the effectiveness of management changes in relation to long-term environmental changes is assessed through stock assessments and monitoring (Table 3), such as through research by the Institute for Marine and Antarctic Studies (e.g. surveys and modelling to

**Table 4. Main themes mentioned by interview participants relating to the costs and obstacles associated with implementing climate-related management changes, and future improvements and recommendations for climate adaptation in fisheries management into the future**
Sources, the number of participants who mentioned each 'main theme' (maximum $n = 16$); frequency, the number of new mentions of a 'main theme' by participants

| Research subobjective of interview guide | Main themes encountered in interview | Sources | Frequency |
|---|---|---|---|
| Costs of management changes | Fishing industries absorb costs | 12 | 17 |
| | • Financial costs | 10 | 13 |
| | Tasmanian community absorb costs | 7 | 13 |
| | • Social and economic costs | 5 | 7 |
| | Financial costs of research and monitoring | 2 | 3 |
| | Social costs of negotiations | 2 | 2 |
| | Government does not have enough resources | 2 | 2 |
| | Government does not have extra costs | 1 | 1 |
| | Not applicable or difficult to differentiate (no management changes were identified as directly responding to climate change | 1 | 1 |
| Obstacles or barriers to effective climate adaptation | People, politics and resistance | 8 | 11 |
| | Resources, capacity and funding | 6 | 13 |
| | Not enough research or expertise | 6 | 6 |
| | Government inaction | 3 | 3 |
| | Not enough education, outreach, extension, engagement or interaction between stakeholder groups | 2 | 5 |
| | Industry limitations and handicaps | 2 | 3 |
| | No barriers | 2 | 2 |
| Necessary changes and future improvements | More and different scientific information, better understanding or better application | 12 | 22 |
| | Government reviews, reforms or action | 11 | 33 |
| | Industry changes and responsibility | 10 | 33 |
| | More funding, resources and support | 10 | 16 |
| | More education, extension and more interaction between stakeholder groups | 9 | 20 |
| | Unsure | 2 | 2 |

track abundance) or through government monitoring, including the use of logbooks (e.g. catch rates) and setting stock rebuilding targets. By contrast, 10 participants mentioned that effectiveness is not measured or assessed by the participants' organisations or research (Table 3).

## *Costs, obstacles and future improvements for fisheries management adaptation to climate change*

This section outlines the results of the next three research subobjectives of the interview guide: (1) the costs of implementing climate-related management changes; (2) the obstacles currently hindering Tasmanian fisheries management climate adaptation; and (3) what changes and future improvements are necessary for effective fisheries management adaptation to climate change into the future.

When asked about the costs or setbacks in implementing management changes in relation to minimising the negative effects or maximising the positive outcomes of long-term environmental change, participants identified seven main themes (Table 4). Twelve participants mentioned that fishing industries absorb the costs of implementing management changes, primarily financial costs (e.g. short-term pain for long-term gain, otherwise the long-term costs transfer to future generations; abalone industry royalties redirected back towards the Abalone Industry Reinvestment Fund; commercial fishers see their allowable catches significantly reduced). Mental health and well-being costs within industry were also mentioned (Table 4); for example, environmental changes may affect leadership ability, self-esteem and well-being in people who have a long-term relationship with marine resources. Seven participants mentioned that the Tasmanian community absorbs the costs of management changes, with many identifying social and economic costs for the Tasmanian community (Table 4).

When asked about whether there is anything preventing commercial fisheries from responding to the impacts of long-term environmental changes, participants identified seven main themes (Table 4). Eight participants mentioned 'people, politics and resistance' as a barrier to effective climate adaptation (Table 4). For example, participants mentioned industry resistance, that industry is consumed by other pressures, such as regulations and safety requirements, a lack of willingness to understand the scientific detail by industry and short-term economic factors preventing a long-term view. Also mentioned was a lack of risk and uncertainty thinking, a lack of systems thinking and negative feedback among decision makers hampering willingness to accept quite definite signals about the effects of long-term environmental changes. Six participants mentioned limited resources, capacity and funding as obstacles to fisheries responses to climate change (Table 4). Another six participants also mentioned not having enough available research or expertise as an obstacle (Table 4), and that there is a need for different sorts of information that managers can more easily work with.

When asked about what changes are necessary to minimise the future negative effects and maximise future positive

**Table 5. Summary of recommendations and implementation strategies to improve responses of Tasmanian fisheries to climate change mentioned by interview participants**

| Recommendation | Strategy |
|---|---|
| Science-led opportunities | More basic fieldwork and biological information to create stronger baseline information to which change can be compared |
| | Monitoring to evaluate what species are shifting here, and forecasting to predict when additional changes are expected |
| | Move modelling and projections towards application, extension and interpretation at a fishery level |
| | More ecosystem-integrated thinking |
| | Identify where the long-term strongholds are for certain wild species |
| Government-led opportunities | Improve flexibility in management arrangements (e.g. novel or discretionary spatial and temporal management, relaxing fishing trip restrictions for vessels on gear types and number of permits) and reduce lag times to be able to change more quickly in response to changes |
| | Take a strategic approach to managing implications of climate change and extreme events (e.g. marine heatwaves), such as building in climate adaptation as a key part of every strategy |
| | Keep bolstering stocks and building biomass to a level that is more resilient to shocks in a system, and applying a precautionary approach to management and decisions |
| | Increase capability in risk and uncertainty thinking, systems thinking and negative feedback among decision makers to break the cycle of inaction |
| | Review property right regimes (e.g. introduce a 'resource rent' to access fisheries, an auctioning system for property rights on a 5-year basis, allow fishers to lease an area of the sea floor) |
| Industry-led opportunities | Diversify to spread the risk (e.g. alternative target species, new or different markets) and ensure fisheries are more resilient to changes and variability in catch and demand |
| | Implement more cooperative structures to allow for the financing and security to move between different species and markets, value adding and sharing resources between groups (e.g. vessels, crew and processing and storage facilities) |
| | Industry to take a long-term view and reconsider asset and property right regimes (e.g. return control to vessel owners and skippers, away from quota owners) |
| | Doing and demonstrating environmentally clean industry practices (e.g. conscious of fuel consumption and plastics use, shift to more energy-efficient operations, increase communication and extension on the good things fishers are doing) |
| | Change infrastructure to cope with the effects of climate change (e.g. change heights of walls to adapt to sea level rise, provide better access to coastlines, re-gear fisheries) |
| Cross-cutting opportunities | Increase transdisciplinary and transboundary thinking (i.e. across two or more disciplines; e.g. knowledge brokers, intermediary roles, boundary work) and foster learning from and collaboration with stakeholder groups |
| | Develop more projects on (or with) engagement and communication, and more extension services to allow fishers to share their local knowledge |
| | Increase funding, resources and support for stakeholder collaborations, research and action |
| | Improve the scientific literacy of the public, decision makers and fishers |
| | Showcase the benefits of investing in climate change by framing climate change in a way that highlights what industry will gain and what they will save by investing |

outcomes, and what may improve proactive fisheries responses to climate change moving forward, participants identified six main themes (Table 4). Twelve participants mentioned needing more and different scientific information, better understanding and better application (Tables 4, 5). Examples mentioned by many participants included forecasting, monitoring and proactively looking at what species are coming to our shores into the future, and when, having a greater understanding of the effects of the environment on the productivity of target species and more ecosystem-integrated thinking. Another main theme encountered frequently in the interviews was that of government reviews, reforms or actions, mentioned by 11 participants (Tables 4, 5). For example, participants mentioned that: (1) management should increase and maintain biomass to increase resilience; (2) government needs to be stronger in its actions and decisions, and implement strong apolitical government actions (i.e. actions and decisions that are less politically driven); and (3) management arrangements need to be more flexible (e.g. more novel ways of conducting spatial and temporal management, allowing multiple permits on the same fishing trip and relaxing restrictions on gear types).

Further changes mentioned by participants to improve the fisheries response to climate change included industry changes and industry taking more responsibility, mentioned by 10 participants (Tables 4, 5). For example, participants suggested that industry need to ensure it is more resilient to changes in variability in catch and demand, that it should diversify to spread the risk (e.g. diversifying to other species and new or different markets) and that it should be practising and demonstrating environmentally clean practices. Ten participants also mentioned the need for more funding, resources and support to improve fisheries responses to climate change (Tables 4, 5) to be put, for example, towards science, monitoring, industry and government, as well as for decision-maker collaborations.

Finally, nine participants mentioned the need for more education and extension, as well as a greater interaction between stakeholder groups to improve fisheries adaptation to climate change (Tables 4, 5). Examples included the need for proactive collaborations between stakeholders and greater interplay between academia and management, the need for better extension work and services (particularly for fishers) and an improvement in scientific literacy among the public and decision makers. Differences in responses between stakeholder groups were observed; one of the top responses by six managers was the need for 'more funding, resources and support', whereas the top mentioned themes as necessary changes to improve fisheries response to climate change among academics were 'industry changes and responsibility' and 'government reviews, reforms or actions'.

## Discussion

The results of this study indicate that Tasmanian fisheries stakeholders accept that long-term environmental changes, like climate change, are affecting Tasmanian marine environments, and are consequently affecting Tasmanian fisheries. Participants raised particular concern over the effects of warming water on the east coast of Tasmania and the associated effects on rock lobster and abalone stocks as a result of the loss of kelp forests. Other main issues included climate-driven range extensions of species shifting from warmer northern waters into the cooler (but warming) Tasmanian waters, such as the long-spined sea urchin *C. rodgersii*. These claims of climate-driven effects in Tasmania are acknowledged and supported by the scientific literature (e.g. Johnson *et al.* 2011; Last *et al.* 2011; Robinson *et al.* 2015; Sunday *et al.* 2015). Similarly, participants identified environmental changes that will affect Tasmanian marine environments and fisheries as being oceanographic changes and regime shifts, in particular increasing ocean temperatures and warm water events, as well as changes in species' abundances and ecological dynamics. Participants in the present study indicated that climate change adaptation within Tasmanian commercial fisheries management is minimal, and that the response to climate change has so far been largely passive or incidental through traditional management levers, such as catch limits and season or area closures. Similarly, fisheries management agencies in the US acknowledge capacity shortfalls and institutional limitations in addressing the current and projected effects of climate change on marine fisheries (Lomonico *et al.* 2021).

Because of the difficulties in differentiating between the effects of climate change and those of other factors or pressures on ecosystems and fisheries, some participants identified that the effectiveness of management responses to climate change is currently not assessed because management addresses changes to stocks and productivity resulting from any effect. Climate change adaptation may not necessarily require individual response strategies that are implemented specifically for climate change where existing management strategies adequately address all environmental changes, such as with ecosystem-based fisheries management (EBFM) or an ecosystem approach to fisheries (Grafton *et al.* 2007; Ogier *et al.* 2016, 2020). However, there may be limits to this approach; for example, a disease outbreak linked to temperature will not be addressed through EBFM. Thus, our results support the existing literature that shows that best practice fisheries management should be dynamic, flexible and forward looking, and proactively address climate change in planning to get ahead of projected changes and related effects on fisheries and ecosystems (Free *et al.* 2020; Whitney *et al.* 2020). This could mean that management should consider shifting productivity and distributions in planning strategies to maximise future (sustainable) catches and profits (Link *et al.* 2011; Free *et al.* 2020).

Sustainable and productive fisheries should minimise environmental degradation and biodiversity loss while maximising social and economic benefits (Food and Agriculture Organization of the United Nations 2020). The fisheries stakeholders interviewed in this study believe that the fishing industry absorbs many of the costs related to the implementation of management changes to respond to climate change, with these largely arising as financial costs. Participants also identified that management changes impose substantial costs on the Tasmanian community, particularly social and economic costs to the state, such as loss of jobs (largely in regional areas), loss of cascading economic benefits to Tasmanian communities and the social costs of political action. The literature supports that the extent of socioeconomic costs may vary dependent on aspects such as human population size, adaptive capacity, resource dependence and local climate change exposure and biological sensitivity (Metcalf *et al.* 2015). Despite increasing costs to fishers resulting from climate change (e.g. less-productive fishing trips mean expending more fishing effort to make operations worthwhile), fishers may be opposed to moving from their local area or into alternative employment because they see fishing as their passion or identity (Coulthard *et al.* 2011; Metcalf *et al.* 2015). Participants identified that if fishers and industry decreased financial operational and running costs, this could help improve industry resilience, which is supported by the literature (Daw *et al.* 2009).

The present study also suggests that fishers are susceptible to negative costs related to their mental health and well-being because of climate change. The participants in this study identified that obstacles preventing Tasmanian commercial wild-catch fisheries from responding to the effects of long-term environmental changes included resistance from people, politics and insufficient resources and funding to be able to adequately consider adaptation, as well as insufficient research or expertise to inform effective adaptation strategies. Solutions identified by participants that may decrease the hindrance of these obstacles included having industry make changes and taking on more responsibility and government undertaking reviews or reforms to increase industry flexibility and taking stronger action in addressing climate adaptation in fisheries. Further solutions presented included gaining more funding and resources, having more education, extension and interactions between stakeholder groups to improve understanding and acceptance of why fisheries climate adaptation is important, having more or different scientific information and a better application of knowledge (e.g. application at the fisheries level). Similar findings have been reported in the US, where, for example, a lack of scientific information on the relationship between climate change and fish biology has been identified as a primary challenge facing fisheries (Gregg *et al.* 2016).

Although participants identified that fish stocks and ecosystems related to fisheries are already monitored to some extent through logbook reporting and research activity, participants also identified that additional monitoring was necessary. Some areas related to research and knowledge that participants believed to require more attention were: (1) forecasting what species are shifting into Tasmanian waters and when;

(2) gaining a better understanding of the effects of the environment on the productivity of target species; and (3) applying more ecosystem-integrated thinking into fisheries management and research. Similarly, previous studies have suggested that fisheries management improvements largely do not require new science or understanding (Holbrook and Johnson 2014), but an ecosystem approach to fisheries management where appropriate (Hobday *et al.* 2011; Johnson 2012). Applying more ecosystem-integrated thinking into fisheries management and research would be useful in fisheries climate adaptation, because an ecosystem approach to fisheries management embraces and integrates all drivers affecting coastal fisheries production and is beneficial in adapting to climate change (Johnson 2012; Heenan *et al.* 2015; Ogier *et al.* 2016). EBFM may forestall fisheries declines due to climate change in the near term, but the long-term benefits may be limited as the effects of climate change magnify (Holsman *et al.* 2020). Adaptive and dynamic management approaches may be favourable in addressing environmental changes (Hobday *et al.* 2018*b*), but fixed long-term measures may be better to address shifting socioeconomic and political conditions (Holsman *et al.* 2019). Therefore, it may be valuable to consider a dynamic–adaptive–fixed approach to climate change in fisheries management (Holsman *et al.* 2019).

Based on the results of this study, we also posit that citizen science can be used to inform stakeholders of environmental change. Citizen science has the additional benefit of increasing public education and engagement with scientific issues (Nursey-Bray *et al.* 2017, 2018), something that the participants of the present study identified as being necessary for future improvements in fisheries climate adaptation. In Tasmania, there is already an established citizen science program to provide an early indication of climate-driven species redistributions: Redmap Australia (www.redmap.org.au). Redmap Australia asks regular marine users to submit observations of unusual marine species sighted in local waters to a growing dataset (Pecl *et al.* 2019*b*), which could be used to predict climate-driven species redistribution (Fogarty *et al.* 2017). There may be room to grow 'early indication' datasets, which would require further outreach, extension and engagement with the public and fisheries stakeholders, as well as more funding and resources and the right people, skills and training.

Vulnerability and risks assessments are important stages of climate adaptation, allowing the setting of regional priorities for further research and monitoring, informed planning and implementation of adaptation actions, as well as understanding the economic costs of climate impacts (NOAA Fisheries 2015; Gregg *et al.* 2016; Whitney *et al.* 2020). Vulnerability and risk assessments of the effects of climate change for key marine species and fisheries around Australia have been completed over the past decade (for a full synthesis, see Fulton *et al.* 2018). Recommendations from that work include: (1) assessing the capacity of existing management strategies to sustain long-term ecological and resource management objectives; (2) implementing flexible regulations and adaptive approaches as rapid responses to climate change effects; and (3) integrating concepts of regime shifts and extreme events into fisheries policy, management and assessment methods. Furthermore, implementing integrated management thinking (i.e. addressing the interaction of the multiple users of the marine and coastal environments that supplement dedicated industry-specific management efforts) into fisheries management will allow for the coordination of successful management approaches (Daw *et al.* 2009; Fulton *et al.* 2018).

The participants in the present study also identified that commercial fisheries climate adaptation requires changes within existing government arrangements, including making management arrangements more flexible, reducing management lag times to allow for faster adaptive responses and reviewing property rights regimes. Property rights regime reviews should discourage business strategies that favour short-term economic gains by sacrificing long-term gains and the integrity of the fishing stock, and should seek to couple 'rights' with 'responsibility' to further ensure adequate protection for future beneficiaries (Moon *et al.* 2021). Suggested solutions from the study participants included the introduction of a 'resource rent' to allow access to the fishery, returning control to vessel owners and skippers away from quota owners, auctioning systems for property rights or leasing an area of the sea floor to fishers to increase stewardship. Flexibility in management arrangements of fisheries may incorporate novel or discretionary spatial and temporal management approaches that can respond to isolated or localised changes and effects on fisheries or ecosystems.

This study found that fisheries managers are most likely to think additional resources and funding are required to aid fisheries climate adaptation not only for their own department, but also for investment in research and industry. Although a lack of funding and resources was identified as an obstacle to fisheries climate adaptation only by fisheries managers, other stakeholder groups did identify that increasing funding and resourcing is a necessary change to improve fisheries adaptation to climate change. Similarly, in the US, insufficient staff capacity has been identified as a hindrance to incorporating climate change into fisheries management and operations (Gregg *et al.* 2016).

A successful science–policy relationship requires trust between climate science 'producers' and 'users' (Lacey *et al.* 2018) to produce effective climate science-informed policies (e.g. Cvitanovic and Hobday 2018). The results of the present study suggest that this may need to be improved within the context of Tasmanian fisheries management. Resource and capacity gaps related to climate change adaptation in fisheries management may be addressed through more effective partnerships among managers, industries, academia and the private sector (Lomonico *et al.* 2021). The participants in the present study identified that fisheries climate adaptation requires more transdisciplinary and transboundary thinking, stakeholder collaborations and improved public, decision maker and fisher scientific literacy. These suggestions may be achieved through actions such as increasing transparency and accountability in the process (Lacey *et al.* 2018) and increasing the use of boundary organisations and the sharing of staff between stakeholder organisations (Cvitanovic *et al.* 2018; Roux *et al.* 2019). Using intermediaries such as boundary spanners (e.g. knowledge brokers) may help overcome inherent biases from stakeholders (Bednarek *et al.* 2018; Cvitanovic *et al.* 2019), and greater collaboration and knowledge exchange between fisheries stakeholder groups should also be fostered (Cvitanovic *et al.* 2016;

Hobday and Cvitanovic 2017). Improving communication and knowledge exchange with fishers would increase awareness and acceptance of climate change, and would therefore allow for better future adaptation and action (Nursey-Bray *et al.* 2012).

Barriers to fisheries climate adaptation identified by the participants of the present study were resistance and not enough willingness to accept responsibility by industry. Participants believed that industry needs to take a more long-term view so as not to compromise the integrity of the resource or industry. Similarly, commercial fishers in south-east Australia have previously identified that economic objectives are very important when determining appropriate adaptation strategies (Jennings *et al.* 2016). Increasing fishers' understanding of climate change and its effects may lead to more adaptation being accepted and implemented by fishermen (Mulyasari *et al.* 2018). The participants of the present study mentioned that the benefits of investing in climate change need to be demonstrated and showcased to industry, and that framing climate change in a way that highlights what industry will gain, and what they will save, will help improve industry acceptance of climate adaptation. This is something that can be demonstrated, because climate-adaptive fisheries management has been assessed as more profitable than business-as-usual fisheries management and is the better option for fisheries to be resilient under all climate emission scenarios (Brown *et al.* 2012; Free *et al.* 2020). Furthermore, comanagement in fisheries governance can help foster trust and cooperation with management changes by providing fishers and their communities with both the rights and responsibilities to improve management outcomes, and increase the agency and adaptive capacity of fishers and marine users (Grafton 2005; Ogier *et al.* 2016; Nursey-Bray *et al.* 2018).

The participants of this study highlighted that industry should implement changes to improve resilience and adaptability to climate change, including diversifying target species and targeting new or different markets to spread the risks associated with climate change and other long-term environmental changes (Daw *et al.* 2009; Johnson 2012; Plagányi *et al.* 2014; Gregg *et al.* 2016). Other improvements included increasing flexibility and implementing more cooperative structures to allow for the financing and security to move between different species and markets, value adding and sharing resources between groups, as well as a greater uptake, and demonstration of the use of, environmentally clean industry practices. In addition, establishing international climate-informed cooperative agreements between countries will help achieve the long-term viability of the fishing industry by creating shared fisheries management goals and objectives (Gregg *et al.* 2016). Therefore, improving the extension services available to fishers would allow for better communication with the public about the things fishers are doing to ensure environmental sustainability.

## Conclusion

This research identified, through interviews, that Tasmanian commercial wild-catch fishery stakeholders acknowledge that long-term environmental changes like climate change are affecting Tasmanian marine environments and fisheries. However, climate adaptation in Tasmanian fisheries management is minimal, and has largely been passive or incidental. Fisheries stakeholders identified that implementing government, industry and research changes relating to climate adaptation is necessary in Tasmania, but perceived a range of economic and social costs, largely absorbed by industry and the Tasmanian community, that could have various negative cascading effects. Lessons for fisheries elsewhere include the need to improve knowledge exchange and engagement between stakeholders to build trust, understanding and acceptance of climate adaptation in fisheries. Although different stakeholder groups may have different priorities, acceptance and understanding of fisheries climate adaptation may be improved by fostering collaboration and engagement between stakeholders and by improving scientific literacy among the public, decision makers and fishers. Governments and industry can implement various changes and reforms to enable climate adaptation; similarly, scientific knowledge may need to be better applied at a fisheries level by researchers to assist decision making. To best adapt to climate change and other long-term environmental changes, fisheries and fisheries management will need to become more flexible and dynamic to increase resilience and diversify operations. Overall, more can be done to proactively prepare fisheries for climate change in Tasmania, but this is not unique to Tasmania as international studies have found underutilised adaptation options and implementation barriers in other regions (Gregg *et al.* 2016; Miller *et al.* 2018; Sumby *et al.* 2021). Implementation of the suggestions in this study would help create a more forward-thinking and proactive response to climate change, and a more flexible and resilient fishing industry that is better able to absorb shocks related to climate change and other long-term environmental changes. Fostering a long-term strategic view with stakeholders of the fishing industry may increase industry sustainability and resilience to long-term environmental changes, and may sustain financial returns into the future.

## Conflicts of interest

The authors declare that they have no conflicts of interest.

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