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Guidance on Adaptation of Commonwealth Fisheries management to climate change

E.A. Fulton, E.I van Putten, LXC. Dutra, J. Melbourne-Thomas, E. Ogier, L. Thomas, N. Rayns, R. Murphy, I. Butler, D. Ghebrezgabhier, A.J. Hobday

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Researcher Contact Details

Name:
Address:

Phone:
Fax:
Email:

FRDC Contact Details

Address:	25 Geils Court
	Deakin ACT 2600
Phone:	02 6285 0400
Fax:	02 6285 0499
Email:	frdc@frdc.com.au
Web:	www.frdc.com.au

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Abbreviations

AFMA – Australian Fisheries Management Authority

CSIRO – Commonwealth Scientific and Industrial Research Organisation

FRDC – Fisheries Research and Development Corporation

HIMI – Heard Island and McDonald Island

NPF – Northern Prawn Fishery

RAG – resource assessment group

SBT – Southern Bluefin Tuna

Keywords

Climate change, adaptation, fisheries management

Executive Summary

Climate change is reshaping ecosystems and fisheries that rely upon them, in Australia and around the world. While a lot of research has gone into observing change or modelling what change may be coming, much less has been done on laying out a reliable means of finding adaptation options that can mitigate the worst effects and allow for fisheries to remain sustainable, profitable and equitable. This project aimed to fill that gap.

The project team made up of CSIRO scientists, university researchers and fisheries managers assessed climate associated risk to the ecological resources of Australia's Commonwealth fisheries and to the Australian Fisheries Management Authority's (AFMA's) capacity to meet its policy and legislative objectives. The project team then worked with industry and other stakeholder groups to develop and trial a risk assessment-based means of identifying potential adaptation strategies for Australian Commonwealth fisheries.

This body of work leveraged off and was motivated by the multi-million-dollar investment in climate change research projects funded through the 2010-2014 FRDC Climate Adaption Program. It also drew on the 2016-2018 CSIRO led project (FRDC project 2016/139) that updated the suite of ecosystem models that exist for Australian waters and created projections for key fishery species out to 2050, with a particular focus on the short-medium term (out to 2025-2030). This previous work highlighted the potentially significant impacts of climate change on marine ecosystems, fisheries and fisheries management in Australia. It provided a solid foundation for developing a process to both evaluate the ability of Australian fisheries and resource management to adapt to climate change effects and identify sound adaptation options.

This project focused on Commonwealth fisheries as to-date no fisheries jurisdiction in Australia has laid out a clear guide for how it will adapt in response to climate change. AFMA is a prime candidate for developing and trialling the process as it has substantive responsibility for many fishing zones around Australia (spanning all ecosystem types, including climate effects hotspots) and already has established best practice adaptive co-management approaches.

Consequently, the objectives of the project were:

1. To assess how well the existing Commonwealth fisheries management framework will cope with climate change impacts.
2. To develop a methodology and approach for AFMA and other fisheries to adapt their regulatory environment to climate change impacts on Commonwealth fisheries.
3. To develop strategies and priorities to account for effects of climate change in the management of Commonwealth fisheries.

These objectives were met in full by taking a structured approach to considering the biophysical, operational and governance aspects of risk to the fisheries. The biophysical risks were dealt with by drawing on the large body of existing research on effects of climate change on marine species and using that to undertake a climate sensitivity analysis for the main target, byproduct, bycatch and threatened, endangered and protected species (TEPS) for each of the Commonwealth managed fisheries.

Aspects of operational risk were explored in participatory workshops with industry representatives (typically resource assessment group members) and other experts who had knowledge of how climate is, or might, affect specific fisheries.

The governance dimension involved an evaluation of how a change in either (i) stock or ecosystem status, or (ii) fishery operations could influence AFMA's ability to pursue its policy and legislative objectives within the current regulatory framework. This involved discussing with experts in fisheries, environmental and coastal resource policy and law regarding how the likely changes in ecosystems and fishery operations would meet (or not) the objectives and requirements of the relevant Acts.

Learnings and information from each of these steps was then used as a basis for developing the risk assessment approach. A handbook (and associated assessment tool) was written to summarise this material and to act as a guide for future evaluations, stepping interested stakeholders, industry and managers through a structured process to rate risks and identify adaptation options – both to do with fishery operations and management actions. The process and handbook were specifically developed with AFMA needs and Commonwealth fisheries in mind, but can be applied to fisheries in other jurisdictions. Users could adjust them as needed for the context of their fishery, adding or removing ecosystem factors, industry operations and management actions based on relevance to their fishery.

This project found that the existing Commonwealth fisheries management framework has many vulnerabilities with respect to climate impacts and has many potential points of failure with respect to pursuing policy and legislated objectives and international obligations. While Commonwealth fisheries follow best practice management approaches, which means they are starting from the best possible response foundation, adaptive responses will be required to cope with the multi-faceted impacts climate change is having and is anticipated to have on Australian marine ecosystems.

As a whole the project activities have highlighted some general adaptation options that are likely to be of value in many Australian fisheries.

Key findings are:

- All AFMA fisheries contain valuable species sensitive to climate change, with some of the most valuable fisheries amongst those fisheries showing the greatest sensitivity
- All fisheries, but especially short lived and invertebrate fisheries are likely to become far more variable into the future, that is, when, where and how much fish is caught
- Bycatch and TEPS are likely to be highly sensitive to climate change effects, meaning there will be a need to understand how that interacts with any fishing effects
- A shifting ecosystem state over multiple years (or decades) has the potential to go unnoticed and eventually undermine the sustainability of Australian fisheries and the businesses and livelihoods that depend upon them
- Cross jurisdictional management coordination will be required to improve adaptation to climate change, maximising flexibility needed for adaptive capacity and minimising the risks arising from cumulative effects
- Monitoring and forecast capacity will become key to understanding system change that supports evidence-based decision making, fishery sustainability and business profitability
- Australia needs to find a way of making monitoring and forecasting possible and supported long term to maintain our position and reputation as having well managed fisheries (Australia's monitoring capacity is currently insufficient given the degree to which climate change will likely reshape Australian ecosystems)
- There can be significant implications (positive and negative) for fishing industries arising from climate change effects that can extend from operational issues to community impacts and economic consequences.

The project also found that the most common adaptation options include:

- Shifting fishing grounds (and potentially infrastructure) or targeting as species distributions and ecosystem composition changes
- Diversifying markets and post-harvest value adding to increase the value of existing product or find outlets for new products
- Develop operational and multi-year forecasts capability (so can redirect resources/effort in poor condition years, or switch between pre-agreed management arrangements)
- Mainstream climate inclusive assessments and decision-making processes
- Verify that assumptions behind assessment tools and management regulations (e.g. zoning) are still valid
- Undertake targeted research to reduce sources of uncertainty (such as how climate affects recruitment)
- Develop new technologies or processes to maintain/improve safety under the changed conditions (e.g. to deal with more intense sea states) and to deal with changed needs for mitigation measures (e.g. due to changed levels or types of TEPS interactions)
- Lay out a timeline of prioritised research and management actions, which may have associated trigger points (the implications of delaying or bringing forward actions in that timeline should be well understood)
- Education of consumers and the public on what is being done and why so that well intentioned public action does not undermine sustainability and fishery viability.

Many of these adaptation options concur with what has been found to be successful elsewhere and are being recommended by the FAO (Bahri et al 2021).

The outcomes of this project can support AFMA's (and industry's) short to medium term adaptation responses. However, for greater direct benefits to be realised, fisheries need time to go through the dedicated process described in this report and implement its outcomes. While project resources (the *Adaptation Handbook* and associated excel tool) will be publicly available for download from CSIRO and AFMA websites, further funding support will be required by individual fisheries to individually step through the process for their specific context. While the resources required are not extensive for a qualitative assessment it does need to be done on a fishery-by-fishery, or regional ecosystem basis (which may involve working on stocks across jurisdictional boundaries). Fisheries and funding agencies would also be well served to consider the timeline of research and other activities needed to support the implementation of identified adaptation options. This can help with prioritising actions and associated research spending (to ensure needed information, technologies etc are available when needed).

Introduction

Globally and within Australia, a significant amount of research has been undertaken on how the physical changes to the environment caused by climate change may affect fisheries in the future (Brown et al. 2009; Brown et al. 2012; Fulton and Gorton 2014; Blanchard et al. 2017; IPCC 2019; Lotze et al. 2019; Pethybridge et al. 2020) and what observed changes have already been witnessed (Babcock et al. 2019; IPCC 2019). Much of this research has focused on how ocean warming, and (more recently) changed frequency of extreme events, may affect the abundance and distribution of species and the timing of key life history events (such as migrations or spawning). There are other ways in which climate change will influence fisheries (see Figure 1), with acidification (Riebell and Gattuso 2015), de-oxygenation (Ito et al. 2017) and ocean stratification (Li et al. 2020) gaining more research attention over the last decade.

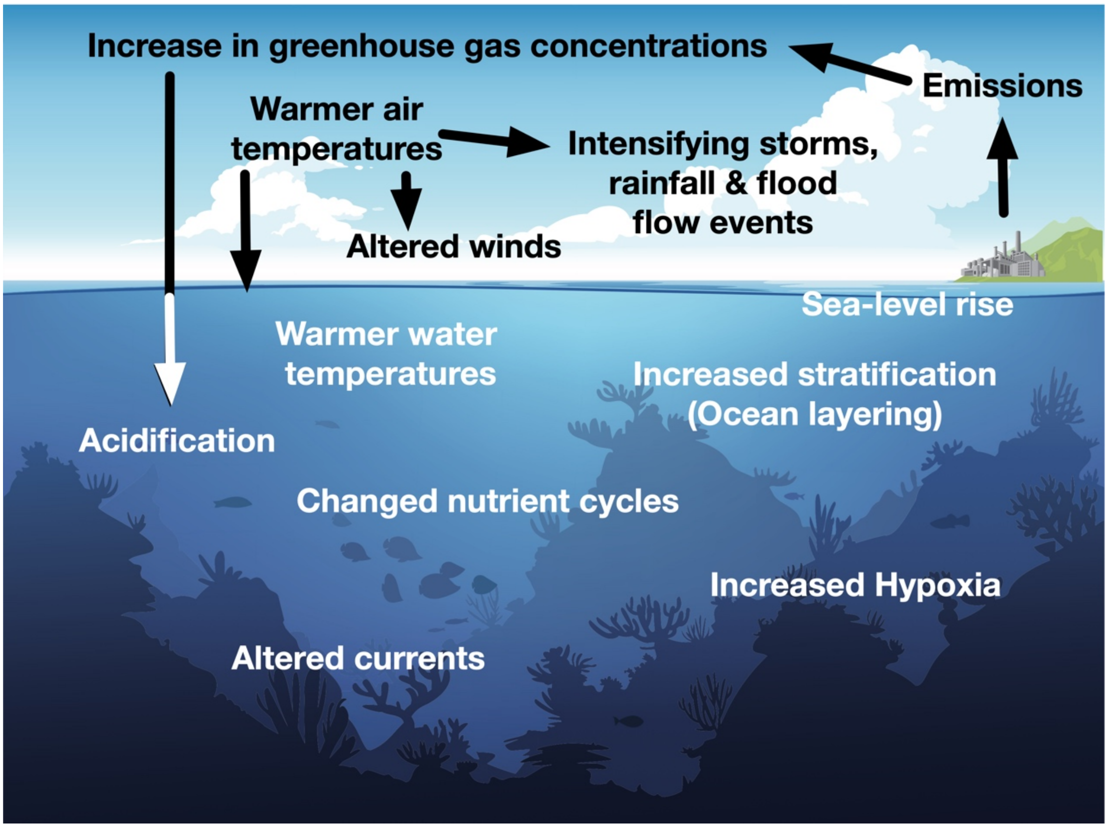


Figure 1: Schematic diagram showing the ways in which climate change influences the physical environment of ocean ecosystems.

Between 2010 and 2014, $9 million AUD was spent through the FRDC Climate Adaption Program on 25 climate change research projects. This work was led by FRDC in partnership with the Commonwealth and state governments, CSIRO and universities as the lead co-investors. This work culminated in the December 2014 FRDC report *Fostering strategic fisheries management responses to Australia's changing climate* (Creighton 2014) and the associated publication (Creighton et al. 2016), which generated a checklist of thirteen elements (encompassing findings from the 25 projects) to assist managers and scientists in incorporating climate change considerations into their assessments and other work and to aid in steering progress towards improving marine policy and management. The 13 elements outlined in Creighton et al. (2016) are grouped into three broad areas: preconditioning; future proofing; and transformational changes and opportunities. Pecl et al. (2014) also laid out a clear framework for rapidly assessing the sensitivity of species to climate change induced shifts in environmental conditions.

Coincident with this work on climate change effects, multiple ecosystem models have been developed (for various reasons) for the majority of Australian marine ecosystems. A project run in 2017-2018 (FRDC project 2016/139) updated these models and created projections for key fishery species out to 2050, with a focus on the short-medium term (out to 2025-2030). This work highlighted that 60-70% of target species in Australia are sensitive to climate change in some way and that (under the latest available physical environmental information from the CSIRO and IPCC) many species are projected to decline in abundance. Indeed, based solely on preferred temperature ranges, nearly all target species were projected to decline to some extent. Although, including trophic interactions in the models saw more uncertainty introduced, with some species increasing, as predators or competitors are more strongly affected by projected environmental shifts and resulting food web feedbacks (Fulton et al. 2018; Pethybridge et al. 2020).

Overall, this large body of research highlights the potentially significant impacts of climate change on fisheries and fisheries management in Australia, not just in terms of dealing with declining stocks, but also responding to new opportunities – as existing research predicts that climate change will have both positive and negative impacts on reproduction, recruitment and distribution of biomass of Australia's commercially important marine species. While this existing research provides plentiful information on the effects of climate change, it only lightly touches on the next step of informing Australian fisheries managers of options for adaptation to climate change effects.

Explicit strategies for fisheries management to respond to climate change impacts have been lacking, despite many fishery stakeholders acknowledging that the issue of climate change should be a high priority issue for fisheries management. The ability of Australian fisheries management to adapt to coming change is as yet largely unknown and a pivot is needed towards considering the resilience of management systems to the expected future state of the marine environment and identifying effective response options that can help ensure sustainable fishing into the future. This means support is required, not only for highlighting where management gaps exist but in providing tools that aid in identifying adaptation options that are likely to work given the conditions of a specific fishery and the observed and projected effects of climate change for that region.

To-date no jurisdiction in Australia has laid out a clear guide for how it will adapt its fisheries and management system in response to climate and anticipated levels of change. AFMA is a prime candidate for leading an active effort looking at what may need to be done for management systems to effectively adapt, as AFMA has substantive responsibility for many fishing zones around Australia; including those areas that are expected to be hot-spots for climate change effects, such as SE Australia, one of the fastest warming areas in the ocean (Hobday and Pecl 2014). Thus, this project was initiated to help lay out a guide for how adaptation can be tackled, providing a general guide that can produce advice tailored to a specific fishery; and to trial that process in a few fisheries. A key part of this work was to look at options available to fishers not just managers, as all aspects of a fishery will need to respond. Moreover, the participatory approach to AFMA fisheries engagement with and participation from key fishery stakeholders is always essential for success, as all stakeholders will need to assist in any subsequent fisheries management change processes. The guides created by this project have the potential to benefit the marine ecosystem and fisheries stakeholders, increasing the benefits and reducing the risks.

Objectives

The objectives of the project were:

1. To assess how well the existing Commonwealth fisheries management framework will cope with climate change impacts.
2. To develop a methodology and approach for AFMA and other fisheries to adapt their regulatory environment to climate change impacts on Commonwealth fisheries.
3. To develop strategies and priorities to account for effects of climate change in the management of Commonwealth fisheries.

Method

A number of methods were used in delivering this report, these are summarised below.

Consideration of the different dimensions of climate change associated risk

Climate change poses three dimensions of risk to a fishery:

- biophysical – the direct physical change in the system and how species respond, which has been the primary focus of much previous work (IPCC 2019);
- operational – how fishing itself is changed, perhaps because fishing grounds have shifted, or the safety or efficiency of past practices has been degraded (Sainsbury et al. 2018), infrastructure is under threat or no longer in a useful location or because the supply chain is impacted in some way (Plaganyi et al. 2014; Lim-Camacho et al. 2015);
- governance – where fisheries management is unable to meet its policy or legislative objectives (including international obligations)

The first dimension was tackled by drawing on the large body of existing research around Australia of specific effects of climate change on marine species; and where gaps remained, by drawing on relevant material from the global body of relevant literature.

The second dimension was dealt with via participatory workshops with industry representatives (typically RAG members), but in some instances going further to other experts to elicit information on how climate is, or might, affect their fishery.

The third dimension involved an evaluation of how a change in either (i) stock or ecosystem status, or (ii) fishery operations could influence AFMA's ability to meet its policy and legislative objectives within the current regulatory framework. This evaluation involved discussing with experts in fisheries, environmental and coastal resource policy and law regarding how the likely changes in ecosystems and fishery operations would meet (or not) the objectives and requirements of the relevant Acts.

The methods and lessons learnt in considering these dimensions of risk were distilled into a handbook and associated assessment tool to act as a guide for future evaluations.

High level biophysical climate sensitivity assessment of AFMA fisheries

As it was clear that there were insufficient project resources to assess all three dimensions of risk in depth for each of AFMA's fisheries, but that AFMA needed guidance on where its risks most likely sat, the biophysical climate sensitivity of species in each fishery were rated. This sensitivity assessment involved:

- Compiling a list of relevant species per fishery – taken from the latest Ecological Risk Assessment (ERA) for that fishery. These assessments identify species as target, byproduct, bycatch (discard) or TEPS (threatened, endangered, protected species) and that identifier was kept for the sensitivity assessment so that statistics per fishery for each class of species could be provided (e.g. proportion of target species sensitive to climate change etc).
- Compiling biomass trajectories from species distribution models and ecosystem models (as reported in Fulton et al. 2018);
- Performing a sensitivity analysis. Where the sensitivity of a species had previously been assessed (as summarised in Fulton et al. 2018) that sensitivity rating was used, otherwise climate sensitivity assessments were done following the method of Pecl et al. (2014). This

was done via an automated assessment using the criteria listed in Table 1-1 of Fulton et al. (2018) and the attribute values used in the ERAs.

- Where additional physical environmental information was needed (in checking for appropriate projections or completing the sensitivity analysis) the best available information was used, including: extreme events projections made by Oliver et al. (2018); and expected trajectories of climate change (temperature, pH, oxygen, salinity, rainfall) as projected by (a) the modified Ocean Forecasting Australia Model version 3 (OFAM-v3) from the CSIRO Ocean Downscaling Strategic Project (and as reported in Fulton et al. 2018), which specifically focuses on fine scale ocean environment around Australia; and (b) the Australian region of the ensemble of climate model outputs available from the latest Coupled Model Intercomparison Project (CMIP6), which will inform the upcoming 2021 IPCC sixth assessment report (AR6).

As many species had missing attributes an assessment wasn't possible for all species listed in a fishery's ERA. Consequently, reporting of the sensitivity per fishery focuses on those species with both estimated sensitivities and projections. For some fisheries (e.g. Norfolk Is) projections were not available for all/many species so only sensitivities were included in the assessment. Where many species (e.g. sharks) with similar life history had matching sensitivities and projections of the same magnitude and direction these were pooled for the purposes of reporting.

Preliminary guidance on where management is likely to be undermined as a result of this sensitivity is provided; with initial management/research suggestions made for each fishery based on the sensitivities and projections and insights gained from the in-depth analyses performed for the HIMI, SBT and Northern Prawn Fisheries. These management/research suggestions are by intent high level (as a rapid guide to help prioritisation), because greater elaboration of the adaptation options, and what needs to be done to support them, requires a more detailed process (involving people from those fisheries) as outlined in the *Adaptation Handbook*.

Potential Operational Effects - Impact pathways and Qualitative models

Laying out the potential effects on a specific fishery involves working with experts to determine the chains of interacting factors that describe how a physical change (climate change) expresses itself in terms of changes to catch, fishing operations, market opportunities, social reputation etc. The method used in this project was to run a short series of workshops (Oct 2018-March 2020) to elicit the factors involved and information on how those factors were connected and how people might look to influence those factors (or change things entirely) into the future.

Two methods were used here to help structure these discussions – impact pathways and qualitative models (described briefly below). While these methods are not as time and resource intensive as fully quantitative methods it was still not feasible to carry them out for all AFMA fisheries. At a joint workshop in late 2018 preliminary pathways were created for the Small Pelagics Fishery, Southern Bluefin Tuna (SBT), Torres Strait Tropical Rock Lobster, the Northern Prawn Fishery (NPF) and parts of the trawl sector of the Southern Eastern Scalefish and Shark Fishery. It was only possible to follow up in depth on the SBT and NPF within the project. In 2020 the Heard Island and McDonald Islands (HIMI) fishery was also run through the entire process to double check the level of resources and feasibility of undertaking the approach as laid out in the handbook on a fishery that had not previously been exposed to the process.

Impact Pathways

Building impact pathways is a useful way of capturing the broader understanding of how a fishery system works (across its physical, ecological and human components). This method involves drawing pathways showing the chains of potential impacts of climate change on other parts of the system.

The impact pathways developed during this workshop were created collaboratively with commercial, recreational and indigenous fishers, managers, eNGOs, international fishery experts and researchers to understand how they understand their fisheries, current and potential interventions from both operators and management agencies and how they expect these interventions to affect issues affecting the fisheries. Mayne (2015) suggests that drawing impact pathways collaboratively helps workshop participants understand: a) issues related to management and implementation (e.g. how to monitor if an intervention is successful and how to manage interventions adaptively); b) causal links and identify potential unintended links and consequences (evaluate interventions); and c) adequately scale the range of interventions. Diverse views and expertise are important to include in drawing impact pathways as they provide a rich picture of potential interventions and impacts, based on expert opinion of how changes to the environment can influence the fishery.

In essence, impact pathways represent a simple mental model of the chains of potential impacts of climate change and potential interventions and understand how these are meant to work (Mayne, 2015). They are useful for understanding how changes in the environment can influence the fishery and design adequate interventions.

Taking a structured approach to building impact pathways ensured nothing was intentionally overlooked and that pathways drawn up by different people or for different fisheries were comparable. Given the complexity of some of the larger fisheries, impact pathways were drawn at a sub-fishery level – that is, for groups of fishers or sets of vessels of similar size operating in similar ways (as such groups are assumed to have similar levels of exposure, similar constraints, similar motivations and desires, similar behaviours and capacity to respond). Key considerations when creating an impact pathway include the identification of key features to be represented and how they relate to one another. Key elements are: key physical and/or chemical ocean properties; biological and ecosystem impacts; direct fisheries response; socio-economic impacts of the direct fishery response; management responses and knock-on effects. All of these are explained in further detail in the *Adaptation Handbook* appendices.

Identifying the key elements of the impact pathway help participants conceptualise how the changes in the environment are affecting the fishery and what to do about these changes. The next step is to understand how the interventions are meant to work by adding causal links between impact pathways elements and management interventions. Causal loops were drawn up during the fishery workshop and further refined post-workshop via the development of a narrative for the impact pathway. This helps communicate the impacts on the fishery in a graphic form (supported by details from the narrative), how the interventions are expected to influence fishery outcomes and what needs to change.

Qualitative modelling

Qualitative models represent a more structured approach compared to impact pathways to drawing conceptual models of how a system works. Information from experts (or other sources) can be used to construct conceptual models of how the fishery system is interconnected – what the key components are and how they influence one another. These conceptual models can be based on the impact pathways or can be drawn up separately. The conceptual models are transcribed into qualitative models (signed diagraphs) which show the nature of the connections – whether a relationship leads to growth or shrinkage of sets of linked components (e.g. where the growth/shrinkage of one thing causes the connected component to also grow/shrink). These qualitative models can then be analysed, using the mathematical properties of the connections to explore what might happen if the system is perturbed (Dambacher and Ramos-Gilberto 2007; Melbourne-Thomas et al. 2013).

Considering additional risks to AFMA's objectives

AFMA's policy and legislative objectives were listed. Information on potential changes to the status of target stocks, species of conservation concern, ecosystem structure and function, catches, profits etc were collated from ecosystem and fisheries projections, the sensitivity analysis and the causal loops drawn up in the impact pathways and qualitative models. Researchers than worked with experts in fisheries, environmental and coastal resource policy and law to step through how those likely changes would see the objective met or not and how the changes could prevent/weaken AFMA's capacity to meet each of the objectives. The results of those discussions were tabulated as standalone information (Appendix 4), but also informed thinking on the breadth of potential management considerations included in the Step 3 of the assessment process outlined in the handbook. While not quantitative Step 3 of the assessment process does reflect thinking around how the management actions intervene, reshape or incentivise action, provide new knowledge, deliver (or not) to legal requirements and policy convention, but also how they interact with other forms of governance (whether that comes from Traditional Owners, broader community norms or other considerations). While there is no claim it is completely exhaustive the intent was to highlight as many potential general options as possible so that individual choices could be structured for individual system details and needs (rather than be prescriptive).

Creating a Climate Change Adaptation Handbook

Leveraging all the other parts of the project, a handbook was drawn up outlining how to run through the process of assessing sensitivity and then identifying opportunities for adaptation both by fishers and managers. The intent is to provide a risk-based assessment of the extant fisheries management system with respect to expected climate change effects and in doing so identifying and prioritising feasible response and intervention options and any residual risks for further action. The method provided in the handbook allows for a qualitative assessment of hazards (risks) to key elements of the fisheries management system, including objectives, management plans and harvest strategies. It also provides insight into where additional quantitative assessment may be beneficial.

As noted above, the methods in the handbook were carried out for the SBT and NPF as the handbook was shaped, with the HIMI fishery also run through the entire process to check the process works for a fishery without prior exposure. Trialling it in this way allowed for the resolution and troubleshooting of the steps before finalising the handbook. The handbook was also circulated to the project steering committee and other fisheries experts for input before it was finalised. These additional reviewers checked that: outputs were useful (especially for the resources required); that the handbook process was clearly laid out; that the methods could be employed across other fisheries; and that the criteria/methods laid out were appropriate for wider application.

Results and Discussion

Climate change is causing significant changes in many physical ocean drivers – including sea surface temperature (IPCC 2019), marine heat waves (Hobday et al. 2018), extreme weather events (Babcock et al. 2019), patterns of ocean circulation (Ridgway 2007), stratification (Li et al. 2020), ocean acidification (Turley and Gattuso 2012), deoxygenation (Ito et al. 2017) and sea level rise (Taherkhani et al. 2020). These physical changes in turn influence the abundance, distribution, phenology and physiological condition of marine species, affecting the productivity, location and composition of fisheries resources (Pecl et al. 2014). Shifts or turnover in fished resources affects fishing operations – their efficiency, timing, location, safety, cost structure and profitability (Barange et al. 2018).

Experience from elsewhere in the world shows that the capacity of the fishing industry to react and adapt to climate change induced shifts in ecosystems tends to be much greater than for the management decision making process (FAO in press). Fortunately, strong best practice fishery management is one of the best-known means of ensuring ecosystems that are as resilient as possible to climate effects on fisheries (Grafton, 2010). This means Australia's Commonwealth fisheries, which have invested in improving stock status over the past twenty years, should be in a good starting position. Moreover, co-management of the kind used in Commonwealth fisheries (supporting a good working relationship between industry, management and other stakeholders) has the potential to help management respond in a timely manner while also allowing for input from management on what might be maladaptive (FAO in press). Although, whether such relationships will survive should change reach a point where issues span jurisdictions or see the objectives of different stakeholders pull in different directions remains to be seen, such trade-offs and tensions have plagued efforts at marine integrated management more generally for some time (Antunes and Santos 1999; Lombard et al. 2019).

While some general adaptation steps may be shared across fisheries (e.g. move to centralised coordination of management for shared stocks), fishery specific adaptation options will need to be built on dialogue amongst fishery stakeholders, because the broader context of the fishery and ecosystem will influence the success of different adaptation options. Some of this is to do with the kinds of species and fishing operations, while some is to do with the financial, technical and other resources available to implement any adaptation options.

Biophysical climate sensitivity assessment of AFMA fisheries

The detailed results of the sensitivity assessment per fishery is provided in Appendix 3 and are summarised in Table 1. The majority of projections summarised from Fulton et al. (2018) are declines, though a few species (especially TEPS recovering from past depletion) show strong increases. While the projections associated with target species have medium to high confidence, the other species projections are a lot less certain.

Table 1: Summary of climate sensitivity of each AFMA fishery. The dominant result per species type per fishery are presented (for target, byproduct, bycatch and TEPS as defined by the most recent ERA for that fishery). Confidence refers to confidence in any biomass projections (i.e. the decline ▼, or increase ▲ etc). Note hatched colouring indicates where a mixed result occurred as no single result was dominant for the set of species considered.

Sensitivity				Confidence					
	Low	Medium	High		Low	Low-Med	Medium	High	Not Avail.

Fishery	Number of species assessed	Dominant Response				Median Confidence
		Target	Byproduct	Bycatch	TEPS	
Coral Sea	42	▼	-	▼	▼	
Eastern Tuna and Billfish	58	▼	▼	▼	▼	Target Other species
Heard Is., McDonald Is.	109	▼	▼	-	▼	
Macquarie Is.	52					
Norfolk Is.	31			▼		
Northern Prawn	117	▼	▼	▼	▼	Target Other species
Northwest Trawl	21	Steady	▼	▼	▼	
SBT	25	Uncertain	▼	▼	▼ ▲	
Scallop	27	Variable	Uncertain	Mixed	Mixed	
SESSF	225	Variable	▼	▼	▼	
Skipjack	51	▼	▼	Mixed	▲	
Small Pelagics	24		▼	▼	▼	
Squid Jig	27	Uncertain	▼	Variable	Mixed	
Torres Strait	20	Mixed	Steady	▼	Mixed	Target Other species
Western Deepwater Trawl	63	▼	▼	▼	▼	
Western Tuna and Billfish**	50	Mixed	▼	▼	Variable	

** Includes Christmas Island and Cocos Island fisheries

As already discussed in Fulton et al. (2018) and Pethybridge et al. (2020), trophic interactions also make the projections more uncertain. The species distribution models consistently predict declines in abundance (and shifted distributions in many cases), while far fewer of the trophic models do, as a species may increase even under deteriorating conditions if their predators or competitors are more heavily impacted (releasing the species of interest from that constraint and allowing for some increase).

While confidence in quantitative projections is mixed, the qualitative sensitivity ratings indicate that fisheries jurisdictions will need to begin to act even when forecast skill is only poorly developed. This is because no regrets actions will be needed even while more quantitative methods are being developed/refined.

The key points to take from this analysis are that:

- All AFMA fisheries contain valuable species sensitive to climate change, with some of the most valuable fisheries amongst those fisheries showing the greatest sensitivity.
- All fisheries, but especially short lived and invertebrate fisheries are likely to become far more variable into the future, that is, when, where and how much fish is caught
- Tropical species are often more sensitive to climate driven change (due to their life history and because they live closer to the limits of the environmental conditions they can tolerate).
- Bycatch and TEPS are likely to be highly sensitive to climate change effects, meaning there will be a need to understand how that interacts with any fishing effects
- There can be significant implications, both positive and negative, for fishing industries arising from climate change effects that can extend from operational issues to community impacts and economic consequences.

Considering risks to pursuing AFMA's objectives

As can be seen from Table A1 in Appendix 4, climate change could potentially undermine AFMA's capacity to deliver on a number of its policy and legislative objectives and international obligations within the current regulatory framework. Looking across all relevant acts key risks to delivery objectives include (these points are made in the Appendix but repeated here for the reader's convenience):

- The potential for shifts (even regime shifts) in fished ecosystems to change what would represent a reference point for a sustainable use of those harvested stocks. Even where a regulatory scheme was on target for delivering a sustainable and profitable fishery in the past it could be under/over what is suitable now and go unnoticed because (a) the assessment and decision-making process does not yet take climate effects into account and (b) unavoidable delays in the fishery management process (at best data from last year is used this year to set rules for next year, less frequent or statistically powerful data collection would exacerbate issue). This means overfishing (and IUU) could unknowingly occur.
- There is the strong possibility that (at least in some fisheries) traditional assessment processes will be insufficient for evaluating and managing climate affected ecosystems and stocks or to take all sectors (commercial, recreational and indigenous) into account. This is not just for single species (or current multispecies) assessments but ecological risk assessments (ERAs) too; such assessments may become out of date quickly (in terms of the species to be considered but also the productivity and other parameters used in the assessments)
- Increasing pressure on systems and the shifting nature of systems requires coordinated action, without which there is a significant risk that cross jurisdictional dynamics and cumulative effects are being overlooked
- Changes in ecosystems could also see discards, bycatch and TEPS interactions change; any increases could erode public perception of the sustainability and performance of fisheries in Australia and also potentially undermine compliance with international obligations/agreements
- TEPS (but also other species) that are strongly increasing or decreasing due to climate change, potentially in combination with other human interventions (e.g. also increasing

due to restoration, or alternatively declining more sharply due to cumulative effects across multiple pressures), can create a number of issues. For example, such species can create a bottleneck restricting catch to a level that some areas become unfishable or TACs cannot be caught. Changing abundance and/or distribution of TEPS, target species and fisheries will likely lead to new interactions in locations not seen before. Moreover, fisheries can be caught in the middle as conservation managers trade off pressures on different TEPS (Chasco et al. 2017).

- Australian ecosystems may be changing rapidly as a result of climate induced environmental shifts and extreme events (Babcock et al. 2019). However, estimates of the magnitude of the change are uncertain as there is a lack of relevant/suitable data. For fisheries management processes to account for climate effects to the standard set by past management strategy and fisheries standards (or even to a standard where it can be said decisions are evidence based) requires monitoring not only to be maintained, but in some instances expanded.
- The resources required to manage through the increased uncertainty, may see costs of management become disproportionate with respect to the value of some individual fisheries with levies unable to be paid and government agencies unable to bridge the gap within the current budgetary arrangements. Technological advancements may make large scale monitoring feasible in future, though it would likely still require government investment (such an investment would deliver to needs across regulatory agencies and benefit industry, who are globally turning to digital data services and analytics to improve fishing efficiency).
- There is the potential for management surveillance and enforcement to have ever increasing demands on it. Shifts in ecosystems across Australia's EEZs and beyond could see activities and need for attention increase in many regions simultaneously, and at a time when operating conditions may become more hazardous (due to heavier sea states), stretching surveillance and enforcement (and putting Australia in a position where it may not be able to meet agreements or obligations). This means that data/information sharing across sectors and jurisdictions is crucial for delivering sustainable resource use and management.
- Management arrangements – such as specific national and international regulations (e.g. static zoning and the quota system) – may restrict industry adaptative capacity (such as changing species or locations); and while co-management remains the best practice for inclusive approaches to tackling resource management questions, it is unclear whether the co-management structure can cope with rapid change across member objectives and jurisdictions
- The increased uncertainty may lead to management inefficiencies; either through a perception that management is inadequate (even when it is not) or due to real inefficiencies resulting from reactive layering of additional regulatory requirements/rule setting rather than more proactive and structured set of responses.
- Apparent management accountability may also be eroded by climate change. Changed resource levels and distribution is likely to lead to resource sharing issues and potentially conflict between and within sectors. There could be flow-on effects for levels of confidence in management performance and public (or other sector) perception of the acceptability of fisheries activities, including interactions with habitats/bycatch/TEPS or changes in what is considered acceptable ownership of Australian resources.

The challenge arising from these issues of how to best pursue AFMA's objectives helped shape thinking in the *Adaptation Handbook* (see section below). Tables of potential management adaptation options have been included in the handbook to help anyone applying it to find management adaptation options that mitigate these risks. In addition, the criteria used to rate those new management options (such as complexity and cost of implementation) capture aspects that could increase/decrease these management risks (or lead to new risks). Finally, the Excel tool created to help people step through the handbook assessment process has a question-and-answer section to help highlight where there are risks to current management objectives.

Adaptation options for AFMA fisheries

The recommended actions from the climate sensitivity assessment for the Commonwealth fisheries (see Appendix 3) identified a number of general potential fishery and management adaptation options that could be considered by many fisheries in Australia.

The most common fishery response options were:

- Consider relocation of infrastructure as species range shift
- Repurpose existing infrastructure to diversify into fish sales, tourism etc
- Quota owners pool vessels and other infrastructure to reduce costs and risks
- Develop operational and multi-year forecasts capability (so can plan to redirect resources/effort due to poor fishing years or changed fishing locations)
- Identify alternative target species options (e.g. cephalopods, mesopelagics), but verify that regulatory arrangements, market, processing and the phenology/abundance/distribution of those species will not be an insurmountable obstacle.
- Explore value adding options for product and education of consumers – both around the value and quality of the product but also what the fishery is doing about its climate response and interactions with TEPS, habitats, animal welfare etc.
- Develop greater information sharing capability amongst the fishing fleet in real time to know areas to avoid (e.g. areas with high incidence of bycatch or TEPS) and areas to fish (e.g. good catch rates)
- Diversify investments across a range of fisheries and/or out of fishing altogether.

The management options identified included:

- Require climate aware assessments (e.g. via incorporating environmental co-variates), reference points and quota management system; adjust reference points and catch limits if climate impacts stock abundance/recruitment. The form of such an approach would benefit from management strategy evaluation testing, including the implications of different delays in implementation. Moreover, the multi-dimensional nature of the issues at hand – addressing both environmental drivers/variability/uncertainty and triple bottom line harvest strategies – means MSE will increasing need to move away from classical population dynamics models to 'Models of Intermediate Complexity for Ecosystem assessments' (MICE) (Plagányi et al. 2012).
- Use frame-based management, adjusting reference points, harvest strategies (etc) depending on whether the environmental variables are in a "good" (production supporting) or "bad" (production inhibiting) state. This kind of management is already used, or being discussed, for large upwelling stocks (e.g. off South Africa or in the California Current), but requires monitoring to track states.
- Develop operational and multi-year forecasts capability (so managers and fishers can plan to redirect resources/effort in poor condition years)
- Use trigger points to identify when action is needed; this might be catch trigger points (especially for currently lightly fished species) to signify when catch in combination with climate may put too much stress on a species, or trigger points on observed demographics (abundance, distribution, recruitment, age structure) which may indicate the species being

impacted to a level more action is needed (these should be made more conservative for shallow water and habitat dependent species as these are likely to be more heavily impacted)

- Respond and manage as a stock (i.e. across jurisdictions), this requires monitoring of relevant variables for stocks of interest. Even where tactical management and annual assessment is constrained to key commercial species, information should still be collected, where possible, on secondary (e.g. byproduct) and bycatch species so that it is possible to rigorously assess a species at a later date if there is concern that climate impacts have occurred.
- Verify spatial (or rotational or seasonal) management is still achieving its objectives. Additional or relocated zoning (or shift to an alternative management approach) may be required if species range shifts or shifts in behaviour have undermined the efficacy of the extant zoning plans
- Add trip limits for new hotspot locations
- Undertake awareness programs, communication around climate effects. This may be particularly important to help stakeholder and public understanding of the relative contribution of climate vs fisheries pressure on TEPS.
- Additional mitigation measures may be needed if TEPS (or bycatch) species increase in abundance, increasing the number of interactions, or if their abundance is impacted by climate and even low levels of additional mortality could be particularly deleterious. Similarly, reconsideration of baskets or companion species-based rules may be required.
- Need for centralised coordination of management for mobile and range shifting species
- Targeted research to reduce sources of uncertainty (such as how climate affects recruitment)

Reports detailing the initial impact pathways drawn up for the Small Pelagics Fishery, Torres Strait Tropical Rock Lobster and the trawl sector of the SESSF, as well as more in-depth assessments for the SBT, Northern Prawn and HIMI fisheries have been shared with those fisheries and AFMA. These reports should help future management planning and research prioritisation. Specific details of these reports will not be shared here due to commercial in-confidence of some of the key materials included in the impact pathways. However, some general learnings can be presented.

Current information for the HIMI, SBT and Northern Prawn fisheries suggests that of the three HIMI is likely to have targets species most sensitive to climate change. However, all fisheries are very likely to see increased variability into the future (short-medium term), especially with the increasing magnitude and frequency of extreme events (which can strongly and negatively impact target stocks).

Extreme events aside all the fisheries have substantial adaptive capacity, as best practice management practices are largely in place and the industry members have already demonstrated a strong willingness to explore options such as value adding to their products, exploring the development of alternative markets and technological innovation to improve safety, efficiency and product quality. In the short to medium term (within the next decade) that should help buffer any effects on target and byproduct species. Into the longer-term adaptation may prove harder and more radical options, such as relocating infrastructure, changing fleet make up etc may be required if increasing costs cannot be mitigated in some way. One more complicated management response that should prove beneficial in many fisheries is to have centralised coordination of management of species spanning jurisdictions and increased cross-jurisdictional flexibility and monitoring. Such undertakings are not trivial and action would likely need to begin soon to ensure it is in place ahead of absolute need.

Some of the greatest risks are associated with spatial and temporal changes in distribution of target and byproduct species (where risks are moderate to high). Risks associated with bycatch and TEPS also typically tend to be moderate to high, which may lead to regulatory, compliance and social acceptance issues into the future.

While the immediate risk of sharp declines in Commonwealth fisheries may not be high, climate issues have already been recognised in tropical fisheries (e.g. in the Torres Strait) and other fisheries, such as the SESSF, have seen a long period of incremental change where there have been declines in multiple species over multiple years, associated with significant economic impacts (especially in coastal communities of NSW and Victoria where fisheries made substantial local contributions to the economy), which may be (at least in part) climate associated. Given these changes and the lead time on research and changes to management, consideration of a timeline of needs and potential actions would be highly recommended. This would enable high priority actions to be considered as part of the normal fisheries management process. Actions to consider include:

1. Inclusion of climate/environment and ecosystem/habitat update in the annual RAG meeting schedule (e.g. the same meeting as the annual decision making so the ecosystem and environmental context is understood at the time decisions are made). Similarly, climate effects should be folded into future planning exercises and into the ERA process (as noted in a recent review of AFMA's ERA program; Fulton et al. 2019).
2. Exploration of the implications and viability of changing effort distribution or targeting if projected species and ecosystem changes are realised; this may require negotiation of cross-jurisdiction coordination and flexibility
3. Targeting new markets, additional value adding, product diversification and consumer education could be credible adaptation options, but are not straightforward and expansion of these options would take time and in some cases require careful communication to help the broader community understand why these changes are necessary.
4. A focus on safety at sea along with company, fleet and management flexibility is likely to be beneficial in many fisheries.
5. Surveys and monitoring are imperative and must be maintained or expanded to fully and proactively understand stock status. This is true in all fisheries, but especially ahead of the fishing season and recruitment in highly variable stocks that are likely to require timely responses and different (pre-agreed) management actions in "good" and "poor" years (such as different fishing seasons or allowed catches, as has been considered in upwelling systems; Punt et al. 2016). "Ship of opportunity" (or citizen science) environmental monitoring systems could be of great benefit to fisheries in helping resolve uncertainty, but would need to be set up and supported long term. Guidance should be sort (e.g. from IMOS ships of opportunity data collection program) on the true potential for additional on-board data collection to leverage fleet movements for expanding the collection of environmental data and what such a program would cost (including the cost of developing the system required to rapidly translate data streams into information useful for informing management responses). Implementation of this kind of fisher collected monitoring has its statistical and practical challenges (it does not have the spatial representativeness of a statistically designed fisheries independent survey) but can still provide useful environmental and demographic information. It has also been found to strengthen and empower co-management relationships and trust between resource users, managers and scientists (Pittman et al. 2019; FAO in press). An added benefit of within-season monitoring of this kind is that it can provide an early warning system, safeguarding catches and seafood consumers from known health threats associated with events such as harmful algal blooms (Barth et al. 2019; Lercari et al. 2018).
6. Education of consumers and public on what is being done and why so that well intentioned public action does not undermine sustainability and fishery viability

7. Additional research work will be required, particularly in terms of:
    a. Adding environmental drivers to harvest strategies (acknowledging that this is already being looked into) and providing climate change scenarios in assessment documents so that risk-equivalent advice can be provided to decision makers. Applications in other jurisdictions (FAO in press) shows that this is feasible and cost effective in both data poor and data rich situations.
    b. Dedicated efforts to understand physical drivers in the fishery regions and development of both multi-year forecast capacity (acknowledging that this is also already underway) and extreme events forecasts (including harmful algal blooms as well as storms, marine heatwaves etc). These forecasts can help with both short- and long-term planning (to minimise negative impacts and improve safety) and allow for more efficient fishing operations (to minimise additional costs incurred due to the devaluation of past knowledge of fishing locations and species behavioural patterns).
    c. Looking into how to stage future shifts in triggers/timing/boundaries/targeting/gear/marketing if abundance/distribution/catch composition changes; and the implications of acting earlier/later in terms of cost, effectiveness and outcomes (including the sustainability of any new target species, the technology required to profitably and sustainably harvest them and depredation implications)
    d. Additional consideration of TEPS interaction mitigation technology may be required due to changes in interactions arising from climate effects.

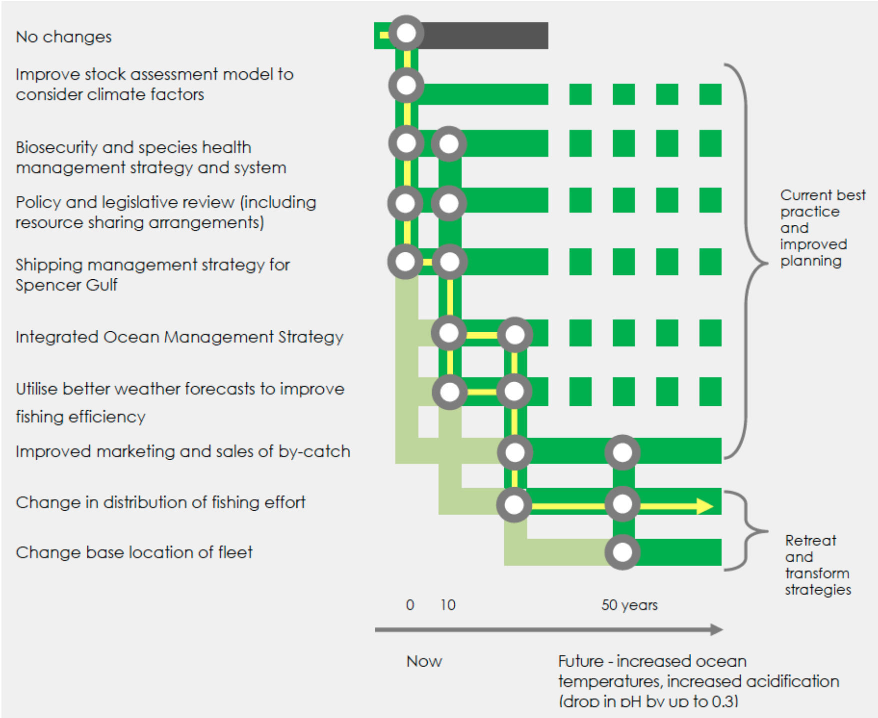
Looking beyond Australia and the process developed in this project the adaptation options put forward match those highlighted by this project. The major exceptions are: (a) insurance schemes that indemnify fishers against loss and damage due to climate events, or due to 'forced' changes in fisheries operations, through to having to exit a fishery (Tietze and van Anrooy 2019); and (b) active interventions, such as translocations to compensate for changes in productivity (as has been done in Tasmania for Rock Lobster; Chandrapavan et al. 2010). The latter could be expanded to other more direct interventions to maintain and recover impacted habitats (or other species), such as the kind of technical interventions being considered for the Great Barrier Reef (Bay et al. 2019).

A final lesson that can be taken from the global progress in advancing fisheries adaptation is that it is a challenging process and one that is currently typically progressing much more slowly than would be ideal given the rate of ecosystem and stock change. Challenges to successful and timely implementation included uncertainty, mistrust, a lack of political will, governance structures, rights disputes and inflexible legal frameworks (FAO in press). Moreover, few places have thought through the path dependency aspects of adaptation responses – considering the longevity of response pathways, how a decision may close off future options or what precursor steps are required before an adaptation option can be implemented. An exception to this is the regional planning done on the Eyre Peninsula for fisheries and other industries in the region (Siebentritt et al. 2014). That process explicitly considered rough timelines for when actions would cease to be useful or when they could come online and how they are potentially interconnected (see the example in Figure 2). A number of actions have been proposed to assist with implementation (FAO in press), many of which are also the marks of good management practice (Pomeroy et al. 2001), including:

- cost-benefit analyses (including the cost of inaction);
- active engagement of relevant stakeholders and supporting knowledge exchange (across disciplines, sectors, knowledge systems);
- raising ocean literacy and the awareness of society in general;
- development of coordinated management across jurisdictions (including formalised transboundary or multi-jurisdictional agreements) to allow for decisions to be made based on a more complete picture of cumulative effects; and

- allowing for flexibility and adaptive responses in legislation and/or having key actions in policy rather than legislation (to increase flexibility).

(a)



(b)

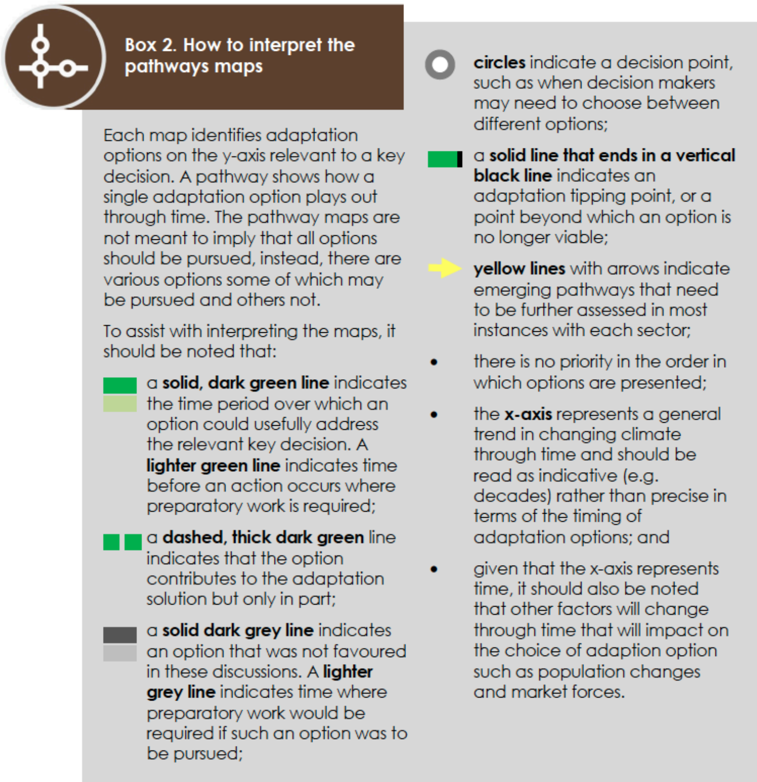


Figure 2: Example adaptation pathways showing how different pathways may emerge or terminate at different times (a) map of pathways (b) key to the map (from Siebentritt et al. 2014 which discusses Regional Climate Change Adaptation Plans for the Eyre Peninsula).

Climate Change Adaptation Handbook

The *Adaptation Handbook* developed in the project provides a step-by-step guide to help fisheries managers and other fishery stakeholders to formally consider changes shaping fisheries through a process of risk assessment and identification of adaptation options. The objective of the handbook is to help:

i) develop strategies and priorities to account for effects of climate change in the management of fisheries using a risk assessment approach;
ii) to assess how well the existing fisheries management framework will cope with climate change impacts; and
iii) to develop an approach for fisheries managers to adapt their regulatory environment in the light of climate change impacts.

The handbook (and the associated summary sheets and excel tool) is presented as a generic instrument to help the reader think about their circumstances and fishery issues. It is not fixed in form, it can be adjusted and adapted to better suit different contexts and potential users are encouraged to re-shape it as needed for their system (e.g. removing irrelevant factors or adding additional factors that are unique to the fishery of interest). In particular, implicit assumptions have been made about risk in the default process provided in the handbook. For example, in Steps 2 & 3 it is assumed that having progressively more options reduces risk (you have a greater chance of finding something that will help). However, this may not always be true, and readers/users must continuously keep thinking about the circumstances of their fishery.

A risk-based approach was taken in the handbook (and project more broadly) as such approaches are used widely to structure strategic planning by banks, individual businesses, military, disaster response ministries and the World Economic Forum. Like most risk assessments the process laid out in the handbook follows several phases: a pre-risk assessment (scoping phase), the actual risk assessment, and then a post risk assessment which provides actions and/or recommendations (Figure 3).

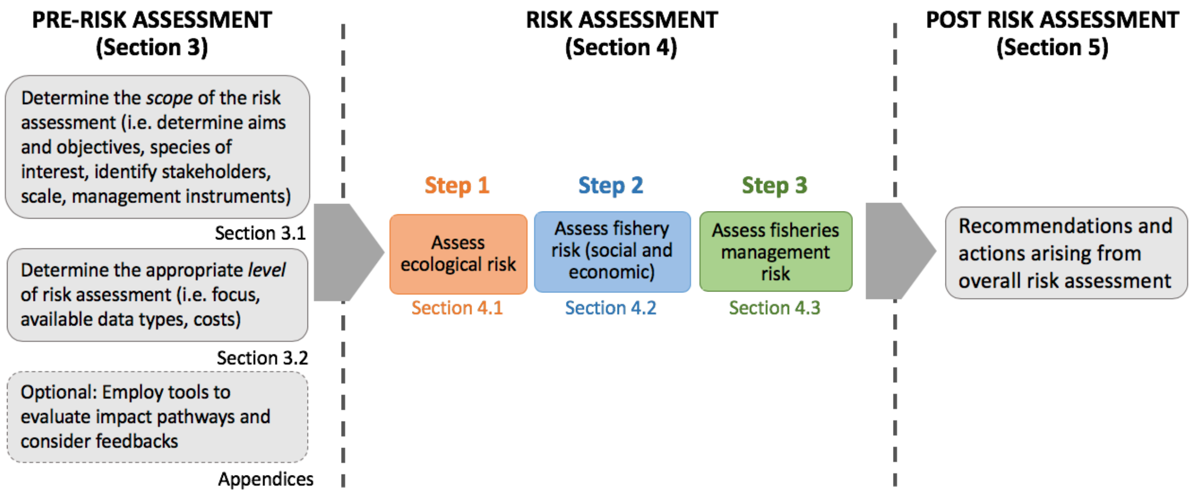


Figure 3: The handbook steps (section numbers refer to sections in the Adaptation Handbook).

To make this process as easy to follow as possible the handbook provides an overview of the five major topic areas (equating to steps in the process):

1. **Pre-assessment** to determine the scope and level of risk assessment. This includes deciding whether an assessment is needed – the decision tree provided in Figure 3 was designed to help with this decision-making step.
2. **Climate driven changes** in physical and chemical ocean variables. This helps structure thinking on what kinds of changes are occurring in the region of the fishery.
3. **Direct and indirect effects of climate change** on marine biology and ecology (i.e. the fish stocks, habitats and ecosystem the fishery relies on). This forms the basis of the ecological risk assessment step.
4. **Responses available to fishery participants** to address the change in physical or chemical ocean variables and any consequential changes in the fish stocks and ecosystems that the fishery relies on. This is the starting point for assessing the operational fishery risk.
5. **Fisheries management decision points and adaptation options** for fisheries managers. This is basis of the management risk assessment step

The order of these topic areas follows the flow of the overall assessment process, which begins with the pre-assessment (1), which is then followed by a three-step risk assessment (2 to 4) and these are brought together to determine effects, potential fishery and management responses and options (5). The full process is shown in Figure 4 and Figure 5 and described in more detail in the *Adaptation Handbook* (Appendix 6). This form of structured assessment, which includes inclusive discussion with all fishery stakeholders has a high likelihood of producing outcomes that are effective and acceptable to all involved, even with limited quantitative information, providing robust no-regret adaptation measures that are cost-effective under prevailing climate conditions (FAO in press).

A worked example for a hypothetical fishery is provided in the handbook to give a sense of what is involved in implementing the process for a fishery. The handbook's appendices also include information on tools (such as impact pathways and qualitative models) that can help the process by providing a means of bringing information together on how climate effects fisheries in a structured and clear way. An excel spreadsheet, which includes all the tables and information from the handbook, has also been created. The intent is for this spreadsheet to provide an accessible digital platform for completing the assessment and to act as an additional tool to help complete the process. This will be available for download from the same websites as the handbook. The spreadsheet is set up with text entry slots for individual fishery species or species groups and any information that must be input by a fishery and then lookup tables and automated links work through the tables to create a consistent risk assessment rating based on the input information. Additional notes sections help identify where these risks may put policy and legislative objectives at risk.

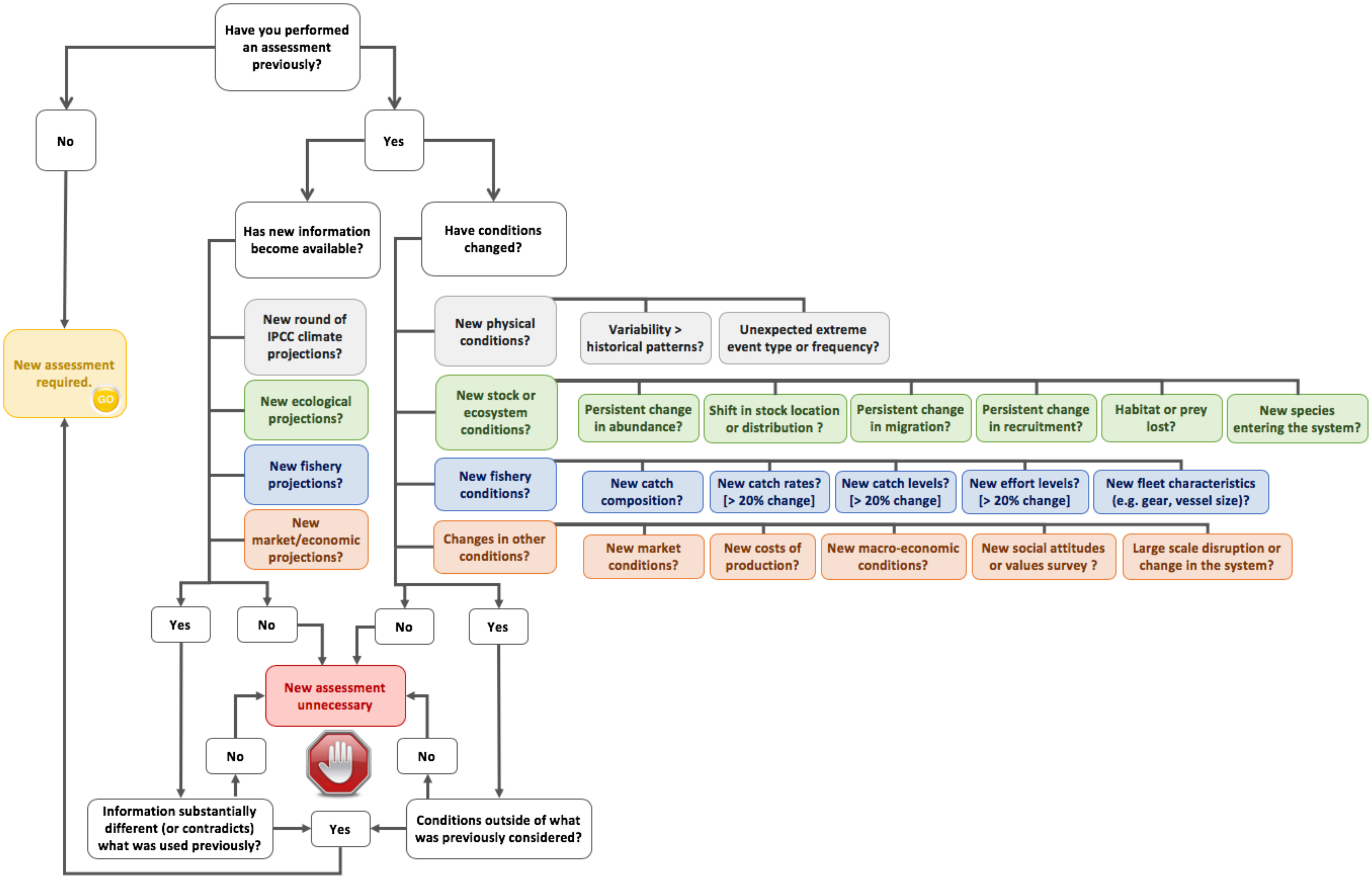


Figure 4:Decision tree for checking whether an adaptation and risk assessment is required.

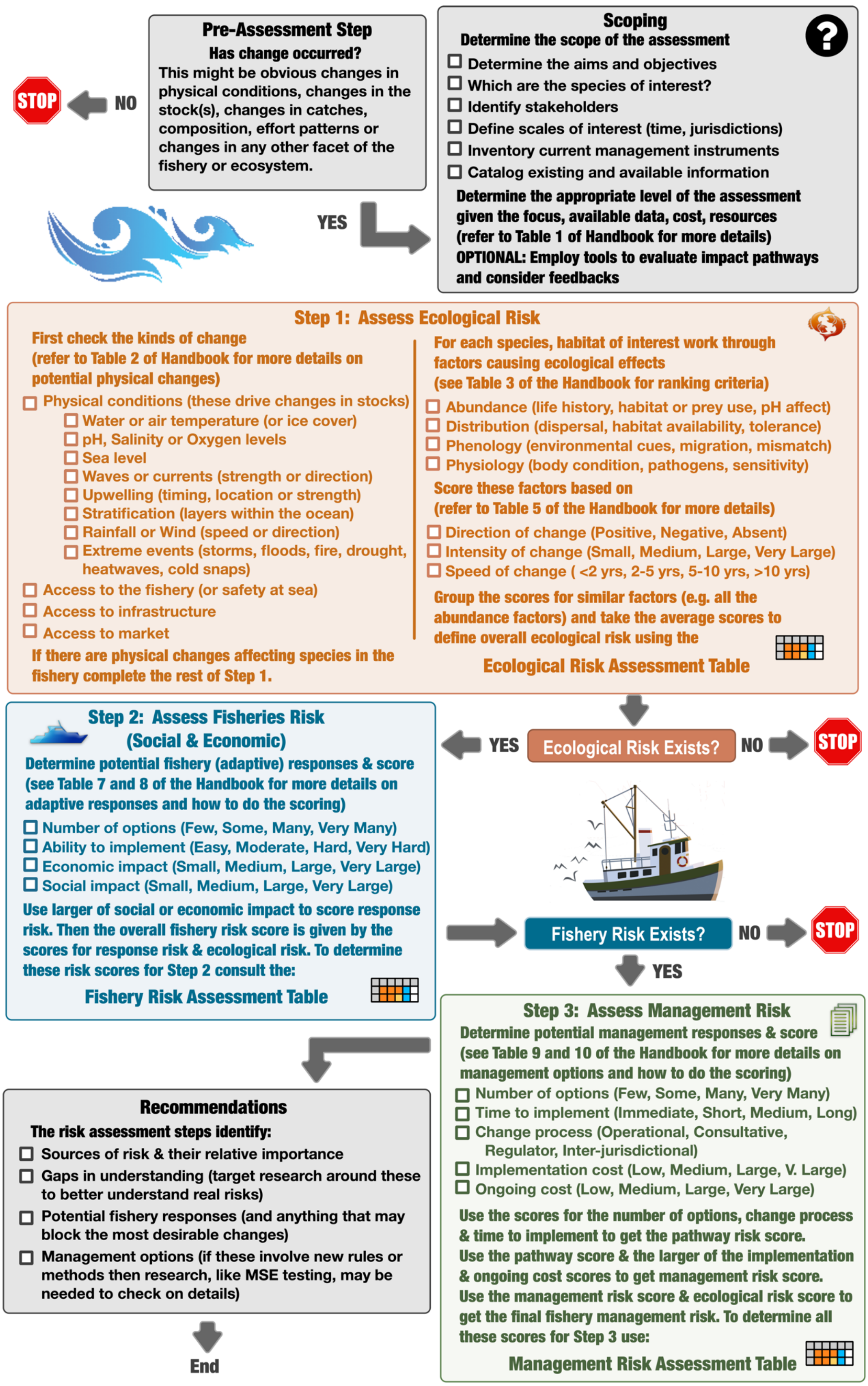


Figure 5: Summary sheet showing the steps involved in the climate adaptation and risk assessment process summarised in the Adaptation Handbook.

Step 1: Assess Ecological Risk — Ecological Risk Assessment Table

Group the scores for similar factors (e.g. all the abundance factors) & take the average scores to define overall ecological risk using this table. Cross reference the Direction of change, Intensity of change & the Speed of change to find the final level of ecological risk

Table A: Ecological Risk

	Negative Direction of Change				Positive	Absent
	Intensity of Change					
Speed of Change	Very Large	Large	Med.	Small		
< 2 years	High	High	High	Low	Low	None
2 - 5 years	High	High	Med.	Low	Low	None
5 - 10 years	High	High	Med.	Low	Low	None
> 10 years	High	High	Med.	Low	Low	None

Step 2: Assess Fisheries Risk (Social & Economic) — Fishery Risk Assessment Table

Tally up the potential options available to the fishery and rate these responses in terms of how easy they will be to implement & any economic and social impacts. Then use larger of social or economic impact to score response risk - cross reference the impact score (which ever is the larger of the social and economic impacts), ease of implementation and the number of options available and this will give you the response risk.

Table B: Response Risk

Options Available		Economic or Social Impact (whichever is LARGER)			
	Implementation	Very Large	Large	Medium	Small
Few	Hard / Very Hard	High	High	High	Medium
	Moderate	High	High	Medium	Low
	Easy	Medium	Medium	Medium	Low
Some	Hard / Very Hard	High	High	Medium	Low
	Moderate	High	High	Medium	Low
	Easy	Medium	Medium	Low	Low
Many or Very Many	Hard / Very Hard	High	High	Medium	Low
	Moderate	Medium	Medium	Low	Low
	Easy	Medium	Medium	Low	Low

Then determine the overall fishery risk score by cross referencing the scores for response risk & ecological risk.

Ecological Risk from Table A & Response Risk from Table B

Table C: Fishery Risk

	Response Risk		
Ecological Risk	High	Medium	Low
High risk	High	High	Medium
Medium risk	High	Medium	Low
Low risk	Medium	Low	Low
Absent	None	None	None

Step 3: Assess Management Risk — Management Risk Assessment Table

Determine the list of potential management responses & score them based on time to implement, how difficult it will be to change the relevant management processes or policies, and any associated implementation or operational costs. Cross reference the scores for the number of tools available, change process & time to implement to get the pathway risk score.

Table D: Pathway Risk

Tools Available	Process & Pathway	Time to Implementation			
		Long	Medium	Short	Immediate
Few	Inter-jurisdiction	High	High	High	High
	Regulator	High	High	High	Medium
	Consultative	High	Medium	Medium	Medium
	Operational	High	Medium	Low	Low
Some	Inter-jurisdiction	High	High	High	Medium
	Regulator	High	Medium	Medium	Medium
	Consultative	High	Medium	Medium	Low
	Operational	High	Medium	Low	Low
Many or Very Many	Inter-jurisdiction	High	High	High	Medium
	Regulator	High	Medium	Medium	Low
	Consultative	High	Medium	Low	Low
	Operational	High	Medium	Low	Low

Then cross reference the pathway score & the cost scores to get the base management risk score.

Pathway Risk from Table D

Table E: Base Management Risk

	Implementation Cost OR Ongoing Cost (whichever is LARGER)			
Pathway Risk	Very Large	Large	Medium	Small
High	High	High	Medium	Medium
Medium	High	High	Medium	Low
Low	Medium	Medium	Low	Low

Lastly, cross reference the base management risk score & ecological risk score to get the final fishery management risk.

Ecological Risk from Table A & Base Management Risk from Table E

Table F: Fishery Management Risk

	Base Management Risk		
Ecological Risk	High	Medium	Low
High risk	High	High	Medium
Medium risk	High	Medium	Low
Low risk	Medium	Low	Low
Absent	None	None	None

Figure 6: Summary of the tables used in the risk assessment steps - as detailed in the Adaptation Handbook

Conclusion

Environmental conditions shape ecosystems and resources exploited by fisheries. Climate change is presenting some of the greatest challenges faced by fisheries, especially in hotspot locations like Australia.

This project found that the existing Commonwealth fisheries management framework has many vulnerabilities with respect to climate impacts and has many potential points of failure with respect to pursuing policy and legislated objectives and international obligations. While Commonwealth fisheries follow best practice management approaches, which means they are starting from the best possible response foundation (FAO in press) adaptive responses will be required to cope with the many faceted impacts climate change is having and is anticipated to have on Australian marine and coastal ecosystems (Creighton et al. 2016).

To assist the adaptation process, this project developed a process documented in an *Adaptation Handbook* (and associated excel tool). This process steps interested stakeholders, industry and managers through a structured process to rate risks and identify adaptation options – both to do with fishery operations and management actions. The process and handbook were specifically developed with AFMA needs and Commonwealth fisheries in mind, but can be applied to fisheries in other jurisdictions. Users could adjust them as needed for the context of their fishery, adding/removing ecosystem factors, industry operations and management actions based on relevance to their fishery.

The project activities – the initial ecological sensitivity analysis undertaken for all Commonwealth fisheries, the assessment of potential risks to AFMA's capacity to deliver on policy and legislated objectives and the initial illustrative implementations of the risk assessment and adaptation process – have highlighted some general adaptation options that are likely to be of value in many Australian fisheries.

Key findings are:

- All AFMA fisheries contain valuable species sensitive to climate change, with some of the most valuable fisheries amongst those fisheries showing the greatest sensitivity
- All fisheries, but especially short lived and invertebrate fisheries are likely to become far more variable into the future, that is, when, where and how much fish is caught
- Bycatch and TEPS are likely to be highly sensitive to climate change effects, meaning there will be a need to understand how that interacts with any fishing effects
- A shifting ecosystem state over multiple years (or decades) has the potential to go unnoticed and eventually undermine the sustainability of Australian fisheries and the businesses and livelihoods that depend upon them
- Cross jurisdictional management coordination will be required to improve adaptation to climate change, maximising flexibility needed for adaptive capacity and minimising the risks arising from cumulative effects
- Monitoring and forecast capacity will become key to understanding system change that supports evidence-based decision making, fishery sustainability and business profitability
- Australia needs to find a way of making monitoring and forecasting possible and supported long term to maintain our position and reputation as having well managed fisheries (Australia's monitoring capacity is currently insufficient given the degree to which climate change will likely reshape Australian ecosystems).

There can be significant implications (positive and negative) for fishing industries arising from climate change effects that can extend from operational issues to community impacts and economic consequences. The project also found that the most common adaptation options include:

- Shifting fishing grounds (and potentially infrastructure) or targeting as species distributions and ecosystem composition changes
- Diversifying markets and post-harvest value adding to increase the value of existing product or find outlets for new products

- Develop operational and multi-year forecasts capability (so can redirect resources/effort in poor condition years, or switch between pre-agreed management arrangements)
- Mainstream climate inclusive assessments and decision-making processes
- Verify that assumptions behind assessment tools and management regulations (e.g. zoning) are still valid
- Undertake targeted research to reduce sources of uncertainty (such as how climate affects recruitment)
- Develop new technologies or processes to maintain/improve safety under the changed conditions (e.g. to deal with more intense sea states) and to deal with changed needs for mitigation measures (e.g. due to changed levels or types of TEPS interactions)
- Lay out a timeline of prioritised research and management actions, which may have associated trigger points (the implications of delaying or bringing forward actions in that timeline should be well understood)
- Education of consumers and the public on what is being done and why so that well intentioned public action does not undermine sustainability and fishery viability.

These responses concur with what has been found to be successful elsewhere and are being recommended by the FAO (in press).

Implications

The outcomes of this project can support AFMA's (and industry's) short to medium term adaptation responses to climate change that, in turn, will enable AFMA and the fishing industry to have a higher likelihood of sustainably fishing Commonwealth fish stocks. However, the reality of climate change is that while the trends in biophysical parameters are reasonably well understood, as is the increasing variation in many of them, how these translate into economic and social consequences is less well understood. The *Adaptation Handbook* and associated excel tool represent the best we have at the present time so their use should be encouraged in taking the first steps in responding to this existential impact on Australian fisheries.

Recommendations

1. AFMA considers adopting the *Adaptation Handbook* and associated excel tool as a starting point for its climate adaptation responses.
2. Subject to Recommendation 1 being agreed, AFMA progressively incorporates climate change considerations into its stock assessment, harvest strategy, ERA and R&D prioritisation processes
3. Support is given to the states/Northern Territory to test Adaptation Handbook and associated excel tool in their fisheries.

Further development

This project has developed the method, but climate risk assessments, adaptation response implementation and structured planning at all time scales to coming climate changes will be a required mainstreamed fisheries operational and management activity now and into the future.

The report recommends that for greater direct benefits to be realised from the project, individual fisheries should go through the dedicated adaptation handbook process and implement its outcomes. This will take time and resources, but will result in identification of specific adaptation strategies and risk each fishery is presented with.

The handbook has been designed to be used by a range of fishery stakeholders including industry, management, Indigenous and recreational sectors. While its development focused on application to Australia's Commonwealth fisheries it can equally be applied to fisheries managed by other jurisdictions. The report recommends that support is given to the states/Northern Territory to test the Adaptation Handbook (and the associated instructional excel tool) in their fisheries.

Extension and Adoption

The content of the framework has already been shared with fishery, RAG, AFMA and Department of Environment personnel. The content of the impact pathways, qualitative model findings and results of the risk assessments for the HIMI, SBT and Northern Prawn fisheries have also been shared with the RAGs for those fisheries via a series of confidential reports, workshops and briefing sessions held through 2019 and early 2020.

The detailed reports on the individual fisheries and the climate sensitivity analysis (Appendix 3) have been lodged with AFMA. The regional summaries will be made available to help industry members in fisheries in each region, and managers responsible for those regions, will have easily accessible information on observed and anticipated change in their region. They have also been posted on the CSIRO Climate Adaptation research website https://research.csiro.au/cor/home/climate-impacts-adaptation/climate-adaptation-handbook/

The *Adaptation Handbook* will be formally launched in September 2021 at the World Fisheries Congress and will also be made freely available via the AFMA and CSIRO websites (CSIRO: https://research.csiro.au/cor/home/climate-impacts-adaptation/climate-adaptation-handbook/). A professional graphic designer has been employed by the project team to ensure the Handbook is both attractive and accessible for a broad audience. The project team is also looking to develop an app to allow the steps to be more easily implemented. The excel tool was sufficient for initial proof of concept but there needs to be a tool that is more accessible, attractive and user-friendly to make the approach as accessible as possible.

As COVID restrictions ease the intent is to introduce the risk assessment framework and methodology to key stakeholders through workshops. If that proves impossible in a timely manner then a series of briefing sessions will be held for key stakeholders: DAWE, commercial fishing bodies, recreational fishers, indigenous fishers, science bodies and interested resource managers in other jurisdictions. As part of this roll out a paper has been prepared for the Australian Fisheries Management Forum (all Directors of Fisheries; AFMF) and a briefing will be provided to them during a meeting in the later part of 2021.

Project coverage

The content of the regional summaries (provided in Appendix 5) informed an article on climate change impacts on fisheries published by the Sydney Morning Herald in January 2020 (https://www.smh.com.au/national/empty-nets-and-tropical-fish-in-tasmania-as-climate-change-hits-southern-ocean-20200131-p53wmc.html)

Glossary

Abundance is the total (or local) population size of a species of interest.

Adaptation is the process of adjustment to actual or expected change, in order to moderate harm or exploit beneficial opportunities.

Autonomous adaptation is adaptation that is triggered by ecological changes in natural systems and by market or welfare changes in human systems.

Directed adaptation is adaptation that is supported by interventions (such as new rules, grants, assisted migration etc).

Distribution is the geographic location (range) of where the fish (marine species) mainly reside.

Ecosystem impacts are broader scale impacts due to climate change that are mediated by food web interactions, habitats or other ecological processes.

Hazard is something that can cause harm.

Impact pathway is a way to represent chains of potential impacts of climate change and potential interventions and understand how these are meant to work.

Risk is the chance (high or low) that any hazard will cause harm.

> **Ecological risk** is used here to refer to the risk of climate driven ecological change that could impact on fishery resources;
>
> **Fishery risk** is used here to refer to economic and social risk to industry arising from ecological change and including the potential adaptation responses that fishers might implement; and
>
> **Management risk** is used here to refer to the risk to fisheries management resulting from ecological change and influenced by the nature of management instruments and tools that are available to adapt to or mitigate climate change impacts.

Phenology is the timing of biological events.

Physiology is how organisms (via the function of cells, organs) carry out the internal chemical and physical functions that determine the condition (how fat or nutritious) of the animal.

Qualitative modelling is a structured approach to developing conceptual models of how a system works and responds to change.

Threatened, Endangered and Protected Species (TEPS) are species classified as threatened, endangered and protected in accordance with the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). For example, marine mammals such as Australian sealion.

Vulnerability is a weakness or gap in capacity that means the species or fishery exposed to the possibility of being affected by climate driven change.

Project materials developed

The key products of the project are:

- Summary of climate sensitivities for all AFMA managed fisheries (provided in Appendix 3)
- Regional summaries of the state of the science on observed and anticipated changes in 5 regions around Australia – southern, eastern, northern, western and the Kerguelen Plateau (see Appendix 5)
- A climate adaptation handbook, which provides a step-by-step guide on how to undertake the climate risk assessment and adaptation option discovery approach developed by the project team (see Appendix 6). An excel spreadsheet, which provides a digital platform for completing the assessment has been created to as an additional tool for helping people complete the process. This will be available for download from the same websites as the handbook.
- Detailed short technical reports on the full risk assessment process for the HIMI, SBT and Northern Prawn fisheries, these contain commercial in confidence material and so are not included here but have been lodged directly with AFMA.
- A scientific journal article on the process described in the handbook is currently in preparation.

Appendices

Appendix 1: List of researchers and project staff

The project staff included

- Alistair Hobday (who was the original PI, but had to transfer research leadership on taking up a new senior leadership position at CSIRO)
- Beth Fulton (who picked up research project leadership from Alistair)
- Ingrid van Putten
- Leo Dutra
- Jess Melbourne-Thomas
- Emily Ogier
- Linda Thomas
- Nick Rayns
- Ryan Murphy
- Ian Butler
- Danait Ghebrezgabhier
- Tom Kompas

The steering committee and repeat workshop attendees who provided the greatest advice into the project and helped shape the method summarised in the handbook included:

- Brett Cleary
- Brian Jeffriess
- Carolyn Stewardson
- Clayton Nelson
- Dallas D'Silva
- David Smith
- Glenn Sant
- Jo-anne McCrea
- Michael Baker
- Anne Jarrett
- Phil Ravanello
- David Ellis
- Anna Willock
- David Power
- George Day
- Matt Daniel
- Ian Knuckey
- Nick Rayns
- Michelle Heupel
- Anissa Lawrence
- Sandy Morrison
- Stuart Curran

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Appendix 3: Summary of Commonwealth Fishery Climate Sensitivity

This appendix (attached as a separate document) summarises the exposure of AFMA managed fisheries to ecologically mediated climate change effects. It is attached as a separated document for ease of sharing with AFMA managers.

Appendix 4: Risk to AFMA's capacity to meeting policy and legislative objectives and international obligations

This appendix (attached as a separate document) summarises the exposure of AFMA managed fisheries to ecologically mediated climate change effects. It is attached as a separated document for ease of sharing with AFMA managers.

Appendix 5: Regional summaries of projected change around Australia

This appendix (attached as separate documents) provides a collection of summaries of observed changes and projections for 5 regions around Australia:

- Appendix 5.1 Regional Summary – projection of change for Northern Australia
- Appendix 5.2 Regional Summary – projection of change for Eastern Australia
- Appendix 5.3 Regional Summary – projection of change for Southern Australia
- Appendix 5.4 Regional Summary – projection of change for Western Australia
- Appendix 5.5 Regional Summary – projection of change for the Kerguelen Plateau

These summarise draw together existing information on each region and present it in relatively non-technical language to help people understand what issues exist and the state of knowledge for that region. This kind of information can help inform workshop groups looking to undertake the process outlined in the *Adaptation Handbook*.

Appendix 6: Adaptation Handbook

This appendix (attached as a separate document) is the *Adaptation Handbook*. The handbook is designed to be used by a range of fishery stakeholders, including industry, management, Indigenous and recreational sectors. While the handbook (and this project) was initially focussed on application to Australia's Commonwealth fisheries it can equally be applied to fisheries managed by other jurisdictions.

The handbook takes a risk assessment approach and has been designed in a series of steps, each focussing on a different aspect of a fishery's operation. As a result, the assessment steps can be used in their entirety or specific steps can be undertaken as needed. For example, the fisheries risk management assessment could be used more generally as checklist on how climate proofed any new alternative management strategy under consideration would be. Or industry groups might want to take the ecological risk assessment and consider financial factors outside of management decision making.

Please consult the handbook for more details.

Also note that an excel spreadsheet, which provides a digital platform for completing the assessment has been created to as an additional tool for helping people complete the process. This will be available for download from the same websites as the handbook.