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An Assessment of How Australian Fisheries Management Plans Account for Climate Change Impacts

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For Australian fisheries to remain productive and sustainable (environmentally and commercially), there is a need to incorporate climate change considerations into management and planning, and to implement planned climate adaptation options. Here, we determine the extent to which Australian state fisheries management documents consider issues relating to climate change, as well as how frequently climate change is considered a research funding priority within fisheries research in Australia. We conduct a content analysis of fisheries management documents investigating categories and themes relating to Australian state fisheries, climate, and environmental change. We also reviewed recent Research Priorities from the major fisheries research funding body for reference to climate change related themes, and the number of subsequently funded projects which considered climate change or related topics. Results show that commercial state fisheries management documents consider climate only to a limited degree in comparison to other topics, with less than one-quarter of all fisheries management documents having content relating to climate. However, we find that the south-east and south-west regions of the Australian coastline have the highest incorporation of "climate" and "environmental protection considerations" in their fisheries management documents, and that fisheries are more likely to have more "climate-related mentions" within their related management documents, if they (i) primarily target species with higher economic commercial catch values, (ii) commercial catch weights, or (iii) a greater number of commercial fish stocks existing. Only a small number of recently funded fisheries research projects considered climate change, representing only a small proportion of fisheries research investment. Given the extensive climate-driven impacts recently documented among key Australian fisheries species and associated ecosystems, we conclude that there is a clear need for fisheries management in Australia to consider longer-term climate adaptation strategies for Australian commercial state fisheries to remain sustainable into the future. We suggest that without additional climate-related fisheries research and funding, many Australian agencies and fisheries may not be prepared for the impacts and subsequent adaptation efforts required for sustainable fisheries under climate change.

Keywords: adaptation, climate change, fisheries research, fisheries management, research priorities

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INTRODUCTION

Climate change is already having significant impacts on oceans globally, and this is affecting commercial (Brander, 2010; Cheung, 2018), recreational (Townhill et al., 2019), and Indigenous (Johnson and Welch, 2015; Sarkar et al., 2018) fisheries around the world (Barange et al., 2018). Many of the effects of climate change are greatest where waters are warming the fastest (Poloczanska et al., 2013), and Australia has some of the fast warming marine regions in the world (Hobday and Pecl, 2014). The south-east and south-west Australian coastlines are particularly vulnerable to the effects of climate change, due to rapid warming in these regions (Hobday and Pecl, 2014). Within these regions climate change is affecting marine systems and marine-dependent users (van Putten et al., 2016), including fisheries, through changes to the physical and chemical properties of the ocean, including water temperature, salinity, and acidity, as well as current and upwelling strength, for example (Brierley and Kingsford, 2009; Hobday and Lough, 2011; Pörtner et al., 2014; Weatherdon et al., 2016). In turn climate change can lead to changes in species characteristics, most commonly affecting species distribution, abundance, and phenology (Brierley and Kingsford, 2009; Johnson et al., 2011; Pecl et al., 2014b). Where harvest species are affected (directly or indirectly, e.g., indirectly via prey species or habitat being affected), this can lead to significant impacts on fisheries, causing changes to fishing location, duration or jurisdictional management processes (Hobday et al., 2018). We know fishers are already starting to adapt autonomously (Pecl et al., 2019a), and where adaptation options are available (Pecl et al., 2014a; Cheung et al., 2018; Ogier et al., 2020; Pinsky et al., 2020) they should be considered in all relevant areas of planning and management.

Australian commercial wild-catch fisheries are an important industry within Australia, employing ∼11,000 people (in fishing, hunting and trapping; **Figure 1**), and contributing significantly to the 341,272 tons of seafood eaten by Australians, and 50,741 tons (AUD1.58 billion) of exported edible seafood in 2017–18 (Steven et al., 2020). Wild-catch fisheries make up the majority of the gross value production (GVP) relating to commercial fishing and aquaculture industries (173,434 tons valued at AUD1.79 billion; 56% of economic value and 64% of weight of total Australian seafood production; **Figure 1**), with state wild-catch making up most of that production (122,344 tons valued at AUD1.40 billion; Steven et al., 2020). For fisheries to be productive and sustainable (both environmentally and commercially) into the future, fisheries management needs to be informed, flexible, and adaptive to respond to current and future climate changes (Hobday and Cvitanovic, 2017; Hobday et al., 2018). As climate change is likely to worsen existing fisheries management challenges (McIlgorm et al., 2010; Sumaila et al., 2011), it is an important factor to consider and address within management (Brown et al., 2012; Ogier et al., 2016). However, adaptation options need to be assessed in the context of current development and governance goals, as objectives may differ for various stakeholder groups (McIlgorm et al., 2010; Jennings et al., 2016).

Incorporating climate research and adaptation into fisheries management plans and practices will be a vital component to successful fisheries management, although this alone will not be sufficient to avoid or minimize all impacts of climate change on fisheries. In a country with an established and highly productive fisheries research sector (Hobday and Cvitanovic, 2017), climate-related literature relating to Australia's main fisheries harvest species still has large gaps (Pecl et al., 2014b), with only a third of species having any research on the biological or socio-ecological implications of climate change at all (Fogarty et al., 2019). Climate-related research effort among Australian fisheries species to date appears to be related to the number of fish stocks per species, and commercial catch weight, meaning that species fished on a larger scale tend to have greater investments of climate-related research effort (Fogarty et al., 2019). Fisheries research in Australia is funded by a variety of sources, however, applied fisheries research is largely organized by the Fisheries Research and Development Corporation (FRDC), which is a co-funded partnership between the Australian Government and the fishing and aquaculture sectors. Other fisheries research is funded by the Australian Research Council, however, this tends to be further from tactical needs (Ling and Hobday, 2018), and so is not covered here.

While the knowledge gaps relating to climate-focused fisheries research in Australian are documented (Fogarty et al., 2019), the extent to which climate change considerations are currently incorporated into fisheries management plans, or the degree to which climate research is a priority area within Australian fisheries research, has not been assessed. Filling this gap is important to also understand how prepared Australian fisheries managers and agencies are for the impacts of climate change to ensure the long-term sustainability of the sector. Thus, this study investigates (i) how extensively Australian state fisheries management plans and other directive management documents incorporate climate change (or climate variability) into current strategies and considerations, i.e., the willingness and preparedness to adapt to and/or consider climate change, and (ii) the extent that relevant research is being conducted and tactically funded in Australia that could inform fisheries management decisions, by examining the FRDC Research Priorities and funded research projects to see how many priorities and projects (underway and completed) include references to climate change.

METHODS

To address the aims of this study we used quantitative content analysis (as described in Bryman, 2012; Coe and Scacco, 2017)—a research method that systematically categorizes attributes of written text, visual, and aural material for analysis (e.g., Cvitanovic et al., 2014; Vourvachis and Woodward, 2015; Stecula and Merkley, 2019). Two sets of documents were analyzed to investigate the extent to which Australian commercial state fisheries consider long-term environmental changes such as

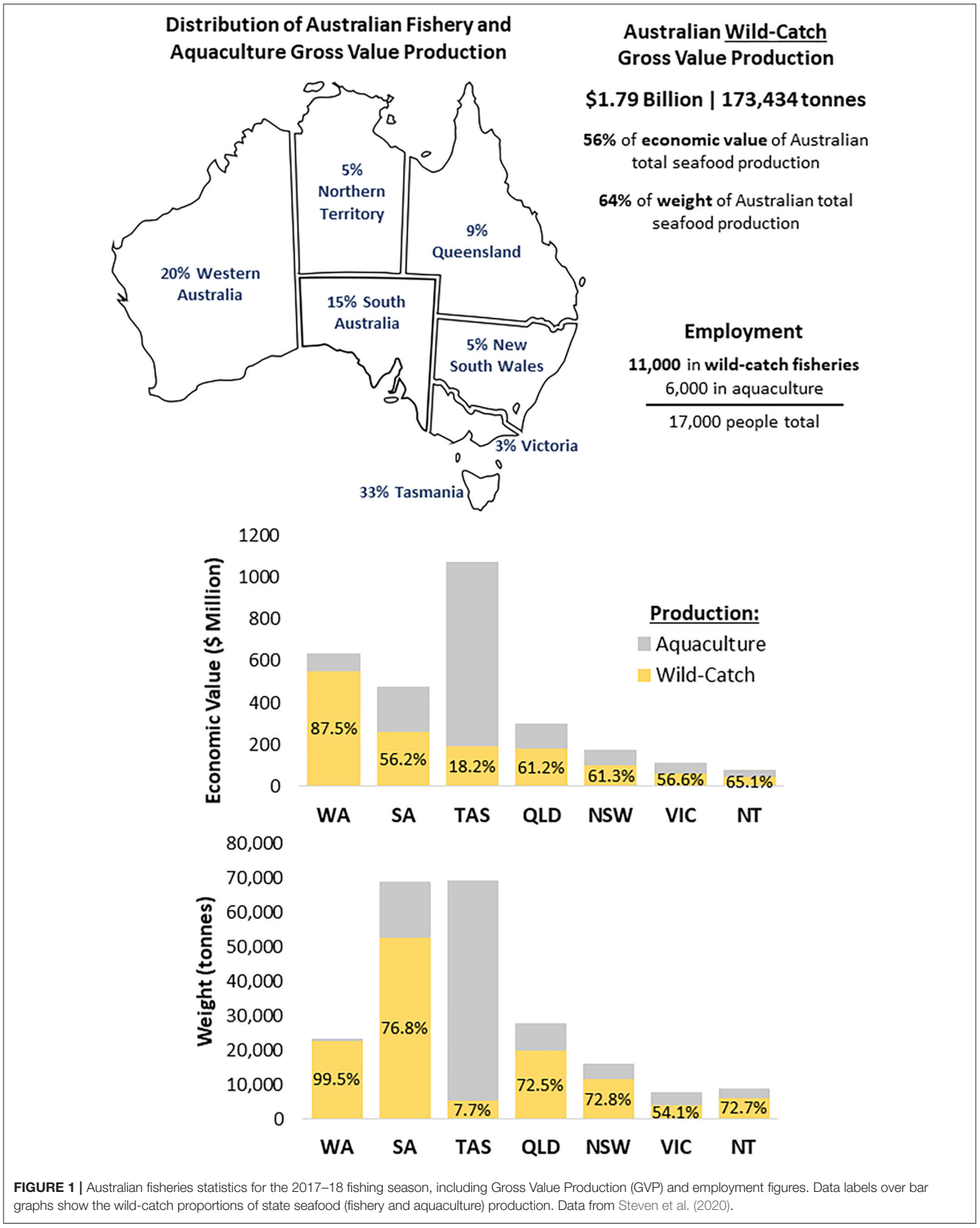

FIGURE 1 | Australian fisheries statistics for the 2017–18 fishing season, including Gross Value Production (GVP) and employment figures. Data labels over bar graphs show the wild-catch proportions of state seafood (fishery and aquaculture) production. Data from Steven et al. (2020).

climate change. The first were fisheries management documents that relate to Australian State fisheries. The second set of documents are those relating to FRDC research priorities, to understand the extent to which climate change related fisheries research is has been proposed and funded in Australia.

Fisheries Management Documents

The management documents that were included in the analysis were for species previously identified in Fogarty et al. (2019), which compiled a list of 99 species relevant to Australian fisheries from four national climate change and fisheries reports (Pecl et al., 2011; Welch et al., 2014; Caputi et al., 2015; Fulton et al., 2018). These species formed the basis of our analysis as they are the main commercially harvested species in Australian wild-catch fisheries. We compiled a list of state fisheries management documents gathered through searches on Australian state government websites, and individual searches of fisheries and target species (**Online Resource 1**). Here, we define "management documents" as the collective group of directive management documents we assessed, which included a wide range of document types (e.g., management plans, regulations, harvest strategies, etc.). Management documents were excluded where the document did not mention "commercial" fisheries, but were included where they alluded to the fact that they included commercial fisheries (i.e., they did not specifically rule out commercial fisheries as included, or they did not state that they were in reference to only non-commercial fisheries), and/or it was already known the document encompassed commercial fisheries. We used the latest available version of each management document, as many had been updated from their original format, and the latest versions were the most likely to include climate-related mentions. See **Figure 2** for a flow diagram for methods on investigating the extent that climate is included in fisheries management documents.

Content analysis of management documents was performed using NVIVO in two stages. First, all management documents were analyzed to understand their publication details. That is; the year of original publication of the management document; the year of publication of the most updated version of the document; the Australian state in which management document was published; type of management document (i.e., Act, Regulation, Rules, Management Plan, Management Strategy, Harvest Strategy, Operational Guidelines, Action Plan, Control Rules, Policy, or Policy and Procedure); and the Hierarchical Level of the Document [i.e., (1) Higher-Level = Acts, Regulations, Rules; (2) Mid-Level = Policy, Procedure, Guidelines, Harvest Strategy, Control Rules, Resource Report, Resource Allocation Report, Operational Guidelines, Strategy, Strategic Research Plan, Action Plan, Resource Sharing Framework; and (3) Lower-Level = Management Plan, Management Arrangements, Management Framework].

The second stage of the content analysis was focused on identifying specific mentions relating to "climate," to determine the frequency of their occurrence within the documents. To help with consistency and robustness of our methods, we used pre-determined terms to search the management documents for climate-related mentions (see **Online Resource 2** for the full list of search terms). Where these search terms were identified in text, they were then verified as correctly referencing climate and not another topic (for example, the term "impact" may have been discussing any range of impacts on a fishery or environment, not just climate impacts). Climate-related mentions were divided into four pre-determined categories: (i) "Direct Climate Mention;" (ii) "Indirect Climate Mention" (where climate-related topics were mentioned); and (iii) "Direct Climate Action;" and (iv) "Indirect Climate Action" (where actions either had knowledge to be acted upon, or involved reviewing the knowledge to identify new responses). In addition, we noted where the management document incorporated "Environmental Protection Considerations," such as implementing a "precautionary approach," or "ecosystem-based approach" (i.e., references relating to "environment," "precaution," and "protect," were all considered for this category). Climate-related mentions within each of these four pre-determined categories were further divided into "Overarching Themes" and "Sub-Themes," to identify trends within the data. Metrics used in this analysis included the total number of documents included the number of documents with climate mentions (direct or indirect), the number of documents with climate-related mentions (including "climate actions"), the number of documents with mentions on environmental protection considerations, the number of direct climate mentions, the number of indirect climate mentions, and state wild-catch production value (AUD million) (Mobsby, 2018).

To determine whether there were any relationships between fisheries species and the number of climate-related mentions in management documents, we first identified the target species groups and/or fisheries that were addressed in each management document, and categorized the management documents by those species groups or broader groupings. These were (1) "Single-Species Groups" (i.e., these management documents addressed the management of a single fisheries species or species group, such as abalone, crab, etc.), (2) "Multi-Species Groups" (i.e., these management documents addressed the management of one fishery that targets multiple species or species groups, such as commercial dive, finfish, or shellfish fisheries, etc.), and (3) "Multi-Fisheries" (i.e., these management documents addressed the management of multiple fisheries that targeted multiple species, such as developmental, trawl, or all state-wide fisheries, etc.). We then investigated the degree of climate preparedness relative to other fisheries categories using "Climate Sensitivity Scores" to climate change for individual species as assessed in a previous study (Fogarty et al., 2019), and calculated the "Number of Management Documents," "Number of Climate Mentions," "Number of Climate Actions," and the "Number of Environmental Protection Considerations" for each of the three fisheries categories above.

Next, we looked more closely at the individual fisheries species that could be assigned to Single-Species Groups (i.e., species that had or could be included in the "Single-Species Management Documents"), from the list of 99 Australian fisheries species (see Fogarty et al., 2019). We then calculated the "Number of Management Documents," "Number of Climate

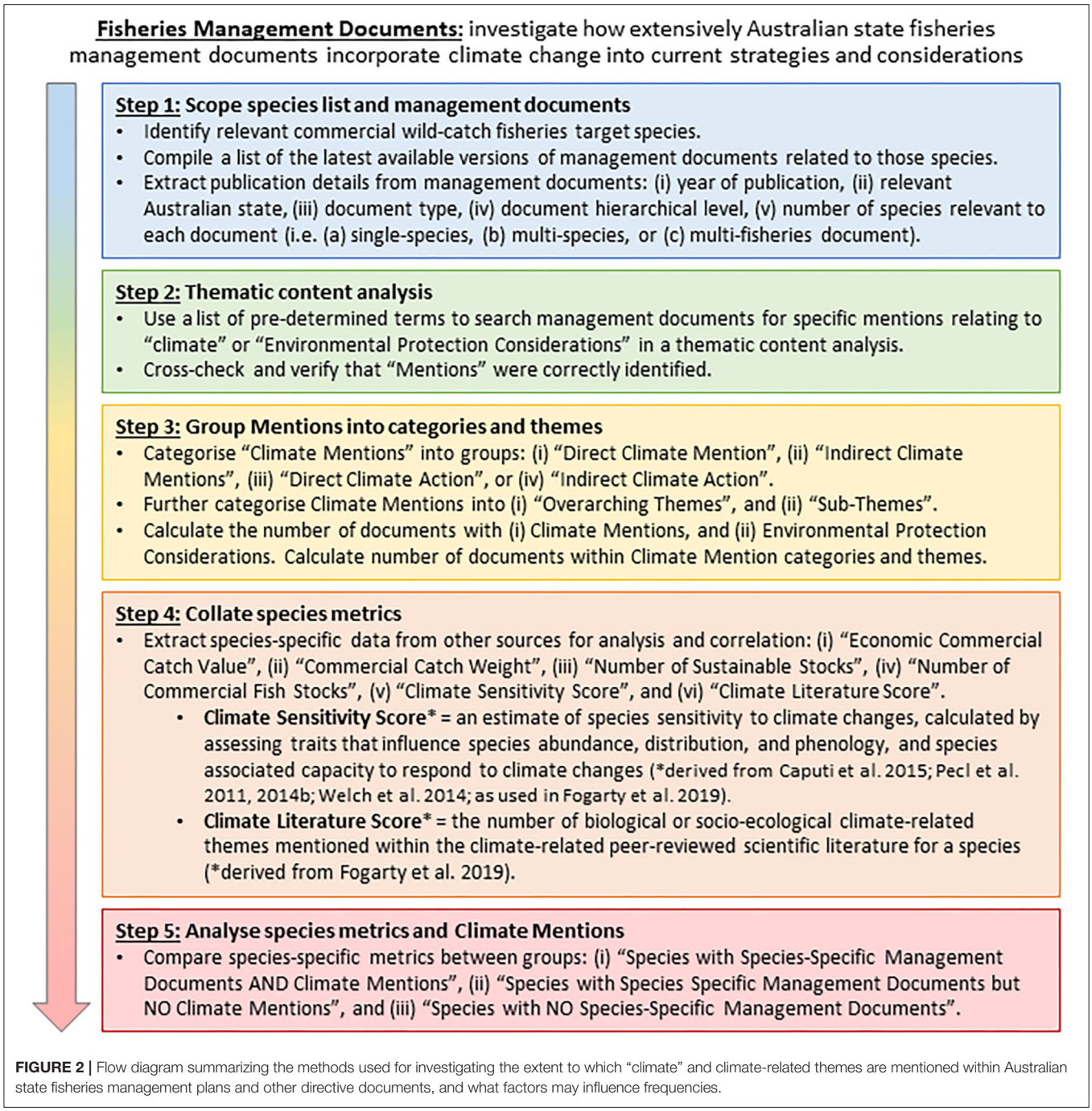

FIGURE 2 | Flow diagram summarizing the methods used for investigating the extent to which "climate" and climate-related themes are mentioned within Australian state fisheries management plans and other directive documents, and what factors may influence frequencies.

Mentions," and the "Number of Environmental Protection Considerations" for each Single-Species Group. Where available, we collected or assigned metric data for the Single-Species Groups, including "Economic Commercial Catch Value ($'000)" and "Commercial Catch Weight (tons)" (from Mobsby, 2018 in Fogarty et al., 2019), the "Number of Sustainable Stocks" (i.e., the number of sustainable or recovering commercial fish stocks, including Commonwealth stocks) and the "Number of Commercial Fish Stocks" (i.e., the total number of fish stocks, including Commonwealth stocks, that the species group had) [both collected in the Fogarty et al. (2019) study from the Status of Australian Fish Stocks Reports (SAFS; www.fish.gov.au); SAFS data is displayed as species-specific, but data for some species is not yet available], "Commercial Catch Weight (tons)" [i.e., commercial catch volume (tons), also collected in the in the Fogarty et al. (2019) study from the Status of Australian Fish Stocks Reports (SAFS; www.fish.gov.au)] was listed for individual

species, and was used in metric comparisons for the Single-Species Groups.

Single-Species Groups were also assigned a "Climate Sensitivity Score," which was an estimate of species sensitivity to climate changes, calculated by assessing traits and other factors that influence species abundance, distribution, and phenology, and their associated capacity to respond to climate changes, and therefore their level of risk [i.e., (1) low sensitivity-high capacity, (2) medium sensitivity-medium capacity, or (3) high sensitivity-low capacity]. Each species was allocated a score out of a possible maximum Climate Sensitivity Score of nine (from Pecl et al., 2011, 2014b; Welch et al., 2014; Caputi et al., 2015; as used by Fogarty et al., 2019). Where species occurred in multiple regions, the species Climate Sensitivity Scores sometimes differed according to regional differences, in which case species were assigned their highest score here for the purposes of this study. Single-Species Groups were also assigned a "Climate Literature Score" for the amount of climate-related peer-reviewed scientific literature discussion a species had (a measure assigned to the individual species in Fogarty et al., 2019, identified there as "Total Literature Score"). This score was calculated from the number of climate-related "themes" that were mentioned within the peer-reviewed literature for each of the 99 fisheries species. There were 20 different themes, related to either the biological or socio-ecological impacts of climate change related to a species. See Fogarty et al. (2019) for full methods on Climate Sensitivity Scores and Climate Literature Scores. We compared these overall metric values for the 99 species divided into three further groups: (i) "Species with Species-Specific Management Documents AND Climate Mentions" (i.e., climate mentions in the management documents), (ii) "Species with Species-Specific Management Documents but NO Climate Mentions," and (iii) "Species with NO Species-Specific Management Documents."

FRDC Research Priorities and Funding

We investigated the extent to which the FRDC (Fisheries Research and Development Corporation) is funding climate-related fisheries research, which could be used to inform fisheries management climate adaptations. Firstly, we investigated how many climate-related research priority areas have been identified in recent years through applications for research priority areas to the FRDC by various jurisdictions (i.e., research advisory bodies/committees, subprograms, and reference groups). We compiled a list of recent FRDC Calls for Applications for Research Priorities which were supplied to the authors by the FRDC. We assessed nine Calls for Research Priorities over 7 years (2013, 2014, 2015, 2016, 2017, 2017 May, 2017 Nov, 2018 Apr, and 2019 Apr), and we present the data here as years with multiple calls combined to just the year (i.e., we combined the 2017, 2017 May, and 2017 Nov calls as "2017"). Years prior to 2013 were unavailable for comprehensive assessment. We then conducted a second content analysis in NVIVO of these Research Priorities, searching for climate-relevance using the same pre-determined search terms identified earlier for the first management documents content analysis. See **Figure 3** for flow diagram of methods for investigating FRDC research priorities and projects. See **Online Resource 3** for a list of jurisdictions and climate-related FRDC research proposals.

Next, we investigated the number of climate-related research projects (underway or completed) that have been funded by the FRDC (i.e., through Tactical Research Funding). Climate-related projects were extracted from the FRDC website (FRDC "Marine climate change adaptation projects" http://www.frdc.com.au/Industry-and-Environment/Climate-change/Marine-climate-change-adaption-projects accessed 10/4/2019; and FRDC "Climate Adaptation Program" http://www.frdc.com.au/en/Industry-and-Environment/Climate-change/Climate-Adaptation-Program accessed 10/04/2019). In addition, the FRDC provided the authors a list of all FRDC funded projects (both completed and underway), omitting administration projects and projects with IP restrictions, from which we extracted projects between 2009 to mid-2019. See **Online Resource 4** for a list of the climate-related FRDC-funded research projects.

After establishing a relative level of priority given to "climate change" as a research topic funded by the FRDC, we collated the text from the "Topic," "Objectives," "Need," and "Background" sections of all FRDC funded research project proposals (1,208 projects) between 2009 and 2019 (supplied to us as a list by the FRDC), and used it to conduct a keyword search, from which we determined the number of times a word was used (i.e., "keywords"). The text was converted to all lower-case to minimize duplication of words based on the case used, and "filler" words (i.e., words which helped to complete a sentence, e.g., "will," "need," "can," "within," "including," "using," etc.), plurals or word variations (leaving the word with the highest use, e.g., "results," "result," "resulted," "resulting," etc.) were removed. Next, we looked at the keywords that were used in the project proposals more frequently than the word "climate" (i.e., had a higher weighted value). We further removed less informative words that did not add any richness or context to the research topics (for example, "FRDC," "aquatic," "Australian," "national," "species," etc. did not add richness to the research topics). The remaining top keywords were then grouped by color into similar or relating themes, to reveal trends in research topics. To provide further context of the in-text use of these keywords, we searched for key word combinations (*key phrases*) using the search function ("Ctrl+F") in Microsoft Word, and noted the number of times keywords such as "climate" were used in conjunction with other words. See **Online Resource 5** for a list of other commonly used keyword combinations and their frequencies.

RESULTS

Analysis of Fisheries Management Documents

Of the 125 Australian state fisheries management documents included in the content analysis, 37 (29.6%) made no mention of "climate," or "Environmental Protection Considerations" (**Figure 4A**). Another 25 documents (20%) mentioned both "climate" and "Environmental Protection Considerations" and

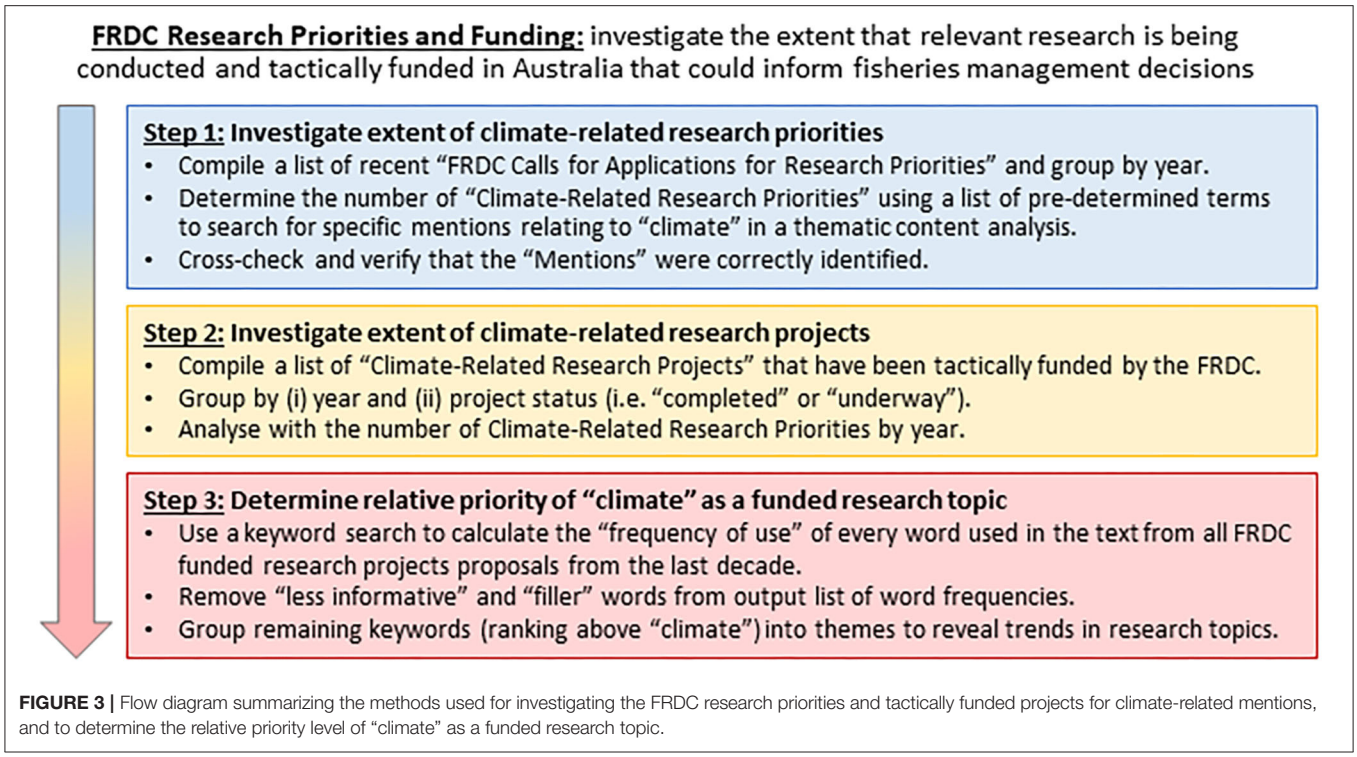

FIGURE 3 | Flow diagram summarizing the methods used for investigating the FRDC research priorities and tactically funded projects for climate-related mentions, and to determine the relative priority level of "climate" as a funded research topic.

were more likely to be Mid-Level or Lower-Level documents, primarily from South Australia, followed by Victoria and Queensland (**Figure 4**). Meanwhile, 98 documents (78.4%) did not mention "climate" and were more likely to be recent and Higher-Level documents, mostly from Tasmania, Western Australia, New South Wales, and the Northern Territory (**Figure 4**). We found 86 documents (68.8%) mentioned "Environmental Protection Considerations," increasing with year of publication, and were proportionately mostly Mid-Level documents from Western Australia, followed by New South Wales and Northern Territory (**Figure 4**). The Northern Territory was the only region to have no climate-related mentions at all, followed by Tasmania having only 2 documents with climate-related mentions (**Figure 4D**). However, 81.8% of Northern Territory documents did mention Environmental Protection Considerations (**Figure 4D**). As the number of documents produced increased over the study period, the proportion of documents mentioning climate decreased, even though the actual number of documents mentioning climate increased (**Figure 4B**, **Online Resource 1**). See **Online Resource 1** for more details on the fisheries management documents included in this study.

Results of the content analysis showed there were 108 individual climate-related mentions (total) from the 27 management documents *with* climate-related mentions, divided into 14 overarching themes (total), and 52 sub-themes (total) (**Tables 1**, **2**). The category "Direct Climate Mentions" had 44 mentions from 20 fisheries management documents, split into 7 overarching themes and 19 sub-themes (detailed in **Table 1**). Meanwhile, "Indirect Climate Mentions" had 35 mentions from 18 management documents, split into 3 overarching themes and 24 sub-themes (detailed in **Table 1**). "Indirect Climate Actions" had 29 mentions from 11 management documents, split into 4 overarching themes and 9 sub-themes, making up just under a third of all climate-related mentions (detailed in **Table 2**). We found no mentions to be classed as "Direct Climate Actions," as we found no actions aimed at specifically addressing or adapting to the effects of climate change on fisheries.

Investigating these categories more closely, we found the most frequent "direct" reference to climate within the management documents was identifying climate change as a key threat to fisheries, followed by themes of management considerations and goals to respond to climate change (**Table 1**). "Indirectly," the most frequent reference to climate related to identifying oceanographic conditions as risks affecting fisheries performance (**Table 1**). Actions to ("indirectly") address climate change predominantly focused on fisheries and ecosystem management changes that could be implemented, followed by increasing and improving research on climate change (**Table 2**). Perhaps unsurprisingly, 24% of the indirect climate actions identified were to "review the threat of climate change in a few years or at the next major assessment" (**Table 2**).

When investigating the fisheries management documents in relation to the fisheries species more specifically (i.e., 99 Australian fisheries species previously identified), we grouped the management documents into 19 "Single-Species Groups," 13 "Multi-Species Groups," and five "Multi-Fisheries" categories. Single-Species Groups and Multi-Fisheries had a similar number of management documents, while Multi-Species Groups had just less than half of these (**Figure 5**). The Number of Climate

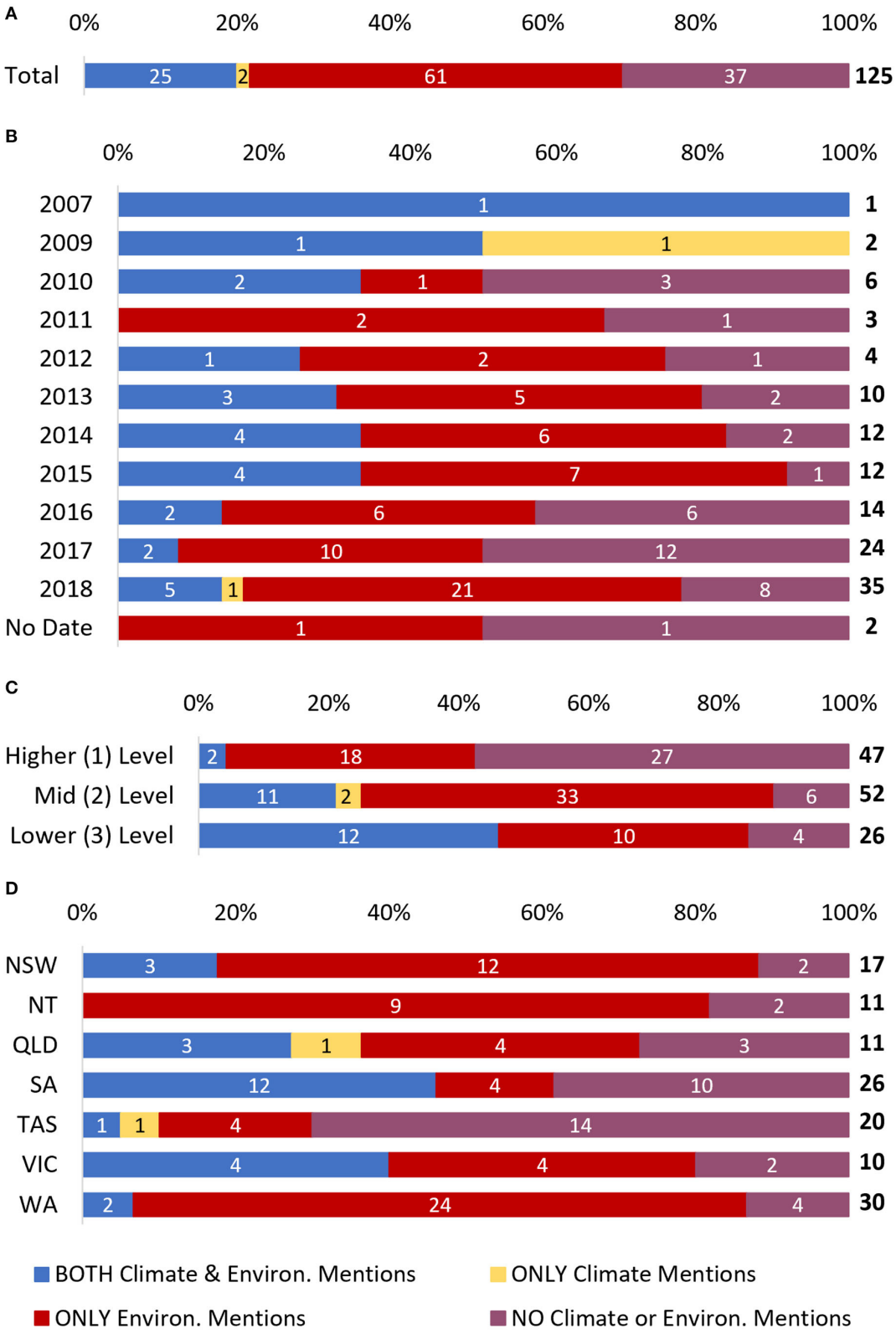

FIGURE 4 | The percentage and count of the number of fisheries management documents with climate-related mentions ("climate"), mentions of environmental protection considerations ("environ."), or none of the above, separated by; **(A)** All documents as one group; **(B)** The year of publication of the current document version; **(C)** Hierarchical level of management document; and **(D)** Australian state where the document is relevant to. NSW, New South Wales; NT, Northern Territory; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia. Data labels represent the count of documents for each category, with the labels to the right of the bars representing the overall counts of management documents.

TABLE 1 | The numbers of "direct climate mentions" and "indirect climate mentions" identified in the content analysis of the fisheries management documents, detailed by overarching theme and sub-themes.

Direct climate mentions		
Overarching themes	**Sub-themes**	**Mentions (*n*)**
1. Climate change as a key threat to fisheries	1.1. Climate change is a key process threatening fisheries	9
	1.2. Issue = climate change; Risk/Priority = High	7
	1.3. Issue = climate change; Risk/Importance Rating = Moderate	4
	1.4. Issue = climate change; Risk/Priority = Negligible	2
	1.5. Climate change: high risk rating; development of objectives and management strategies that directly mitigate the effects of climate change is limited, and therefore the risk is not referred to in objectives and strategies	1 (Theme 1 Total Mentions = 23)
2. Management goals to respond to climate change	2.1 Goal: Management adaptive to climate change	4
	2.2 Operators to have clear contingency plans in place to respond to climate change events	1 (Theme 2 Total Mentions = 5)
3. Considerations for management of climate change	3.1 Avoiding/taking into account the effects of development on climate change	3
	3.2 Knowledge area for effective management: impacts of climate change	1
	3.3 Key consideration for management: climate change/climate-induced events; Unsuitable for management within this policy	1 (Theme 3 Total Mentions = 5)
4. Climate changes lead to changes in species dynamics and habitats	4.1 Climate change affects long-term sustainability of fishery/species	2
	4.2 Transition in ocean currents/climate leads to varied/complex habitats and species	1
	4.3 Climate variability: risk affecting water temperature and ocean currents, leads to changes in species survival, growth rates, and distribution	1 (Theme 4 Total Mentions = 4)
5. Buffers against climate change impacts	5.1 Refugia definition = habitats where fish are able to survive the impacts of climate change	2
	5.2 Stock rebuilding as a buffer against climate change	1 (Theme 5 Total Mentions = 3)
6. Climate change definition as physical oceanographic changes/intricately related to other physical factors	6.1 Climate change: altering ocean temperature, chemistry, sea level, storm frequency and severity, amount of freshwater entering aquatic systems and patterns of regional oceanography	1
	6.2 Climate is intricately linked to other physical factors	1 (Theme 6 Total Mentions = 2)
7. Climate change studies/research	7.1 Department involved in regional climate change studies	1
	7.2 Area a critical baseline to measure climate change effects	1 (Theme 7 Total Mentions = 2)
Total overarching themes = 7	**Total sub-themes = 19**	**Total mentions = 44**
Indirect climate mentions		
1. Issue = Oceanographic conditions (water temperature, weather, upwelling) affecting performance of fishery	1.1. Issue = Weather; Risk/Priority = Moderate	4
[-20pt]	1.2. Issue = Oceanographic conditions; Risk = Moderate	2
	1.3. Issue = Oceanographic, Temperature, Weather; Risk = Moderate	2
	1.4. Issue = Oceanographic (Temp, Weather, Upwellings); Risk/Priority = Moderate	2
	1.5. Issue = Temperature; Risk = Moderate	2
	1.6. Issue = Upwelling; Risk = Extreme	2
	1.7. Issue = Upwelling; Risk/Priority = Moderate	1
	1.8. Issue = Temperature, Weather, Upwelling; Risk/Priority = Negligible	1
	1.9. Fishery subject to oceanic influences, including bad weather (swell and wind), and cold upwelling events	1
	1.10. Fishery/catch weather dependent—access to certain areas	1
	1.11. Changing ocean temperatures and strengthening of the EAC may lead to a significant shift in the distribution of many marine species	1
	1.12. Distribution influenced by wind patterns and tidal currents	1 (Theme 1 Total Mentions = 20)
2. Goal/Recommendation for environmental/ ecosystem drivers/changes to be considered in fishery management	2.1. Goal—Manage fishery as part of the broader ecosystem	2

(Continued)

TABLE 1 | Continued

Direct climate mentions		
Overarching themes	**Sub-themes**	**Mentions (*n*)**
	2.2. Glossary: Environmentally limited stock—biomass reduced due to environmental change	2
	2.3. Management considerations: changing environmental conditions/environmental changes	2
	2.4. Management considerations: Environmental changes, habitat changes, effects of weather	1
	2.5. Environmental drivers to be considered in management	1
	2.6. Ecosystem changes to be considered in management	1
		(Theme 2 Total Mentions = 9)
3. Extreme/adverse events/conditions affecting fishery, species, and area	3.1. Species vulnerable to natural catastrophic environmental impacts: freshwater floods, temperature extremes	1
	3.2. Area vulnerable/susceptible to environmental impacts/changes	1
	3.3. A resilient system will bounce back from adverse environmental conditions (floods, bleaching, cyclones)	1
	3.4. Fishery impacted by extreme stress events: bleaching events	1
	3.5. Issue = Stormwater, Hypersalinity (desaliation); Risk/Priority = Low	1
	3.6. Sea level rise—setback coastal development	1
		(Theme 3 Total Mentions = 6)
Total overarching themes = 3	**Total sub-themes = 24**	**Total mentions = 35**

"Mentions (n)" in column 3 = the number of "climate-related mentions" found that related to each category. "(Total=n)" = the sum of "climate-related mentions" in each overarching theme. Sub-Themes listed are variations of quotes lifted from the management documents.

Mentions, Climate Actions, and Environmental Protection Considerations identified within the documents were all mostly from Single-Species Group management documents (**Figure 5**). In addition to having a high number of management documents, Multi-Fisheries also had middle values of Climate Mentions and Environmental Protection Considerations (still proportionately high) but had the lowest number of Climate Actions.

One third (34 of 99) of species from the list of Australian fisheries species could be assigned into the "19 Single-Species Groups" that had management documents relating specifically to them or their species groups. Of these 34 individual species, 19 (making up nine Single-Species Groups) had Climate Mentions within management documents, while 25 individual species (17 Single-Species Groups) had Environmental Protection Considerations mentioned within management documents relating specifically to them or their species group (**Figure 6**). Additionally, a second grouping of 19 (out of the 34) individual species were also found to have "peer reviewed climate-related species literature" in Fogarty et al. (2019). Of these two different groups of 19 individual species, 13 species overlapped, having both Climate Mentions in their management documents *and* climate-related species literature in Fogarty et al. (2019). These 13 individual species were from five Single-Species Groups "Abalone," "Crab," "Lobster," "Prawn," and "Sardines," of which the first four Single-Species Groups had the majority of management documents (58%), Climate Mentions (61.5%) and/or Environmental Protection Considerations (60.5%; **Figure 6**). Furthermore, 16 of the 65 individual species in the present study without *single-species* management documents did have climate-related species literature in Fogarty et al. (2019). These 16 individual species, however, were almost all Perciformes ("Perch-like") fish species (e.g., finfish), and therefore their management was covered by management documents for Multi-Species Groups and/or Multi-Fisheries.

Of the 19 Single-Species Groups with management documents, "Economic Commercial Catch Value" and "Commercial Catch Weight" data were located for 11 species groups (Mobsby, 2018), while the "Number of Commercial Fish Stocks" data were located for eight (from SAFS, www.fish.gov.au), and Climate Sensitivity Scores were assigned for 12 species groups. Among the Single-Species Groups data, we found the strongest apparent relationship between having higher Economic Commercial Catch Value, and having more management documents, Climate Mentions and/or Environmental Protection Considerations, as the five Single-Species Groups with both climate-related management *and* climate-related scientific literature (identified above) also held the top five highest Economic Commercial Catch Values (i.e., Economic Values ranking order: 1. *Lobster*, 2. *Prawn*, 3. *Abalone*, 4. *Crab*, 5. *Sardines*, 6. Scallop (italics used to identify the five Single-Species Groups identified earlier); **Figure 6**). In addition, species having increased climate sensitivity (or even having had a Climate Sensitivity Score calculated at all), also tended to have more management documents, Climate Mentions, and/or Environmental Protection Considerations, with four of the five Single-Species Groups noted above ranking within the top six for Species Climate Sensitivity (i.e., Climate Sensitivity ranking order: 1. Sea Cucumber, 2. *Lobster*, 3. *Abalone*, 4. *Prawn*, 5. Scallop, 6. *Crab*; **Figure 6**). Furthermore,

TABLE 2 | The numbers of "indirect climate actions" identified in the content analysis of the fisheries management documents, detailed by overarching themes and sub-themes.

Indirect climate actions		
Overarching themes	**Sub-themes**	**Mentions (*n*)**
1. Fisheries and ecosystem management changes: influence and implement management processes	1.1. Management: set annual TACC within sustainable levels; precaution/precautionary principle	4
	1.2. Develop flexible fisheries to adapt to change	3
	1.3. Influence other management processes that impact on ecologically sustainable development of the fishery	2
	1.4. Combination management: develop flexible fisheries, influence other management processes, set TACC precaution, ensure sufficient information to inform management decisions	2 (Theme 1 Total Mentions = 11)
2. Increase and improve research on climate change	2.1. Promote, support, and undertake additional research	5
	2.2. Ensure sufficient information for informed management decision (e.g., surveys)	2
	2.3. Monitor environmental changes	2 (Theme 2 Total Mentions = 9)
3. Review threat in a few years/at next major assessment	3.1. Review threat in a few years/at next major assessment	7 (Theme 3 Total Mentions = 7)
4. Increase/promote engagement between fisheries managers and RD&E, water resource management agencies, and infrastructure authorities, etc.	4.1. Increase/promote engagement between fisheries managers and RD&E, water resource management agencies, and infrastructure authorities, etc.	2 (Theme 4 Total Mentions = 2)
Total overarching themes = 4	**Total sub-themes = 9**	**Total mentions = 29**

"Mentions (n)" in column 3 = the number of "climate-related mentions" found that related to each category. "(Total=n)" = the sum of "climate-related mentions" in each overarching theme. Note: no "Direct Climate Actions" were found in any documents. Sub-Themes listed are variations of quotes lifted from the management documents.

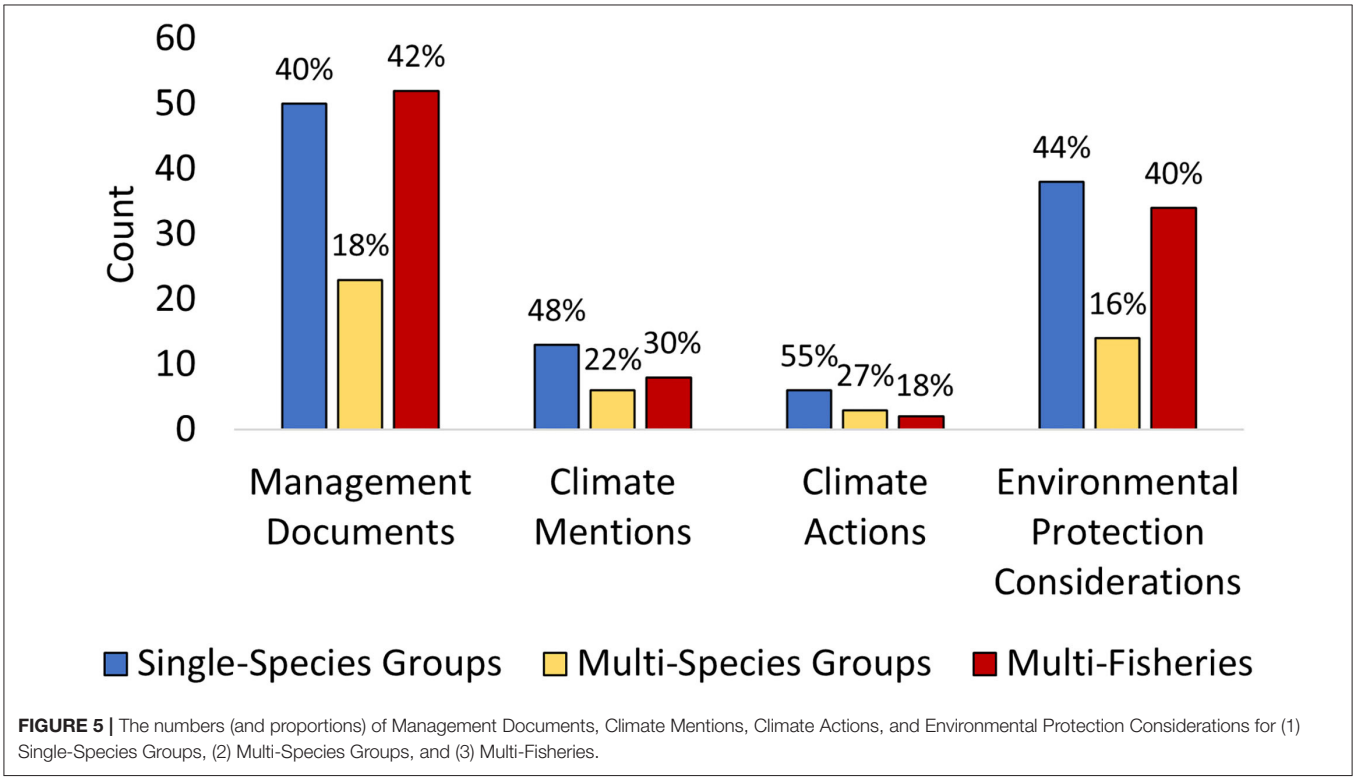

FIGURE 5 | The numbers (and proportions) of Management Documents, Climate Mentions, Climate Actions, and Environmental Protection Considerations for (1) Single-Species Groups, (2) Multi-Species Groups, and (3) Multi-Fisheries.

these five Single-Species Groups were also among the top six Single-Species Groups with the highest Commercial Catch Weights (i.e., Catch Weights ranking order: 1. *Sardines*, 2. *Prawn*, 3. *Lobster*, 4. Scallop, 5. *Crab*, 6. *Abalone*; **Figure 6**), and three of these five groups had the highest Number of Commercial Fish Stocks (i.e., Fish Stocks ranking order: 1.

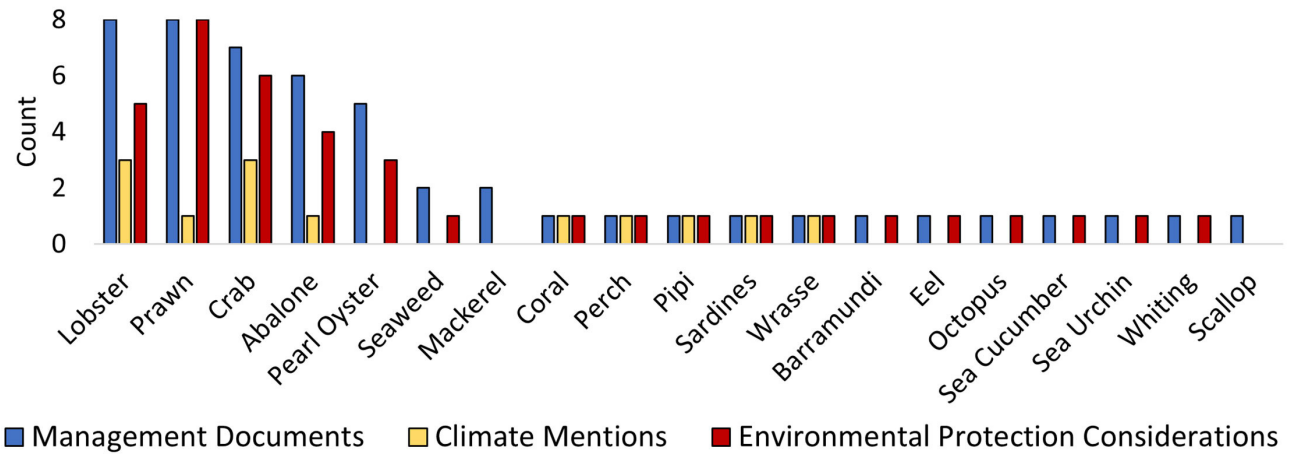

FIGURE 6 | The Number of Management Documents, Climate Mentions, and Environmental Protection Considerations for each of the 19 Single-Species Groups. Species name orders are by highest to lowest Number of Management Documents, then by highest to lowest Number of Climate Mentions, and then by highest to lowest Number of Environmental Protection Considerations.

Prawn, 2. *Crab*, 3. *Abalone*, 4. Mackerel, 5. Barramundi, 6. Whiting; **Figure 6**).

Finally, we compared metrics from Fogarty et al. (2019) between three groups for the 99 individual fisheries species: (1) "Species *with* Species-Specific Management Documents AND Climate Mentions" (19 of 99 species); (2) "Species *with* Species-Specific Management Documents but NO Climate Mentions" (15 of 99 species); and (3) "Species with NO Species-Specific Management Documents" (65 of 99 species). Species-specific metrics included Climate Sensitivity Score, the Number of Sustainable Stocks, Commercial Catch Weight, and Climate Literature Score. The first group of species (19 species) had the greatest Climate Sensitivity Scores, more sustainable commercial fish stocks, larger Commercial Catch Weights, more Commercial Fish Stocks, and the most peer-reviewed climate-related species literature per species (**Table 3**, first column). Within this first group, 11 species (57.9%) had over 1,000 tons Commercial Catch Weight (from SAFS), while four species (21.1%) were missing catch weight data from SAFS. The second group of species (15 species) held the middle values for Climate Sensitivity Scores, the Number of Sustainable Stocks, Number of Commercial Fish Stocks, and Climate Literature Scores per species, but had the lowest average value for Commercial Catch Weight (**Table 3**, second column). Within this group, only 2 species (13.3%) had over 1,000 tons of commercial catch weight, while four species (26.7%) were missing catch volume data from SAFS. The third group of species (65 species) held the lowest values for Climate Sensitivity Scores, the Number of Sustainable Stocks, the Number of Commercial Fish Stocks, and Climate Literature Scores, but held the middle value for Commercial Catch Weight, partly increased due to a single species outlier (Pilchard) having a much greater Commercial Catch Weight at 38,671.5 tons (**Table 3**, third column). In fact, this group had only six species (9.2%) with Commercial Catch Weights over 1,000 tons, while 38 species (58.5%) were missing catch weight data from SAFS.

FRDC Research Priorities and Funding

From seven years of FRDC Calls for Applications for Research Priorities (a total of nine Calls), there was a total of 351 research priority applications included from a total of 21 jurisdictions (see **Online Resource 3** for list of jurisdictions; not all jurisdictions were included in Calls every year). We found nine research priority applications with a reference to climate (**Online Resource 3**), which were divided into seven "direct" climate references (each proposed by the major state Fisheries Research Advisory Body (FRAB) or Research Advisory Committees (RAC): 1x from Tas FRAB 2014, 1x WA FRAB 2015, 1x Commonwealth RAC 2017, 1x NT RAC 2017, 1x Q RAC 2017 Nov, 1x SA RAC 2017 Nov, 1x Vic RAC 2019 Apr), and 2 "indirect" climate references (1x WA RAC 2015, 1x Tas RAC 2018 Apr). These nine climate-related research priorities identified came from only seven jurisdictions, with New South Wales being the only state with a "jurisdiction" that did not propose a climate-related research priority. With so few climate-related research priority applications it is difficult to see a trend over the years, however, the number of climate-related priorities does mirror the number of jurisdictions and total research priorities each year to some extent, with higher values in 2015 and 2017 (**Figure 7**).

Investigation of the projects funded by the FRDC found 36 completed climate-related projects, and 19 underway climate-related projects between 2009 and 2019, out of 1,208 funded projects assessed (**Online Resource 4**). It is evident that the number of climate-related projects, relative to the total number of FRDC funded projects varies over time, peaking in 2014 and 2015 (11.7 and 11.5% of FRDC funded projects are climate-related, respectively), with the number and proportion of climate-related projects decreasing in the years after, down to between 0 and 1.9% of projects each year (**Figure 7**). The year 2010 follows as having the next highest proportion of climate-related research projects, with 8.8% of projects funded that year being climate-related. Overall, 4.6% of the research projects assessed within the research

TABLE 3 | Mean/modal data for the Climate Sensitivity Score (i.e., a measure of species risk and capacity to respond to climate changes), Number of Sustainable Fish Stocks, Number of Commercial Fish Stocks, and Commercial Catch Weight, for the 99 Australian fisheries species, divided into three categories based on whether they had species-specific management documents and Climate Mentions within those management documents.

	Species with species-specific management documents AND climate mentions ($N = 19$)	Species with species-specific management documents but no climate mentions ($N = 15$)	Species with NO species-specific management documents ($N = 65$)
		Climate Sensitivity Score (_/9)	
Mode	**6.75** (highest = 7.25)	**6.25** (highest = 8)	**5.5** (highest = 7.75)
		Commercial Fish Stocks (SAFS)	
Mean	**5.3** (highest = 13)	**4.1** (highest = 9)	**3.4** (highest = 10)
		Sustainable Stock Status (SAFS)	
Mean	**3.5** (highest = 8)	**3.1** (highest = 7)	**2.1** (highest = 4)
		Commercial Catch Weight (t) (SAFS)	
Mean	**2082.6** (highest = 6,050 t)	**436.9** (highest = 2142.8 t)	**1978.2** (highest = 38671.5 t)
		Climate Literature Score (_/20)	
Mean	**4.5** (highest = 12)	**2.4** (highest = 12)	**0.9** (highest = 11)

Red, highest value; orange, middle value; yellow, lowest value.

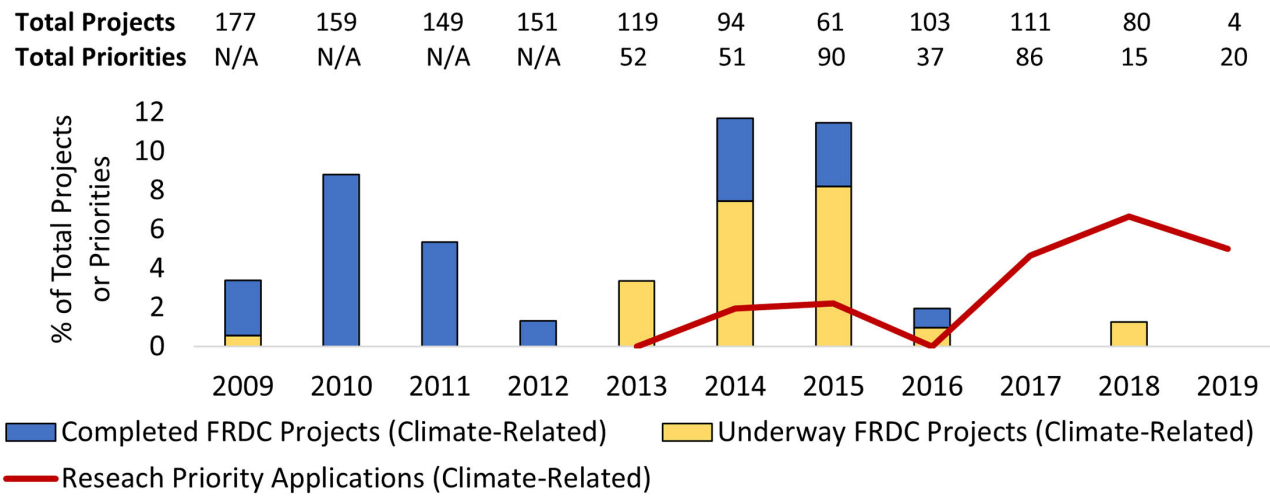

FIGURE 7 | FRDC support in climate-related fisheries research by year (2009–2019), presented as the percentages of completed and underway climate-related research projects, and climate-related research priorities extracted from the FRDC Calls for Applications for Research Priorities each year (2013–April 2019), with data labels above presenting the total number of FRDC funded research projects each year, and the total number of research priority applications overall each year.

period were climate-related, with a mean value of 4.4% calculated from the proportions of projects each year. The number of total projects funded by the FRDC does decline in the latter half of the decade. Additionally, the proportion of climate-related research priority applications significantly increases over time, and it appears that almost no funded climate-related research projects in the last 3 years paradoxically corresponds with an increase in climate-related research priority applications (**Figure 7**).

Investigating which research topics or themes may have been a higher priority than "climate" within fisheries research, "climate" was the 36th most commonly used word within the "Topic," "Objectives," "Need," and "Background" sections of 1208 research projects funded by the FRDC between 2009 and 2019, when all "filler" words and "low context" words (i.e., less informative words) were removed. From a similar theme, "environmental" and "sustainable" placed 20th and 33rd, respectively, in frequency of their use (**Figure 8**). Grouping these top 36 keywords into similar themes or topics showed seven research themes of interest (**Figure 8**). The category "commercial fisheries topics" had the highest number of top keywords identified as relating to the theme (11 keywords), followed by "climate and environmental considerations" (7 keywords), "community (non-commercial) and social aspects of fisheries" (5 keywords), "fisheries management and planning" and "fisheries knowledge and assessments" (both themes with 4 keywords), "fisheries economics" (3 keywords), and "health and disease" (2 keywords; **Figure 8**). Finally, we investigated key phrases using the keywords, in particular "climate," to give more context to the keywords. "Climate-change" was the third most used key phrase that included at least one of the top 36 keywords, with 427 uses,

coming below "fisheries-management" (548 uses), and "seafood-industr(y/ies) (534 uses). Other key phrases identified that used the word "climate," included "climate-varia(bility/tion)" with 18 uses, "changing-climate" with 16 uses, and "climate-impact(s)" with 13 uses. With a similar theme, key phrases identified using the keywords "environmental" and "sustainable" included "environmental-conditions" with 89 uses, "sustainable-development" with 88 uses, "ecologically-sustainable" with 73 uses, "sustainable-fish(ing/eries/ery)" with 54 uses, "sustainable-management" with 48 uses, and "environmental-change(s)" with 32 uses. See **Online Resource 5** for a further list of key phrases.

DISCUSSION

Fisheries Management Documents

In this study we undertook a content analysis of Australian fisheries management documents to assess how they account for and incorporate climate change impacts. Our assessment showed that for wild-catch fisheries only 21.6% of all documents specifically had "climate-related" content, and that these tended to be (i) more recently published; (ii) largely from South Australia, followed by Victoria; and (iii) were Lower-Level or Mid-Level documents (in terms of their directive aims). This was reflected by Single-Species Groups management documents having a greater number of Climate Mentions, while Multi-Species Groups had a large proportion of Climate Mentions in relation to the lower proportion of management documents within that group. Multi-Fisheries documents did however have a high proportion (40%) of the Environmental Protection Considerations that were identified within the text, which may reflect that a fishery that is well managed does not degrade the natural environment, thereby in looking after and responding to environmental changes, fisheries management may simultaneously respond to climate change, as a well-managed fishery is best able to adapt to climate change (McIlgorm et al., 2010; Ogier et al., 2016).

The documents with no mention of "climate" or "Environmental Protection Considerations" were predominantly from Tasmania and South Australia. In contrast, the Northern Territory, Western Australia, and New South Wales did have a high proportion of documents with Environmental Protection Considerations, which may indicate that climate is more indirectly addressed and incorporated into their respective management strategies. It is therefore worth noting that a state having little-to-no mention of climate in their fisheries management documents may not necessarily mean that they do not have ground-level actions in place that assist their adaptation to climate change, or that they are unprepared for climate change, but rather it may be a reflection of the style of writing and/or format the management documents are written in. For example, many of the Tasmanian management documents related to specific fisheries, but were set out as legislation, and therefore did not provide the same background information and/or deeper context that other state management documents did. This may be a result of comparative resourcing and funding allocations to fisheries management departments in each state, which would allow for deeper contextual management documents. Resourcing and funding levels in each state may be influenced by GVP proportions that wild-catch fisheries account for in each state, for example, although Tasmania has the highest total seafood GVP (33%) in Australia, Tasmanian wild-catch fisheries have the third highest dollar value (AUD194.3 million) of all Australian states (behind Western Australia and South Australia), and proportionately the lowest catch value (18.2%) and weight (7.7%) of any state (**Figure 1**; Steven et al., 2020). However, how relative fisheries resourcing and funding levels influences management in each state requires further investigation into the future.

Another interesting correlation is that the fastest warming waters in Australia are the south-east and south-west coastlines (Hobday and Pecl, 2014), which tended to have higher proportions of climate-related mentions and Environmental Protection Consideration. These two climate "hotspot" regions include the coastlines of South Australia and Victoria, which had the two highest proportions of climate-related mentions, and New South Wales and Western Australia, which had the two highest proportions of Environmental Protection Considerations, therefore potentially indicating that climate vulnerability may factor into respective climate preparedness and adaption implementation (Ling and Hobday, 2018). Species climate sensitivity has also previously been found to have a positive influence on research effort, as species with higher industry value or importance are more likely to have higher (and more accurately determined) climate sensitivity scores (Fogarty et al., 2019). Similarly, we find here that species with higher climate sensitivity are also likely to have higher numbers of management documents, and Climate Mentions and Environmental Protections Considerations mentioned within the management documents. This could be interpreted positively, as greater climate considerations are desirable for more climate-vulnerable species. However, it would also be beneficial to increasingly incorporate climate adaptations into more (if not all) species fisheries management documents, as there are still climate-vulnerable species with no Climate Mentions and/or species-specific management documents.

After thematically categorizing the individual climate-related mentions from the content analysis of the management documents, we found "Direct Climate Mentions" to be the largest category, followed by "Indirect Climate Mentions." The most frequent "direct" references to climate within the management documents were identifying climate change as a key threat to fisheries, and management considerations or goals to respond to climate change, while the most frequent "indirect" reference to climate related to identifying oceanographic conditions as risks affecting fisheries performance. Actions to ("indirectly") address climate change predominantly focused on fisheries and ecosystem management changes that could be implemented, as well as increasing and improving research on climate change. In addition, one-quarter of the indirect climate actions identified were to "review the threat of climate change in a few years or at the next major assessment," which means that on ground climate adaptation for that fishery is still some time away. Similarly, another recent study also found a lack of climate action within management plans of Regional Fisheries Bodies (RFB), with a large portion of RFBs placing climate change "permanently

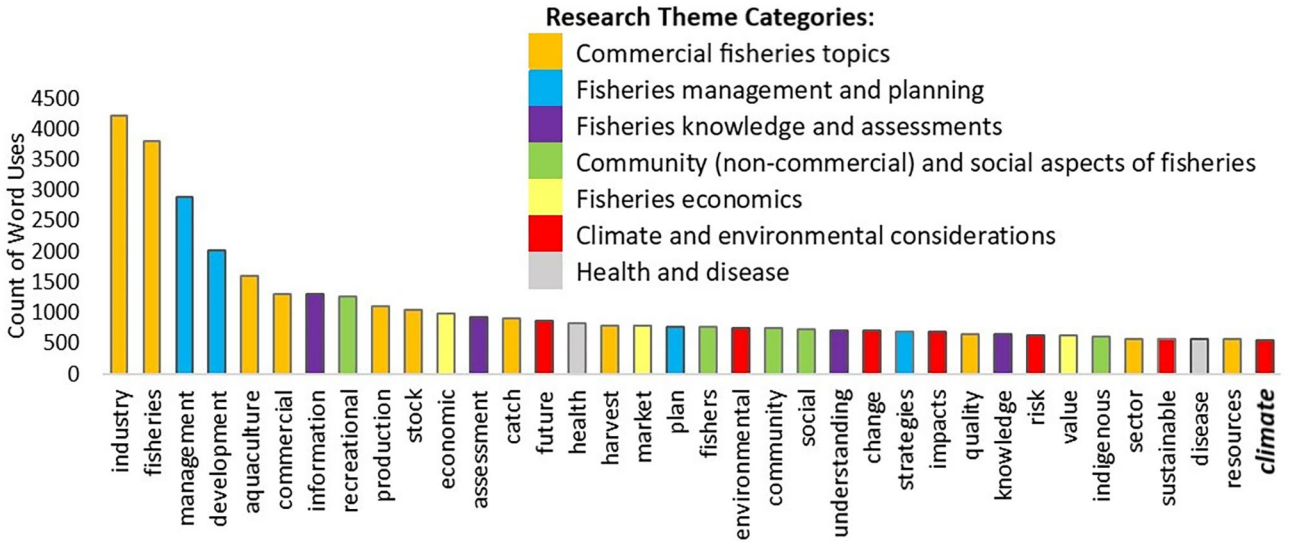

FIGURE 8 | The count of uses of the top 36 most *informative* keywords including and above "climate" (i.e., filler words and *less* informative words removed). Colors represent seven categories of similar or related research themes.

on the agenda for attention" (Sumby et al., 2021). It is likely the uncertainty of climate change which encourages the use of short planning horizons to focus on immediate problems, and supports the dangerous idea that mitigating actions can wait until more information is available (McIlgorm et al., 2010). Although different species and fisheries have differing levels of vulnerability or sensitivity to climate change, there is an increasing need to increase the frequency of inclusion of Climate Mentions and Climate Actions within fisheries management documents.

The combination of results from the current study and Fogarty et al. (2019) indicates that economically important fisheries species are more likely to be better prepared for climate change in terms of scientific climate knowledge availability as well as climate management implementation/adaptations. We also found a correlation between species having climate-related peer-reviewed scientific information available, and those species having more climate-related content identified within their respective management documents, meaning that species with more climate-related peer-reviewed literature available also had associated management documents that were more scientifically informed on climate changes. This finding reinforces the importance of having scientifically informed fisheries management to allow for better preparation and adaptation to climate change. Further investigation of the individual Australian fisheries species that the management documents might relate to found that of the 34 species (out of 99) which could be assigned to the Single-Species Group, 56% (19 species) had Climate Mentions within those management documents. We also found another 19 species within the Single-Species Groups that had climate-related species literature published, of which 13 species overlapped having both Climate Mentions within management documents in the current study, *and* peer-reviewed climate-related species literature in Fogarty et al. (2019). These were identified as species of abalone, crab, lobster, prawn, and sardines, and we therefore determine that their respective fisheries are the most prepared or equipped to adapt to climate change, in terms of knowledge and implementation. These five Single-Species Groups also had some of the highest Economic Commercial Catch Values, Commercial Catch Weights, and Numbers of Commercial Fish Stocks, indicating that these factors, in particular Economic Catch Value and Commercial Catch Weight, may influence which species have the most climate-prepared fisheries management. This is a similar result to our previous study (Fogarty et al., 2019) which found these factors influenced species climate-related research effort and direction, that these species were also more likely to have higher climate sensitivity and were less likely to have species data missing from the SAFS database, compared with other species assessed. It is possible that species *with* Climate Mentions in this study having higher proportions of sustainable fish stocks is due to the fact they also have more peer-reviewed climate-related literature available (Fogarty et al., 2019), *and* Climate Mentions within their management documents, therefore leading to better management of these fisheries. Species *with* Climate Mentions are also likely to be "more important" fisheries species, as they had greater Commercial Catch Weights, and have more resources (i.e., time and money) invested into better management of those fisheries. Furthermore, species that did not yet have data in the SAFS database were most likely to have no species-specific management documents, indicating that those species are "less important" to the fishing industry.

Based on our analysis, we argue that the fishing industry would benefit from having proactive policies which pre-emptively put in place planned emergency responses and adaptations for climate change, in addition to other management directives. The lack of climate-related mentions in fisheries management documents assessed here may be reflective of: (i) insufficient knowledge exchange among scientists and managers about the

ways we can manage climate change in Australian fisheries; (ii) lack of political will for addressing climate change; and/or (iii) a lack of adaptive capacity within fisheries management due to many of the management documents being older and updated so infrequently that there is no scope to revise them as new knowledge is generated. Mechanisms to overcome some of these issues include implementing strategies that foster greater collaboration and knowledge exchange among fisheries scientists and managers (i.e., principles underpinning successful knowledge exchange between marine scientists and decision-makers are provided by Cvitanovic et al., 2016; Hobday and Cvitanovic, 2017). For example, through institutional level changes that facilitate and promote engagement activities such as those embodied by notions of co-production (Norström et al., 2020), using "hot desk" rotations of staff from other institutions (i.e., "embedding," see Roux et al., 2019), increasing boundary organizations (Cvitanovic et al., 2018), and by increasing the use of knowledge brokers to act between institutions (Fazey et al., 2012; Cvitanovic et al., 2015). Directing a more concerted effort toward engaging a wide range of stakeholders (e.g., the public) to foster support for climate-ready fishery policies and programs may also overcome some of these barriers and encourage adaptive capacity (Hobday and Cvitanovic, 2017; Le Cornu et al., 2018).

FRDC Research Priorities and Funding

The FRDC has annual targets for research expenditure for five program areas, being 40% Environment, 40% Industry, 10% People, 8% Adoption, and 2% Communities (FRDC, 2015). Climate-related projects may fall within any of these five program areas, however, the FRDC expenditure in the Environment program area is relatively high, and likely includes projects researching environmental protection. This does not necessarily mean that climate-related fisheries research is not occurring within Australia, as research may be occurring that is funded within universities, state fisheries departments or the R&D departments of fishing companies, rather than by the FRDC. However, the low levels we find in this study suggest that there is currently a lack of up-to-date climate-related fisheries research available to inform fisheries managers and decision-makers on fisheries adaptations to climate change in Australia, although some regions (such as the south-east and western Australian coasts) are more prepared than others (Fogarty et al., 2019). As the number of climate-related research priority applications submitted to the FRDC, and FRDC-funded climate-related research projects are low in recent years, it may indicate that climate is not a high priority when it comes to fisheries research in Australia. This could be because (i) climate change is not considered the most pressing issue by FRDC, (ii) Australia already has a strong legacy of fisheries climate science and FRDC want to invest in other things, (iii) climate change is not yet a high priority topic for fisheries stakeholders and communities, and/or (iv) previous climate-relating funding cycles have led to the perception that climate research has been "done" already.

Our study shows keywords such as "climate" and "environment" were not discussed at the same frequencies as more common topics such as fisheries "production" and "stock" within research priority applications submitted to the FRDC. Even so, we found two peaks in the number of climate-related FRDC-funded research projects in our analysis which may be explained by several concerted efforts to boost climate-related fisheries research around those times. For example, the National Climate Change Adaptation Research Facility (NCCARF) was established in 2007, and its' key role is to coordinate the development of National Climate Change Adaptation Research Plans (NARPs) across a range of priority areas (Hobday et al., 2017). One of these priority areas was addressed by the Marine NARP in 2010 (Mapstone et al., 2010), which has since been updated twice (Holbrook et al., 2012; Hobday et al., 2017). The Marine NARP identified research knowledge gaps with respect to helping marine systems adapt to climate change, and developed research priority questions to enable researchers to focus their efforts on filling these gaps. Following this, there were 26 Marine NARP-funded research projects undertaken from 2010 to 2015 (described in Creighton et al., 2016), 17 of which addressed priority questions on fisheries. At the same time, the FRDC led and funded the "Climate Adaptation Program" from 2010 to 2014, in partnership with Australian and State Governments, CSIRO, and universities (FRDC, 2020).

In the more recent years since these peak funding periods for climate-related fisheries research, our analysis found only low counts of both FRDC funded projects and priority research topics proposed to the FRDC that related to climate, but a small increase in proportions of climate-related research priorities from 2017 onwards. This is not to say that there has been little climate-related fisheries research, as there has in fact been an increased volume of peer reviewed climate-related species literature from 2012 onwards (Fogarty et al., 2019). The 2017 update of the Marine NARP (Hobday et al., 2017), IPCC Climate Report released in 2018 (IPCC, 2018), 2019 UN Climate Action Summit (United Nations, 2019), and the 2019 IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (IPCC, 2019), may have helped to stimulate and keep interest in climate-related research going. Nevertheless, we find that the injection of funds into climate-related fisheries research in Australia has been limited in recent years (Ling and Hobday, 2018). It is evident that future initiatives like the FRDC-led Climate Adaptation Program or Marine NARP climate research funding will help stimulate climate-related research in the field.

Furthermore, to help funders know where to invest money for Australian fisheries in response to climate change, and to help guide national priorities, we propose that future research may seek to undertake a horizon scan of fisheries research needs in Australia, such as those conducted by Holder et al. (2020) and Wilson et al. (2010), to understand what the key climate-related fisheries questions are. This will in turn lead to an increase in climate-related fisheries literature that fisheries management can draw from when updating management directives. In addition, future research is required to investigate more specifically which topics are discussed more frequently than "climate change" in management documents, research project descriptions, priority applications, or other similar documents, to determine whether research priorities need to be re-evaluated.

The small proportions of climate-related FRDC-funded research and research priority proposals may reflect a deeper

problem than just a lack of climate-related research being funded, but rather that climate change is not yet a priority for fisheries stakeholders and communities, as such, leading to fewer climate-related research projects being proposed, and fewer climate-related research projects to fund. This may be part of a cycle within fisheries management and climate change. For instance, fisheries management does not have many "climate-related mentions" and focuses more on maintaining a sustainable industry by responding to environmental and stock changes (e.g., short-term, annual fluctuations). A component of fisheries management is about managing people and navigating politics (Hoel, 1998; Fulton et al., 2011). As fisheries stakeholder and communities do not yet prioritize climate-research highly, research priority applications largely focus on topics other than climate change, and therefore FRDC does not fund many climate-related fisheries research projects. This leads to fisheries management having access to minimal climate-related fisheries research to inform decisions around climate adaptation, and therefore only incorporating climate change into fisheries management to a limited degree, and so on. However, a well-managed fishery should be capable of easily adapting to climate change through the implementation of flexible management measures that can be rapidly changed to address rapid environmental or stock changes. By increasing community and fisheries stakeholder engagement in climate-related research, we can increase awareness and concern of climate-related marine impacts. For example, citizen science programs such as Redmap Australia (see www.redmap.org.au; Pecl et al., 2019b) have been shown to increase public education and engagement on scientific issues (Nursey-Bray et al., 2017, 2018), by giving participants a sense of ownership over the data they have helped collect (Martin et al., 2016) which is then able to be used by various user groups such as scientists (Pecl et al., 2019b; Adler et al., 2020). By increasing public engagement on the issues of climate change, and how it will affect industries such as fisheries, could be beneficial in increasing funding and resourcing in this area, and improve fisheries "social license to operate" (Kelly et al., 2017; van Putten et al., 2018). Although this research focuses on Australian state wild-catch fisheries, our results may also be relevant to other commercial and recreational fisheries, and aquaculture, both in Australia and internationally.

CONCLUSION

The south-east and south-west regions of the Australian coastline have previously been identified as being "most prepared" to implement climate-related scientific information into fisheries management (Fogarty et al., 2019). Here we find that these two regions also have the highest incorporation of "climate" and "environmental protection considerations" in their fisheries management documents, led by South Australia and Victoria (for climate-related content), and New South Wales and Western Australia (for environmental protection content). We also identify that fisheries are more likely to have more climate-related mentions within their associated management documents, if they target species with (i) a higher Economic Commercial Catch Value (primarily), (ii) higher Commercial Catch Weight, or (iii) greater Number of Commercial Fish Stocks. Overall, although our results may have found that "climate" is not necessarily a highly discussed topic within fisheries management documents, research projects, or priority applications (relative to other topics), it may be assumed that "climate" is captured through the discussion of other related topics (e.g., "environmental protection" or "sustainability"), and that if fisheries are managed well, through flexible and scientifically-informed strategies, then climate change and its' associated impacts may be inadvertently addressed by day-to-day fisheries management. However, we argue that the fishing industry would benefit from also having more proactive policies in place which pre-emptively put in place planned emergency responses and adaptations for climate change. It is also evident that initiatives promoting climate-related research, such as the FRDC-led Climate Adaptation Program, or Marine NARP climate research funding, do help stimulate climate-related research, which has the potential to lead to more expert-informed fisheries management, and therefore fisheries that are better prepared for climate change. We believe that climate-related fisheries research in Australia needs to be accelerated for Australian fisheries management to overcome and adapt to future climate changes. Without climate-related fisheries research and funding continuing and increasing into the future, many management agencies and fisheries may not be adequately prepared for the long-term implications of climate change.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

HF, CC, AH, and GP conceived and designed the study. Data collection and analysis was undertaken by HF, who also led the drafting of the manuscript with input from all authors.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.591642/full#supplementary-material

REFERENCES

Adler, F. R., Green, A. M., and Sekercioglu, C. H. (2020). Citizen science in ecology: a place for humans in nature. *Ann. N. Y. Acad. Sci.* 1469, 52–64. doi: 10.1111/nyas.14340

Barange, M., Bahri, T., Beveridge, M. C. M., Cochrane, K. L., Funge-Smith, S., Poulain, F. (eds.). (2018). Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, in *Adaptation and Mitigation Options. FAO Fisheries and Aquaculture Technical Paper No. 627* (Rome: FAO), 628.

Brander, K. (2010). Impacts of climate change on fisheries. *J. Marine Syst.* 79, 389–402. doi: 10.1016/j.jmarsys.2008.12.015

Brierley, A. S., and Kingsford, M. J. (2009). Impacts of climate change on marine organisms and ecosystems. *Curr. Biol.* 19, R602–R614. doi: 10.1016/j.cub.2009.05.046

Brown, C. J., Fulton, E. A., Possingham, H. P., and Richardson, A. J. (2012). How long can fisheries management delay action in response to ecosystem and climate change? *Ecol. Appl.* 22, 298–310. doi: 10.1890/11-0419.1

Bryman, A. (2012). *Social Research Methods*. Oxford: Oxford University Press.

Caputi, N., Feng, M., Pearce, A., Benthuysen, J., Denham, A., Hetzel, Y., et al. (2015). *Management Implications of Climate Change Effect on Fisheries in Western Australia. Part 1. Environmental Change and Risk Assessment*. Fisheries Research Report 260. Department of Fisheries, North Beach, WA, 176.

Cheung, W. W. L. (2018). The future of fishes and fisheries in the changing oceans. *J. Fish Biol.* 92, 790–803. doi: 10.1111/jfb.13558

Cheung, W. W. L., Jones, M. C., Reygondeau, G., and Frolicher, T. L. (2018). Opportunities for climate-risk reduction through effective fisheries management. *Glob. Chang. Biol.* 24, 5149–5163. doi: 10.1111/gcb.14390

Coe, K., and Scacco, J. M. (2017). "Content analysis, quantitative," in *The International Encyclopedia of Communication Research Methods,* eds J. Matthes, C. S. Davis, and R. F. Potter (Hoboken NJ: John Wiley & Sons, Inc.), 345–356.

Creighton, C., Hobday, A. J., Lockwood, M., and Pecl, G. T. (2016). Adapting management of marine environments to a changing climate: a checklist to guide reform and assess. *Prog. Ecosyst.* 19, 187–219. doi: 10.1007/s10021-015-9925-2

Cvitanovic, C., Fulton, C. J., Wilson, S. K., van Kerkhoff, L., Cripps, I. L., and Muthiga, N. (2014). Utility of primary scientific literature to environmental managers: an international case study on coral-dominated marine protected areas. *Ocean Coast. Manag.* 102, 72–78. doi: 10.1016/j.ocecoaman.2014.09.003

Cvitanovic, C., Hobday, A. J., van Kerkhoff, L., Wilson, S. K., Dobbs, K., and Marshall, N. A. (2015). Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: a review of knowledge and research needs. *Ocean Coast. Manag.* 112, 25–35. doi: 10.1016/j.ocecoaman.2015.05.002

Cvitanovic, C., Lof, M. F., Norstrom, A. V., and Reed, M. S. (2018). Building university-based boundary organisations that facilitate impacts on environmental policy and practice. *PLoS ONE* 13:e0203752. doi: 10.1371/journal.pone.0203752

Cvitanovic, C., McDonald, J., and Hobday, A. J. (2016). From science to action: Principles for undertaking environmental research that enables knowledge exchange and evidence-based decision-making. *J. Environ. Manage* 183, 864–874. doi: 10.1016/j.jenvman.2016.09.038

Fazey, I., Evely, A. C., Reed, M. S., Stringer, L. C., Kruijsen, J., White, P. C. L., et al. (2012). Knowledge exchange: a review and research agenda for environmental management. *Environ. Conserv.* 40, 19–36. doi: 10.1017/S037689291200029X

Fogarty, H. E., Cvitanovic, C., Hobday, A. J., and Pecl, G. T. (2019). Prepared for change? an assessment of the current state of knowledge to support climate adaptation for Australian fisheries. *Rev. Fish Biol. Fish* 29, 877–894. doi: 10.1007/s11160-019-09579-7

FRDC (2015). *RD&E Plan 2015-2020*. ACT: Fisheries Research & Development Corporation. Available online at: https://frdc.com.au/en/research/rde-planning-and-priorities/frdc-rde-plan-2015-2020

FRDC (2020). *Climate Adaptation Program*. Fisheries Research & Development Corporation. Available online at: https://www.frdc.com.au/environment/climate-change/climate-adaptation-program (accessed May 15, 2020).

Fulton, E. A., Hobday, A. J., Pethybridge, H., Blanchard, J., Bulman, C., Butler, I., et al. (2018). *Decadal Scale Projection of Changes in Australian Fisheries Stocks Under Climate Change*. CSIRO Report to FRDC. FRDC Project No: 2016/139. Available online at: http://www.frdc.com.au/project?id=3000

Fulton, E. A., Smith, A. D. M., Smith, D. C., and van Putten, I. E. (2011). Human behaviour: the key source of uncertainty in fisheries management. *Fish Fish.* 12, 2–17. doi: 10.1111/j.1467-2979.2010.00371.x

Hobday, A., Pecl, G., Fulton, B., Pethybridge, H., Bulman, C., and Villanueva, C. (2018). "Climate change impacts, vulnerabilities and adaptations: Australian marine fisheries," in *Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options, Fisheries and Aquaculture Technical Paper 627*, eds M. Barange, T. Bahri, M. Beveridge, K. Cochrane, S. Funge-Smith, and F. Poulain (Rome: FAO), 347–362.

Hobday, A. J., and Cvitanovic, C. (2017). Preparing Australian fisheries for the critical decade: insights from the past 25 years. *Marine Freshw. Res.* 68, 1779–1787. doi: 10.1071/MF16393

Hobday, A. J., Ling, S. D., Holbrook, N. J., Caputi, N., McDonald Madden, E., McDonald, J., et al. (2017). *National Climate Change Adaptation Research Plan Marine Biodiversity and Resources: Update 2017*. Gold Coast, QLD: National Climate Change Adaptation Research Facility, 75.

Hobday, A. J., and Lough, J. M. (2011). Projected climate change in Australian marine and freshwater environments. *Marine Freshw. Res.* 62, 1000–1014. doi: 10.1071/MF10302

Hobday, A. J., and Pecl, G. T. (2014). Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. *Rev. Fish Biol. Fish* 24, 415–425. doi: 10.1007/s11160-013-9326-6

Hoel, A. H. (1998). Political uncertainty in international fisheries management. *Fish. Res.* 37, 239–250. doi: 10.1016/S0165-7836(98)00140-4

Holbrook, N., Creighton, C., Robertson, J., Vu, H., and McKellar, R. (2012). *National Climate Change Adaptation Research Plan: Marine Biodiversity and Resources - Update Report*. National Climate Change Adaptation Research Facility, Gold Coast, QLD, 60.

Holder, P. E., Jeanson, A. L., Lennox, R. J., Brownscombe, J. W., Arlinghaus, R., Danylchuk, A. J., et al. (2020). Preparing for a changing future in recreational fisheries: 100 research questions for global consideration emerging from a horizon scan. *Rev. Fish Biol. Fish* 30, 137–151. doi: 10.1007/s11160-020-09595-y

IPCC (2018). "Summary for policymakers," in *Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context Of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, eds V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, et al. (Geneva: World Meteorological Organisation), 32.

IPCC (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, eds H. O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, et al. 755. Available online at: https://www.ipcc.ch/site/assets/uploads/sites/3/2019/12/SROCC_FullReport_FINAL.pdf

Jennings, S., Pascoe, S., Hall-Aspland, S., Le Bouhellec, B., Norman-Lopez, A., Sullivan, A., et al. (2016). Setting objectives for evaluating management adaptation actions to address climate change impacts in south-eastern Australian fisheries. *Fish. Oceanogr.* 25, 29–44. doi: 10.1111/fog.12137

Johnson, C. R., Banks, S. C., Barrett, N. S., Cazassus, F., Dunstan, P. K., Edgar, G. J., et al. (2011). Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. *J. Exp. Mar. Biol. Ecol.* 400, 17–32. doi: 10.1016/j.jembe.2011.02.032

Johnson, J. E., and Welch, D. J. (2015). Climate change implications for Torres Strait fisheries: assessing vulnerability to inform adaptation. *Clim. Change* 135, 611–624. doi: 10.1007/s10584-015-1583-z

Kelly, R., Pecl, G. T., and Fleming, A. (2017). Social licence in the marine sector: a review of understanding and application. *Marine Policy* 81, 21–28. doi: 10.1016/j.marpol.2017.03.005

Le Cornu, E., Doerr, A. N., Finkbeiner, E. M., Gourlie, D., and Crowder, L. B. (2018). Spatial management in small-scale fisheries: a potential approach for climate change adaptation in Pacific Islands. *Marine Policy* 88, 350–358. doi: 10.1016/j.marpol.2017.09.030

Ling, S. D., and Hobday, A. J. (2018). National research planning accelerates relevance and immediacy of climate-adaptation science. *Marine Freshw. Res.* 70, 62–70. doi: 10.1071/MF17330

Mapstone, B., Appleford, P., Broderick, K., Connolly, R., Higgins, J., Hobday, A., et al. (2010). *National Climate Change Adaptation Research Plan for*

Marine Biodiversity and Resources. Gold Coast, QLD: National Climate Change Adaptation Research Facility, 68.

Martin, V., Smith, L., Bowling, A., Christidis, L., Lloyd, D., and Pecl, G. (2016). Citizens as scientists: what influences public contributions to marine research? *Sci. Commun.* 38, 495–522. doi: 10.1177/1075547016656191

McIlgorm, A., Hanna, S., Knapp, G., Le Floc'H. P., Millerd, F., and Pan, M. (2010). How will climate change alter fishery governance? Insights from seven international case studies. *Marine Policy* 34, 170–177. doi: 10.1016/j.marpol.2009.06.004

Mobsby, D. (2018). *Australian Fisheries and Aquaculture Statistics 2017, Fisheries Research and Development Corporation project 2018-134*. Canberra, ACT: ABARES.

Norström, A. V., Cvitanovic, C., Löf, M. F., West, S., Wyborn, C., Balvanera, P., et al. (2020). Principles for knowledge co-production in sustainability research. *Nat. Sustain.* 3, 182–190. doi: 10.1038/s41893-019-0448-2

Nursey-Bray, M., Nicholls, R., Vince, J., Day, S., and Harvey, N. (2017). "Public participation, coastal management and climate change adaptation," in *Marine and Coastal Resource Management: Principles and Practice*, eds D. Green and J. Payne (Oxon: Taylor & Francis Ltd), 223–239.

Nursey-Bray, M., Palmer, R., and Pecl, G. (2018). Spot, log, map: assessing a marine virtual citizen science program against Reed's best practice for stakeholder participation in environmental management. *Ocean Coast. Manag.* 151, 1–9. doi: 10.1016/j.ocecoaman.2017.10.031

Ogier, E., Jennings, S., Fowler, A., Frusher, S., Gardner, C., Hamer, P., et al. (2020). Responding to climate change: participatory evaluation of adaptation options for key marine fisheries in Australia's South East. *Front. Marine Sci.* 7:97. doi: 10.3389/fmars.2020.00097

Ogier, E. M., Davidson, J., Fidelman, P., Haward, M., Hobday, A. J., Holbrook, N. J., et al. (2016). Fisheries management approaches as platforms for climate change adaptation: comparing theory and practice in Australian fisheries. *Marine Policy* 71, 82–93. doi: 10.1016/j.marpol.2016.05.014

Pecl, G. T., Doubleday, Z., Ward T,Clarke, S., Day, J., Dixon, C., Frusher, S., et al. (2011). *Risk Assessment of Impacts of Climate Change for Key Marine Species in South Eastern Australia*. Part 1: Fisheries and Aquaculture Risk Assessment. Project 2009/070, Hobart, TAS: Fisheries Research and Development Corporation, 159.

Pecl, G. T., Ogier, E., Jennings, S., van Putten, I., Crawford, C., Fogarty, H., et al. (2019a). Autonomous adaptation to climate-driven change in marine biodiversity in a global marine hotspot. *Ambio* 48, 1898–1515. doi: 10.1007/s13280-019-01186-x

Pecl, G. T., Stuart-Smith, J., Walsh, P., Bray, D. J., Kusetic, M., Burgess, M., et al. (2019b). Redmap Australia: challenges and successes with a large-scale citizen science-based approach to ecological monitoring and Community engagement on climate change. *Fron. Marine Sci.* 6:349. doi: 10.3389/fmars.2019.00349

Pecl, G. T., Ward, T., Briceño, F., Fowler, A., Frusher, S., Gardner, C., et al. (2014a). P*reparing Fisheries for Climate Change: Identifying Adaptation Options for Four Key Fisheries in South Eastern Australia*. Project 2011/039, Hobart, TAS: Fisheries Research and Development Corporation, 278.

Pecl, G. T., Ward, T. M., Doubleday, Z. A., Clarke, S., Day, J., Dixon, C., et al. (2014b). Rapid assessment of fisheries species sensitivity to climate change. *Clim. Change* 127, 505–520. doi: 10.1007/s10584-014-1284-z

Pinsky, M. L., Fenichel, E., Fogarty, M., Levin, S., McCay, B., St. Martin, K., et al. (2020). Fish and fisheries in hot water: what is happening and how do we adapt? *Popul. Ecol.* 1–10. doi: 10.1002/1438-390X.12050

Poloczanska, E. S., Brown, C. J., Sydeman, W. J., Kiessling, W., Schoeman, D. S., Moore, P. J., et al. (2013). Global imprint of climate change on marine life. *Nat. Clim. Chang.* 3, 919–925. doi: 10.1038/nclimate1958

Pörtner, H.-O., Karl, D. M., Boyd, P. W., Cheung, W. W. L., Lluch-Cota, S. E., Nojiri, Y., et al. (2014). "Ocean systems," in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, et al. (Cambridge; New York, NY: Cambridge University Press), 411–484.

Roux, D. J., Kingsford, R. T., Cook, C. N., Carruthers, J., Dickson, K., and Hockings, M. (2019). The case for embedding researchers in conservation agencies. *Conserv. Biol.* 33, 1266–1274. doi: 10.1111/cobi.13324

Sarkar, U. K., Roy, K., Karnatak, G., and Nandy, S. K. (2018). Adaptive climate change resilient indigenous fisheries strategies in the floodplain wetlands of West Bengal, India. *J. Water Clim. Change* 9, 449–462. doi: 10.2166/wcc.2018.271

Stecula, D. A., and Merkley, E. (2019). Framing climate change: economics, ideology, and uncertainty in American news media content from 1988 to 2014. *Front. Commun.* 4:6. doi: 10.3389/fcomm.2019.00006

Steven, A. H., Mobsby, D., and Curtotti, R. (2020). *Australian Fisheries and Aquaculture Statistics 2018, Fisheries Research and Development Corporation Project 2019-093*. Canberra, ACT: ABARES.

Sumaila, U. R., Cheung, W. W. L., Lam, V. W. Y., Pauly, D., and Herrick, S. (2011). Climate change impacts on the biophysics and economics of world fisheries. *Nat. Clim. Chang.* 1, 449–456. doi: 10.1038/nclimate1301

Sumby, J., Haward, M., Fulton, E., and Pecl, G. (2021). Hot fish: the response to climate change by regional fisheries bodies. *Marine Policy* 12:104284. doi: 10.1016/j.marpol.2020.104284 Available online at: https://www.sciencedirect.com/science/article/pii/S0308597X20309301

Townhill, B. L., Radford, Z., Pecl, G., Putten, I., Pinnegar, J. K., and Hyder, K. (2019). Marine recreational fishing and the implications of climate change. *Fish Fish.* 20, 977–992. doi: 10.1111/faf.12392

United Nations (2019). *UN Climate Action Summit 2019*. United Nations. Available onliene at: https://www.un.org/en/climatechange/un-climate-summit-2019.shtml (accessed May 15, 2020).

van Putten, I., Cvitanovic, C., and Fulton, E. A. (2016). A changing marine sector in Australian coastal communities: an analysis of inter and intra sectoral industry connections and employment. *Ocean Coast. Manag.* 131, 1–12. doi: 10.1016/j.ocecoaman.2016.07.010

van Putten, I. E., Cvitanovic, C., Fulton, E., Lacey, J., and Kelly, R. (2018). The emergence of social licence necessitates reforms in environmental regulation. *Ecol. Soc.* 23:24. doi: 10.5751/ES-10397-230324

Vourvachis, P., and Woodward, T. (2015). Content analysis in social and environmental reporting research: trends and challenges. *J. Appl. Account. Res.* 16, 166–195. doi: 10.1108/JAAR-04-2013-0027

Weatherdon, L. V., Magnan, A. K., Rogers, A. D., Sumaila, U. R., and Cheung, W. W. L. (2016). Observed and projected impacts of climate change on marine fisheries, aquaculture, coastal tourism, and human health: an update. *Front. Marine Sci.* 3:48. doi: 10.3389/fmars.2016.00048

Welch, D. J., Saunders, T., Robins, J., Harry, A., Johnson, J., Maynard, J., et al. (2014). *Implications of Climate Change Impacts on Fisheries Resources of Northern Australia. Part 1: Vulnerability Assessment and Adaptation Options*. FRDC Project No: 2010/565. Townsville, QLD: James Cook University, 236.

Wilson, S. K., Adjeroud, M., Bellwood, D. R., Berumen, M. L., Booth, D., Bozec, Y. M., et al. (2010). Crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes. *J. Exp. Biol.* 213, 894–900. doi: 10.1242/jeb.037895

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