Adaptation of fisheries management to climate change HANDBOOK

Australian Government
Australian Fisheries Management Authority

CSIRO

FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

NOVEMBER 2020

CITATION

Fulton EA, van Putten EI, Dutra LXC, Melbourne-Thomas J, Ogier E, Thomas L, Murphy RP, Butler I, Ghebrezgabhier D, Hobday AJ, Rayns N (2020) Adaptation of fisheries management to climate change Handbook, CSIRO, Australia.

CATALOGUING-IN-PUBLICATION

ISBN: 978-1-925994-16-2 (print)   ISBN: 978-1-925994-17-9 (online)

Cataloguing-in-Publication entry is available from the National Library of Australia http://catalogue.nla.gov.au/

ACKNOWLEDGEMENTS

The authors would like to acknowledge all those who contributed to shaping this handbook, especially inputs from Gretta Pecl, Rob Stephenson and Merrick Burden.

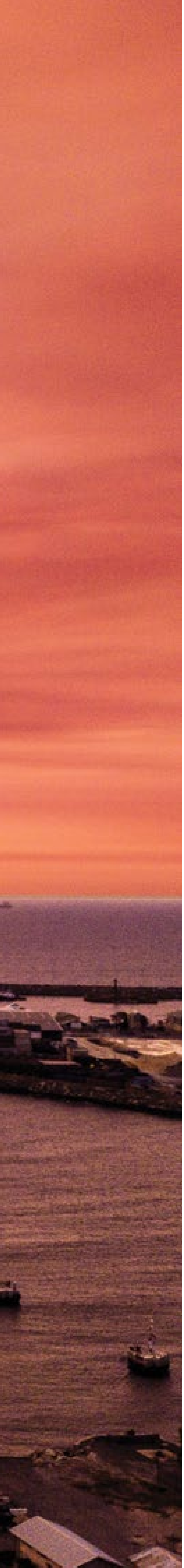

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Image (front cover): **AFMA** (left): **Josh Spires**

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Foreword

This Handbook was written as a core deliverable of the AFMA/CSIRO project Adaptation of Commonwealth fisheries management to climate change (FRDC 2016-059)[1]. The basic aim of that project is to understand the risks climate change presents to Commonwealth fisheries so that the following questions can be answered:

1. What changes does AFMA need to make to its regulatory system so that it can still effectively deliver its management objectives?
2. What are the consequences of those changes for the fishing industry and other fishery stakeholders?

However, this handbook has been designed to be used by a range of fishery stakeholders including industry, management, traditional and recreational sectors. While its development focussed on application to Australia's Commonwealth fisheries it can equally be applied to fisheries managed by other jurisdictions.

The risk assessment 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.

Key strengths of the method are its:

- **Inclusive approach** – the Handbook is designed to involve committees of industry, management and other stakeholders to work through to come to a more shared understanding of climate risks and develop more robust adaptive management options;
- **Scalability** – the method was designed to be applied with differing degrees of detail and at different scales so that it can be adjusted for the available information and the resources available. In its simplest form it is something that an expert group could run through relatively quickly (within 1–2 focused meetings), if resources are larger, then more quantitative information or more involved analyses can be used. Uncertainty is typically higher for expert driven processes, but users should feel free to shape the scope and scale as needed rather than shying away because it is considered to be "too hard". Another option is to invest in a larger process initially (effectively a baseline assessment) and then to have a "light revisit" on a regular (e.g. annual) basis to ensure conditions are as assumed in the assessment (potential triggers of a new assessment have been included in the decision tree provided under Risk Assessment at a Glance – Steps to Follow);
- **Flexibility** – the method is not limited to the climate-driven risks to ecological components of fisheries as other types of risks can be included. For example, climate-driven loss of infrastructure, disease-driven loss of markets. This is because these risks arising from other drivers can lead to the same types of economic and social impacts, and the same types of management levers can be pulled.

The handbook sets out the steps to understand the potential sensitivity of a fishery's management to physical and ecological change, whether the fishery can easily and rapidly autonomously adapt to these changes or whether it will be a longer process that requires management plans and methods to be modified. We have endeavoured to make this handbook as user friendly as possible. Nevertheless, we stress that this document is a guide only and that users should seek their own professional advice specific to their fishery before taking any action to adapt to climate change.

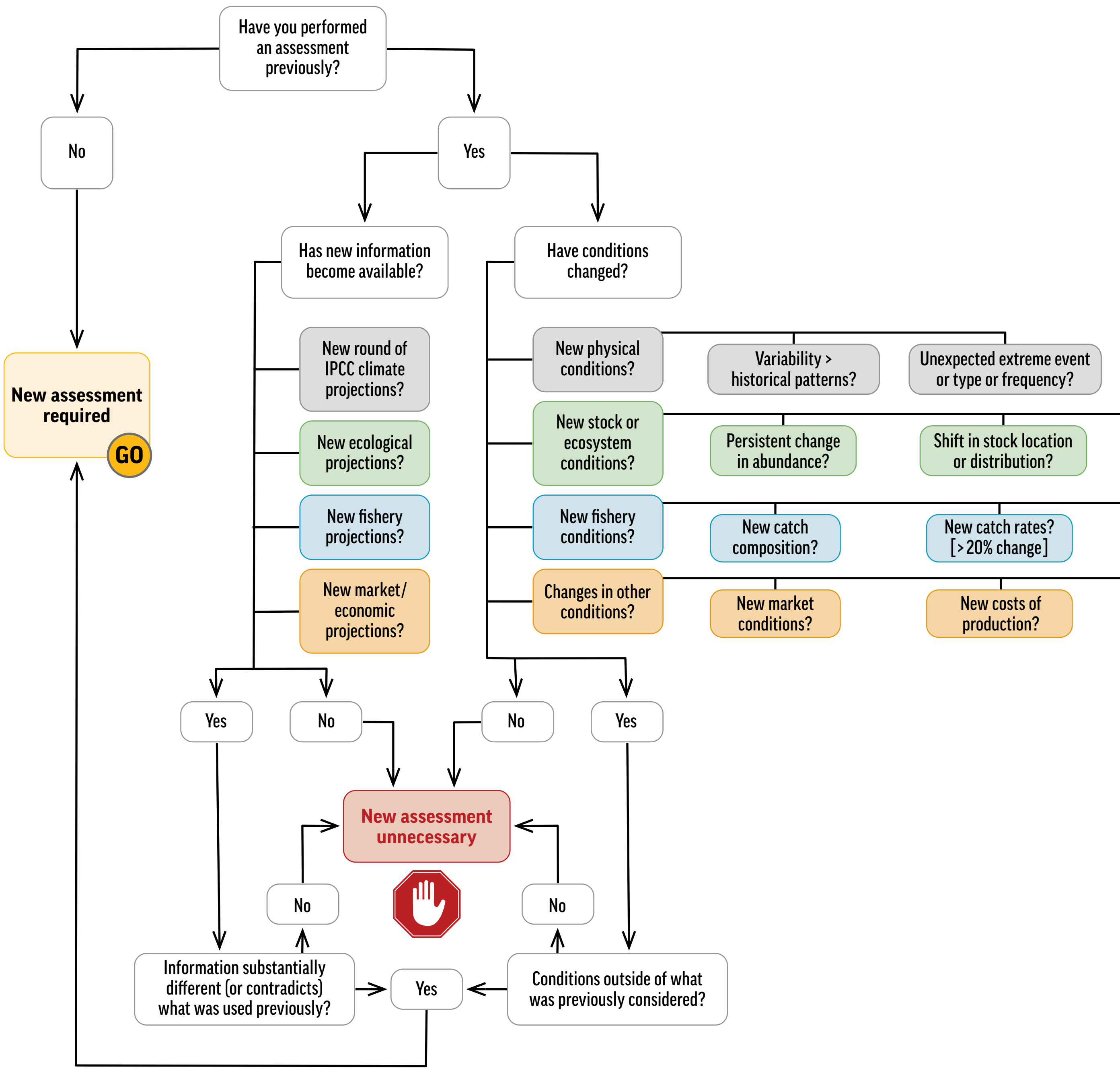
1 The final report of the AFMA/CSIRO project Adaptation of Commonwealth fisheries management to climate change (FRDC 2016-059) is available separately from the FRDC website.

Image: **AFMA**

Risk assessment at a glance

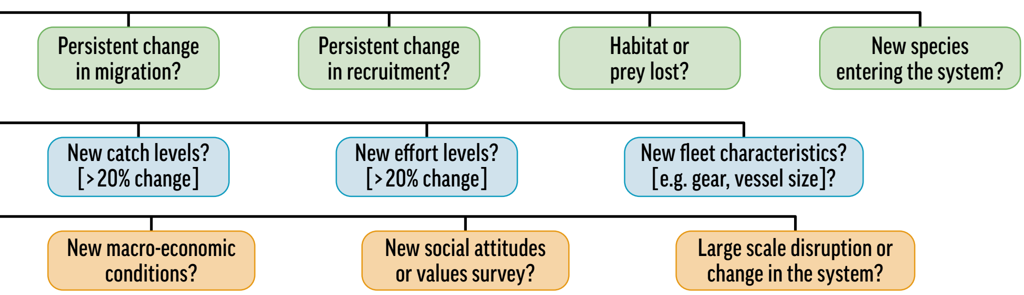
These summary sheets are provided to help as prompts for anyone trying to follow the steps described in the Handbook. Please read the handbook first. This will make clear how to step through the process.

In all steps use the best available information. In some instances that may be from a scientific study (e.g. around ecological effects of climate change), fisher observation (e.g. on what they have seen on the water; or in Step 2 the options they can feasibly do to change fishing operation). In some locations there will be information for every checkbox and for every step, but for others many boxes will remain blank, not because they are not relevant, but because it is simply unknown what the answer is (e.g. has change occurred or not). Where a box is left blank intentionally because it really is not a problem, make note of that and take it into account when using the risk tables – for example in Table 4-4 use "Absent". However, where its left blank because we don't know, step through the steps as if it was known and it was likely to be negative and large (i.e. worst case) – in that way you will be precautionary, understanding what issues you



may face and thus the pressure to put resources into finding out for sure whether that check box should be ticked or not. Alternatively, if decisions are pressing look to expert guidance on what is most likely and cycle back and review again as more information becomes available.

How to do all this is explained in the handbook, so please always consult the text first (and even when you have read it please refer back to be reminded of details). Also we have written this handbook based on best available information and expert fisheries guidance (by fisheries managers and a small number of fishers). This means in some cases implicit assumptions are made about risk – for example, in Steps 2 and 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 continuosuly keep thinking about the particular circumstances of their fishery/issue. This handbook and stepwise guide are a generic tool, shape them to be of maximum use for your specific circumstances.



STOP ← NO

PRE-ASSESSMENT STEP
Has change occurred?

This might be obvious changes in physical conditions, changes in the stock(s), changes in the catches, composition, effort patterns or changes in any other facet of the fishery or ecosystem.

YES →

SCOPING
Determine the scope of the assessment

- ☐ Determine the aims and objectives
- ☐ Which are the species of interest?
- ☐ Identify stakeholders
- ☐ Define scales of interest (time, jurisdictions)
- ☐ Inventory current management instruments
- ☐ Catalog existing and available information

Determine the appropriate level of the assessment given the focus, available data, cost, resources (refer to **Table 3-1** of the Handbook for more details).
OPTIONAL: Employ tools to evaluate impact pathways and consider feedbacks.

STEP 1: ASSESS ECOLOGICAL RISK

First check the kinds of change (refer to **Table 4-1** of the Handbook for more details on potential physical changes)

- ☐ Physical conditions (these drive changes in stocks)
  - ☐ Water or air temperature (or ice cover)
  - ☐ pH, salinity or oxygen levels
  - ☐ Sea level
  - ☐ Waves for currents (strength or direction)
  - ☐ Upwelling (timing, locations or strength)
  - ☐ Stratification (layers within the ocean)
  - ☐ Rainfall or wind (speed or direction)
  - ☐ Extreme events (storms, floods, fire, drought, heatwaves, cold snaps)
- ☐ Access to the fishery (or safety at sea)
- ☐ Access to infrastructure
- ☐ Access to market

If there are physical changes affecting species in the fishery complete the rest of STEP 1.

For each species, habitat of interest, work through factors causing ecological effects (refer to **Table 4-2** of the Handbook for ranking criteria).

- ☐ Adundance (life history, habitat or prey use, pH effect)
- ☐ Distribution (dispersal, habitat availability, tolerance)
- ☐ Phenology (environmental cues, migration, mismatch)
- ☐ Physiology (body condition, pathogens, sensitivity)

Score these factors based on (refer to Table 4-4 of the Handbook for more details).

- ☐ Direction of change (positive, negative, absent)
- ☐ Intensity of change (small, medium, large, very large)
- ☐ Speed of change (<2 yrs, 2–5 yrs, 5–10 yres, > 10 yrs)

Group the scores for similar factors (e.g. all the abundance factors) and take the average scores to define overall ecological risk using the:
ECOLOGICAL RISK ASSESSMENT TABLE (page 24)

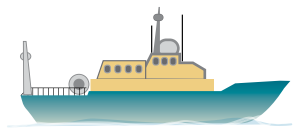
← YES **ECOLOGICAL RISK EXISTS?** NO → STOP

STEP 2: ASSESS FISHERIES RISK (social and economic)

Determine potential fishery (adaptive) responses and score (see **Table 4-6** and **4-7** of the Handbook for more details on adaptive responses and how to do the scoring)

- ☐ Number of options (few, some, many, very many)
- ☐ Ability to implement (easy, moderate, hard, very hard)
- ☐ Economic impact (small, medium large, very large)
- ☐ Social impact (small, medium large, very large)

Use larger of social or economic impact to score response risk. Then the overall fishery risk score is given by the scores for response risk and ecological risk.
To determine these risk scores for STEP 2 consult the:
FISHERY RISK ASSESSMENT TABLE (page 30)



→ **FISHERY RISK EXISTS?** NO → STOP

↓ YES

STEP 3: ASSESS MANAGEMENT RISK

Determine potential management responses and score (see **Table 4-8** and **4-9** of the Handbook for more details on management options and how to do the scoring)

- ☐ Number of options (few, some, many, very many)
- ☐ Time to implement (immediate, short, medium, long)
- ☐ Change process (operational, consultative, regulator, inter-jurisdictional)
- ☐ Implementation cost (low, medium, large, very large)
- ☐ Ongoing cost (low, medium, large, very large)

Use the scores for the number of options, change process and time to implement to get the pathway risk score.
Use the pathway score and the larger of the implementation and ongoing cost scores to get management risk score.
Use the management risk score and ecological risk score to get the final fishery management risk. To determine all these scores for STEP 3 use:
MANAGEMENT RISK ASSESSMENT TABLE (page 40)

RECOMMENDATIONS
The risk assessment steps indentify:

- ☐ Sources of risk and their relative importance
- ☐ Gaps in understanding (target research around these to better understand real risks)
- ☐ Potential fishery responses (and anything that may block the most desirable changes)
- ☐ Management options (if these involve new rules or methods then research, like MSE testing, may be needed to check on details)

↓

END

STEP 1: ASSESS ECOLOGICAL RISK ► (see Table 4-4, page 24)

Group the scores for similar factors (e.g. all the abundance factors) and take the average scores to define overall ecological risk using this table. Cross reference the direction of change, intensity of change and 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**	**Medium**	**Small**		
Next 2 years	High	High	High	Low	Low	None
Next 2-5 years	High	High	Medium	Low	Low	None
Next 5-10 years	High	High	Medium	Low	Low	None
More than 10 years	High	High	Medium	Low	Low	None

STEP 2: ASSESS FISHERIES RISK (social and economic) ► (see Table 4-7, page 31)

Tally up the potential options available to the fishery and rate these responses in terms of how easy they will be to implement and 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 and ecological risk.

> Ecological risk from **Table A**
> Response risk from **Table B**

Table C: Fishery risk

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

STEP 3: ASSESS MANAGEMENT RISK ► (see Table 4-9, pages 41 and 42)

Determine the list of potential management responses and 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 and time to implement to get the pathway risk score.

Table D: Pathway risk

Tools available	Process and pathway	Time to implementation			
		Long	**Medium**	**Short**	**Immediate**
Few options	Inter-jurisdictional	High	High	High	High
	Regulator	High	High	High	Medium
	Consultative group	High	Medium	Medium	Medium
	Operational	High	Medium	Low	Low
Some options	Inter-jurisdictional	High	High	High	Medium
	Regulator	High	Medium	Medium	Medium
	Consultative group	High	Medium	Medium	Low
	Operational	High	Medium	Low	Low
Many options	Inter-jurisdictional	High	High	High	Medium
	Regulator	High	Medium	Medium	Low
	Consultative group	High	Medium	Low	Low
	Operational	High	Medium	Low	Low

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

> Pathway risk from **Table D**

Table E: Base management risk

	Cost (implementation & ongoing, whichever is LARGER)			
Pathway risk	**Very high**	**High**	**Medium**	**Low**
High	High	High	Medium	Medium
Medium	High	High	Medium	Low
Low	Medium	Medium	Low	Low

Lastly, cross reference the base management risk score and 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	High	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low
Absent	None	None	None

Glossary ▼

Abundance is the total (or local) population size of a species of interest (see Table 3-1).

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 (see Table 3-1).

Ecosystem impacts are broader scale impacts due to climate change that are mediated by food web interactions, habitats or other ecological processes (see Table 4-3).

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.

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 (see Table 3-1).

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 (see Table 3-1).

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.

Traditional fishing refers to fishing carried out by First peoples in accordance with their particular traditional laws and customs.

1 Intent and use of the handbook

Fisheries face many sources of change. Indeed, they respond to variability on all temporal scales, from day to day to seasonal and annual bases. One of those sources of change is ocean climate and its effects on many fisheries are already substantial.

Australia's marine environment is changing faster than at any other period in recorded history. While this is predicted to continue, the specific mixes of atmospheric and ocean current patterns around Australia mean the magnitude of climate change will differ place-to-place, and different fisheries and sectors will face different challenges[2]. To cope with the changes, fisheries – operators, managers and anyone else helping to support the fishery (whether commercial, recreational or traditional) – will need to understand how change may come about and how to most appropriately respond. This means understanding the pressures on fisheries – particularly those stemming from the physical environment (e.g. temperature and pH) – and how they may affect the fishery over the next decade or two. While longer term changes are also predicted, changes over the next 20 years are the primary focus of this project (and handbook) since they are most relevant to current commercial, traditional and recreational fishers. In this handbook the focus is mainly on the commercial sector, as there is substantially more available information for that sector. However, where possible relevant information for recreational and traditional sectors has also been highlighted. In addition, for those familiar with those fisheries, it should be relatively straightforward to take the general process outlined in the guide and substitute in appropriate adaptation responses or management tools.

The objective of this handbook is 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. While this handbook was commissioned to assist with climate change adaptation, similar thinking can be applied to all kinds of change. If you do not consider climate change an issue for your fishery the general layout of the ecological, fishery and management risks may still be insightful for identifying risk factors and potential responses for other issues you may be dealing with. For example, if you're facing changes that aren't due to shifts in the fish stock(s) but are due to some other external factors affecting access to the fishing grounds, markets or changed policies (e.g. changed export rules) just skip Step 1 and work through the logic of Step 2 to the point you calculate Response risk, or Step 3 until you get to the calculation of Base Management risk.

We encourage potential users of the handbook to read through the main text in full before attempting an assessment. Once ready to do an assessment we have provided a worked example in Appendix A and a set of summary sheets (at the front of the handbook) that provide some prompting questions and reproduce key tables from the handbook. However, remember this handbook (and the summary sheets) are presented as a generic tool to help the reader think about their particular circumstances and fishery issues. **It can be adjusted and adapted to better suit different contexts; please re-shape it as needed for your system** (there might be bits that are relevant, there might be extra factors you need to include).

1.1 Objectives of the handbook

Existing research provides plentiful information on the effects of climate change (Hobday 2006; Barange et al., 2018; Fogarty et al., 2019), but only lightly touches on the next step of informing fisheries managers about options for adaptation to climate change effects (Ogier et al., 2020; Pratchett et al., 2017). However, fisheries managers will need to use research findings to generate management strategies to address the changes already occurring and predicted to occur under climate change and to help fisheries adapt more generally. Consequential changes may need to be made to fisheries operations and governance to ensure sustainable fishing into the future. Sustainable fishing includes ecological, economic and social considerations that inform strategies for fisheries management to address climate change (Hobday et al., 2016; 2018; Stephenson et al., 2018). The objective of this 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;[3]
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.

2 As shown in Hobday et al. (2006) and Decadal scale projection of changes in Australian fisheries http://www.frdc.com.au/Archived-Reports/FRDC%20Projects/2016-139-DLD.pdf

3 In the technical jargon of risk assessments, the words "risk assessment" have a very specific meaning which is much tighter than used in general conversation. In those technical terms, the handbook is in fact a combination of a vulnerability, risk, and hazard assessment. The vulnerability assessment applies to the ecological component, the (qualitative, relative) risk assessment to the fishery, and the hazard assessment to the management of the fishery. A **hazard** is something that can cause harm. A **risk** is the chance (high or low) that any hazard will cause harm. A **vulnerability** is a weakness or gap in being protected. We will, however, make it easier on people who want to use the handbook (who may not have a background in the technical details of formal risk assessment) use the term 'risk assessment' throughout the handbook for each step of the process the handbook describes.

Image: **William White**

Risk based approaches are used widely – for example: the world economic forum releases a global risk report annually to highlight the greatest potential risk factors to economic activity and society around the world in the coming year(s); risk based approaches underly a lot of strategic planning by banks, individual businesses, military, and disaster response ministries.

1.2 What risk does climate change pose?

Anything that could disrupt or degrade the state of Australia's fisheries can be considered a risk factor. These factors may be physical (e.g. to do with the climate or physical environment), ecological (to do with the fish stocks or ecosystem), economic (such as seafood markets) or social (changes in societal expectations); and others may stem from management and governance of the fishery. Some of these factors act directly – e.g. increased wind strength could pose safety threats at sea – while other factors will work indirectly via changing species distributions, ecosystem conditions and connections, or by changes in market preferences for seafood. An example of an indirect risk is where changes in water temperature affects the abundance or location of prey species and so also making target species less abundant or harder to find or access. Another example is where social relationships within a community mean a fishing family opt out of a fishery rather than have to move to another port to follow the fish.

Links between the ocean, biology, fishers, and the management system need to be understood as they will influence the capacity of the fishery to adapt to climate change. Those links can amplify the impact of climate change. For instance, ecological change can be magnified depending on how fishers and managers respond. Equally, some risk factors may result from management regulations that were implemented to reduce risk in non-climate factors (e.g. to improve fisheries compliance). Such arrangements will not automatically be removed, but they need to be identified as a risk factor and understood so everyone involved can consider whether the benefits provided by the regulation outweigh the costs with regard to climate adaptation. This advice can then be provided to decision makers.

Careful consideration should be given to each type of risk factor to understand:

(a) what the likelihood of the risk is (this could be something that is almost sure to happen through to something that will rarely if ever happen);

(b) what the consequence would be if the risk actually materialised (consequences could range from those that are incidental or unimportant to the fishery through to those that may prove catastrophic);

(c) what the final level of risk is, that is the combination of likelihood and consequence. Using information specific to the fishery and a table of generic risk levels associated with various combinations of likelihood and consequence the final list of risks is created;

(d) what the level of control over the risk factors are, how easily can the factors be influenced (directly or indirectly); and

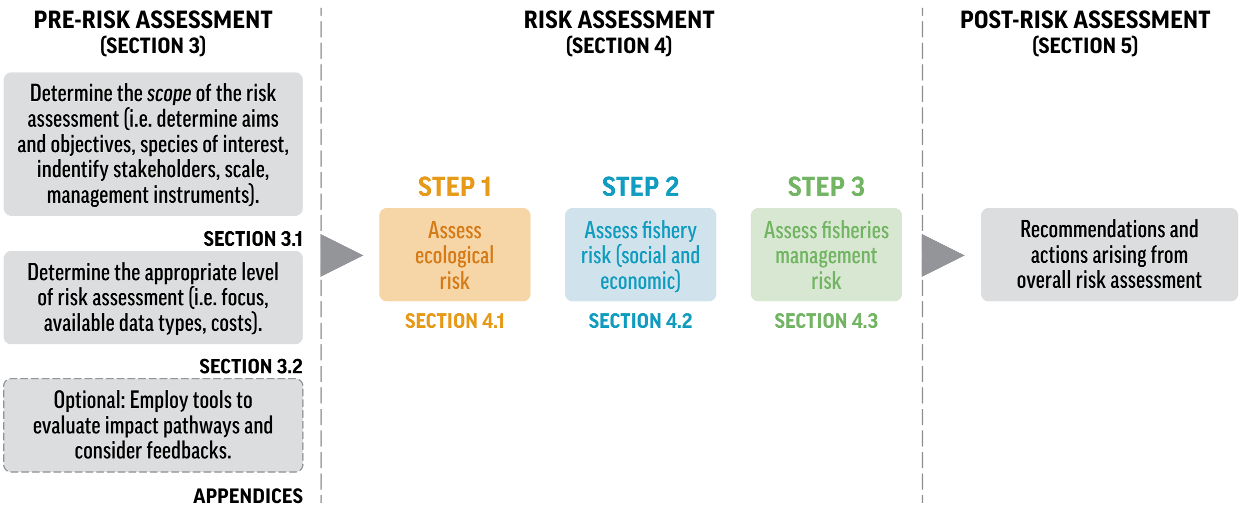
(e) what changes may be needed to do something about the final level of risk – this begins with having some agreement on what acceptable levels of risk may be (as risks may not need addressing if they are already at an acceptable level). In the absence of any agreement the default position is to address the highest risks first with the aim of reducing them to medium or low. Once those are dealt with then a more nuanced discussion is held about what to do (if anything) about medium and low risks (this is because the cost-benefit trade-off is usually weaker at these lower risk levels). In dealing with each risk, consideration is given to what level of change is needed to reduce the risk, including whether anything can be done about it at all, or whether it is something the fishery will need to adapt to. In doing so the benefits and costs associated with any change are determined, as in some cases the cost of doing something about a risk might outweigh the losses that occur even if the risk played out.

This handbook aims to help step though these considerations.

1.3 What is in this handbook?

This handbook provides a step-by-step guide to help fisheries managers and other fishery stakeholders assess and help address the risks posed by climate change. Like most risk assessments it 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 1-1).

FIGURE 1-1 The role of the pre risk assessment and post risk assessment in relation to the risk assessment (shown in the middle).

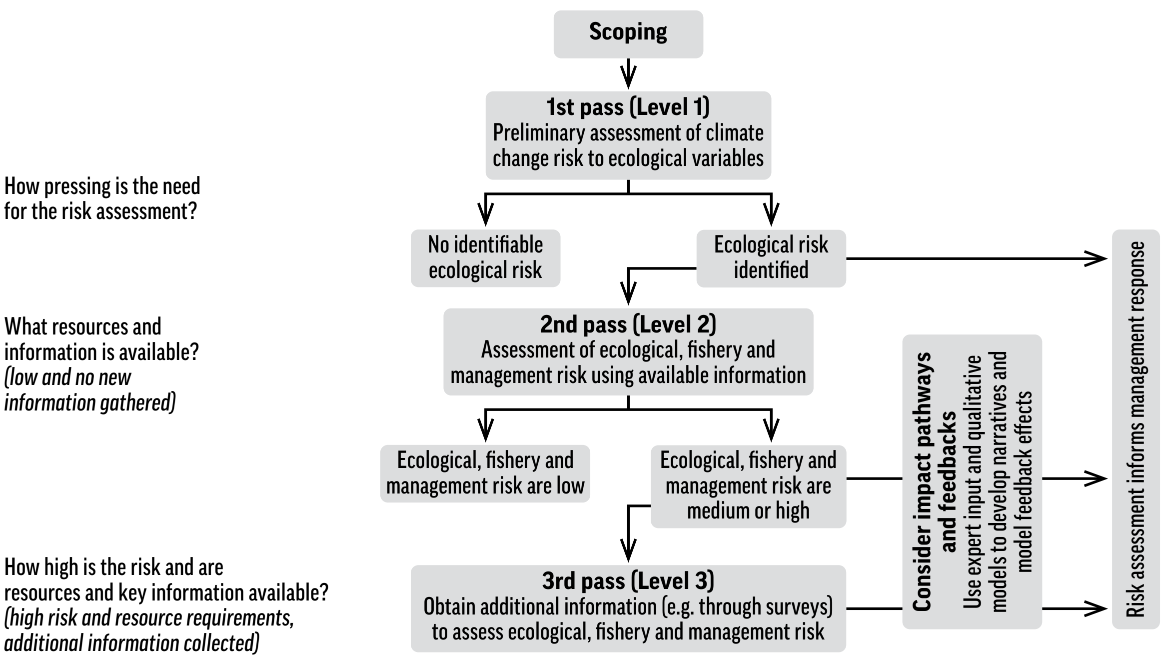


To make this process as easy to follow as possible the handbook provides an overview of five major topic areas:

1. Pre-assessment to determine the scope and level of risk assessment (this includes seeing whether an assessment is even needed – the decision tree included in the section Risk Assessment at a Glance – Steps to Follow should help);
2. Climate driven changes in physical and chemical ocean variables;
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);
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;
5. Fisheries management decision points and adaptation options for fisheries managers.

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 1-2 and described in more detail below.

FIGURE 1-2 Different risk assessment levels and the resource requirements for each level (see also Table 3-1).

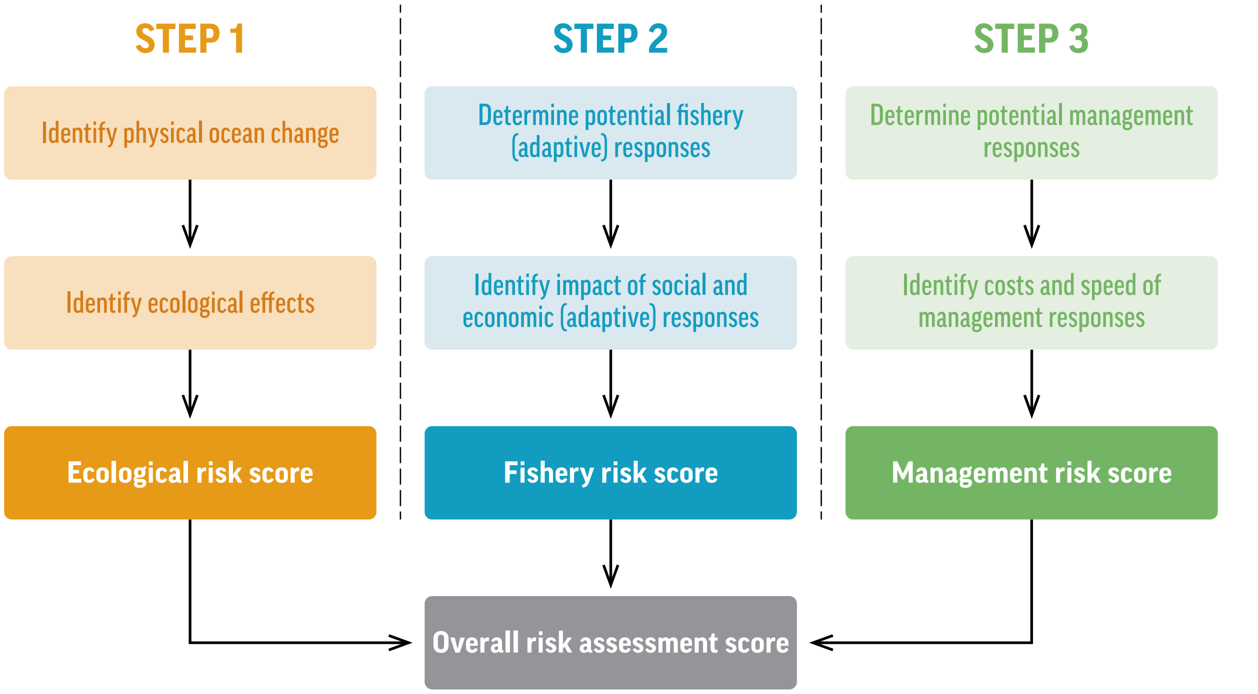


While scoping (a pre-assessment step) is important for setting the bounds on the assessment, it is a relatively small step and the main focus of the Handbook will be on the three step risk assessment process shown in Figure 1-3. The main aspects of each step of this three part assessment process are described in the remainder of this handbook.

To help provide a tangible example of what stepping through an assessment would involve a worked example for a hypothetical fishery is given in Appendix A . The rest of the appendices provide examples of instrument(s) that help to carry out the risk assessment steps – including surveys, elicitation of expert advice, impact pathway analysis, and qualitative modelling. Applying the risk assessment approach will allow fisheries authorities, operational managers within commercial fishing companies, or other groups concerned with natural resource management, to evaluate how to best adapt management to address climate change impacts. It also allows the agencies to determine residual risks after fisheries management process changes are applied – to see how climate is effecting their capacity to meet management objectives (including legislated requirements) and to stimulate action (research, discussion, planning) to find new instruments to close the gap, make good on new opportunities or to initiate a process to reconsider what is achievable given the changed conditions.

Assessing a whole fishery and ecosystem can be complex. We have broken the process down into steps to make this easier, but it will never be simple. Using a facilitator who has experience with hazard analyses or risk assessment will help. While it may initially seem like a process that will be easier in a data rich situation, it can in fact be done for any fishery by calling on the many different experts and knowledge holders who work in/around the fishery and ecosystem - traditional owners, fishers, managers, researchers, economists and other interest groups. An initial assessment can be done quite rapidly (via a workshop or two), but putting in greater time to draw together the information (via impact pathways or the other methods detailed in the appendices) will lead to richer outcomes.

FIGURE 1-3 **Three risk assessment steps.**



2 Background

2.1 Management responses to climate change

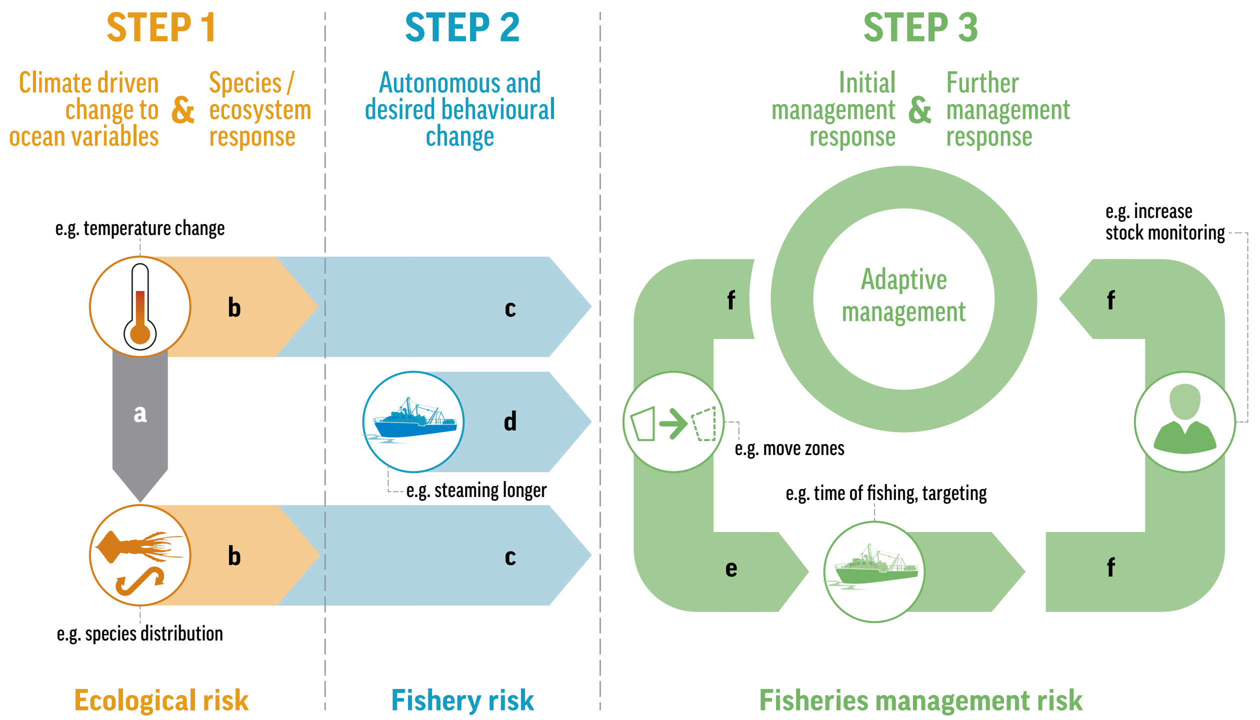
Aquatic systems that sustain fisheries and aquaculture are undergoing significant changes as a result of climate change and projections indicate that these changes will be even larger in the future (Barange et al., 2018).

The effects of climate change on marine life extends to all levels of organization, from individuals, populations, and communities, to entire ecosystems (Rijnsdorp et al., 2009; Hoegh-Guldberg and Bruno 2010; Walther 2010; Poloczanska et al., 2013). Environmental changes associated with climate change are projected to intensify in the coming decades (Poloczanska et al., 2007; Stocker et al., 2013). Consequently, impacts on marine species are expected to exacerbate (Burrows et al., 2011, 2014; Poloczanska et al., 2013, 2016). The impacts of climate change on the marine environment and the species within requires adaptive management responses from the responsible management authorities.

Theoretically the properties of some fisheries management approaches better enable climate change adaptation than others. Model based studies have found that adaptive ecosystem-based management represents the most robust form of management in the face of climate change (Fulton and Gorton 2014). This supports empirical investigation, which finds that ecosystem-based management, in combination with adaptive management and co-management as nested management approaches, possesses the full array of adaptation capacities and attributes required for adaptation in fisheries (Ogier et al., 2016).

At the most fundamental level the relationship between climate change and management responses can conceptually be shown as in Figure 2-1 (which marks where the bullet points (a) to (f) described below sit in the figure)[4].

FIGURE 2-1 Schematic representation of why a risk assessment needs to be undertaken – showing the relationship between climate change, autonomous fleet adaptation and response and any management responses.



4 The three steps and the colour scheme reflect those of the risk assessment (Figure 1-2). We have used this colouring throughout to help readers/users keep track of the steps and flow through the process.

The logic underlying the assessment process contains several components – the bullet points (a) to (f) described below – which sit at different points along the diagram of how changes in the environment influence species/ecosystems and fisheries, how operators may respond and how the management process may be involved (Figure 2-1). These steps also map into the 3 risk assessment steps shown in indicated in Figure 1-2. For clarity these components are:

STEP 1 ▶ The biophysical components of the system – the physical climate drivers and the species and ecosystems affected.

1

a) ***Climate driven changes*** *in ocean variables will impact marine species and ecosystems* (left hand panel in Figure 2-1 – shown by the arrow between temperature change and species distribution).

b) *Climate driven changes and consequent impact on* ***marine species and ecosystems*** *will have an impact on the fishery and the fleets* (indicated by the right facing orange arrows in the left hand panel in Figure 2-1.

STEP 2 ▶ How the fishery operators are likely to respond and adapt, autonomously at first, to any changes in the marine environment (Pecl et al., 2019).

2

c) *Climate driven changes and consequent impact can also have a direct impact on management* (shown by the blue arrows that go directly to Panel 3).

d) *Autonomous adaptation by the fishery in response to change in marine species and ecosystems* (the middle panel in Figure 2-1) – for example where the fleet deals with species redistribution by following the fish and steaming longer (though this may be a limited response, as other parts of government may act to constrain emission levels which may limit this response unless alternative fuels are found).

Some of these initial autonomous responses may be able to take place within the bounds of the current regulations, that is, they take place prior to, and independently from, any management responses. Nevertheless, these initial autonomous responses are likely to impact fleet/vessel profitability, for instance, due to extra fuel costs. There are some responses that the fishery/fleet may wish to take that are not possible with current technology or not allowed within current regulations and these would require explicit responses by fisheries management.

STEP 3 ▶ The way in which management authorities also have to account for changes in the behaviour of fishers/ fleets and respond where adaptive behaviour by the fishery is not possible within current regulations (and where allowing those responses will not act contrary to overall management objectives or legislative requirements).

3

e) *Management authority response to climate driven changes and consequent impact on marine species and ecosystems* (right hand panel in Figure 2-1).

f) *Management authorities continue to respond to climate driven changes in an adaptive management cycle* (right hand panel in Figure 2-1).

The management options may be immediately available to authorities (i.e. that they can be implemented relatively quickly given the current management approach in that fishery, such as moving zones) or they may require some lead time before they can be implemented (i.e. increasing stock monitoring or entering into a larger process of policy review and legislative change). Fishery operators will respond to these short- and long-term management changes, and these responses may be synergistic or antagonistic (Pecl et al., 2019). The outcome of these responses, and the long-term climate impact on marine fish populations, means a process of continual adjustment is needed so that things can change with the new and shifting operating reality for fisheries and fisheries managers. Thankfully this can already be easily accommodated within an adaptive management cycle.

Each of the three stages is discussed in more detail below, based on general principles and steps for doing risk assessments. But before undertaking the three steps of the actual risk assessment a pre-risk assessment phase applies.

3 Risk scoping: Pre-risk assessment phase

The pre-risk assessment will determine the scale and the scope of the actual risk assessment. It is important to determine the scope of the assessment because more in-depth risk assessments require more resources. Depending on data and resource availability the level of the assessment is likely to differ.

3.1 Determine the scope of the risk assessment

The first step in the pre-assessment is to determine the scope of the risk assessment in combination with determining the level of the risk assessment (Section 3.2). At this scoping stage the **aims and objectives** of the assessment must be made explicit. The objectives may be as simple as being prepared for change. They may be more complex such as maintaining a profitable commercial sector and vibrant recreational sector under climate change.

This step is very important. Climate change may have substantially changed the ecosystem or fishery and so people may hold new objectives for this new state. If there has been large scale change in the system and objectives, then the steps of the assessment may even need to step through to what new policies would be needed to help transition to the new goals.

As well as the objectives, the **species of interest** must be determined. For example, some may wish to focus on just key target species, or a habitat type, or to carry out the assessment just for species of concern to a management authority. These species may be at particular risk of climate change impacts, or where the effects are already being observed and impacts felt. In other cases, the decision may be to choose a broader scope, such as an entire fishery including all the species it interacts with, or specific components of the fishery, such as a particular geographic region, or a specific gear type or vessel sizes. For example, the Southern and Eastern Scalefish and Shark Fishery (SESSF), which is a large multispecies, multifleet fishery in southeastern Australia fishes a group of species that are linked by foodweb and habitat connections, as well as technical interactions between gear types and fleets from different ports. This interconnected nature of the fished species caught in the SESSF means that an assessment should be undertaken for the system as a whole (across its entire geographic area and the entire suite of species), rather than simply pulling out a single species or gear type. That is quite a large and complicated task, but without doing that the potential for suggested changes for one sector/species to impact another sector/species would be missed and the effectiveness of any solutions put forward undermined.

Scoping may be assisted by available lists of species and habitats that are compiled as part of an Ecological Risk Assessment (ERA) process (Hobday et al., 2011). For fisheries that do not already have access to such lists, a good way of defining the species is to combine information from species composition of the catch and any scientific surveys of the region, as well as any observer records.

At this point of the risk assessment it is also advisable to understand the level of **participation and values** associated with the species, fishery, or habitat. For example, does the fishery have a traditional component that also has to account for cultural values? Does the fishery have a recreational aspect representing important social values? Are there species of conservation concern that must be explicitly considered?

In conjunction with the fishery component it is advisable to also identify the relevant scales. What is the spatial extent to be considered – the entire range of the species, the EEZ of Australia, the fishery boundaries or some smaller geographic region. Equally it is important to consider the **timescale** that is most pertinent to the risk assessment. Most of the assessments would be aiming to assess risks out to 2030 or perhaps 2040 (immediate, short and medium term). Specifically identifying an explicit space scale and timeframe is important for planning purposes. More immediate assessments could be beneficial for operational planning or in locations that are climate change hotspots (e.g. south eastern Australia), where shifts in drivers and ecosystems are occurring more rapidly, or where system thresholds may be closer (e.g. in the tropics). The increasing likelihood of marine heatwaves and the intensification of storm events may mean all fisheries opt to consider horizons of ten years or less, with a re-evaluation every two to five years.

In preparation for the risk assessment it is advisable to also create an inventory of current **management instruments** used in the fishery. Information on current management instruments will provide baseline information that can be used when determining the management changes that may be needed to enable fishery adaptation.

Without running the full assessment, it can sometimes be hard to see where to draw the line and it may turn out to be an iterative process, where partway through an assessment it becomes clear the scope must be slightly adjusted given what has been uncovered. To try to keep such adjustments to a minimum and to help structure the logic going into defining the scope it is beneficial to create some conceptual sketches of how the system works, what is connected to what, what influences what. Consider what might be mechanisms creating the links between the components. We have summarised the most common ones in the Tables given in this Handbook, but there may be more specific to your fishery so make sure to talk to those who know your fishery and ecosystem well. In Appendix J to Appendix L we also summarise some methods that can be helpful in drawing up these sketches. Impact Pathways help show how a change in one part if the system can flow on to other parts (e.g. physical environment **>** fish **>** fishery **>** management response), while qualitative conceptual models can help identify feedbacks in the system that might help or hinder adaptation. We would advocate using multiple methods (these methods, as well as surveys of literature, industry or academic experts and traditional knowledge holders). The reason to use different ways of identifying factors is to make it more likely that nothing has been missed. The impact pathways and qualitative models may seem like an additional complexity but these are worth doing as they represent structured ways to check whether a factor may have an unrecognised role – it is possible that a factor thought to be trivial by experts may have a key role due to system feedbacks (which can be too complex for experts to keep track of).

Another useful precursor step is to list out attributes of the system that make it more or less robust to then effects of climate change, or more or less able to adapt. We have provided a starting list of attributes to consider in Appendix M. When thinking through the adaptation options in Steps 2 and 3 of the process it is good to aim to bolster those attributes that maximise adaptive capacity.

3.2 Determine the appropriate level of the risk assessment

Once the scope of the assessment has been defined (i.e. objectives, species, stakeholders, management instruments) the availability of relevant information is catalogued, and the level of the risk assessment must be decided upon (see the hierarchical steps in Figure 1-1). This is commonly referred to as a 1st, 2nd, or 3rd pass risk assessments, this is analogous to level 1, 2, and 3 analyses in existing hierarchical risk assessment approaches – such as the ERA (Hobday et al., 2011).

The ultimate level of risk assessment depends on the **aim, focus, available data types, cost, and other assessment characteristics** (Table 3-1). However, just as with the ERA process, we would recommend beginning with level 1 and progressing through level 2 and 3. This will ensure that all components get some degree of consideration without requiring all components to go through a highly detailed and resource intensive assessment.

TABLE 3-1 Broad characteristics of different levels of risk assessments (adapted from Hobday et al., 2011; NCCARF 2016a; 2016b; and 2016c).

Assessment characteristics	1st pass (level 1)	2nd pass (level 2)	3rd pass (level 3)
Aim	Develop a preliminary understanding of climate change risks.	Build on 1st pass assessment to commence climate change risk related discussions among stakeholders within and outside the organisation.	Similar to 2nd pass assessment, to be used where detailed modelling or hazard studies are required before implementation or investment decision-making.
Focus	General broad focus.	Focus on specific sectors, areas or aspects that were identified as being at-risk.	Develop a better understanding of site-specific climate change-related risks.
Data types	Qualitative (typically expert based).	Semi-quantitative. Can be used in combination with local expert knowledge to identify the likelihood of a given climate change risk and its consequence.	Quantitative. Required if the consequences of system failure are severe or if a higher degree of precision is required for making decisions. This step also often involves incorporating qualitative decisions from stakeholders on how they might respond.
Cost (time)	Cheaper.	More time consuming and requiring more resources.	Detailed – highest costs in terms of time and resources needed.
Analysis	All ecological units at a gross level.	Consideration of ecological, fisheries and management risks at least at a qualitative level. Where sufficient resources and data are available, statistical analysis of the most vulnerable units (i.e. those components connected to ecological groups at moderate to high risk in 1st pass).	Full quantitative assessment (with spatial and temporal dynamics), using a mix of process-based and statistical methods, currently typically of individual units/stocks.
Screen out	Low consequence activities affecting components.	Low risk units.	Do not screen out anything (screening done in previous steps – but still leads to priorities).

Images (left) Okan Younesi; (above): **AFMA**

4 Risk assessment

The risk assessment process consists of three main steps. In this section each of the steps is detailed. The focus of the assessments included in the handbook are:

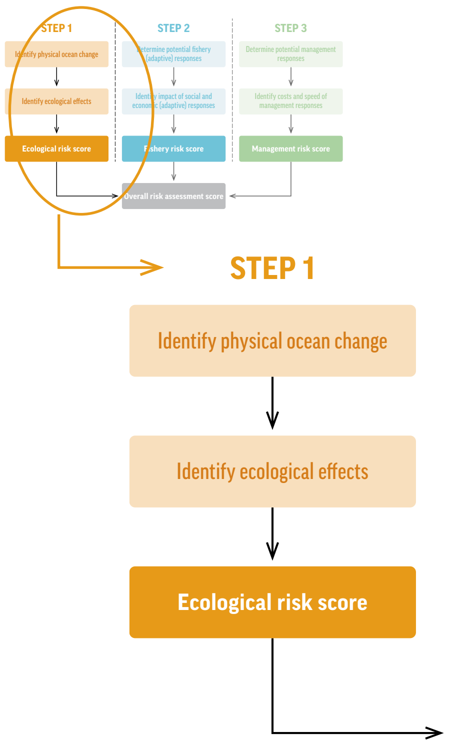
- Commercial, recreational and traditional fisheries within a specific region;
- The local/regional environmental (or other) changes occurring within the region of interest;
- The species living in that area that interact with the fishery – as target species, but also byproduct, bycatch, discards, threatened-endangered-protected species or habitat for species; and
- Management agencies and other key fisheries stakeholders involved with the fishery.

Global scale climate drivers and markets, as well as changes in consumer behaviour may be incidentally considered (i.e. how they may influence the focal fisheries aspects) but are not the direct focus of the handbook or the assessment process.

4.1 STEP 1 – Determine ecological risk (physical and biological change)

In this step of the risk assessment the different types of climate impacts on the fisheries resource are evaluated, we refer to this as the ecological risk posed by climate change. First the physical changes in ocean variables are identified. Secondly the potential responses of species and changes in ecosystems that could occur as a consequence of the physical changes are identified (panel 1 in Figure 1-2 as highlighted in Figure 4-1).

FIGURE 4-1 **Key steps in Step 1 of the risk assessment process – the physical changes and ecological effects (ecological risk).**



Assessing the ecological risk is important for the fishery resource and people that use this resource. It is also important for conservation reasons as changes can affect Threatened, Endangered and Protected Species (TEPS), for instance if there is substantial habitat or prey loss. The ecological risk is important to policy, as changes in ecological status and productivity will impact **the ecological sustainability of fisheries, which are managed to generate benefit to present and future generations** (which is consistent with the principles of ecologically sustainable development (ESD)).

Depending on the scope and level of the assessment (determined in Section 3.1 and 3.2), this step could be for target species or a broader set of species (or classes of species – target, by-product, discard, TEPS, habitats) the fishery interacts with. Just focusing on a target species may miss the effect of a physical change on a prey species or habitat, and thereby potentially misjudging the risk to the target species of interest.

The ecological risk is generally expressed as four different types of ecological change: abundance, distribution, phenology (timing of events, such as reproduction or migration), and physiology (which effects matters such as product quality) (Section 4.1.2). In the next section information is provided to help assess the changes to physical ocean variables and species/ecosystem impacts.

4.1.1 Climate driven changes to physical ocean properties and variables

Exposure to climate change can be observed through changes in chemical and physical ocean properties such as acidity and temperature (Hare et al., 2016). However, atmospheric factors, extreme events and the timing and duration of events also have effects (Table 4-1). There are also important interactions between different ocean variables that need to be considered. For example, wind speeds along the shore can stir up sediments and increase suspended materials, or layering in the ocean may intensify, both of which affect dissolved oxygen levels. Similarly, some extreme events can change chemical and physical ocean factors. An extreme rainfall event can reduce salinity levels and it can also temporarily increase sea levels.

The combined impact of different ocean factors can mean that predicting exact changes is difficult; although ongoing improvement in ocean forecasting and global ocean-atmosphere and ecosystem models are increasing the capacity of scientists to create more detailed and accurate predictions. For example, ecosystem models can provide useful information on the direction and potential magnitude of change to support the pre-risk/scoping stage and 1st pass assessments. Specific, finer scale forecasts can then be used for 2nd and 3rd pass assessments in specific locations.

Studies of predicted change in ocean factors (National Center for Atmospheric Research Staff 2016, Cheung et al., 2016) provide maps with change hotspots around the world (including Australia). These and specific Australian information (e.g. CSIRO-BOM state of the climate reports are available at https://www.csiro.au/en/Research/OandA) provide predictions of key ocean factors Australia-wide, such as water temperature, pH and oxygen levels. Regionally focused summaries of observed and predicted change also exist – e.g. the NRM Cluster reports (available at www.climatechangeinaustralia.gov.au). The maps and time series for physical and chemical changes (e.g. for Sea Surface Temperature) can be used as the starting point for the risk assessment.

In trying to create a list of possible changes (or hazards/risks) for a fishery try to initially be as inclusive as possible. Create a list made up of:

- The (risk/hazard) factors listed in reports and other literature; factors defined by talking to experts and surveying stakeholders;
- The factors (components) in any impact pathways and qualitative models developed for the fishery (see the pre-assessment discussion of these methods in Appendix K).

Also consider what might be mechanisms creating the links between the factors.

The reason to use different ways of identifying factors is to make it more likely that nothing has been missed. Regardless of how factors are identified, key aspects of the fishery to consider when trying to identify potential factors include:

- Ocean properties that act as physical and chemical drivers, such as temperature
- Salinity, river flow or rainfall
- Shoreline change and sea level rise
- Ocean acidification
- Changing oxygen levels
- Weather patterns and extreme events like storms or marine heatwaves
- Larger weather and climate patterns, such as an El Niño
- The response of fish species to these physical drivers (e.g. moving to new locations, changing the timing of spawning or migrations, changing productivity or changed incidence of disease).

More details on these factors is given in Table 4-1. **We have summarised the most common (risk/hazard) factors in the Tables given in this Handbook, but there may be more specific to your fishery so make sure to talk to those who know your fishery and ecosystem well.**

TABLE 4-1 **Categories of ocean properties and associated change variables that are directly impacted by climate change (based on Duncan et al., 2013; CSIRO-BOM state of the climate report 2015; NRM cluster reports available at www.climatechangeinaustralia.gov.au; Hobday et al., 2018; chapter 16 in Barange et al., 2018).**

Ocean properties	Change variables	Explanation and reference
Ocean temperature	Sea surface temperature	Changes in sea surface temperature are now clear from observations globally and around Australia (Bureau of Meteorology and CSIRO 2018). In Australia SST changes are particularly evident on the east and west coast, which have warmed faster than many other places in the world. South East Australia has already warmed more than 1°C since 1950. Even Australia's tropical ocean is warming almost twice as fast as the global average. While 1°C does not sound like much, like the human body, it does not take much change in temperature for serious change to occur, for species to start responding and ecosystems to be affected.
	Deep water temperature	The deep ocean off Australia (and elsewhere) has been warming by up to 0.1oC per decade since the 1950s. This means the bulk (>90%) of the heat due to climate change has been taken up by the oceans. More than 80% of this warming has been between the surface and 2000 m deep. While this means the deepest waters may not be affected to the same degree, 0–2000 m completely overlaps with Australian fisheries (which fish down to 1800 m).
Chemical nature of ocean	CO_2 absorption	Approximately 25% of CO_2 that is released into the atmosphere is absorbed by the ocean. The amount of carbon absorbed is affected by climate change (dropping as climate change intensifies).
	pH	Decreases in the pH of the ocean (ocean acidification) is caused by the uptake of carbon dioxide from the atmosphere. Changing pH levels have been observed in Australia with the waters having already become 26–30% more acidified (CSIRO-BOM 2015). Cooler southern waters are being more heavily affected than northern waters, but effects are being felt in all ocean systems.
	Salinity	Climate change may cause changes in the overall water cycle with a redistribution of evaporation and water transported to different latitudes. This may affect salinity levels. In Australia it is still difficult to predict exact patterns of change over large areas but changed rainfall and run-off patterns will have a big influence on local salinity levels around estuaries and in coastal waters.
	Dissolved oxygen	Dissolved oxygen levels have already changed by approximately 2%, with a further 5% decline forecast by 2040, which affects the liveability of the oceans.

Ocean properties	Change variables	Explanation and reference
Physical nature of ocean	Sea surface temperature	Sea level rise is caused by (i) thermal expansion of warming ocean waters and (ii) increased melting of land-based ice, such as glaciers and ice sheets. Sea levels around Australia have already risen by 15–20 cm around Australia since 1950 with further rises of between 10 and 40 cm likely by 2040.
	Wave height and direction	Storm-related hazards on Australia's open coast beaches are usually associated with both extreme waves and higher water levels. Projected climate change impacts on storm frequency, intensity and distribution over the oceans are associated with considerable regional variability and uncertainty, although there is fairly good agreement that more intense storms will be more likely into the future.
Atmospheric properties	Alongshore wind speed	Under global warming, the severity and frequency of future wind gust events is likely to change, with winds in some locations and seasons likely to intensify. The pattern will not be uniform across Australia however, so it is important to use regionally focused projections (such as available in the NRM cluster reports).
	Air temperature	Mean surface air temperature has increased by around 1.0°C since 1910 (Bureau of Meteorology). This can be important for coastal habitats like mangroves. Models indicate that over the next 10–20 years change locked in by past emissions will see surface air temperatures increase by 0.5–1°C across coastal Australia. Beyond 2040 the level of change depends on the level of global emissions, with temperatures rising more than 2°C beyond today if emissions are not reduced.
	Rainfall / Precipitation	Rainfall averaged across Australia has slightly increased since 1900, with a large increase in north-west Australia since 1970. A declining trend in winter rainfall persists in south-west Australia. Autumn and early winter rainfall has mostly been below average in the south-east since 1990 (Bureau of Meteorology). The major consequences of these shifts for the ocean are to do with changed freshwater runoff and the effect of that on coastal species and habitats influenced by estuarine river flow. Future rainfall projections are highly uncertain, but they do indicate that intense rainfall events will become more likely (even if overall average annual rainfall declines).
Timing and duration of events	Seasonal shifts	The growing seasons are shifting. Spring is arriving earlier, winters are shorter, the number of freezing days is declining, while the number of exceedingly hot days is increasing (Bureau of Meteorology and CSIRO 2018). This is happening on land and in the ocean and can affect not only the growth conditions experienced by marine life but also the timing of key life history events, such as reproduction or migration.
	Ocean circulation	Changes in ocean currents can be pre-cursors to larger climate shifts (e.g. as might happen if the slowing of the ocean currents in the North Atlantic continues), but they can also have an immediate effect on ecosystems. Over the last 20 years the East Australian current has extended more than 280 km further south (Ridgeway & Godfrey 1997), now reaching Tasmania rather than deflecting east off NSW. This has brought many new species into Tasmania waters (Last et al., 2011).
	Upwelling	Changed current and wind patterns can change upwelling, this is when deeper waters (often colder and nutrient rich) are brought to the surface. Upwellings can support much higher productivity than the surrounding ocean. Australia lacks the west coast upwelling seen alongside most other continents (the large upwelling systems off Africa, South and North America support some of the largest fisheries in the world). However, Australia does still have short lived ephemeral upwellings or smaller scale upwellings (with the Bonnie coast the most notable). The location and intensity of these upwellings may shift with climate change.
	Stratification	Vertical stratification (layering of the water) is caused by warmer (less dense) water pooling on top (and failing to mix) with colder (denser) water below. The resulting strong density gradients reduce vertical mixing of dissolved nutrients and oxygen, impacting upon potential production in the surface layers.
	Sea ice extent	Changes in the amount of sea ice can disrupt normal ocean circulation. The way in which this happens is through changes in the density of water and thermocline circulation. In addition, there is a change in water mixing due to winds.

4.1.2 Biological and ecological impact

The second part of the ecological risk assessment is to determine how changes in physical and chemical ocean factors influence marine species and ecosystems. At this point the sensitivity of the species, habitat (or even ecosystem) of concern is identified, and the impact of the changing ocean factors is described. These species need not only be target species, but could also be by-product, discard, or threatened, endangered and protected species (TEPs) etc.

Each species will likely be affected in different ways, but the impact can generally be comprehensively described by four main biological impact categories – distribution, abundance, phenology, and physiology (Table 4-2). Changes in distribution and abundance are the most documented responses for marine species (Dulvy et al., 2008; Sunday et al., 2012; Burrows et al., 2014; Boyce et al., 2010). However, there are also phenological changes (where the timing of life history events such as migration, or reproduction shift as the environmental cues have shifted), as well as physiological responses to climate driven change – such as where increased temperatures speed up the metabolism influencing the growth and condition of an individual. Change in the mean value of physical and chemical factors (Edwards and Richardson 2004) are important (Table 4-2), but increased variability can also present an issue to fisheries (as it can impact availability of fish year to year, which is problematic where stability of supply and income is important).

To better understand the potential impact of climate on marine species, vulnerability and sensitivity assessments (specialised forms of risk assessment) have been carried out (see Pecl et al. and Hobday et al., 2011 for those most relevant to Australia). There are different approaches these vulnerability/sensitivity assessments can take, including correlative, mechanistic, or trait based. The latter is less resource-intensive and therefore it is more widely used (Pacifici et al., 2015). The species trait-based approach examines sensitivity to changes in ocean variables through traits (Pecl et al., 2014) that thus influence abundance, distribution, and phenology. For example, specialized species are assumed likely to be more sensitive to the impacts of climate change (Sunday et al., 2015).

Ideally this sensitivity analysis would be done for the specific species in the specific fishery system of interest using the approach as per Pecl et al. (2011, 2014). However, in the absence of resources to undertake such a focused sensitivity assessment, existing sensitivity analyses (which do try to capture key species around Australia) can be used (see the regional summaries available alongside this handbook, which summarise more detailed assessments in Hobday & Lough 2011, Pecl et al., 2011 and Welch et al., 2014, for example).

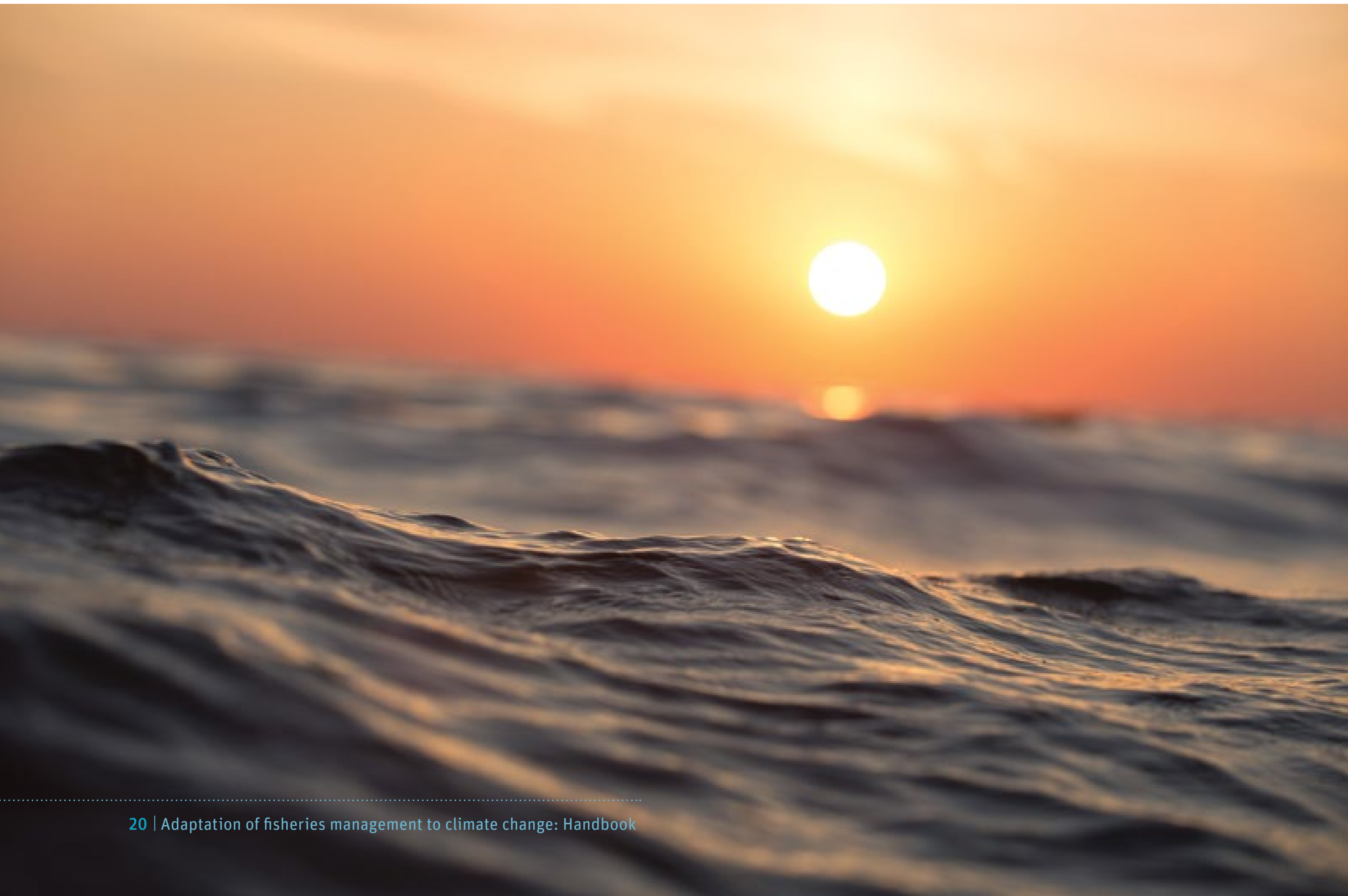


TABLE 4-2 The four main biological impact categories due to changing ocean factors. The attributes of species sensitivity to change are based on Pecl et al., 2011, Hobday et al., 2011, and Gaichas et al., 2014.

Biological impact categories	Description of the change and implications for fisheries	Species attributes that affect their sensitivity to climate change	Low sensitivity (1)	Medium sensitivity (2)	High sensitivity (3)
Abundance	Change in total (or local) population size, which alters the location specific availability of a particular marine species.	Fecundity	> 20,000 eggs per year	100-20,000 eggs per year	< 100 eggs per year
		Recruitment period	Consistent recruitment events every 1-2 years	Occasional and variable recruitment period	Highly episodic recruitment event
		Average age at maturity	≤ 2 years	2 – 10 years	> 10 years
		Generalist versus specialist	Reliance on neither habitat or prey	Reliance on either habitat or prey	Reliance on both habitat and prey
		Sensitivity to ocean acidification	Not shelled and no reliance on shelled species	Not shelled, but reliant on shelled species (as prey or habitat)	Shelled species
Distribution	Changes in the geographic location (range) of where the fish (marine species) mainly reside. This can alter access (especially if the species shifts to a new jurisdiction) or costs (if further from ports/ infrastructure). It can also undermine spatial management (e.g. as the species is no longer covered by a closure meant to protect a spawning aggregation).	Capacity for larval dispersal or larval duration	> 2 months	2 – 8 weeks	< 2 weeks or no larval stage
		Capacity for adult/juvenile movement	> 1,000km	10 – 1000 km	< 10 km
		Physiological tolerance	>20° latitude	10 – 20° latitude	< 10° latitude
		Spatial availability of unoccupied habitat	Substantial unoccupied habitat; >6° latitude or longitude	Limited unoccupied habitat; 2 – 6° latitude or longitude	No unoccupied habitat; 0 – 2° latitude or longitude
Phenology	Changes in the timing of biological events. This can change accessibility (e.g. the fish may no longer be in the system at the same time of the year), abundance (as recruitment may fail if mismatches occur), or it may undermine seasonal management measures (e.g. if spawning or migration is earlier/ later, a seasonal fishery may miss the resource).	Environmental variable as a phenological cue for spawning or breeding	No apparent correlation of spawning to environmental variable	Weak correlation of spawning to environmental variable	Strong correlation of spawning to environmental variable
		Environmental variable as a phenological cue for settlement or metamorphosis	No apparent correlation to environmental variable	Weak correlation to environmental variable	Strong correlation to environmental variable
		Temporal mismatches of life-cycle events (e.g. larval release and presence of a plankton bloom as food source)	Continuous duration; >4 months	Wide duration; 2 – 4 months	Brief duration; < 2 months
		Migration (seasonal and spawning)	No migration	Migration is common for some of the population	Migration is common for the whole population
Physiology*	Changes in the quality of the species.	Fat and muscle content (capacity for energy storage)	High fat and muscle content (capital breeder)	Intermediate	Low energy storage (income breeder)
		Body size	Large (> 100 cm)	Medium (between 20 and 100cm)	Small (<20 cm)
		Metabolic capacity	High metabolic capacity	Medium metabolic capacity	Low metabolic capacity
		Disease or parasite load	Low disease and parasitic load	Medium disease and parasitic load	High disease and parasitic load
		Physiological tolerance and response curve	High tolerance	Medium tolerance	Low tolerance
		Oxygen sensitivity	Low sensitivity (<2 ml/l O_2)	Intermediate (between 2 and 5 ml/l O_2)	High sensitivity (>5 ml/l O_2)

* Not in Pecl et al 2011

Image: **Pexels from Pixabay**

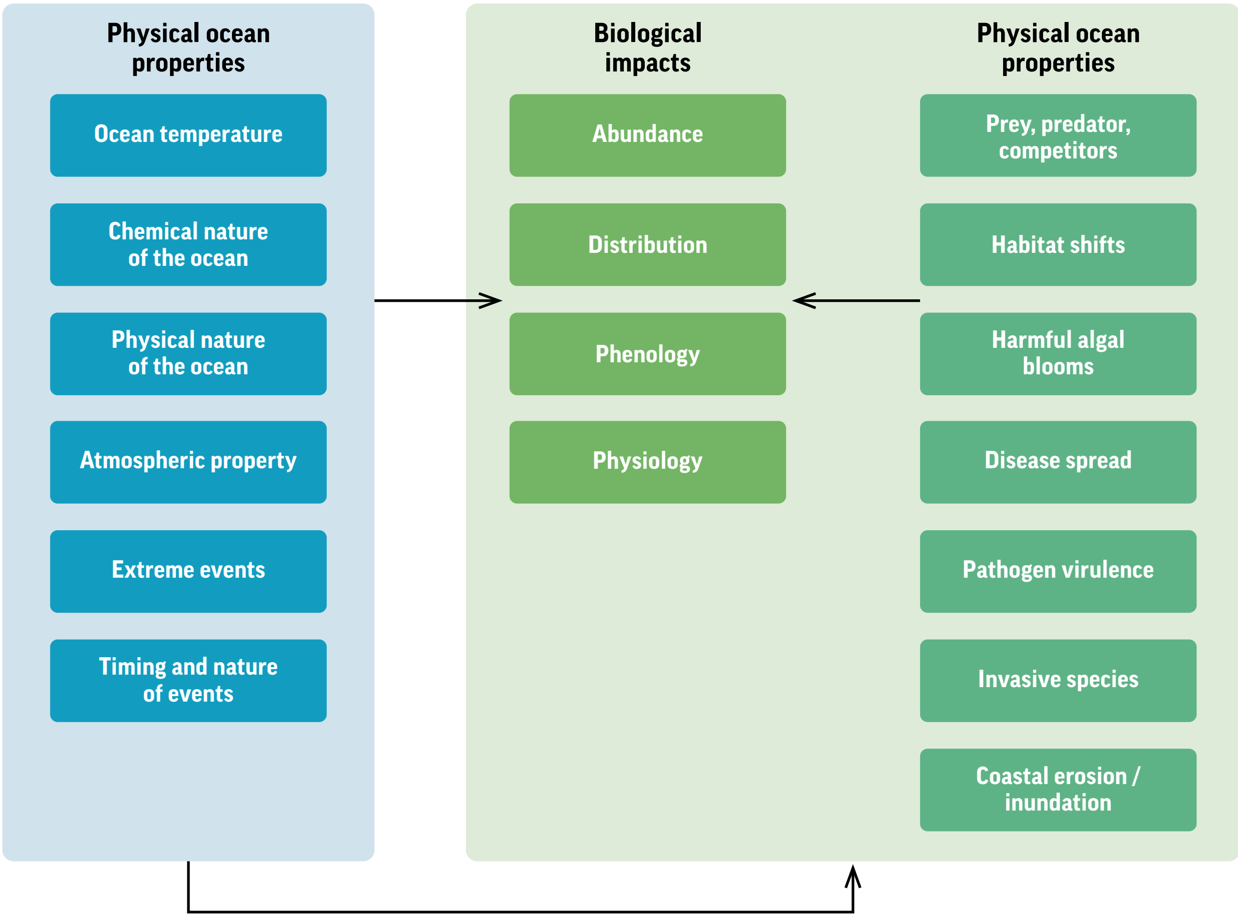
The climate impact on species can also be indirect via food web or habitats (called indirect ecosystem impacts here). These impacts must be considered in conjunction with the direct impact as there might be cumulative effects (Table 4-3).

TABLE 4-3 Indirect ecosystem impacts on marine systems (examples only).

Indirect climate ecosystem impact	Description of the effect
Prey, predators, competitors	Changes in availability of prey or the pressure from predators or competitors can affect abundance or see species move to new locations (as they search for food or seek to avoid predators).
Habitat shifts	Changes in the availability or quality of habitat may see the productivity or survival change (the species may even leave/enter a new area).
Harmful Algal Blooms (HABs)	HABs are temperature sensitive (higher temperature will increase the chance of occurrence). HABs can cause fish kills through poisoning or physical damage. They can also render marine products unsuitable for human consumption.
Disease outbreaks	Some diseases are temperature sensitive and may spread more readily through warmer (or colder) waters, thus posing a risk to marine species not previously exposed to the disease. This may also impact upon quality of the catch.
Pathogen virulence	Some pathogens may become more virulent with changing physical ocean properties and pose a new threat to resident species.
Invasive species	As water temperatures and other ocean variables change species may move, following preferred environmental conditions, which could see them spread to new areas, potentially affecting or displacing resident species.
Coastal erosion / inundation	Changing sea level and wave strength will see changes in rates of coastal erosion and inundation, reshaping coastlines, physical access, habitats and infrastructure.

The direct and indirect effect on the four biological impact categories are shown schematically in Figure 4-2.

FIGURE 4-2 **Conceptual relationships between physical ocean properties, biological impacts, and indirect ecosystem impacts.**



4.1.3 Overall ecological risk assessment

The outputs of sections 4.1.1 (physical ocean changes) and 4.1.2 (resulting biological and ecological impacts) are combined to provide an overall estimate of ecological risk. This ecological risk assessment completes Step 1 of the risk assessment process.

The ecological risk is assessed using qualitative scores (rating the size or type of a change).

The ecological risk for the species, fishery, or habitat, comprises three risk variables:

(i) the direction of the predicted change (increase, decrease, or no change);

(ii) the intensity of the predicted/expected change; and

(iii) the speed of the predicted/expected change.

An explanation for each ecological risk variable and the scoring thresholds are provided in Table 4-4.

Image: Pexels from Pixabay

TABLE 4-4 Ecological risk assessment (STEP 1): for each column (abundance, distribution, phenology, quality) the user enters the appropriate risk level for each ecological factor (predicted change, intensity of change and speed of change for a species or group of species). There is one factor per row. An accompanying spreadsheet tool exists to help with stepping through this scoring and associated record keeping.

Risk factors	Levels	Rationale	Abundance	Distribution	Phenology/ timing	Quality
Predicted direction of change	Positive (good) Negative (bad) Absent	The predicted ecological change and the direction of the ecological change can be obtained from existing reports and publications (e.g. by Pecl et al 2014 and others). Ecological modelling (where available) can provide additional information to determine likely change in species in terms of abundance, distribution, phenology/timing, and quality. If the effect is positive it means that it is likely to be beneficial to the fishery (i.e. greater abundance, more localised distribution, more convenient timing of key events, and better-quality fish). A better outcome for the fishery gets a 'positive' score, a worse outcome gets a 'negative' score. If there is no effect, the score for the column is 'Absent' and is not considered further in the risk assessment.				
Intensity of the change	Very large Large Medium Small	The intensity of the change is defined as the change relative to the current situation – i.e. relative to the status at the current point in time what is the 'severity of the change'? This change can be the proportion of the population of fish that is affected by distribution shifts, or the relative reduction in abundance. The more intense the change the greater the ecological risk (the greater the score/rating given).				
Speed of the change	In the next 2 years In the next 2-5 years In the next 5-10 years More than 10 years	The relative speed of change is also important in terms of the ecological risk with faster change posing a greater ecological risk. The sooner the change happens the greater the risk (more immediate risks are given a higher score). The speed of change ranges from slow (in more than 10 years' time) to fast (within the next 2 years).				
Ecological risk	High ecological risk Medium ecological risk Low ecological risk	To assign the overall final risk score consult this table.				

	Negative Direction of Change				Positive	Absent
	Intensity of Change					
Speed of Change	**Very large**	**Large**	**Medium**	**Small**		
Next 2 years	High	High	High	Low	Low	None
Next 2-5 years	High	High	Medium	Low	Low	None
Next 5-10 years	High	High	Medium	Low	Low	None
More than 10 years	High	High	Medium	Low	Low	None

Image: AFMA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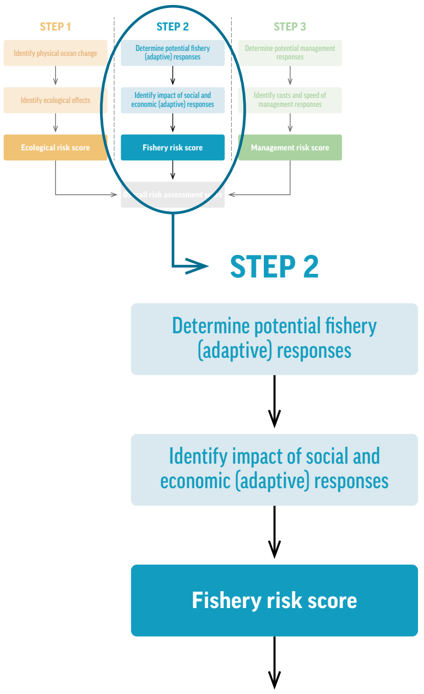
> ***In order for the fisheries managers' economic objective (to maximise the net economic returns of the fisheries to the Australian community) to be pursued, it is important for fisheries managers to understand the types of autonomous and desired fisher adaptive responses.***

4.2 STEP 2 – Assess fishery risk

The next step in the risk assessment is to determine the risk to the fishery – for instance, the fleet of licensed commercial harvesters or recreational or traditional fishers- and the potential adaptation responses that fishers might implement (see Pecl et al., 2019) to deal with any ecological changes and the impact on their operating environment (panel 2 in Figure 1-3 as highlighted in Figure 4-3). Some of these initial adaptation responses can take place within the bounds of the current regulations and are referred to as autonomous adaptations. These behavioural adaptations can take place prior to, and independently from, any management actions.

FIGURE 4-3 Key steps in Step 2 of the risk assessment process – the fishery responses and social and economic effects (fishery risk).



There are some adaptive responses that the fisheries management agency and the fleet may wish to take that are not possible with current technology, or fleet structure, or not allowed within current regulations, we call these desired adaptation responses [5]. Desired adaptation responses could also require a management response by fisheries authorities and/or institutions. For example, due to a change in the distribution of the fish a fishery wants to expand the allowable fishing area – which the management authority would need to instigate and approve.

In order for the fisheries managers' economic objective (to maximise the net economic returns of the fisheries to the Australian community) to be pursued, it is important for fisheries managers to understand the types of autonomous and desired fisher adaptive responses. Having that understanding allows for adaptive management to be implemented and fishery risks to be minimised. For example, a fisher may indicate that they will target other fish (that they are already licenced to catch) if there is a redistribution of their main target species. Increased pressure on this other species may have consequences for the management of that species. Conversely, it might not be possible for the fisher to autonomously respond to a redistribution because they do not have a licence to catch other species. In this case, to minimise economic and social impacts of climate driven species redistribution a fisheries management response or action (e.g. extension of licence schemes) may be desirable.

To determine how fishers might adapt to climate impacts, direct contact with stakeholders is recommended (e.g. surveys or meetings), particularly because the magnitude and timing of change will differ from place-to-place. This includes understanding the adaptive responses available to fishers – whether there really is the capacity to change operations or whether social, financial or regulatory barriers exist – and under what conditions they would implement this adaptive response (i.e. the level of change in catch or physical conditions needed before an adaptive behavioural change is made).

Fisheries managers will need to understand: (i) the type and extent of possible adaptation responses; (ii) the likelihood of implementing these adaptation responses; (iii) the potential economic and (iv) social impact of these adaptive responses. This can be (ideally) achieved through surveys of stakeholder groups (the fishery operators, and/or industry or topic area experts, such as economists, human geographers etc). In this handbook we have developed three surveys – G-1, H-1 and H-2 – that can be implemented to gather some or all this information at different levels of detail (for more information on the surveys see Appendix F to Appendix H). The surveys can be implemented in different ways, and could, for instance, be implemented through internal consultative processes (i.e. consultative or co-management groups) using Expert Elicitation, which is a structured way of gathering (eliciting) advice from experts on the fishery, particularly experienced fishers, fleet managers and other experience stakeholders (see Table 4-5). Structured elicitation methods are the best way of gathering this advice in as balanced and impartial manner as possible. Also note that across the different options it is possible to make the approach scalable so

5 These can also be thought of as the responses fishers wish to make but are constrained from completely achieving (in the short to long term) by the regulatory, management or other (e.g. societal) context.

that updating can be included, in a relatively simple way, within ongoing management processes (e.g. updated annually as part of the co-management process, or as part of the process of developing research plans).

The reason for providing three different survey options is to account for respondent availability and their willingness to invest time in completing the survey. While ideally the aim is to obtain the most comprehensive, locally specific, and accurate information for the risk assessment, we acknowledge that it can be difficult to gather survey data (for instance because of survey fatigue).

4.2.1 Adaptive responses of fleets

In circumstances where it is not possible to implement a survey to assess fishery risk, we provide a list of potential adaptive responses for each of the four possible ecological impacts (Table 4-6). Several generic adaptive responses (based mostly on empirically published research) have been observed globally and in Australia in response to ecological impacts of climate changes (Rubio et al., 2020). For example, the ticks in the first row of Table 4-6 indicate that changes in effort have been observed in response to abundance and distribution changes of a target species. This table is the default information used to populate the risk assessment. The list is not exhaustive and other adaptive responses can be added.

TABLE 4-5 Different implementation methods available to assess fishery risk. Note that these can be implemented in various combinations, e.g. an online survey followed by information gathering or clarification in a workshop.

Implementation method	Data collection instrument	Approach	Type of information	Advantage	Disadvantage
Online	Survey-questionnaire	Structured approach (mostly quantitative data)	Population based information	Knowledge of the differences in the likely responses between stakeholders	• Challenging to get good response rates (and representative sample). • Need to access appropriate database or social media platform to implement • Little potential for qualitative information to be gathered.
Phone or face-to-face	Interview or questionnaire	Structured or semi-structured	Key informants can be targeted (thus limiting the number of responses required)	Higher chance of survey completion by participants	• Selecting and getting participation from key informants can be challenging
Expert elicitation	Survey exercise, adapted with each round	Delphi method	Several rounds of survey are implemented (i.e. to a group of experts). The anonymous responses are aggregated and shared with the group after each round – and discussed	Consensus outcome or classes of actions	• No information on the differences between stakeholder groups
Workshop	Survey-questionnaire (conducted by participants) and/or clarification or validation exercise of assessment results	Interpretive and semi-structured	Key stakeholder responses	Higher chance of survey completion by participants Higher likelihood of trust in results and adoption	• Small sample • Quiet voices can be missed

This list does not provide any insight into the likelihood of these adaptive responses being implemented and the social and economic implications of doing so to the fishers. For instance, changing the amount of effort (increasing or decreasing) could have significant implication on the cost of fishing. Increasing effort might

TABLE 4-6 **Relationship between adaptive responses and the four ecological impacts.**

Adaptation response category*	Explanation of response	Abundance	Distribution	Timing	Quality
Change effort	Change the amount of fishing effort	✓	✓		
Move location	Move to another fishing location	✓	✓		✓
Switch species	Switch to a different target species	✓	✓		
Stop fishing	Stop fishing for the target species altogether	✓	✓		
Invest	Invest in new technology or assets	✓		✓	✓
Trade quota	Change the amount of quota trade	✓	✓	✓	
Pricing	Change the sale price of fish	✓	✓		✓
Manage supply chain	Change supply chain management	✓	✓		✓
Fish handling practices	Improve fish handling methods			✓	✓
Target markets	Diversify markets	✓	✓	✓	✓
Value add	Value add to the product	✓			✓
Accessing Information (inward focus)	Seek information about adaptation options	✓	✓	✓	✓
Information dispersal (outward focus)	Communication with concerned stakeholder	✓	✓	✓	✓
Other adaptations	......				
TOTAL NUMBER OF ADAPTIVE RESPONSES		**12**	**10**	**6**	**9**

* Many of these adaptation responses are particular to commercial fisheries (e.g. pricing and trading quota), but a number also apply to recreational and traditional fisheries (e.g. moving location and switching species). Users (from any sector) should also freely add any responses not listed here that are relevant for their fishery.

also mean that more crew is needed (at greater expense). It is also possible that some options may be ruled out by the fishery participants – for instance a specialised fishery may not be in a position to switch species or stopping fishing may be seen as untenable. These are considered in the next steps of the risk assessment.

4.2.2 Fishery risk assessment

The behavior response information gathered in the surveys is used in the fishery risk assessment. The fishery risk is derived from several risk variables: the number of responses (autonomous and/or desired) that are available to the fishers to adapt to the ecological change; the likelihood that those responses are able to be implemented; and the relative economic and social impact of the ecological change (Table 4-7). The entries in the first row (predicted change) is transferred from the ecological component of the risk assessment above. The other rows are filled in based on the information from Table 4-6, and/or the surveys, and/or discussions with the fishery stakeholders.

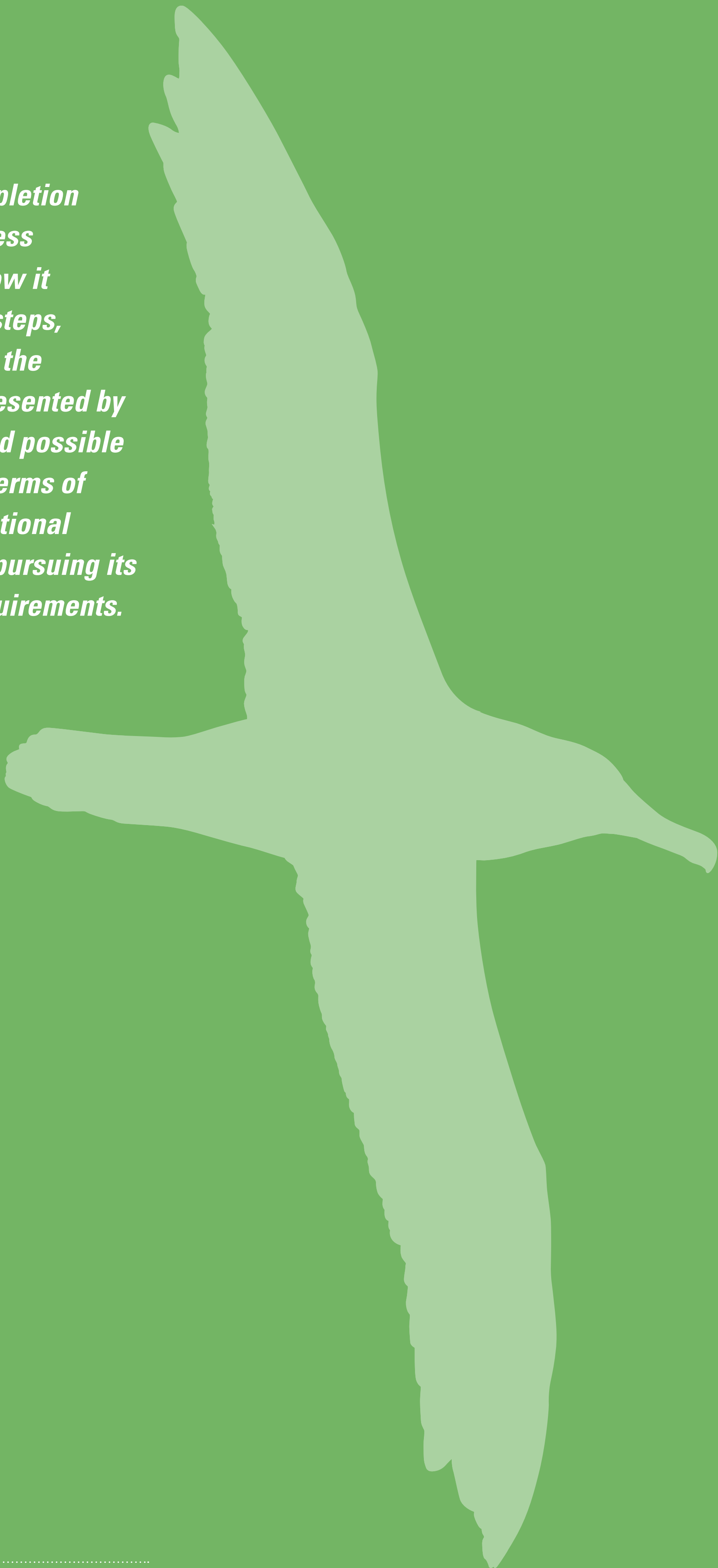
Just as for the ecological step it is important to think and consult broadly about the relevant fisheries characteristics including: cost structures; fishing efficiency; at sea safety; asset damage or loss; market responses (is sufficient product available at the right time?); fishing enterprise size or type; flexibility (regulatory or operationally); magnitude of catch and effort etc; access to the resource, markets and infrastructure etc.

TABLE 4-7 Fishery risk assessment (STEP 2): For each column scored in STEP 1 (Table 4-4) enter scores here for levels of risk for each relevant fishery factor. Numerical values used to help calculate risk scores are given for reference (and are shown in brackets). These values are also used in an accompanying spreadsheet tool that can help with stepping through this scoring and associated record keeping.

Risk factors	Levels (corresponding scores)	Rationale	Abundance	Distribution	Phenology/ timing	Quality
Ecological risk	Absent Low Medium High	The ecological risk score is carried across from Table 4-4.				
Potential number of adaptation responses (options)	Few responses available (<0.25) Some responses available (0.25-0.60) Many responses available (0.60-0.80) Very many responses available (>0.80)	There are a number of adaptive responses outlined in Table 4-6 that can be applied by fishers in response to the ecological change variables. If more potential behavioural responses are available this indicates a lower risk to the fishery. The risk score is calculated as the proportion of the total number of possible responses that are actually available (e.g. 7/13 = 0.54 which is "some"). In Table 4-6, 13 options are provided but this could be more or less depending on any additional responses the user of this handbook enters or deletes as inappropriate for their system (i.e. it could never be a viable potential option).				
Likelihood of implementing the adaptation response	Easy (<0.25) Moderate (0.25-0.60) Hard (0.60-0.80) Very hard (>0.80)	Even though an adaptation response might be available, it does not automatically mean it will be implemented. The ability to implement depends on the circumstance of the operators in the fishery. The likelihood can be assessed using a survey method (e.g. surveys A and B shown in Appendix F and Appendix G respectively) in which information is gathered on the likelihood of implementing each of the adaptive responses. The higher the likelihood of implementing the behavioural response the lower the perceived risk. For each ecological change, consider the list of potential adaptive responses (outlined in Table 4-6) and assign each responses a likelihood score (a number between 0 and 1) based on the responses from the survey (a higher score indicating a higher likelihood of implementation). Then take the average of those likelihoods to get the overall score for this risk factor (e.g. if the overall value is 0.3 then that falls in the range of 0.25–0.6 so the answer is Moderate) – the higher the score the lower the risk.				
Economic impact	Very large (>7) Large (5-7) Medium (2-5) Small (<2)	The economic impact of the ecological change will influence the risk to the fishery. For example, distribution changes may mean that there will be an increase in fuel costs to the fishers, as they chase the fish to new locations, which could impact their profitability and perhaps challenge their long-term economic viability. The economic (and social) impact of the ecological change is also best estimated from a survey (e.g. survey C in Appendix H). The score is calculated by multiplying the likelihood of the impact (between 0 and 3) by the severity of the consequence (between 0 and 3) of that impact. A higher risk score indicates a higher likelihood of the impact occurring and a higher economic (or social) consequence. Scores will range from 0 for "occurrence impossible" through to 9 for a "certain and catastrophic" impact. If there are multiple impacts to consider take the median of the impact scores for the total number of economic (or social) impacts to give the overall economic (or social) impact score.				

<table>
<tr><td>Social impact</td><td>Very large (>7)
Large (5-7)
Medium (2-5)
Small (< 2)</td><td>See explanation for economic impact, but consider social rather than economic aspects.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Response risk</td><td>Social and economic impacts vs Available options</td><td>
<table>
<tr><td rowspan="2">Options available</td><td></td><td colspan="4">Economic or social impact (whichever is LARGER)</td></tr>
<tr><td>Implementation</td><td>Very large</td><td>Large</td><td>Medium</td><td>Small</td></tr>
<tr><td rowspan="3">Few</td><td>Hard / very hard</td><td>High</td><td>High</td><td>High</td><td>Medium</td></tr>
<tr><td>Moderate</td><td>High</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Easy</td><td>Medium</td><td>Medium</td><td>Medium</td><td>Low</td></tr>
<tr><td rowspan="3">Some</td><td>Hard / very hard</td><td>High</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Moderate</td><td>High</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Easy</td><td>Medium</td><td>Medium</td><td>Low</td><td>Low</td></tr>
<tr><td rowspan="3">Many or very many</td><td>Hard / very hard</td><td>High</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Moderate</td><td>Medium</td><td>Medium</td><td>Low</td><td>Low</td></tr>
<tr><td>Easy</td><td>Medium</td><td>Medium</td><td>Low</td><td>Low</td></tr>
</table>
</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fishery risk</td><td>High fishery risk
Medium fishery risk
Low fishery risk</td><td>See explanation for economic impact, but consider social rather than economic aspects.
<table>
<tr><td></td><td colspan="3">Response risk</td></tr>
<tr><td>Ecological risk</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>High</td><td>High</td><td>High</td><td>Medium</td></tr>
<tr><td>Medium</td><td>High</td><td>Medium</td><td>Low</td></tr>
<tr><td>Low</td><td>Medium</td><td>Low</td><td>Low</td></tr>
<tr><td>Absent</td><td>None</td><td>None</td><td>None</td></tr>
</table>
</td><td></td><td></td><td></td><td></td></tr>
</table>

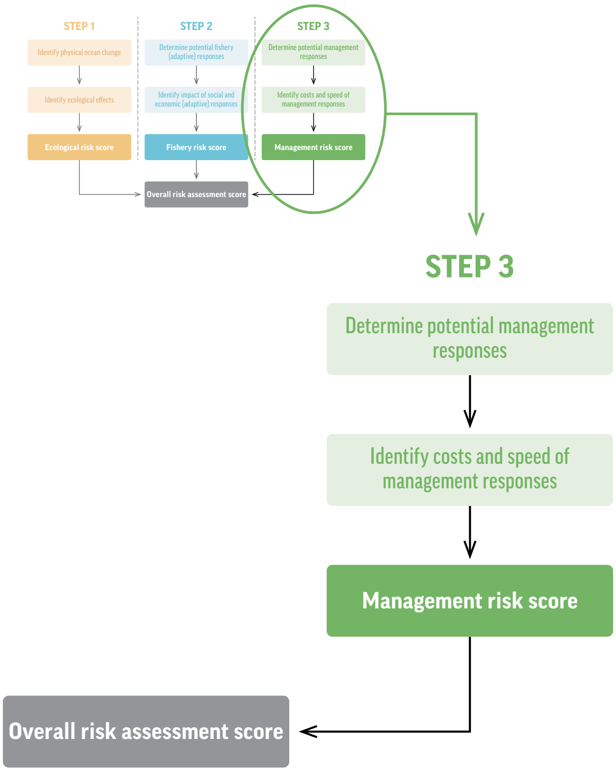
It is only the completion of the step 3 (assess management risk), and how it influences the other two steps, that shows the full risk to the management authority presented by climate-driven change and possible responses to it – both in terms of delivering effective operational management, but also in pursuing its legislative and policy requirements.



4.3 STEP 3 – Assess management risk

The final step in the risk assessment is to determine the management risk to the fishery arising from the ecological changes, how management may respond and costs or delays in that response (panel 3 in Figure 1-2 as highlighted in Figure 4-4).

FIGURE 4-4 **Key steps in Step 3 of the risk assessment process – the management responses (management risk).**



Fisheries management objectives are implemented through the relevant Acts (see Table D-1 in Appendix D for detail but also see https://www.afma.gov.au/about/objectives-functions-powers). The fisheries authority's public policy goals might be at risk if objectives are not pursued. At the highest level, the three public policy goals entail:

1. Ensure the ecological sustainability of fisheries for the benefit of present and future generations (ecological sustainability). The risk to this goal was discussed in Section 4.1;
2. Improve the net economic returns of fisheries to the community (economic benefits). The risk to this goal was discussed in Section 4.2; and
3. Deliver effective, cost efficient and accountable management and regulator arrangements (good governance). This is the topic of this section.

It is only the completion of the step 3, and how it influences the other two steps, that shows the full risk to the management authority presented by climate-driven change and possible responses to it – both in terms of delivering effective operational management, but also in pursuing its legislative and policy requirements.

4.3.1 Management objectives, functions, and instruments

Fisheries managers will need to respond to socio-ecological change caused by climate change. This means they must respond to climate change impacts at the ecological and species level as, for example, abundance changes affect current management effectiveness. But fisheries managers must also be responsive to the fishers and industry behavioural change (adaptive behaviour) (Creighton et al., 2016).

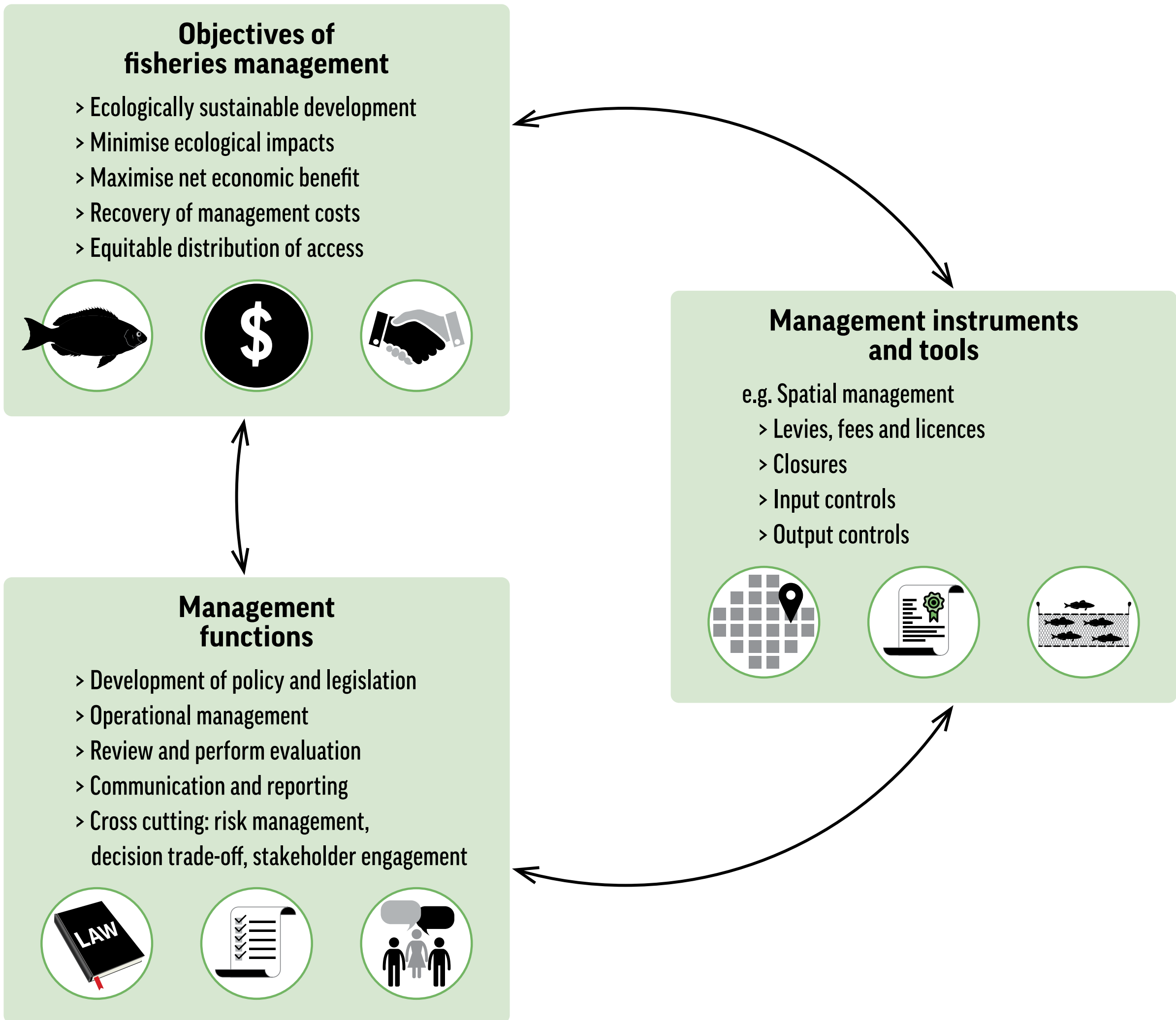
The management approach adopted to deal with socio-ecological change is bounded by the management functions and the objectives of fisheries management (i.e. any legislative or policy requirements/intent). A comprehensive review of existing domestic and international regulatory frameworks, policies, standards and guidelines, undertaken by Hobday et al. (2019) outlines a core set of 21 functions of fisheries management agencies. Five different agency management functions are used to pursue the objectives of fisheries legislation:

1. **Development of legislation and policy** – Setting the stage for good management (legislation and policy development, resource allocation, cost of management, research planning)
2. **Operational management** – Day-to-day functions for management agencies (management plans, development of new fisheries, implementation, data management, licencing, levies and licence fees)
3. **Review and performance evaluation** – Checking agency performance (development of performance indicators, monitoring, review and implementation processes)
4. **Communication and reporting** – Outward-facing agency communication (reporting, communication)
5. **Cross cutting** – issues that are explicit or implicit in many management functions (risk management, decision trade-offs, stakeholder engagement)

In addition, fisheries authorities are bound by the instruments and tools that are available to them. The fisheries authority has available to them many levers by which they can influence fisher behaviour through several spheres of influence (e.g. through constraining catch, effort, where fishing can occur). Adaptive responses to climate change can only be implemented when management functions and objectives are clearly defined. The available management instruments and tools ensure the objectives of fisheries management are pursued (given the management functions). The relationship between fisheries management objectives, functions, instruments and tools is collectively referred to as the management approach (Figure 4-5).

Indicators (and related performance measures which show how management is delivering against objectives) are generally used to measure the performance of management. Assessing the impact of climate change on pursuing fisheries objectives and the link to government policies (e.g. Harvest Strategy Policy) is central to the final steps of the risk assessment. Fisheries management

FIGURE 4-5 Conceptual interactions between fisheries management objectives, management instruments and tools, and management functions (adapted from Ogier et al., 2016).



agencies have available to them five agency management functions along with a series of instruments and tools that can be used to support fisheries adapting to climate change and ensure fisheries objectives are met. The management functions can influence the biological impact of climate change (abundance, distribution, phenology and physiology) via different pathways – such as catch, effort, gear, spatial, and temporal restrictions (Table 4-8). Many of the tools discussed apply to commercial fisheries, but a number also apply across the recreational and traditional fisheries sectors. Only a small number are exclusive to recreational or traditional fisheries only.

To make sense of where and when the different management instruments and tools should be used to mitigate or adapt to climate change, pathways of impact (or spheres of potential influence) should be determined on a case specific basis. Table 4-8 provides some default insights into potential management options under different circumstances (different kinds of change). A number of tools exist that can help think through how climate may impact fisheries, how fleet responses and management actions can may interact with those changes. These tools are touched on briefly in the box below but are discussed in some detail in the appendices.

When looking at what management options are available, there should be some reflection on whether different groups associated with the fishery are affected in the same way. If there are strong differences, with some benefiting strongly and some losing out, this can erode cohesion in the fishery, creating tension and breaking trust in the management process. This will create its own set of risks.

Additional tools to help adaptation mapping and planning

Impact pathways (a method described in Appendix H) can also be helpful for linking fishery changes to management intervention points. Qualitative models (Appendix I) can help flag any feedbacks that might help or hinder alternative management options. Other formal methods – such as the bow tie method (explained in more detail in Appendix K) can help lay out pressures/threats to the fishery and where management actions can help respond to those threats and thereby reduce risk.

The basic structure of the Bow-tie simultaneously identifies: sources of risk, potential consequences, preventive controls (intended to reduce the likelihood of an event), mitigation controls (intended to reduce the magnitude of the consequences of an event), recovery controls (used to recover from the consequences that could not be mitigated), escalation factors (external factors that can undermine the effectiveness of any of the controls) that may require their own targeted controls.

The bow-tie method won't solve all uncertainties, but it can help structure thoughts and information (Astles and Cormier 2018; Cormier et al., 2018).

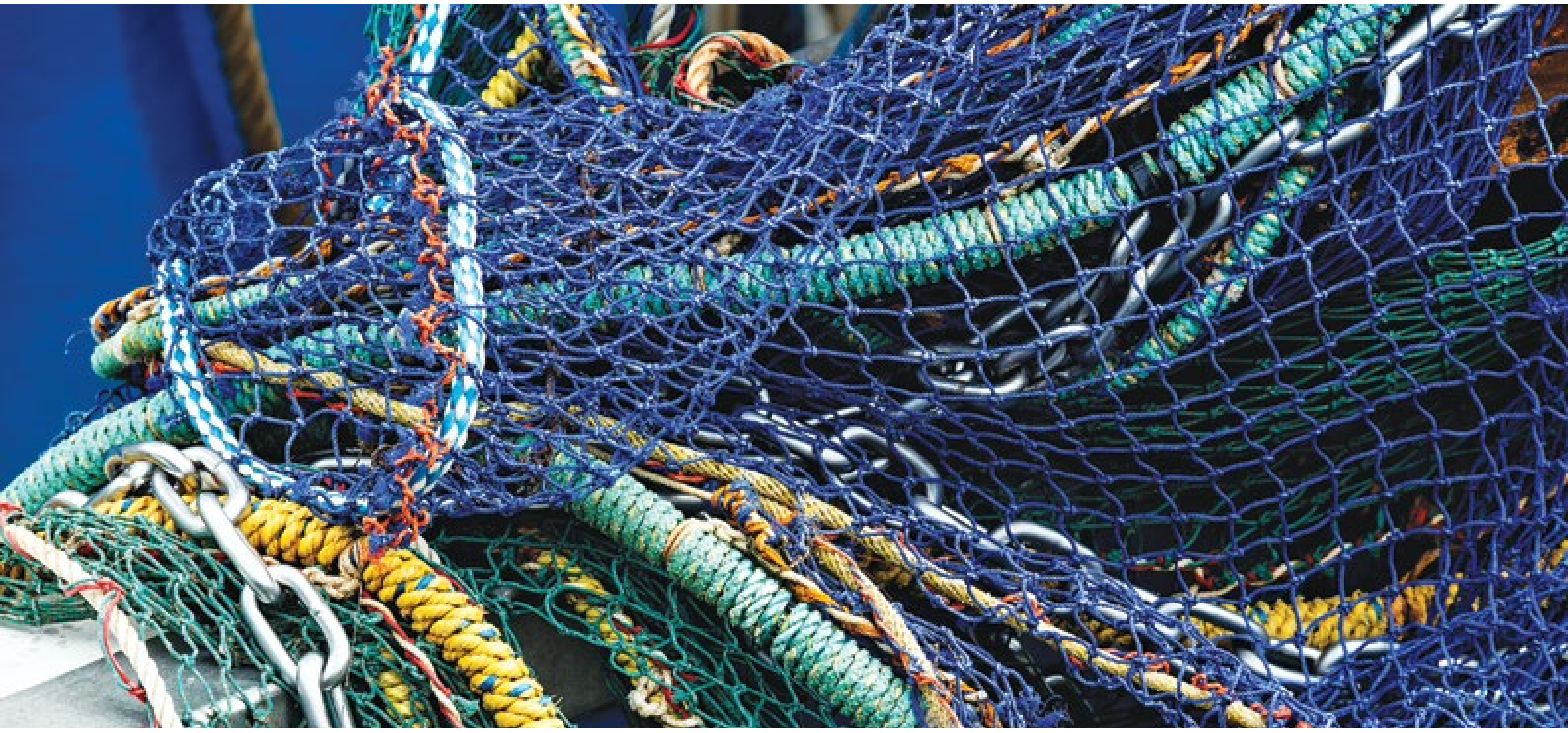


Image: **David Clode**

TABLE 4-8 **Management responses and the biological response that they will likely act on.**

Pathway of influence	Management instruments (management response)	Abundance	Distribution	Phenology	Physiology
Catch	Adjust TAC/ITE for quota species	✓	✓		
Catch	Implement TAC/ITE for new species	✓	✓		
Catch	Adjust trigger limits for by-products	✓	✓		
Catch	Landing restrictions	✓			✓
Catch	Introduce automatic triggers for key environmental parameters (as a proxy for stock changes)	✓	✓		
Catch	Introduce/adjust automatic triggers for non-target TEPS (e.g. dolphins, seabird TAP)	✓	✓		
Catch	Introduce/adjust automatic triggers for general bycatch	✓	✓		
Catch	Change / adjust performance indicators for harvest strategies	✓	✓		
Catch	Change in reference points	✓	✓		
Catch	Re-assessment of model parameterisation (e.g. recruitment, natural mortality estimates)	✓	✓		
Catch	Quota administration (this can include non-commercial sectors)	✓	✓	✓	✓
Catch	Quota transaction monitoring	✓	✓		✓
Catch	Sectoral (re)allocation	✓	✓		
Catch	Catch spreading (ensuring not all catch is taken within one spatial area)	✓	✓		
Catch	Move-on rules	✓	✓		
Catch	Adjust bag/possession limit for species**	✓	✓	✓	
Catch	Implement minimum/maximum size limit for species**	✓	✓		
Catch	Introduce handling requirements (depressurising, venting fish)**	✓	✓		
Catch	Introducing catch and release requirements**	✓		✓	✓
Catch	Traditional use only species**	✓	✓		

Catch data	Crew-based observation	✓	✓	✓	✓
Catch data	Adjust level/coverage of monitoring and data collection for management (observers/EM – scientific or other)	✓	✓	✓	✓
Catch data	Automated data transmission	✓	✓	✓	✓
Catch data	Data collection protocols	✓	✓	✓	✓
Catch data	Real-time data collection and reporting	✓	✓	✓	✓
Catch data	Explore the potential of citizen science and ranger/stewardship/guardian programs for data collection efforts (all sectors, but especially recreational)**	✓	✓	✓	✓
Catch data	Draw on traditional knowledge of the species, ecosystem and fishery**	✓	✓	✓	✓
Catch data	Require recreational fishers to record catches**	✓	✓	✓	
Catch policy	Change compliance capability	✓	✓		
Catch policy	Review compliance risk assessment settings	✓	✓	✓	
Catch policy	Implement/adjust bycatch policy	✓	✓	✓	✓
Catch policy	Change TEPS rules	✓	✓	✓	✓
Catch policy	Negotiate jurisdiction of shared stock	✓	✓		
Catch policy	Change to harvest strategy policy settings	✓	✓		
Effort	Adjustment of levies	✓			
Effort	Implementing / scrapping subsidies	✓			
Effort	Buy out licences	✓	✓		
Effort	Review/changes to fishing access rights	✓	✓		
Effort	Limit (encourage) new entrants	✓	✓		
Effort	Revoke (issue new) licences	✓	✓		
Effort	Cap the number of charter boats (and/or passengers per charter boats)**	✓			
Effort	Introduce recreational or customary fishing licence**	✓	✓		
Effort	Traditional management (resting/crop rotation)**	✓	✓	✓	

TABLE 4-8 Management responses and the biological response that they will likely act on. *Continued from page 37*

Pathway of influence	Management instruments (management response)	Abundance	Distribution	Phenology	Physiology
Structure	Communication tools to support increased awareness or behaviour change	✓	✓	✓	✓
Structure	Educational instruments	✓	✓	✓	✓
Structure	Develop and implement habitat and community policy	✓	✓	✓	✓
Structure	Develop, implement, review and adjust resource sharing framework	✓	✓		
Structure	Change industry co-management	✓	✓		✓
Structure	Change consultative framework	✓	✓	✓	✓
Structure	Change the make-up of consultative groups	✓	✓	✓	✓
Structure	Coordinate allocation and management controls across jurisdictions/sectors	✓	✓	✓	
Structure	Recognise/integrate traditional knowledge and practices into education materials and management approaches**	✓	✓	✓	✓
Gear	Adjust Gear restrictions / limitations	✓		✓	✓
Gear	Adjust Vessel restrictions / limitations	✓		✓	✓
Spatial	Change fishery area (management plan)		✓		
Spatial	Close areas to fishing	✓	✓	✓	✓
Spatial	Open areas to fishing	✓	✓	✓	✓
Spatial	Re-zone fishing areas		✓		
Spatial	Recognise customary food gathering area (which can restrict access for other users)**	✓	✓	✓	✓
Spatial	Recreational only zoning **	✓	✓	✓	✓
Temporal	Adjust (shift) timing of fishing period	✓	✓		
Temporal	Adjust length of fishing season	✓	✓		

* There may need to be different rules/reference points used depending on the observed/forecast environmental conditions for the current/upcoming fishing season. This is the approach already taken in some highly variable upwelling systems (e.g. the California Current).

** Note these management instruments apply to recreational and traditional fishing specifically. A number of the other instruments listed in the table apply across all three fishing sectors (commercial, recreational and traditional), but some are exclusive to commercial (e.g. adjustment of levies, by catch policy, quota administration, and others).

4.3.2 Management risk assessment

The important next step in delivering on this step 3 of the risk assessment is to determine the management instruments and tools that are available to adapt to, or mitigate climate change impacts. Depending on the management instruments that are used within a fishery already, some adaptations may be implementable without requiring extensive change of current management rules – e.g. adjustments to quota setting procedures or the location or timing of closures; other responses will require significant changes to management, potentially even legislative change. When large changes are required there can be significant delays (and additional barriers) to their implementation. Embarking on this route would require strong justification around the change being needed because it is demonstrably better than any other option.

A number of attributes influence the fisheries management risk: the number of available management instruments; management implementation cost of the alternative management options (instruments); ongoing management costs associated with the management options; time to implementation of the management options; path to impact (direct versus indirect, for catch versus effort); and the level of accountability (of the change process) (i.e. level of stakeholder engagement).

A table with the risk distribution for each of the management options/instruments shown in Table 4-8 is shown in Appendix C.

Note that the use of the number of management instruments as a proxy for an indicator management capacity/effectiveness has been put forward here as a more reliable generic or direct indicator has not been identified. When applying the risk assessment to a specific fishery, please substitute in a more relevant indicator, if one already exists. Also, readers/users should think through how influential the different management instruments are for their specific fishery. It may be the case that for some fisheries a particular management measure might be better than others; indeed there might only be a single influential management measure but it might be just what is needed, versus other cases where many measures may exist, but none of them make a significant difference to the problem at hand, and all have different impacts so using a combination raises even more issues.

Image: **camum from Pixabay**

TABLE 4-9 Management risk assessment (STEP 3): For each column scored in STEP 1 (Table 4-4) enter scores here for levels of risk for each relevant management factor. Numerical values used to help calculate risk scores are given for reference (and are shown in brackets). These values are also used in an accompanying spreadsheet tool that can help with stepping through this scoring and associated record keeping.

Risk factors	Levels (corresponding scores in brackets) **	Rationale	Abundance	Distribution	Phenology/ timing	Quality
Ecological risk	Absent Low Medium High	The ecological risk score is carried across from (Table 4-4).				
Management tools available‡	Min number of available instruments =0 Max number of instruments = 45 Few responses available (<0.25) Some responses available (0.25-0.60) Many responses available (0.60-0.80) Very many responses available (>0.80)	The management instruments that were outlined in Table 4-8 (n=45) can be applied in response to the ecological change variables. But not all instruments can be applied in all situations. However, if there are more potential management instruments that can be implemented this will provide more flexibility (or adaptive capacity) and thus pose a lower management risk. The risk score is calculated as the proportion of the total number of possible responses that are actually available (e.g. 40/45 = 0.9 which is "very many"). In Table 4-8, 4 options are provided but this could be more or less depending on any additional responses the user of this handbook enters, or deletes, as appropriate for their system (i.e. there may be options that would never be a viable potential option for that fishery). A higher score indicates a lower risk.				
Time to implementation	Median time* Long term (4) Medium term (3) Short term (2) Immediate (1)	The more time required until the instruments can be implemented to address ecological change the greater the fishery management risk.				
Change process	Median process type* Inter-jurisdictional (4) Regulator (3) Consultative (co-management) group (2) Operational (1)	The change process is related to the previous risk variable, time to implementation. For instance, changing regulatory processes is likely to take longer to implement than change that is implemented using operational instruments. However, the specific aspect that is considered in this risk variable is the 'openness' of the consultation process. There are four levels of change process – operational, consultative (co-management) groups, regulatory or inter-jurisdictional; each of these has a different consultation process. In the case of changes to regulations, these will have to go to public consultation and will risk being delayed or not gain social licence. The more complicated or large scale the process, the more levels of administration involved, the higher the perceived management risk (inter-jurisdictional is most risky as it involves so many steps and potentially quite large numbers of people to achieve any change).				

Management implementation cost	Median cost* Very high (4) High (3) Medium (2) Low (1)	The cost of implementing each of the management instruments is likely to differ (these are the cost to the management agency and not the cost to the fishery which was defined in step 2). Some implementation costs may, for instance, be very high because they require a large investment in staff and resources (or large R&D programs). The higher implementation costs are associated with higher levels of management risk. The actual level of implementation cost in terms of actual expenditure is context dependent. For instance, $50K spent on implementing a management instrument may be low for some governments but high for others (and some agencies may recover the costs of management from industry and others may not).				
Ongoing management cost	Median cost* Very high (4) High (3) Medium (2) Low (1)	Like implementation cost, the higher the relative ongoing cost the greater the management risk (cost to the management agency and not the fishery which was defined in step 2). The ongoing cost for each management instrument is likely to differ – ranging from very high, to high, medium or low – and will likely be context dependent.				
Overall Fisheries management risk	High management risk Medium management risk Low management risk	To assign the overall final fishery management risk score consult these tables. (A) Pathway risk: Pathway and change process vs time to implementation				

Tools available	Process and pathway	Time to implementation			
		Long	**Medium**	**Short**	**Immediate**
Few options	**Inter-jurisdictional**	High	High	High	High
	Regulator	High	High	High	Medium
	Consultative group	High	Medium	Medium	Medium
	Operational	High	Medium	Low	Low
Some options	**Inter-jurisdictional**	High	High	High	Medium
	Regulator	High	Medium	Medium	Medium
	Consultative group	High	Medium	Medium	Low
	Operational	High	Medium	Low	Low
Many options	**Inter-jurisdictional**	High	High	High	Medium
	Regulator	High	Medium	Medium	Low
	Consultative group	High	Medium	Low	Low
	Operational	High	Medium	Low	Low

TABLE 4-9 Management risk assessment (STEP 3): *Continued from page 41*

Risk factors	Levels (corresponding scores in brackets) **	Rationale	Abundance	Distribution	Phenology/ timing	Quality
Overall Fisheries management risk	High management risk Medium management risk Low management risk	(B) Base Management Risk: Cost vs pathway risk (C) Final fishery management risk score: Ecological vs base management risk				

(B) Base Management Risk: Cost vs pathway risk

	Cost (implementation & ongoing, whichever is LARGER)			
Pathway risk	**Very high**	**High**	**Medium**	**Low**
High	High	High	Medium	Medium
Medium	High	High	Medium	Low
Low	Medium	Medium	Low	Low

(C) Final fishery management risk score: Ecological vs base management risk

	Base management risk		
Ecological risk	**High**	**Medium**	**Low**
High	High	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low
Absent	None	None	None

* The medians are taken over all relevant instruments listed in Table 4-8 for that particular ecosystem change. Simple ordinal scores are attached to each time period here as a guide for use in creating a median if multiple instruments need to be considered simultaneously.

** The risk variables for the management instruments are very context dependent and they are therefore indicated as a relative qualitative value.

‡ If a more appropriate indicator for management capacity/effectiveness has already been identified for the fishery of interest, please substitute it in here. Also note that it is possible that if a management system is highly complex that some aspect of that system may block adaptation, or create complications that are time consuming or complex to overcome. If this is the case for the system of interest and no more appropriate indicator for management capacity/effectiveness exists then the best means of handling that situation is still to count the instruments as suggested but to heavily penalise the potential blockage point via its scoring in terms of Time to implementation, Change process, Management implementation cost or Ongoing management cost (as appropriate for that instrument's characteristics). For instance the introduction of quota management is one management instrument and could be seen as limiting flexibility but it is an adaptive and capable instrument to address climate risks in some species. Introducing such a system is time consuming and complex however and score poorly in terms of time to implement.

Image: **David Clode**

5 Post risk assessment

5.1 Final risk rating and recommendations

All of the steps described above come together to create the final list of risk factors and any potential fishery or management adaptation (response) options. The worked example in Appendix A runs through in detail but the process can be achieved through a dedicated one off workshop or preferably incorporated into regular fisheries consultative process such as the resource / management advisory committees. Following the initial focused work to identify and understand climate risk and potential adaptive responses a work plan and annual monitoring / assessment process can be built into each fishery's annual work plan.

At this point you should have a comprehensive list of potential sensitivities of the fishery to physical and ecological change, whether the fishery can easily and rapidly autonomously adapt to these changes or whether it will be a longer process that requires management plans, policies and/or stock assessment methods to be modified.

It should be possible to lay out a timeline of possible responses and to identify key pieces of information that may be needed to inform fishery or management changes (e.g. locations for new zoning boundaries, how the timing of seasonal restrictions may need to shift through time).

If key pieces of information are not available, then any gaps in understanding should be paired with the timeline and the importance of that response to create a prioritised list of research required and any enabling actions that need to be taken before adaptation responses can be implemented.

If resources are available, you may also want to undertake a risk mapping (plotting where the fishery sits in terms of likelihood and consequence of the identified risk factors) or perform a risk Management Strategy Evaluation (MSE) – which explores what risk might look like under alternative management approaches. These approaches are described in Appendix I

The results of all of these steps form the basis of the recommendations on:

a) whether the fishery is sensitive to climate change (what level of risk does it face? what is the risk that management cannot deliver on its objectives?);

b) what useful adaptation options exist?

Recommendations and actions can be for the management authority, the industry and the research sector to consider and potentially take forward. While it may seem obvious that getting a fishery out of a High-risk situation will be the default thing to act on, recommendations need to go further, to help prioritise risks and options overall. Strong recommendations are made based on the scope/nature of existing management structures and the likely influence of climate on abundance, phenology, spatial distributions of key stocks. For example, if spatial management is used, is the stock expected to shift distribution? If a shift would undermine the value of current zoning then the risks and benefits associated with alternative options (shift in zones or alternative management methods) would be discussed.

In this way, it will be possible to highlight:

- Any high risks that cannot be mitigated (they have to be accepted at the level they are as there is no capacity to control or influence them).
- The risks that you can control (and therefore change), this where much of the focus of stakeholder discussion and management action should be.
- Potential alternative management options that are either more robust to climate change or may allow more flexibility to respond to climate shifts without undermining sustainability. Each of these options should be tagged with at least a qualitative ranking of associated costs of implementation so that infeasible options can be rapidly screened.

Such a list would outline where the fishery has strengths and weaknesses, help structure a timeline of responses and who should respond, and highlight areas where the management objectives and obligations are at risk if no action is taken.

5.2 Risk assessment, operationalising recommendations and ongoing adaptive management

Operationalising recommendations

Operationalising the recommendations sits outside the Climate Risk Assessment framework, but will be a necessary step for any fishery actively attempting to implement adaptation options. This step involves taking the options recommended in the final step and making them the focus of a new level of operational discussions – to fold them into the risk-cost-catch trade-off discussion by undertaking activities such as:

- Creating a prioritised list of strategic research questions to address through time to reduce uncertainty or costs associated with any of the options recommended;
- Fully costing how much the more feasible options would take to implement in practice;

- Standardised testing of any new harvest control rules (or defining trigger points at which to bring in new rules); and
- Evaluation of the costs and benefits of staging interventions to the true climate pathways begin to be resolved.

This is not to say all these activities have to happen at once, but suitable preparation can be made or staged plans with trigger points can be made.

Putting risk assessment into an adaptive management context

Beyond the immediate response to the assessment and its recommendations, it is important to place the approach within the adaptive management processes that are used to manage the fishery. Figure 2 and Section 2.1 at the start of this handbook refer to an adaptive management cycle, where management authorities continue to respond to climate driven changes in a (dynamic) adaptive manner. Ongoing monitoring and assessment of indicators of ecological change, changes in stocks and ongoing autonomous adaptation by fisheries would need to inform such an iterative approach, in tandem with periodic updates of the risk assessment process described in this handbook. This would identify if and how the ecological and fishery risks identified are actually playing out over time, whether there were important changes to the assessed levels of risk, and whether there was a need to update management approaches.

The appropriate interval for conducting updated assessments would be context specific. In some cases a 'light weight' version might be incorporated into the annual management cycle, while in other cases it may be that larger reviews are done only periodically (on the order of several years). It is likely that initial and subsequent assessments may occur at a different level (see Figure 4 and Table 3-1) from previous assessments – an initial assessment might be intensive with later updates only rather light to check for unexpected changes, alternatively, the initial assessment might be a rapid scan with later more in-depth assessments kept for high risk fisheries. The combination is up to the reader who will have a much better sense of available resources and need for their fishery. Data sources that might be used for updated assessments include:

- New/updated physical and ecosystem data (observations of change)
- New/updated physical and ecosystem model output (with reduced uncertainty, improved predictions, higher spatial resolution etc)
- Fishery conditions such as:
  - Changes in on-the-water fishing conditions (information from fishers/scientific observers/ PIs on fishery independent surveys etc);
  - Low/high CPUE or changes in other indicators for the fishery (fishery dependent and independent);
  - Changes in productivity;
  - Changes in availability/location of fish e.g. from aerial surveys for presence/absence and relative abundance (school/boil sizes etc);
  - Product condition (meat content as well as quality); and
- New or repeated expert surveys (see Table 4-5)

This updated assessment might then result in changes to overall risk ratings and recommendations that could be used to inform updates within an adaptive management cycle. Parallel to this process it would also be useful for management and ongoing research to consider key thresholds/tipping points both in terms of ecology and the responses of fisheries to change (i.e. when impacts pass particular thresholds that might be cause for concern). There is an ongoing need for research and development into: (i) where and when such tipping points might occur, (ii) what the key indicators would be, (iii) how monitoring can help identify the proximity of tipping points, and (iv) if and how such tipping points can be avoided (such that a level of resilience to change can be maintained).

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Image: **William White**

Appendix A

Worked example – a hypothetical fishery

A group of fishers, managers and interested stakeholders have come together to undertake a climate adaptation risk assessment for their fishery. They have decided that they want to undertake an assessment because there have been some reports of a change in the distribution of their target species – the Lesser Spotted Snapper. There is also agreement that the time of year when the fish are spawning (and not available to be caught) seems to be later in the year. This fishery used to fish a migration (which coincided with peak value) but now the migration is later in the year, so fishers are unable to find the fish at the right time of year. The fish they are finding are in excellent condition, with even higher quality flesh than in the past, but it is too late in the year and they are getting lower prices for their catch. Therefore, the late migration is influencing the fishery by interfering with catching fish during the peak market season (when they usually get the higher prices).

Pre assessment

In the pre-assessment phase, the group determine that the objective for the risk assessment is to reduce the economic impact of the observed changes to the fishers and to identify what sorts of management and/or industry options they have available in the short and longer term to address the observed changes and improve economic returns. The group noted that industry operators are feeling the economic impact already.

They also decided that while the assessment will focus on their main target species, they will also assess the ecological risk to the byproduct, discarded and TEP species that interact with the fishery. As interactions with these other species are very occasional (and appear to be becoming rarer as conditions change) the intent is to assess these species with respect to ecological risk, unless they are found to be at medium/high risk (i.e. they will not be assessed further if found to be at low risk).

The fishery is relatively well studied with a reasonably complete and accurate catch monitoring dataset. The fishery operates along a 250 km strip of coastline. The commercial fishery has around 25 vessels, all of whom use midwater trawl. This is a relatively clean fishery, with little bycatch. Historically, about a fifth of shots were on mixed schools, where the targeted Lesser Spotted Snapper is found with the Greater Mackerel and Banded Eggfish – both of which are valuable byproduct species. This has changed through time as the migration of the target species no longer appears to coincide with that of the other species (which are now seen in high abundances earlier in the year). Very rarely the trawl shots are contaminated with an unmarketable crustacean species, which is discarded. Rarer still are encounters with a small shark species which appears to be preying on the crustaceans in particular.

There are also large recreational and traditional fishery interests. All components of the fishery currently have seasonal closures to protect spawning and there is a commercial quota system in place for commercial take of the main target and byproduct species. The commercial, recreational and traditional interests are all represented in a co-management committee that meets each year to discuss the Total Allowable Catch for the commercial sector and bag limits for recreational catches. The fishery is not overfished and is in reasonable ecological shape. In fact, as noted, the quality of the fish has improved – with the flesh being much firmer than 10 years ago which would have a positive effect on the price, if only the fish could be landed at the market peak period, initial attempts to create a frozen product have not worked well as the flesh does not freeze well.

The team undertaking the assessment have received some funding but not enough to collect additional ecological information and they will largely rely on the data that is currently available. There is, however, some funding to hold a workshop. They also have available to them a part-time researcher who will be responsible for carrying out, collating, and interpreting the assessment. They are using the handbook to help them. Considering the scope of the assessment, the team agreed that they are undertaking a level 2 assessment (i.e. the scale of the assessment will focus on assessing ecological, fishery and management risks using available information).

Step 1. Establishing ecological and biological changes and risk

The team gathers available information and projections on any physical environmental changes or projected changes to the ecosystem (e.g. the abundance of key species or habitats) to assess the level of ecological risk to the target species.

Ocean change: The ocean temperature has been increasing along the 250 km stretch of coastline where this fishery mostly takes place. Water temperatures have generally warmed and in spots changes in the local current system have meant that while there are stronger eddies, they are further offshore, taking the cooler upwelling waters away from the in-shore areas and leaving them much warmer. Along the coastal zone the rainfall patterns have also changed. While the overall yearly amount has not changed much, rainfall is less evenly spread over the year, instead falling in fewer, severe rainfall events.

Indirect change: The human population in the coastal area has grown significantly over the past 10 years – with many older people moving to this area (which has also driven the increase in recreational fishing activity). These 'sea changers' have built houses right along the foreshore creating many issues with changes to coastal habitat including erosion, physical barriers and increased nutrients (eutrophication) in inshore waters.

Ecological vulnerability: The target species have a high capacity for larval dispersal (low sensitivity) and their physiological tolerance is high (low sensitivity) (Table 4-4). This could explain the remaining high abundance of the species but also its redistribution. The fact that they have a strong apparent connection to an environmental variable (e.g. to a specific spring weather pattern) as a life cycle cue for migration might explain their changes in phenology (timing of a life history event like migration or spawning). It also appears that the target species, which is a species known for its high metabolic capacity (low sensitivity) and its capacity to put on condition rapidly when in good prey environments (high capacity for energy storage), is benefiting from the later migration coinciding with plankton blooms and forage fish balls occurring in conjunction with the stronger eddies.

In looking at the characteristics of the byproduct species, both are highly fecund generalists with wide tolerances and capacity for dispersal and neither relies on environmental cues (meaning they have low sensitivity). Indeed, the observed abundance of the Greater Mackerel is trending upwards, while an extant model of the Banded Eggfish indicates it is likely to be unaffected by the climate related shifts. Similarly, the discarded crustacean is found to have low sensitivity in general (though the group commits to a "watching brief" for this species should it prove to be affected by acidification in future). The shark species is also assessed as low risk in the short to medium term as it is abundant, widespread with no environmental dependencies. However, as its reproductive capacity is low (due to classic shark reproductive strategies) it too is put on a "watching brief" long term (i.e. if any signals from the catch or other data indicates its conditions have changed it will be re-assessed).

This means that the "low risk" criteria has been met for the byproduct, TEP and discard species and the rest of the assessment will be based on the target species alone.

Ecologists specialising in the waters to the south of the current fishery note that should the fishery move that far it would almost certainly encounter new TEP species. As there are no plans at present to allow for such a large shift in grounds these new species are not included in this assessment. Should the fishery move this would again trigger a new assessment so that risks associated with these new species could be considered.

Ecological risk: The fishery is exposed to three direct changes: the effects of the increasing ocean temperature, changes in the local currents in the form of stronger eddies, and changing upwelling system. It is also exposed to several indirect factors due to habitat changes with potentially cumulative effects which have not been defined. These direct and indirect changes are potentially having a negative impact on the distribution and phenology of the target species. Although, it does seem to be having a positive effect on the quality of the fish.

To assess the overall ecological risk the team considers a range of risk factors. For further explanation of the factors and ratings used in Table A-1, please see Table 4-4 of the main text. To find the Ecological risk score the assessment team use the ratings for predicted change, intensity of change and speed of change and read the resulting ecological risk off Table A on the summary sheet that comes with the handbook (reproduced in the last row of Table 4-4).

The information and projections they have gathered indicate that the effects are negative (orange) for distribution of fish and for phenology (timing for migration) changes and positive (blue) for quality of fish. There is currently no expected effect on the overall abundance of the species so they leave this blank. The intensity of the change (the second row in the table) is expected to be small for the distribution change (blue), but the timing of the spawning is likely to be considerably affected – i.e. a large change (orange). Even though the impacts are already beginning to be evident in the information the team has gathered, the speed by which the change is expected to be more clearly evident (row 3) is different for the two variables.

The team is then able to work out the overall ecological risk (row 4), which is low for distribution change and high for changes in the phenology (timing of migration). They find there is no risk from abundance change (as this is not expected to occur) and there is also no risk posed by the quality changes because these have been positive (i.e. better-quality flesh). There is also no significant risk posed by the quality changes because these have been positive (i.e. better-quality flesh), though to be precautionary this risk is recorded as low risk (as change is happening and may lead to unexpected outcomes into the future).

TABLE A-1 Example assessment of the ecological risk variables to evaluate overall ecological risk (filled out for the example fishery).

Row	Risk factors	Levels	Abundance	Distribution	Phenology/ timing	Quality
1	**Predicted change**	Positive/good (blue) Negative/bad (orange) Absent (blank)		Negative	Negative	Positive
2	**Intensity of the change**	Very large (orange) Large (orange) Medium (yellow) Small (blue)		Small	Large	
3	**Speed of the change**	In the next 2 years (orange) In the next 2–5 years (orange) In the next 5–10 years (yellow) More than 10 years (blue)		> 10 years	5–10 years	
4	**Ecological risk**	High ecological risk (orange) Medium ecological risk (yellow) Low ecological risk (blue) No risk or N/A (blank)	N/A	Ecological risk is low	Ecological risk is high	Ecological risk is low

Step 2. Working out the fishery risk

Consulting the handbook the assessment team find they have a number of questions to address when finding the fishery risk. The factors to consider (and how ratings of these factors work) are listed in Table 4-7 of the main text.

Finding the fishery risk involves looking at what options the individual fishing operations have for responding to the changes – i.e. the adaptive options that are available to deal with the changing distribution and phenology – and the risks these responses pose to the fishery. In this fishery the number of available adaptive responses to deal with a change in the distribution of fish was considered quite high. The team works with the industry's representative body, the Resource Assessment Group (RAG) and the Management Advisory Committee (MAC) to identify these adaptive options (Table A-2, row 1), many of which would be autonomous adjustments. For example, fishers (of all kinds) could shift their operations and follow the fish, alternatively fishers and could invest in new technology to reduce the time the trip took (though this option may be limited to commercial fishers or more affluent recreational fishers). In contrast, the number of options to deal with the change in the phenology (timing of spawning) were fewer and more constrained, especially for commercial fishers, so there were fewer desirable autonomous actions that could be taken by the fishery. Realistically, commercial fishers could only diversify their market and start supplying markets that were willing to take their product at a different time of the year. Other responses could include changing fishing seasons or locations to accommodate the phenological changes, though this may require working with management bodies to make this possible.

Given the limited resources for extra data collection, the team decides to gain more detail on the likelihood of implementing different adaptive responses by fishers to the expected ecological risks (Table A-2, row 2) by (i) surveying the fishers on what options are feasible and when they would feel pressure to change and (ii) to get a scientific consensus from experts on what the likelihood might be. They also collect information from both stakeholders and the same experts on the potential economic and social impacts that implementing those adaptive responses might have on their fishery (Table A-2, rows 3 and 4).

The fishery risk assessment showed the team that 7 of the 10 adaptive responses listed in Table 4-6 were available in terms of responding to distribution shift (i.e. 7/10 = 0.7 = Many responses available, Table 4-7). The individual likelihood of implementing these available adaptive responses (Table A-2, row 2) was considered to be moderate to easy – all options scored as 3 out of 10 (i.e. 3/10 = 0.3) or less in terms of implementation likelihood (where 0 was easiest and 10 was hardest), producing an average score <0.25 (which = Easy implementation, Table 4-7). Options for changed phenology (timing of migration) were more limited, with only a change in markets seen as a feasible option out of the 5 possible options listed in Table 4-6 (so 1 out of 5 is 1/5 = 0.2 which is < 0.25 = Few responses, Table 4-7).

If selling into different markets was the only adaptive response to changed timing of migration then there would likely be a large negative economic impact for commercial fishers from the reduced beach prices – the scores from the surveys and expert advice consistently showed likelihood of impact = 3 (scored on a scale of 0 = impossible to 3 = certain), severity of consequence = 3 (scored on a scale 0 = none, 3 = catastrophic) so final score is 3x3=9 = Very large impact (Table 4-7). Therefore, the ability to supply to established markets versus finding other markets that would pay equally well for their product is crucial. Similarly, the social impact on employment was also consistently considered large by survey respondents and expert advice alike, as reduced profits and increased technical efficiency would affect vessel numbers – with likelihood of impact = 3, severity of consequence = 3, final score is 3x3=9 = Very large impact. In contrast, the new phenology means that Lesser Spotted Snapper, which is the focus of a major cultural event for the local traditional owner community, is still present at the right time of year for that event (so impact scores are much lower), although it is now only just entering the local ecosystem at that time of year rather than being at peak biomass. If the shift in timing of migration was to move even later in the year then the cultural impact would be much larger, and a new assessment of risk may be needed.

The survey and expert advice regarding economic and social impact of moving and investing was a little more varied (from 2-3 in terms of likelihood and 1-2 in terms of consequence) but consistently ended in a medium impact scores for economic and social impacts as the new movement patterns do not drastically change recreational fishing access overall, simply when it is best to fish the Lesser Spotted Snapper.

This information allowed the team to work out the level of risk arising from the combination of available adaptive responses and degree of expected economic and social impact (the Response risk, Table A-2, row 5). To get the Response risk score they use the ratings for the potential number of responses, likelihood of implementing the response and the larger of the economic and social impacts and read the resulting response risk off Table B on the summary sheet (reproduced in the second to last row of Table 4-7).

Then to get the final fishery risk take the Ecological and Response risks they consulted Table C on the summary sheet (reproduced in the last row of Table 4-7).

In this example the team was able to produce a combined result. Where risks are very different for different sectors (e.g. perhaps it would have medium impact for commercial fishers but high social costs for traditional fishers who could no longer access the fish on historical grounds) then the results for each sector should be handled separately.

TABLE A-2 Example assessment of fishery risk variables (filled out for the example fishery).

Row	Risk factors	Levels	Abundance	Distribution	Phenology/ timing	Quality
From Table A-1	*Ecological risk*	*High ecological risk (orange)* *Med. ecological risk (yellow)* *Low ecological risk (blue)* *No risk or N/A (blank)*	*N/A*	*Ecological risk is low*	*Ecological risk is high*	*Ecological risk is low*
1	**Potential number of adaptation responses (options)**	Few responses available (orange) Some responses available (orange) Many responses available (yellow) Very many responses available (blue)		Many available responses	Few available responses	
2	**Likelihood of implementing the response**	Easy (blue) Moderate (yellow) Hard (orange) Very hard (orange)		Easy implementation likelihood	Moderate implementation likelihood	
3	**Economic impact**	Very large (orange) Large (orange) Medium (yellow) Small (blue)		Medium economic impact	Large economic impact	
4	**Social impact**	Very large (orange) Large (orange) Medium (yellow) Small (blue)		Medium social impact	Large social impact	
5	**Response risk**	High response risk (orange) Medium response risk (yellow) Low response risk (blue)		Fishery response risk is low	Fishery response risk is high	
6	**Fishery risk (combined ecology and response risk score)**	High fishery risk (orange) Medium fishery risk (yellow) Low fishery risk (blue)		Fishery risk is low	Fishery risk is high	*Not assessed at this time*

Step 3. Determining the management risk

From the preceding risks (ecological and fishery risk) the team now need to provide fishery managers with insight into the management risk and required response. The fisheries management risk is comprised of several key attributes. For further explanation of the factors and ratings please see (Table 4-9) of the main text.

For this fishery the first one is the number of available management instruments to deal with the ecological change. The managing authority for this fishery has quite a few management instruments available to deal with the distribution change (see Table A-3, row 1). Changing the fishery area management plan and re-zone fishing areas are the most obvious and likely easiest to do but the management authority thought the majority of the options listed in Table 4-8 were viable options (37 / 45 options = 0.82 = Very many responses available; Table 4-9).

However, to deal with the phenological issue (i.e. late migration), there are fewer available management options – really only communication tools to support increased awareness or behaviour change and educational instruments (2 / 45 = 0.04 < 0.25 = Few responses available; Table 4-9).

It is also not just a matter of what options are on the table in theory, but what can be feasibly done, how long it will take to implement them, and what can be maintained long term. Consequently, when looking at fishery management risk the team also considers: Time to implement management responses (Table A-3, row 2), the change process required (i.e. level of stakeholder engagement) (row 3), the management implementation cost (row 4), and ongoing management costs (row 5). The team assesses these variables by working with fisheries managers, the MAC and the RAG. Luckily in terms of the distributional change the options on the table involve changes that can be overseen operationally or at the level of the consultative (co-management) group – no changes in policy are needed (which can take longer and be more costly). While there will be high implementation costs to get the work done to change the management plans, the re-zoning is relatively straightforward and is at no extra cost going forward. In addition, the same re-zoning works well for the recreational fishery – helping ensure the different stocks can remain at healthy levels, while maintaining some recreational fishing access. The management group also commits to work closely with the traditional owner community to minimize conflict around access for their cultural event, while not putting the stock at long-term risk.

In contrast, the response to the change in phenology might need to rely on the actions of other government departments or private enterprise (making the change process slower, so it is considered medium time to implementation).

The team are then able to determine the Fishery Management risk by combining the number and effectiveness of available management tools with the implementation and ongoing management constraints and costs (Table A-3). This final step in considering risk has many interacting dimensions and so is broken down into a small number of steps, with later steps building on the earlier ones. The team begins calculating the management risk by first calculating the Pathway risk score, using the ratings for potential number of management tools available, the change process and time to implementation and reading the resulting Pathway risk off Table D on the summary sheet (reproduced in the last row of Table 4-4). Then to get the Base Management risk they take the Pathway risk and the larger of the implementation and ongoing costs and reads the results off Table E on the summary sheet (also reproduced in the last row of (Table 4-7). Lastly, to get the final fisheries management risk they take the Ecological and Base Management risks and read the results off Table F on the summary sheet (also reproduced in the last row of (Table 4-9).

TABLE A-3 Example assessment of fishery management risk values to evaluate overall management risk (filled out for the example fishery).

Row	Change	Levels	Abundance	Distribution	Phenology/ timing	Quality
From Table A-1	*Ecological risk*	*High ecological risk (orange)* *Med. ecological risk (yellow)* *Low ecological risk (blue)* *No risk or N/A (blank)*	*N/A*	*Ecological risk is low*	*Ecological risk is high*	*Ecological risk is low*
1	**Management tools available**	Few responses available orange) Some responses available (orange) Many responses available (yellow) Very many responses available (blue)		Very many available tools	Some available tools	
2	**Time to implementation**	Median time Long term (orange) Medium term (orange) Short term (yellow) Immediate (blue)		Short term	Medium term	
3	**Change process**	Inter-jurisdictional (orange) Regulator (orange) Consultative (co-management) group (yellow) Operational (blue)		Consultative (co-management)	Inter-jurisdictional	
4	**Management implementation cost**	Very high (orange) High (orange) Medium (yellow) Low (blue)		High implementation cost	Low implementation cost	
5	**Ongoing management cost**	Very high (orange) High (orange) Medium (yellow) Low (blue)		Low ongoing cost	Low ongoing cost	
6	**Pathway risk**	High pathway risk (orange) Medium pathway risk (yellow) Low pathway risk (blue)		Pathway risk low	Pathway risk is high	*Not assessed at this time*
7	**Base management risk**	High base management risk (orange) Medium base management risk (yellow) Low base management risk (blue)		Base management risk medium	Base management risk is medium	*Not assessed at this time*
8	**Overall fisheries management risk (combined ecology and base management risk score)**	High fishery management risk (orange) Medium fishery management risk (yellow) Low fishery management risk (blue)		Overall management risk is low	Overall management risk is high	*Not assessed at this time*

Final assessment of overall risk

In the final step of the risk assessment the ecological, fishery and fishery management risks are considered together to determine the implications and next steps.

TABLE A-4 Scoring example table for the final risk assessment with the summary scores for ecological fishery and fishery management risks.

Row	Risk	Levels	Abundance	Distribution	Phenology/ timing	Quality
Row 4 ***Table A-1***	**Ecological risk**	High ecological risk (orange) Medium ecological risk (blue) Low ecological risk (green)	*N/A*	*Ecological risk is low*	*Ecological risk is high*	*Ecological risk is low*
Row 6 ***Table A-2***	**Fishery risk**	High fishery risk (orange) Medium fishery risk (yellow) Low fishery risk (blue)		Fishery risk is low	Fishery risk is high	*Not assessed at this time*
Row 7 ***Table A-3***	**Overall Fisheries Management risk**	High fishery management risk (orange) Medium fishery management risk (yellow) Low fishery management risk (blue)		Overall management risk is low	Overall management risk is high	*Not assessed at this time*

The team is now able to report to the management authority, MAC and RAG about the levels of overall risk, and the implications for any management options being considered. The overall risk levels are:

Distribution: Ecological risk is low, management options available can assist a response to that, and additional fishery adaptation options are available and pose a low risk to the commercial, recreational or traditional fisheries. Monitoring (e.g. in collaboration with the industry) and periodic review will be needed to kept track of the magnitude of distribution shifts. If distributions shift more than currently anticipated this could see ecological risks reach higher levels, in which case the management actions should be implemented quickly to ensure the ecological management objectives of the fishery are pursued.

Phenology: Ecological risk is high and there is a high risk the commercial fishery and traditional owner communities may not be able to adapt. There are, however, some management actions that may be able to help mitigate the commercial and recreational fishery risks; the situation for the traditional owner community is more complicated and the management agency will need to work closely with the traditional owner community to find solutions. Management agencies may also need to look outward in finding ways to help the commercial industry adapt (e.g. via the introduction of incentives), they may need to develop approaches in collaboration with other government departments to help minimise the fishery adaptive and management risk. If the management authorities do not take action, there will likely be implications (increased management risks) because of the high ecological, fishery and management risks.

Quality: Ecological risk is low as the change is on a positive trajectory. Fishery and management risks were not assessed at this time, given the positive trajectory. If the direction of change shifts in future, or leads to unexpected outcomes that are detrimental to other parts of the system then a new complete assessment should be triggered.

Providing further recommendations

The recommendations are fairly simple and somewhat artificial because of the hypothetical nature of the example. The recommendations really need to: highlight strengths and weaknesses of the fishery given the current circumstances and how those may change under climate change; help structure a timeline of responses (identifying who should respond); and highlight areas where the management objectives and obligations are at risk if no action is taken.

For example, a set of recommendations might look like:

- Target species – main risk is due to short term spatial distribution shift, with longer term abundance decline, although a shift in timing of spawning may make it difficult to access sufficient catch in sea states that allow for the use of the current primary gear type. Therefore, the management authority may need to review gear regulations and licensing conditions for the fishery currently accessing the stock.
- Increasing overlap of TEP and target species increases the risk of unacceptably high TEPS interactions with current fishing gears. This may require revision of management plans and a review of spatial or gear regulations.
- Changing location of fishing grounds along with the stock shift is an easily implementable response as the fleet will continue to have access to the stock even as it shifts (i.e. it will remain largely in the same jurisdiction), but there will be increased steaming time and associate costs. This change in cost and its effect on net economic returns will need to be monitored and reviewed as part of research on economic and financial indicators.
- Longer term for the fishery, if stocks drop to a point sustainable catches cannot meet market demand, the fleet may need to look to alternative species; it would likely be wise for the industry to look into the development of new markets for new species ahead of time.
- Adaptive co-management arrangements enabled under fisheries legislation put the fishery in a good position to respond to the changes without requiring significant modification of management arrangements.
- R&D priorities the management authority industry representatives and research sector to consider review of implications of spatial management arrangements; inclusion of environmental drivers in stock assessments; investigation of gear modifications that can reduce interactions with TEPS.

Image: **Squirrel photos from Pixabay**

Appendix B

Pre-risk assessment scoping ▼

TABLE B-1 Summary of key fishery information to consider during pre-assessment scoping.

Fishery	Commercial sector[1]	Recreational sector[1]	Traditional sector[1]	Target and byproduct species (number)[2]	TEPS (number of spp)[3]	Bycatch (number of spp)[4]	Discards (number of spp or simply present)[4]	Timeframe for assessment period[5]	Species that are the focus of the analysis[6]
EXAMPLE FISHERY	The commercial sector has 25 active vessels	Around 200 recreational fishers participate in this fishery	✓	3 (1 target and 2 byproduct)	1 (occasionally encountered)	0	1 (unmarketable crustacean)	Short	1 – Lesser Spotted Snapper [Ecological risk to 4 other species that interact with the fishery also assessed]

1 A tick mark indicates this sector exists for that fishery and a dash indicates this sector does not exist. If available, additional information on the size of the different sectors (and for instance the economic value and employment) can be listed.

2 There may be more than one species that is targeted in the fishery. For example, the SESSF has around 30 species that are landed, in contrast the Southern Bluefin tuna fishery only targets one species (i.e. Tuna). In this column the estimated number (and names if available) of the fishery is listed.

3 TEPs species may be relevant in a fishery. For instance, in some fisheries they might come across albatross or some shark species in certain activities. In this column the relevant TEP species are listed.

4 The fishery may have certain species that are considered bycatch (i.e. not the target species but caught as part of the fishing operations). Some species may not be landed and discarded at sea. In this column the number (and name) of the relevant species are listed.

5 Indicate the assessment time frame which is either the immediate future (<5 years), medium term (5-10 years), or longer term (more than 10 years).

6 A list of the species that are the focus of the risk analysis (which can be 1 or more species).

TABLE B-2 Summary of key fishery management information to consider during pre-assessment scoping.

Description of management instrument	EXAMPLE FISHERY	**Your fishery** – *fill in the details (as a starting point we have included the basic details for the AFMA managed fisheries)*
TAC for current species	✓ 500 tonnes in 2019	
Quota trading	✓ lease and buy	
Catch triggers or size limits		
Licences to fish	✓ 40 licences	
Vessel restrictions		
Seasonal or ToD closure		
Closed areas	✓ MPA of 3 sq km	
Levies or subsidies		
Compliance monitoring	✓ by State Govt.	
Independent monitoring		
Co-management	✓ Quart. mtgs	
Discard policy		
TEP rules	✓ applies to fishery	
Shared stock man.		

Appendix C

Management instrument attributes and feasibility ▼

TABLE C-1 Attributes of management instruments needed for the management risk assessment. Note "GMA" under Agency represents "government management agency" which means the relevant agency – AFMA at a Commonwealth level, relevant department at a State government level. Mark "Available or not" as appropriate for your system.

Management function	Management instruments (management response)	Agency	Available or not (1 or 0)	Implementation cost to management	Ongoing cost	Time	Change process (transparency in consultation)
Operational management	Adjust TAC/ITE for quota species	GMA		medium	low	short term	Operational
	Implement TAC/ITE for new species	GMA		very high	medium	short term	Consultative (co-management) group
	Adjust bag/possession limit for species	GMA		medium	low	short term	Consultative (co-management) group
	Adjust trigger limits for byproducts	GMA		medium	low	medium term	Operational
	Adjust (shift) timing of fishing period	GMA		low	low	short term	Operational
	Adjust length of fishing season	GMA		low	low	short term	Operational
	Implement minimum/maximum size limit for species	GMA		medium	low	short term	Operational
	Introduce handling requirements (depressurising, venting fish)	GMA		low	low	short term	Operational
	Introducing catch and release requirements	GMA		low	low	short term	Operational
	Traditional use only species	GMA		low	low	short term	Operational
	Adjust Gear restrictions / limitations	GMA		low	low	medium term	Operational
	Adjust Vessel restrictions / limitations	GMA		low	low	medium term	Operational
	Change fishery area (management plan)	GMA		medium	low	short term	Regulatory / statutory public consultation
	Close areas to fishing	GMA		low	low	Immediate	Operational
	Open areas to fishing	GMA		low	low	Immediate	Operational

Operational management	Re-zone fishing areas	Multi-agency		very high	medium	short term	Regulatory / statutory public consultation
	Recognise customary food gathering area (which can restrict access for other users)	GMA		medium	low	short term	Regulatory / statutory public consultation
	Recreational only zoning	GMA		medium	low	short term	Regulatory / statutory public consultation
	Catch spreading (ensuring not all catch is taken within one spatial area)	GMA		medium	low	short term	Operational
	Move-on rules	GMA		medium	low	short term	Operational
	Coordinate allocation and management controls across jurisdictions/sectors	Multi-agency		high	medium	medium term	Inter-jurisdiction
	Change industry co-management	GMA		low	low	medium term	Consultative (co-management) group
	Adjustment of levies	GMA		high	low	long term	Regulatory / statutory public consultation
	Implementing / scrapping subsidies	Other agencies		high	medium	long term	Regulatory / statutory public consultation
	Buy out licences	DoA/ DoEE		high	low	long term	Regulatory / statutory public consultation
	Limit (encourage) new entrants	GMA		high	low	long term	Consultative (co-management) group
	Revoke (issue new) licences	GMA		high	low	long term	Consultative (co-management) group
	Sectoral (re)allocation	GMA (DoA)		high	medium	short term	Regulatory / statutory public consultation
	Change compliance capability	All fisheries agencies		high	medium	medium term	Regulatory / statutory public consultation
	Cap the number of charter boats (and/or passengers per charter boats)	GMA		high	low	medium term	Regulatory / statutory public consultation

TABLE C-1 Attributes of management instruments needed for the management risk assessment. Note "GMA" under Agency represents "government management agency" which means the relevant agency – AFMA at a Commonwealth level, relevant department at a State government level. Mark "Available or not" as appropriate for your system. ***Continued from page 63***

Management function	Management instruments (management response)	Agency	Available or not (1 or 0)	Implementation cost to management	Ongoing cost	Time	Change process (transparency in consultation)
Performance Management	Introduce recreation or customary fishing licence	GMA		high	low	long term	Regulatory / statutory public consultation
	Traditional management (resting/crop rotation)	GMA		medium	low	medium term	Consultative (co-management) group
	Review compliance risk assessment settings	GMA		medium	low	medium term	Consultative (co-management) group
	Landing restrictions	GMA		medium	medium	medium term	Regulatory / statutory public consultation
	Introduce automatic triggers for key environmental parameters (as a proxy for stock changes)	GMA		low	medium	short term	Operational
	Introduce/adjust automatic triggers for non-target TEPS (e.g. dolphins, seabird Threat Abatement Plan)	Multi-agency		very high	low	short term	Consultative (co-management) group
	Introduce/adjust automatic triggers for general bycatch	GMA		high	low	short term	Consultative (co-management) group
	Change / adjust performance indicators for harvest strategies	GMA		low	low	short term	Operational
	Change in reference points	GMA		low	low	short term	Operational
	Re-assessment of model parameterisation (e.g. recruitment, natural mortality estimates)	GMA		medium	medium	short term	Operational
	Crew-based observation	GMA		high	low	immediate	Consultative (co-management) group
	Adjust level/coverage of monitoring and data collection for management (observers/EM - scientific or other)	GMA		high	medium	short term	Consultative (co-management) group
	Quota administration	GMA		medium	low	immediate	Consultative (co-management) group
	Quota transaction monitoring	GMA		medium	low	short term	Consultative (co-management) group

Communication and information	Communication tools to support increased awareness or behaviour change	GMA		low	medium	immediate	Operational
	Educational instruments	GMA		low	medium	immediate	Operational
	Automated data transmission	GMA		medium	medium	short term	Operational
	Data collection protocols	GMA		medium	low	short term	Consultative (co-management) group
	Real-time data collection and reporting	GMA		high	medium	short term	Consultative (co-management) group
	Explore citizen science and ranger/stewardship/guardian programs for data collection efforts	GMA		medium	medium	short term	Consultative (co-management) group
	Draw on traditional knowledge	GMA		medium	low	short term	Consultative (co-management) group
	Recognise/integrate traditional knowledge and practices into education materials and management approaches	GMA		medium	low	short term	Consultative (co-management) group
	Require recreational fishers to record catches	GMA		medium	medium	short term	Consultative (co-management) group
Strategy and policy	Implement/adjust bycatch policy	GMA (DoA)		high	low	long term	Regulatory / statutory public consultation
	Develop and implement habitat and community policy	GMA (DoA)		high	medium	long term	Regulatory / statutory public consultation
	Change TEPS rules	DoEE		high	medium	long term	Regulatory / statutory public consultation
	Negotiate jurisdiction of shared stock	Multi-agency		very high	high	long term	Regulatory / statutory public consultation
	Change to harvest strategy policy settings	GMA, DoA		medium	low	medium term	Regulatory / statutory public consultation
	Review/changes to fishing access rights	GMA, DoA		medium	medium	medium term	Regulatory / statutory public consultation

TABLE C-1 Attributes of management instruments needed for the management risk assessment. Note "GMA" under Agency represents "government management agency" which means the relevant agency – AFMA at a Commonwealth level, relevant department at a State government level. Mark "Available or not" as appropriate for your system. ***Continued from page 65***

Management function	Management instruments (management response)	Agency	Available or not (1 or 0)	Implementation cost to management	Ongoing cost	Time	Change process (transparency in consultation)
Cross cutting	Develop, implement, review and adjust resource sharing framework	Multi-agency		high	high	long term	Regulatory / statutory public consultation
	Change consultative framework	GMA, DoA		high	medium	short term	Regulatory / statutory public consultation
	Change the make-up of consultative groups	GMA		low	low	medium term	Operational
	Other . . .						

Image: Torsten Dederichs

Appendix D

AFMA objectives and public policy goals ▼

TABLE D-1 AFMA Acts, objectives, and three goals*.

Relevant Act	AFMA Objective	Ecological sustainability	Economic returns	Effective management
Fisheries Management Act 1991	1. Implementing efficient and cost-effective fisheries management on behalf of the Commonwealth.			✓
	2. Ensuring that the exploitation of fisheries resources and the carrying on of any related activities are conducted in a manner consistent with the principles of ecologically sustainable development (which include the exercise of the precautionary principle), in particular the need to have regard to the impact of fishing activities on non-target species and the long-term sustainability of the marine environment.	✓		
	3. Maximising net economic returns to the Australian community from the management of Australian fisheries.		✓	
	4. Ensuring accountability to the fishing industry and to the Australian community in AFMA's management of fisheries resources.			✓
	5. Achieving government targets in relation to the recovery of AFMA's costs.			✓
	6. Ensuring, through proper conservation and management measures, that the living resources of the Australian Fishing Zone (AFZ) are not endangered by over-exploitation.	✓		✓
	7. Achieving the optimum utilisation of the living resources of the AFZ.		✓	✓
	8. Ensuring that conservation and management measures in the AFZ and the high seas implement Australia's obligations under international agreements that deal with fish stocks.			✓
	9. To the extent that Australia has obligations: i) under international law; or ii) under the Compliance Agreement or any other international agreement; in relation to fishing activities by Australian-flagged boats on the high seas that are additional to the obligations referred to in paragraph (c) – ensuring that Australia implements those first mentioned obligations.			✓
	1. To have regard to the interests of commercial, recreational and traditional fishers		✓	
Environment Protection and Biodiversity Conservation Act 1999	The EPBC Act (1999) requires ecological sustainability in Australia's fisheries by providing for independent assessment of the environmental performance of fisheries management arrangements, through: 1. Strategic assessments of Commonwealth managed fisheries (Part 1) prior to new management arrangements being brought into effect. 2. Environmental assessment for international trade in wildlife (Part 13A). 3. Environmental assessment of fisheries operating in Commonwealth waters for impacts on protected species (Part 13). The EPBC Act 1999 requires that AFMA ensures its fisheries take all reasonable steps to ensure that EPBC listed species (other than conservation dependent species) are not killed or injured as a result of fishing.	✓		

Relevant Act	AFMA Objective	Ecological sustainability	Economic returns	Effective management
Torres Strait Fisheries Act 1984	1. to acknowledge and protect the traditional way of life and livelihood of traditional inhabitants, including their rights in relation to traditional fishing;	✓		✓
	2. to protect and preserve the marine environment and indigenous fauna and flora in and in the vicinity of the Protected Zone;	✓		
	3. to adopt conservation measures necessary for the conservation of a species in such a way as to minimise any restrictive effects of the measures on traditional fishing;	✓		
	4. to administer the provisions of Part 5 of the Torres Strait Treaty (relating to commercial fisheries) so as not to prejudice the achievement of the purposes of Part 4 of the Torres Strait Treaty in regard to traditional fishing;	✓		
	5. to manage commercial fisheries for optimum utilisation;		✓	
	6. to share the allowable catch of relevant Protected Zone commercial fisheries with Papua New Guinea in accordance with the Torres Strait Treaty;		✓	
	7. to have regard, in developing and implementing licensing policy, to the desirability of promoting economic development in the Torres Strait area and employment opportunities for traditional inhabitants.		✓	
Fisheries Administration Act 1991	1. Ensuring that the exploitation in the Australian fishing zone (as defined in the Fisheries Management Act 1991) and the high seas of fish stocks in relation to which Australia has obligations under international agreements and related activities are carried on consistently with those obligations.			✓

* Ensure the ecological sustainability of Commonwealth fisheries for the benefit of present and future generations of Australians (ecological sustainability); improve the net economic returns of Commonwealth fisheries to the Australian community (economic returns); and deliver effective, cost efficient and transparent management and regulator arrangements (efficient management).

Social objectives

Theme 1: AFMA manages Commonwealth fisheries resources for the benefit of all Australians both now and into the future

Theme 2: AFMA takes into account the interests of commercial, recreational and traditional fishers and other relevant stakeholders in our evidence-based decision-making. We work in partnership with our stakeholders and encourage them to share responsibility for fisheries management where appropriate.

Theme 3: AFMA respects the values, culture and diversity of stakeholders.

Theme 4: AFMA pursues transparency and accountability to the Australian community in managing fisheries.

Appendix E

Fishery adaptation surveys

As mentioned in Section 4.2, the information necessary to establish a comprehensive insight into the fishery risk is best obtained directly from the of stakeholders and/or experts. A structured approach to collecting this information is provided here by means a survey. We provide three different example surveys.

Surveys A and B are essentially the same, but Survey A is the most basic adaptation survey (Appendix F). Survey B (Appendix G) gathers more detail than survey A but will take more time to fill out. If the most detailed survey is implemented (i.e. survey B) then A is not necessary. Surveys A and B gather information on the possible and likelihood of adaptive responses. Survey B also provides a basic indication of the likelihood of economic and social impacts. The third survey (Survey C in Appendix H) is intended to be implemented *in addition* to survey A or B and will obtain the most detailed information on the economic and social impacts of change in the ecological variables (including the likelihood and consequence of the impact).

*When **survey A is implemented*** detail is gathered from fishery operators or fishery experts only on the number of adaptive responses. *When **survey B is implemented*** more detail is gathered on the direction of each adaptive response. For example, the respondent might indicate that they will increase or decrease the amount of effort if abundance changes, which is important information for fisheries management. In addition, data on the likelihood of implementing the adaptive response is gathered. Survey B also gathers some high-level information for the economic and social impact. Qualitative information on the type of expected impact is also collected because this is considered useful information for fisheries management (i.e. the expectation for change from key stakeholders). It also provides some opportunity for respondents to convey their beliefs before providing information required for the risk assessment. This qualitative information is not directly incorporated in the risk score. *In the case where **survey C is implemented (in addition to either survey A or B)*** it will gather detailed information for the economic and social impact of climate driven ecological change.

The surveys do not gather detail on whether the responses are autonomous or desired because these can be deduced from the current management context for the fishery (gathered in the pre-risk assessment stage). For example, if a survey respondent indicates that they will want to move with (follow) the fish if a redistribution occurs, but for this fishery there is a spatial limit, this would be a desired response (i.e. it cannot occur autonomously because the current regulations do not permit it).

TABLE E-1 Data to inform fishery risk assessment (Table 4-7) provided by each survey.

Survey	Predicted change (yes/no)	Potential adaptation responses	Likely implementation of adaptation	Economic impact	Social impact
No	Obtained from ecological risk assessment – Table 4-4	Default adaptive responses – Table 4-6			
A	Obtained from ecological risk assessment – Table 4-4	Data on adaptive responses	Not collected	Not collected	Not collected
B	Obtained from ecological risk assessment – Table 4-4 Additional quantitative information on respondents' beliefs about direction of ecological response	Data on direction of the response	Data on likelihood of implementing the response	High level data on whether impact is expected	High level data on whether impact is expected
C	Obtained from ecological risk assessment – Table 4-4	[collected in either survey A or B]	[collected in either survey A or B]	Data on type of impact (positive/negative), likelihood and consequence (degree) of impact	Data on type of impact (positive/negative), likelihood and consequence (degree) of impact

Appendix F

Level A – **Simple adaptation survey**

Some adaptations are more likely to be undertaken than others. Please indicate how likely it is that you will adapt in the way as indicated in the rows in Table 1 for each ecological impact (abundance, distribution, timing, quality, and variability). The choice of options are:

I will not do this	(score 0)
Unlikely	(score 0.2)
Somewhat likely	(score 0.4)
Likely	(score 0.6)
Very likely	(score 0.8)
Certain	(score 1)
I don't know or not relevant	

TABLE F-1 Likelihood of implementing different adaptive responses to ecological impacts of climate change.

Explanation of response	**Abundance** (a change in the number of fish)	**Distribution** (a change in where the fish can be found)	**Timing** (a change in when fish move or spawn, which might change whether they are around or of the right size when the fishing season is open)	**Quality** (a change in the quality of the product, the flesh texture, taste, size etc.)	**Variability** (a change in how variable the abundance or accessible the fish are year to year*)	**Comments**
Change the amount of fishing effort						
Move to another fishing location						
Switch to a different target species						
Stop fishing for the target species altogether						
Invest in new technology or assets						
Change the amount of quota trade (this could be effort or catch, whichever is appropriate)						
Change the sale price of fish						
Change supply chain management						
Improve fish handling methods						
Diversify markets						
Value add to the product						
Seek information about adaptation options						
Communication with concerned stakeholder						

* It may be that you see more extreme highs and lows; or more cases where you get a few very good years or very bad years in a row; what used to be a rare event becomes more common.

Appendix G

Level B – **Comprehensive adaptation survey** ▼

QUESTIONS ABOUT ABUNDANCE CHANGE

(*these questions are repeated for distribution, phenology and quality changes*)

There are many reasons why fish abundance may change into the future and we would like to explore what would happen if that was to occur (over a 30-year time frame – until 2050).

Introductory questions

Do you think that in your fishery there is most likely to be an increase or decrease in the abundance of the main target species?	Increase / decrease
What would be the potential economic impact (i.e. operating cost) from a decrease in the abundance of the main target species?	
Can you identify the main economic impacts (e.g. variable cost, profit, quota price etc.)?	
What would be the potential broader socio-economic impacts (i.e. employment) of a decrease in abundance of the main target species?	
Can you identify the main broad socio-economic impacts (e.g. community acceptance, employment, safety at sea, etc.)?	

Considering the potential impacts – how likely is it that you would change the following aspects of your fishing activity as a consequence of steady **decline** in abundance[6] of the target species (by 2050):

I will not do this	(score 0)
Unlikely	(score 0.2)
Somewhat likely	(score 0.4)
Likely	(score 0.6)
Very likely	(score 0.8)
Certain	(score 1)
I don't know or not relevant	

TABLE G-1 Likelihood of implementing different adaptive responses to abundance change.

Behavioural change	Likelihood that you would do this in response to a decline in abundance	What is the direction of your response (decrease / increase)
Change the amount of fishing effort		
Move to another fishing location		
Switch to a different target species		
Stop fishing for the target species altogether		
Invest in new technology or assets		
Change the amount of quota trade (this could be effort or catch, whichever is appropriate)		
Change the sale price of fish		
Change supply chain management		
Improve fish handling methods		
Diversify markets		
Value add to the product		
Seek information about adaptation options		
Communication with concerned stakeholder		

6 Repeat for distribution, phenology, and quality change if applicable.

Appendix H

Level C – **Impact survey**

The impact survey is implemented to gather detailed information on the economic and social impact of climate driven ecological change. The impact survey should be combined with an adaptation response survey (simple or extended).

The first set of questions are around the impact of **lower abundance**[7] on a range of economic / social factors and the likelihood and consequence of the impact. The economic / social aspects are listed in the rows of the tables. The choice of options for the answers in the columns are:

The direction of the (economic / social) impact	The **likelihood** of the adaptive response	The **consequences** of the adaptive response
☐ Decrease	I will not do this (score 0)	Catastrophic consequence;
☐ Increase	Unlikely (score 0.2)	High consequence;
	Somewhat likely (score 0.4)	Low consequence;
	Likely (score 0.6)	No consequence
	Very likely (score 0.8)	I don't know or not relevant
	Certain (score 1)	
	I don't know or not relevant	

7 Repeat the question for change in distribution, phenology or quality where applicable.

TABLE H-1 Impact, likelihood, and consequence of a decrease in abundance on 13 different economic aspects.

Economic aspects	What is the impact of reduced abundance on the economic aspect?	What is the likelihood of reduced abundance impacting this economic aspect	What is the consequence of reduced abundance impacting this economic aspect
Profitability			
Fixed costs			
Fuel costs			
Other variable costs			
Bait supply			
Availability of credit			
Corporate restructuring			
Market access			
Availability of market information			
Quota price			
Quota trade volume			
Import substitution			
Demand for fish			

TABLE H-2 Impact, likelihood, and consequence of a decrease in abundance on 9 different social aspects.

Social aspects	The impact of reduced abundance on the social aspect (decrease / increase)?	a) What is the likelihood of reduced abundance impacting this social aspect	b) What is the consequence of reduced abundance impacting this social aspect
Number of jobs			
Crew retention			
Attachment to profession			
Skill level requirements			
Social acceptability			
Safety at sea			
Fishing season length			
Conflict between stakeholders			
Consumer access to product information			

Appendix I

Risk rating ▼

As noted at the start of the handbook, this handbook is in fact a combination of a vulnerability, risk, and hazard assessment.

The ecological component simply identifies whether the ecology is vulnerable to change given climate related shifts. If additional information is available on predicted direction and magnitude of ecological change that can be used instead, but we did not make having such information central to the assessment as it may not be available for many species.

The "management risk" discussed in the handbook is actually a hazard assessment, as it identifies things (hazards) that may pose a risk to the management of the fishery. If information on the chance and consequence of those hazards actually occurring is available then that can be used instead. Again we did not demand information on the actual chance (high or low) that any hazard will cause harm as that information is not available in many circumstances.

In the handbook main text only the fishery risk is real risk assessment in terms of the technical jargon definition of a risk assessments – it is a qualitative, relative risk assessment to the fishery, but it is a risk assessment as it uses survey information to elucidate the likelihood and consequence of the different kinds of change.

It is possible to take the ecological vulnerability assessment and management hazard assessment and also make them true risk assessments by providing likelihood and consequence scores for each of the factors included in those assessments. To do this take the factors identified as being relevant in those steps of the handbook and then rated the likelihood and consequence for each factor using either expert knowledge or quantitative models (e.g. process models or statistical metrics should sufficient data, such as monitoring and econometric information, exist). Given the number of species and fisheries to be considered vs available models and data it is very likely that such an assessment would need to rely on expert knowledge. Regardless of what method is used a true risk assessment of this form has a few specific steps.

First the **likelihood of occurrence** of each factor must be rated. For example, if one of the risk factors identified is a change in the distribution of target species (perhaps further from port or into new areas that aren't as accessible) then how likely is a fishery to be affected by that change in distribution? Is change happening in the local area of the fishery or is the fishery far removed from any changes? The species may be moving at the extremes of its range but if those sit far beyond the boundary of the fishery then it is not of immediate concern.

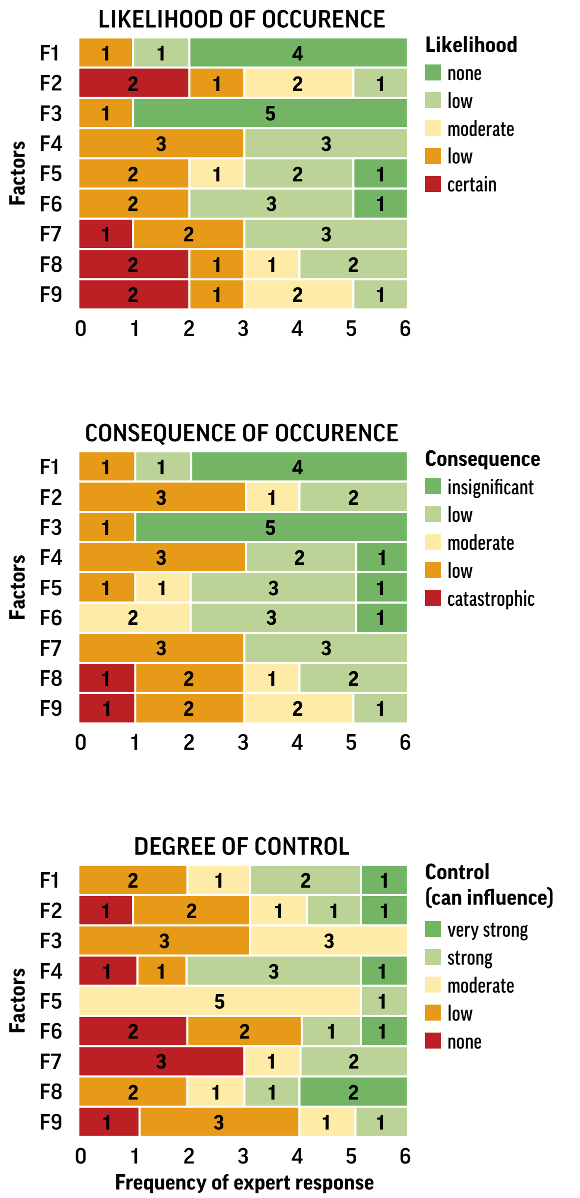
Second the **consequence for the fishery of a change in the factor** must be rated. For example, is the factor a critical aspect of the fishery (e.g. a target stock), or is the fishery relatively unaffected by this factor (e.g. increasing recreational fishing pressure is not a concern for orange roughy)?

Lastly the **degree of control over a factor** is rated. This indicates a **fishery's capacity to respond in a useful manner** – termed **adaptive capacity**. How easy it is to influence the factor (directly or indirectly)? Alternatively, it is useful to consider how easy it is for the fishery to change other aspects to adapt to changes of something they cannot directly control. These ratings of control can also be done by indicating who has the control, for example, whether it is industry (including processors, supply chain components and markets) or management. In terms of this handbook, if a Level 1 ("Ecological Assessment") is chosen then this last step is done in a fairly general sense using expert information alone – essentially "a back of the envelope estimate to help prioritisation and help confirm whether going any further makes sense. In this case experts are asked to rate what they think the likelihood, consequence and degree of control is for each factor. In addition, the academic experts and stakeholders rating adaptive capacity should indicate who has the control – whether it is industry (including processors, supply chain components and markets) or management.

If a Level 2 assessment is chosen (as detailed in the handbook) then this step is explicitly broken down into fishery and management risk steps. If a level 3 assessment is chosen (using fully quantitative analyses) then this adaptive capacity would again be explicitly considered, typically in the form of alternative management and fleet scenarios and strategies.

Obviously this rating will potentially have a lot of associated uncertainty. While such uncertainty can be clearly quantified when using models, it should also be made clear when using expert information. This can be done by tracking the range of ratings across different experts – as shown in Figure A-1.

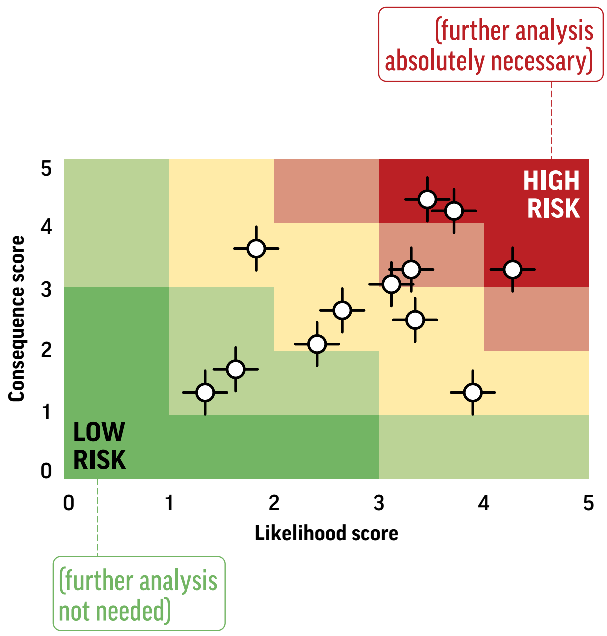
FIGURE A-1 Example rankings. These rankings can be presented as a unified ranking per factor per fishery or the rankings of individual experts can be presented for each factor (as is the case in this example – where 6 experts rated each factor and for the top factor RPP 1 expert rated the likelihood as High, one as Low and 4 as None; and for consequence 1 expert rated the consequence as High, 1 as Low and 4 as Insignificant, while for influence 2 rated the capacity to influence it as Low, 1 as Moderate, 2 as Strong and 1 as Very Strong).



Risk mapping

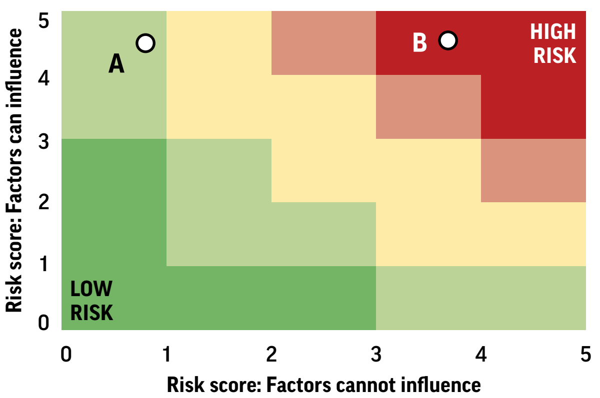
To help understand where a fishery sits in risk space, once the ratings have been determined two plots can be created. The first plots (e.g.) **likelihood of occurrence against consequence and then marks on the current position of the fishery** (or even individual operators if so desired).

FIGURE A-2 Example of what the biplot of consequence vs occurrence scores may look like. Those fisheries in the lower left are at low risk, while those in the upper right are at risk and should be considered priorities for action. Error bars can show uncertainty across the factors defining the risks, but also the span of opinion between those people rating the risks.



The second plot (e.g. Figure A-3) takes adaptive capacity (the capacity of the fishery operators and management actions to adapt to the situation, make changes and reduce risk) by mapping the level of risk associated with factors that can be influenced (controlled), such as risks associated with management regulations, along one axis and those factors that cannot be influenced (e.g. the level of rainfall) along a separate axis. The position of the fishery on the axis that is for risks that can be influenced shows how much scope there is to bring the risk down overall – i.e. it is a measure of adaptive capacity.

FIGURE A-3 Example of a biplot of risk factors that can and cannot be controlled (influenced). Fishery A in this example has little exposure across all the risks it cannot influence (e.g. due to sea level rise), but looking at factors it can influence (such as regulatory controls) it does have a high level of exposure (sits high on that axis). Fishery B in contrast, is high risk across both those factors it can influence and those it cannot influence – this fishery is in a much more negative position.



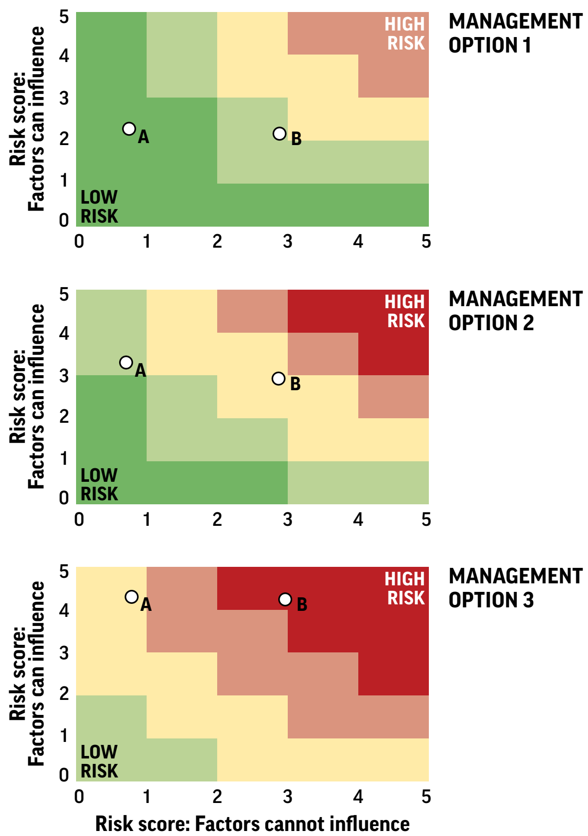
Risk MSE

Once the current situation is understood then there needs to be an evaluation of other management options, or fishery responses (different fishing operations), and how robust these responses are to the same sources of environmental change.

To do this management strategy evaluation (MSE), alternative management options may be suggested based on the conceptual models or impact pathways or they may be suggested by people with an interest in the fishery. The risk scores are recalculated for each of these management options based on how the system would function under those alternative rules (how fishing would function, species targeting flexibility, sizes and areas fished, access to markets etc). Would there be more or fewer risks (i.e. are scores higher or lower as a result)? The plots are then redrawn with these new risk scores (e.g. Figure A-4) – the colour map of exposure to risks that can and cannot be controlled is shifted as the risks have shifted (certain sets of regulations may make you more or less exposed to climate impacts and more or less able to adapt). This is why it is important for stakeholders to advise on what they feel is (or is not) an acceptable level of risk and for managers to be clear on how they ultimately define acceptable risk. If these levels differ between different stakeholders or for different types of fisheries (traditional, commercial or recreational) then the maps can also be recoloured accordingly and compared to understand why there may be different options and priorities across different groups. Reconciling these differences will require the same kind of participatory discussions that sit at the heart of the Commonwealth management processes.

Be redrawing the plots in this way it is also possible to see whether the position with regards to risk is improved or degraded by the new management rules. This serves as a check to see if those changed rules and operations improve the outcome (i.e. would they provide for positive adaptation).

FIGURE A-4 Example of an MSE for the biplot of risk factors that can and cannot be influenced. The three cases represent three different ways the management regulations could be modified – the first introduces flexibility to adapt (e.g. via allowing cross jurisdictional coordination and movement of vessels targeting a species that is shifting distribution); the second allows for some flexibility but not as much as the first option (e.g. via allowing new gears or vessels sizes to try and stabilise catch variability without risking stock status); and the last actually makes the situation more risky (e.g. by introducing rules that may be intended to help but ultimately restrict flexibility without changing the status of the stock).



Providing recommendations

The risk assessment process represents a logical journey (or detective exercise) – stepping through creation of the pathways from physical climate change to ecological and fleet responses to potential behavioural or management changes. Along the way this involves identifying the direct and indirect exposure, estimating the consequences and (where useful) creating biplots of current conditions and future conditions or in some other way (e.g. via relative ranks) listing off the hazards and the level of risk they pose to the fishery, creating the overall risk rating for the fishery.

These lists of risks and the overall risk position are the results of the risk assessment. This then forms the basis of the risk management response. This is in the hands of the decision makers – from operational level (fleet managers) to the regulator, each will have risks they can respond to. Risk management rests on recommendations from the risk assessment – providing a prioritization of risks, categorization of recommended safeguards and mitigation measures, including their feasibility of implementation. From there the decision makers step through the decision making process, comparing options, to select the appropriate response to a potential hazard.

In the context of this handbook recommendations given on the back of the assessment should (a) indicate whether the fishery is sensitive to (at risk from) climate change; and (b) recommend potentially useful adaptation options (rated in terms of feasibility, cost of implementation and support and any other benefits or drawbacks). With very firm recommendations being made based on the scope/nature of existing management structures and the likely influence of climate on abundance, phenology, spatial distributions, physiological condition (quality) and variability of key stocks.

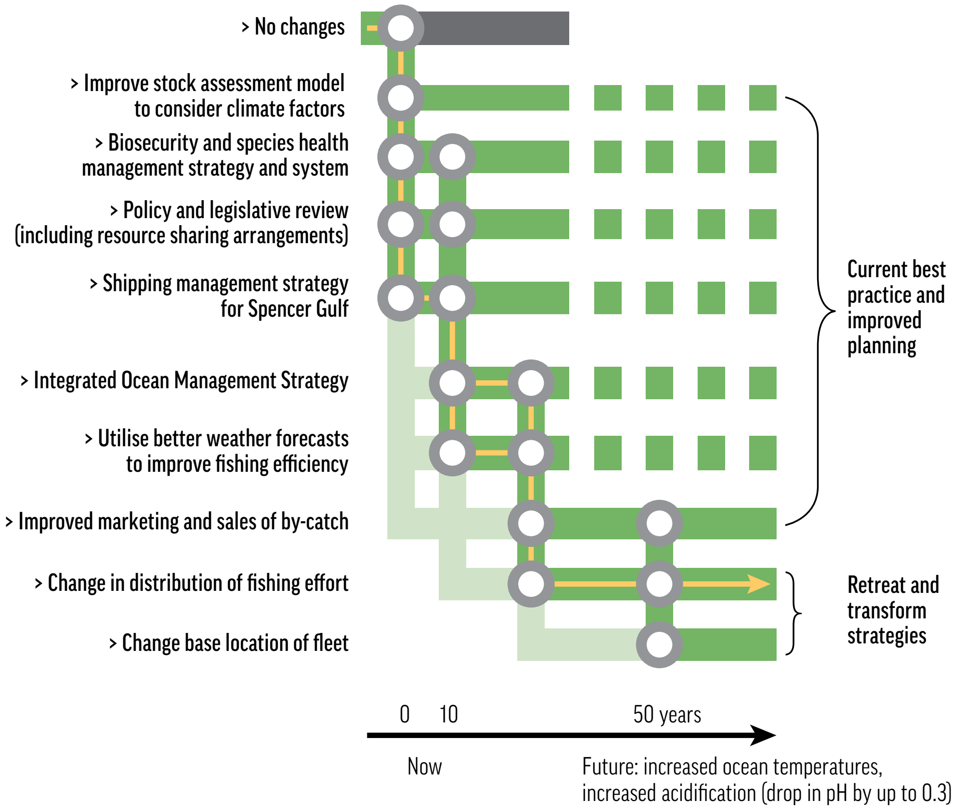
For example, if changes in spatial management are proposed to adapt to a shift in distribution would it undermine the value of current zoning? If so, the costs and benefits associated with alternative options (shift in zones or alternative management methods) would need to be discussed. In this way, it will be possible to highlight potential alternative management options that are either more robust to climate change, or may allow more flexibility to respond to climate effects without undermining sustainability.

The list of risks and possible responses can also be used as a basis for strategic planning. These options can also be laid out in such a way as to show the most beneficial sequence of actions – either options to use as the level of change increases, or a series of actions where one action is needed before a later one can occur (or where an earlier decision may block a later option). See Figure A-5 for an example.

The recommendations can also highlight priority research areas. These may include key uncertainties that need to be resolved before true climate sensitivity (risk) is understood or it may be research that needs to be undertaken before a new approach to management is used. For example, if catch from a fishery is to become more variable in future and frame based management is proposed then there would need to be an evaluation of the appropriate decision rules to use in good versus poor years, what would be the threshold used to define the different conditions (i.e. when to switch between rules for good year from bad years and vice versa). It may also be important to look at what costs and benefits are involved in introducing management options sooner or later.

Image: **Free-photos from Pixabay**

FIGURE A-5 Example map of adaptation pathways showing how different pathways may emerge or terminate at different times (from Siebentritt et al., 2014 which discusses Regional Climate Change Adaptation Plans for the Eyre Peninsula).



How to interpret the pathways map

Each map identifies adaptation options on the y-axis relevant to a key decision. A pathway shows how a single adaptation option plays out through time. The pathway maps are not meant to imply that all options should be pursued, instead there are various options, some of which may be pursued and others not.

To assist with interpreting the maps, it should be noted that:

A **solid, dark green line** indicates the time period over which an option could usefully address the relevant key decision. A **lighter green line** indicates time before an action occurs where preparatory work is required.

A **dashed, thick dark green line** indicates that the option contributes to the adaptation solution but only in part.

A **solid, dark grey line** indicates an option that was not favoured in these discussions. A **lighter grey line** indicates time where preparatory work would be required if such an option was to be pursued.

Circles indicate a decision point, such as when decision-makers may need to choose between different options.

A **solid line that ends in a vertical black line** indicates an adaptation tipping point, or a point beyond which an option is no longer viable.

Yellow lines with arrows indicate emerging pathways that need to be further assessed in most instances with each sector.

- There is no priority in the order in which options are presented;
- The **x-axis** represents a general trend in changing climate through time and should be read as indicative (e.g. decades) rather than precise in terms of the timing of adaptation options; and
- Given that the x-axis represents time, it should also be noted that other factors will change through time that will impact on the choice of adaptation options such as market forces.

Appendix J

Impact pathways ▼

There are a number of ways of drawing together on potential connections within a system that might be important for understanding how changes in one part (e.g. water temperature) influence another part of the system (e.g. the landings). The most obvious is consulting existing reports (e.g. the 2018 report on the sensitivity of Australian fisheries to climate change, which include species projections). While a good place to start this is rarely sufficient as it often misses the knowledge of most stakeholders whose experience and understanding is often undocumented.

Building impact pathways is a useful way of capturing a lot of the broader understanding of the system. This method involves drawing pathways showing the chains of potential impacts of climate change on other parts of the system. These pathways are drawn based on expert opinion of how changes to the environment can influence the fishery. Consulting those who have a knowledge of the fishery will provide insights on the fishery and fisher behaviours that consulting existing reports will miss. These 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). Impact Pathways are useful for understanding how changes in the environment can influence the fishery and design interventions. When done collaboratively drawing impact pathways helps stakeholders 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 (Mayne, 2015).

In the project that was the basis for this handbook we developed impact pathways collaboratively during workshops to understand how fishers and managers understand their fisheries, current and potential interventions form both operators and management agencies and how they expect these interventions to affect issues affecting their fisheries.

In reading through the report you will have seen that there are at least six categories of physical or chemical ocean change categories, 4 direct biological impact categories (with 13 attributes of sensitivity – Table 4-2), and 5 indirect ecosystem impacts (Table 4-3). Furthermore, there are economic impact variables (Table H-1), social impact variables (Table D-1), and 1 governance impact variable. There are also 5 pathways to influence (catch, effort, gear, spatial, and temporal) and 21 management instruments (Table 4-8) that can be used to address climate impacts. This is a lot of complexity but is the reality of the many moving parts that make up a fishery. This long list of categories and variables (factors) means there are many different combinations of impacts and responses. To make sense of this we encourage the use of Impact Pathways drawn with the involvement of climate scientists, social scientists, economists, managers and representatives of traditional, recreational and commercial fishing sectors, as well as potentially other interested groups. Diverse views and expertise are important to include 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.

A structured approach to building an impact pathway ensures nothing is overlooked and that pathways drawn up by different people or for different fisheries are comparable. The pathways should be created for individual fisheries (recreational, traditional and commercial) and ideally 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. The information outlined in this section provides a checklist against which the steps in the impact pathways can be compared.

Key considerations when creating an impact pathway include the identification of key features to be represented and how they relate to one another. We use examples from the hypothetical fishery example (Appendix A) to illustrate the process.

Key elements of impact pathways

Key physical and/or chemical ocean properties and variables and how they are expected to change (e.g. sea surface temperature change as shown in Table 4-1 for different properties and variables). Note that while the primary focus of this handbook is on physical drivers, this step could consider any drivers of change (market forces, changing social or political landscape etc are relevant too).

From hypothetical fishery example:

- **Increase in ocean temperature along the 250 km stretch of coastline where fishery takes place.**
- **Warmer waters affect ocean circulation – stronger eddies and upwelling occurring further offshore**
- **Increase in extreme rainfall events resulting in higher coastal turbidity and eutrophication resulting in poor coastal water quality.**

Biological and ecosystem impacts of the change in physical or chemical ocean factors and variables. This is how the change expresses itself within stocks or ecosystems (e.g. change in species distribution as shown in Table 4-2 for biological impacts and invasive species in Table 4-3 for indirect ecosystem impacts).

From hypothetical fishery example:

- **Species redistribution**
- **Plankton blooms and fish balls (prey) moving offshore**
- **Decline in inshore fishery due to sediment and nutrient runoff**
- **Higher quality of fish caught offshore**

Direct fisheries response (i.e. how operations, landings etc responds) to the change in physical/chemical ocean factors and variables (e.g. sea surface temperature increase) or to the ecological expression (e.g. change in species distribution and invasive species). The fishery response could be to move location, for example.

From hypothetical fishery example:

- **Fishers could shift their operations and follow the fish (change in distribution of fish)**
- **Invest in new technology to reduce the time the trip took (change in distribution of fish)**
- **Diversify in their market and start supplying new markets; but depends on their willingness to take their product at a different time of the year (change in phenology)**

Socio-economic impacts of the direct fishery response. The socio-economic response could be that costs (e.g. fuel or transport cost) will increase (e.g. due to changed location of fishing grounds vs markets), or that market access will be affected (e.g. more irregular catches change might reduce market access as the markets want regular supply), or direct stakeholder conversations can be used to determine who is best able to influence/mitigate the socio-economic impact and at what point they feel they would/could act.

From hypothetical fishery example:

- **Reduced beach prices arising from selling into different markets**
- **Decline in industry profitability due to lower prices and increased fleet efficiency would affect vessel numbers and employment**

Management responses are a commentary on whether current management actions are adequate given the changed conditions. Identify whether alternative management instruments and tools that could address the change might be more appropriate given the impacts, taking note of the high risk and high consequence socio-economic impacts (as per 4a, 4b, and 4c).

From hypothetical fishery example:

- **Change fishing season / zones**

Knock-on effects cover the implications of any change occurring/proposed in the system (these may be ecological, economic, social or policy related), in particular effects beyond those looked at in the earlier parts of the impact pathway (e.g. on bycatch species, species of conservation concern, other sectors, society, etc).

From hypothetical fishery example:

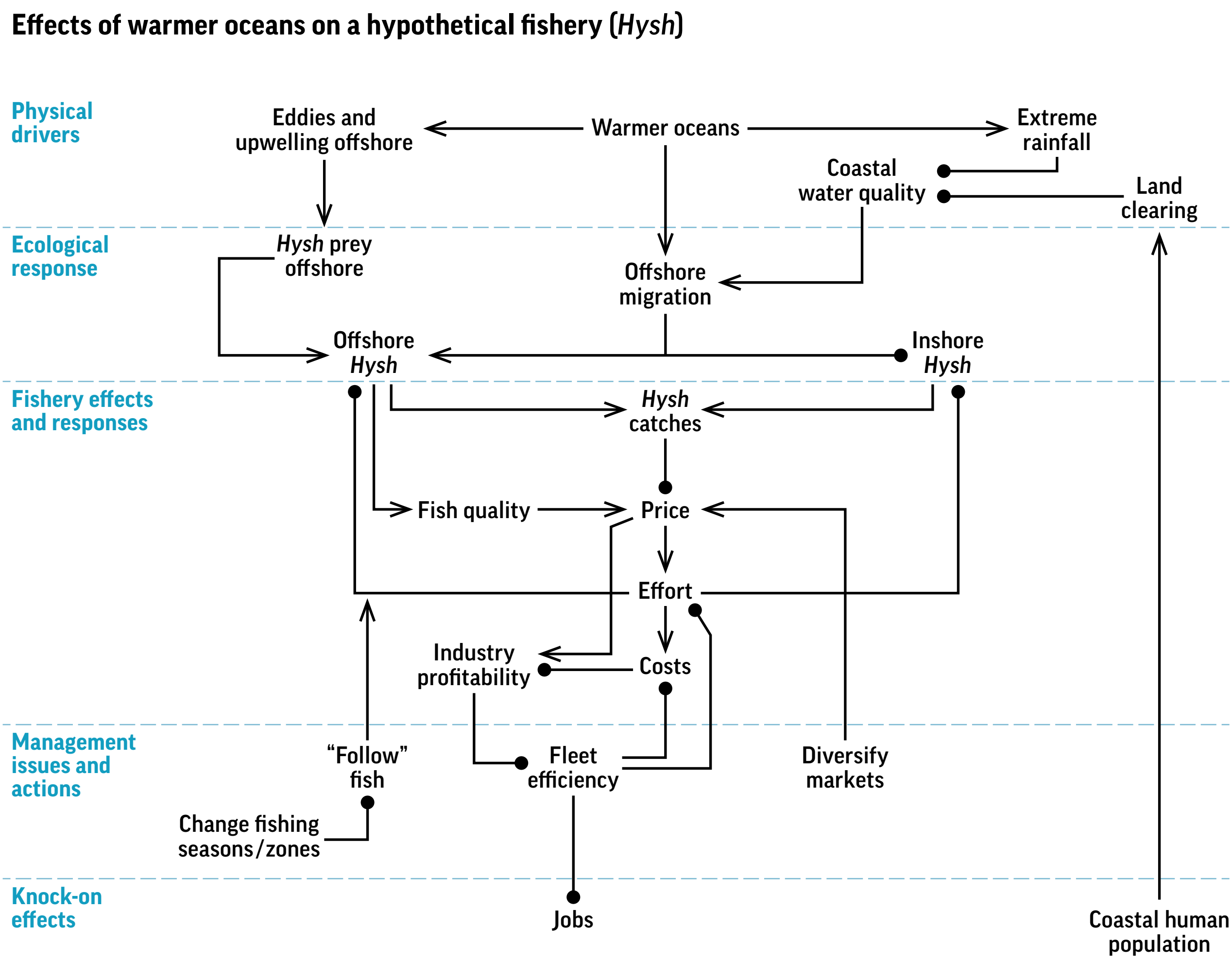
- **Strong population growth in the coastal area which has driven the increase in recreational fishing activity.**
- **Changes in land-use and land clearing to accommodate population growth (more houses) along the foreshore creating many issues with erosion and excessive nutrients increasing turbidity and eutrophication in inshore waters with negative impacts on stocks.**
- **Changes in fishing seasons or zones may lead to more encounters with non-target species (while there has been an observed decrease in overlap with byproduct species there is anecdotal commentary from researchers specialising in waters further south that if the fishery did shift its grounds much further south it may start to encounter new TEP species).**
- **If new TEP encounters were observed this may cause negative perceptions of the fishery or may cause issues with its capacity to meet EPBC requirements**

Adding relationships between impact pathway features

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 can be added during workshop session and further refined post-workshop via the development of a narrative for the impact pathway. This helps communicate in a graphic form (supported by details from the narrative) the impacts on the fishery, how the interventions are expected to influence fishery outcomes and what needs to be changed. The following narrative has been developed for the hypothetical fishery example.

The 'Effects of increase in temperatures on the fishery' impact pathway for the hypothetical fishery focuses on how increasing temperatures and changes in ocean circulation affect the fishery. Higher water temperatures increase eddies and upwelling offshore, thus affecting distribution of prey, and timing of migration of 'hypothetical fish' (*Hysh*). Extreme rainfall events become more frequent which, in combination with urbanisation of coastal areas to accommodate growing human population result in poor inshore water quality triggering *Hysh* relocation offshore. As a result of higher ocean temperature in spring, *Hysh* migration occurs later in the year and catches follow suit. The quality of the fish is higher but fishers are missing out profits because they miss the peak market season. Fishery responses to manage changes in distribution of fish are likely to be around shifting operations to follow the fish offshore and efficiency changes due to reduced profits, for example by reducing fleet size, which will have a negative effect on employment. Only option to manage changes in migration is to diversify their market and start supplying new markets; but this depends on their willingness to take their product at a different time of the year. Negative impacts of extreme rainfall events on water quality is exacerbated by land clearing and coastal development to accommodate a growing human population in the area.

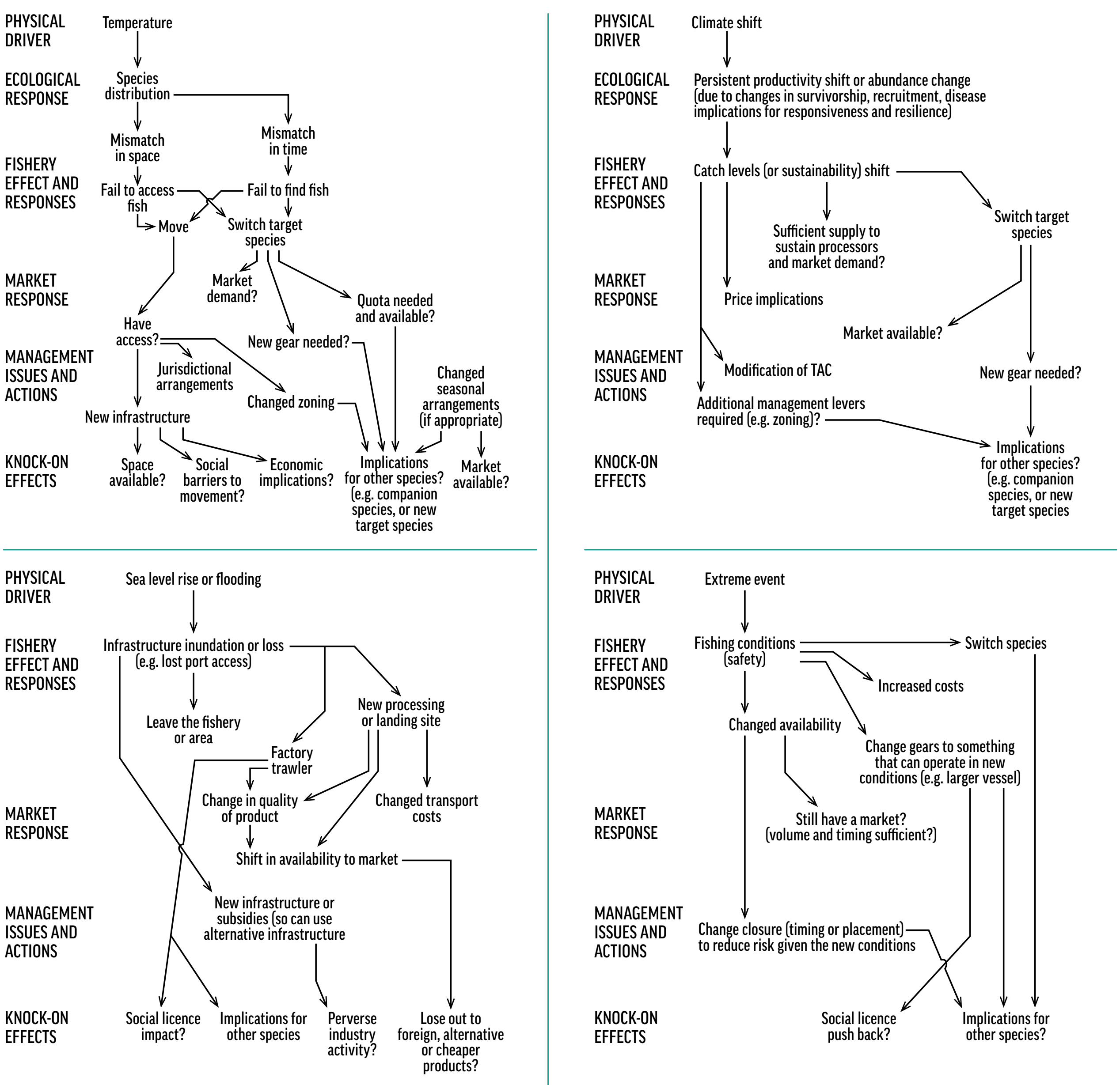
FIGURE A-6 Impact pathway of the effects of warmer oceans on hypothetical fishery.

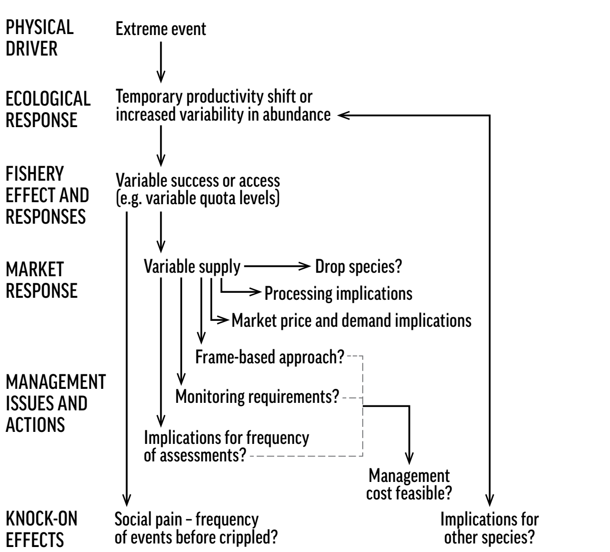


Other generic impact pathways examples

Below (on page 85) are some examples of generic pathways built by scientists, economists and fishery stakeholders that cover some of the major mechanisms by which climate-driven changes can impact a fishery. These can be used to guide specific discussions about the exact mechanisms and pathways appropriate for a specific fishery/sub-fishery of interest.

FIGURE A-7 Example generic impact pathways. These are mechanisms or chain of events from the physical change to the fishery outcome. This may be via the physical environment affecting the fish and their availability to the fishery, or it might be direct effects on vessels or operations.





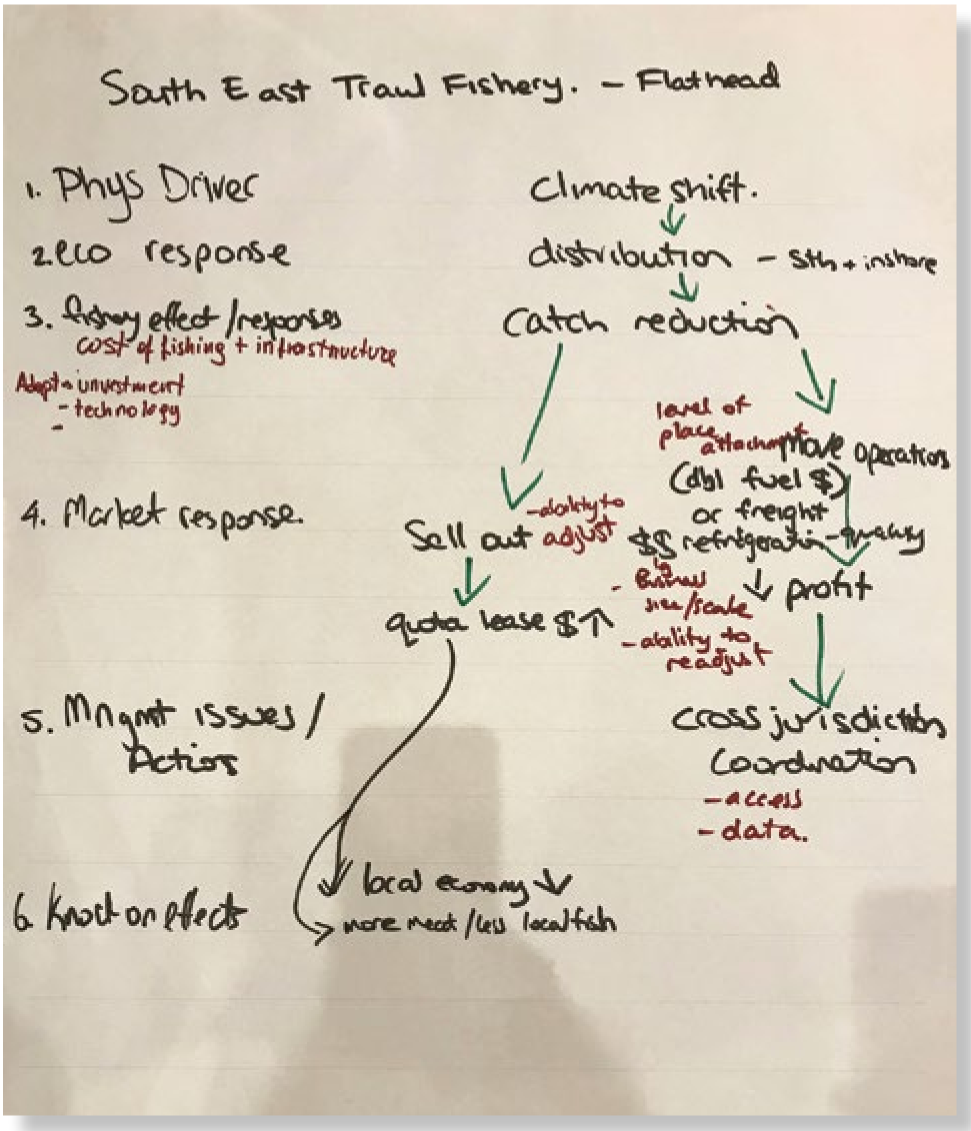
How to elicit impact pathways (learning from workshop)

How to start: Drawing impact pathways follows a general presentation about modelling predictions of climate change impacts on the fishery, including uncertainties related to models and data used. The participants are encouraged to discuss any changes they have seen and what they think may occur. After the presentation and discussion, participants are asked to list the critical components to be represented in the impact pathway – drivers, biological and ecosystem impacts, fishery responses, socio-economic impacts, management responses, and knock-on effects (see above and Figure A-7).

During the exercise participants are encouraged to comment on predictions, describe the mechanisms they think are influencing the fishery, and how climate change is affecting this influence. Practical experience, such as knowledge about currents and water temperature at different depths influencing fish catches are important and represented in impact pathways. The facilitator can start the exercise by making a statement about the effects of higher water temperatures in the distribution of target species, and ask participants if they have experienced this and how they dealt with or would deal with these changes. The idea is to develop a story line containing a chain of events by identifying the effects of climate change on key drivers affecting ecosystem dynamics, impacts on fishery and responses, actions that can be taken, their impact on the fishery, and potential social, economic and environmental implications of actions and changes in the fishery.

As they hold this discussion the participants are asked to draw the pathway connecting those critical components (or the facilitator may draw it as a means of synthesising the discussion, getting feedback from the participants as they go).

FIGURE A-8 Example of 1st stage of developing impact pathway, where participants list key variables to be included.

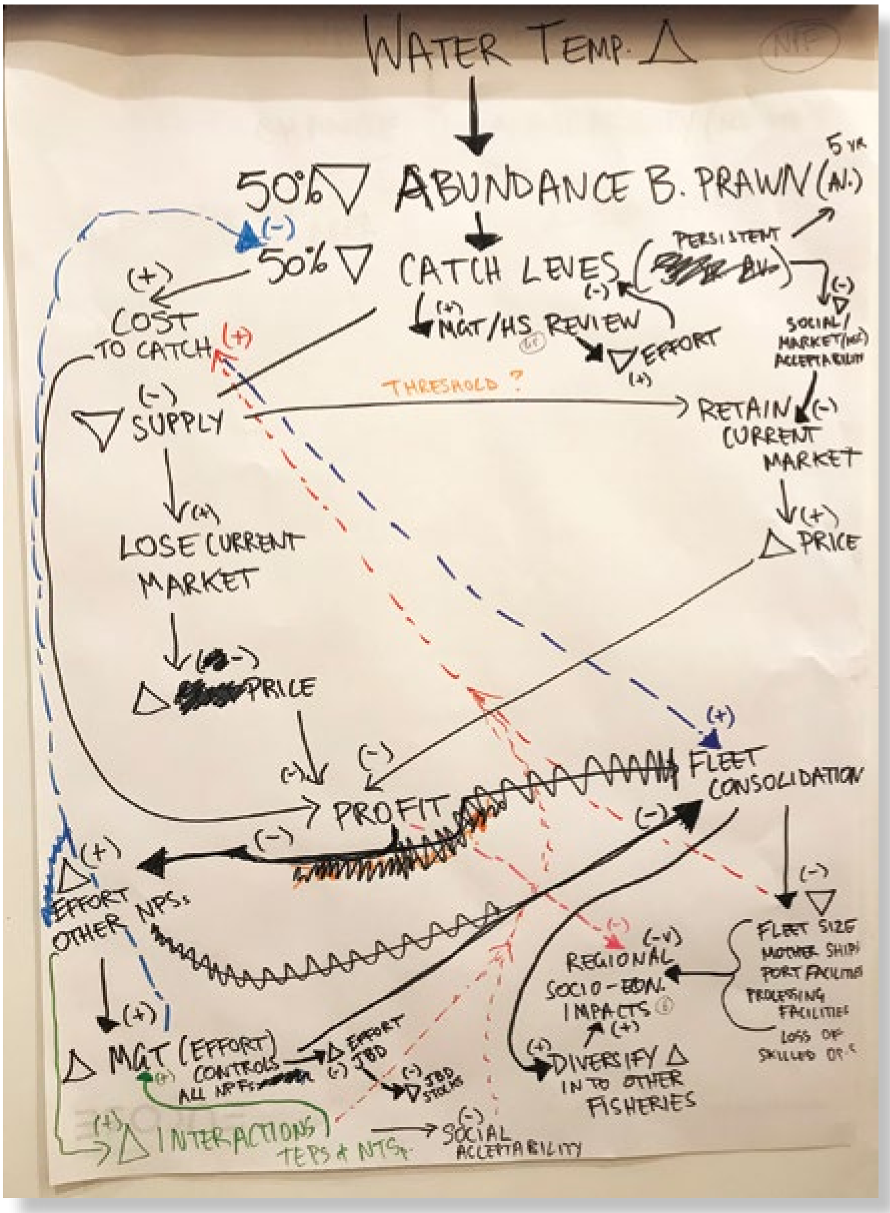


What needs to be represented: Developing the impact pathway may include several variables and relationships that are important to be represented during the exercise. Using colour schemes or line codes (e.g. coloured, dashed, dotted and full lines), and direction of impact (+ or -) (Figure A-8) may help the group understand key variables represented in the impact pathway, relationships and outcomes and how different pathways connect or are overlaid. For example, dashed lines can indicate a weak, uncertain or potential link between variables that can be used as a management action; or when there is no consensus as to the direction of impact from one variable to another both positive and negative impacts can be drawn in the impact pathway. Notes can be added to in the links (arrows) between variables to describe the relationship.

If multiple fisheries are discussed in a workshop setting, groups of participants can then present their impact pathways to one another, discuss differences and synergies thus supporting social learning.

The visual representation of impact pathways to broader audiences outside the workshop requires further work on the visuals of key variables and relationships. A simplified version of the impact pathway developed during a workshop session is drawn based on both workshop graphics (e.g. Figure A-9) and storyline presented by groups. Specific graphic design software (e.g. Adobe Illustrator®) or simplified tools, such as Microsoft Power Point® can be used to draw an electronic version of impact pathways. The simplification process involves removing redundant variables, grouping and renaming variables conveying similar ideas or relationships.

FIGURE A-9 Example of graphical representation of variables, relationships and outcomes of impact pathways where colours and line codes are used to help visualisation to participants.



When drawing impact pathways it is very easy to try to represent everything that is being discussed by the group. Instead the facilitator should direct the discussion towards the key impact pathway considerations (drivers, biological and ecosystem impacts, fishery responses, socio-economic impacts, management responses, and knock-on effects).

During the process the facilitator might need to draw two (or more) parallel impact pathways as the discussion progress. This is where different colour schemes may come handy. However, the facilitator should be very cautious of over-representing variables and relationships in what is often referred to as a 'horrendogram'. This may prevent learning as participants will find it difficult to follow the ideas discussed. Instead the facilitator may use multiple white board / flip charts to park ideas or other impact pathways that can be developed separately.

FIGURE A-10 An example finalised impact pathway drawn for the Australian Small Pelagic Fishery. The assumptions (described in the text on the right-hand side of figure) are given for what needs to happen for the interventions (freezer trawler Trans-shipping) to work. Note that lines ending with a dot represent a negative effect (or drop) in that factor and an arrow a positive effect (growth) in a factor; a ? indicates that the outcome for that factor is unknown.

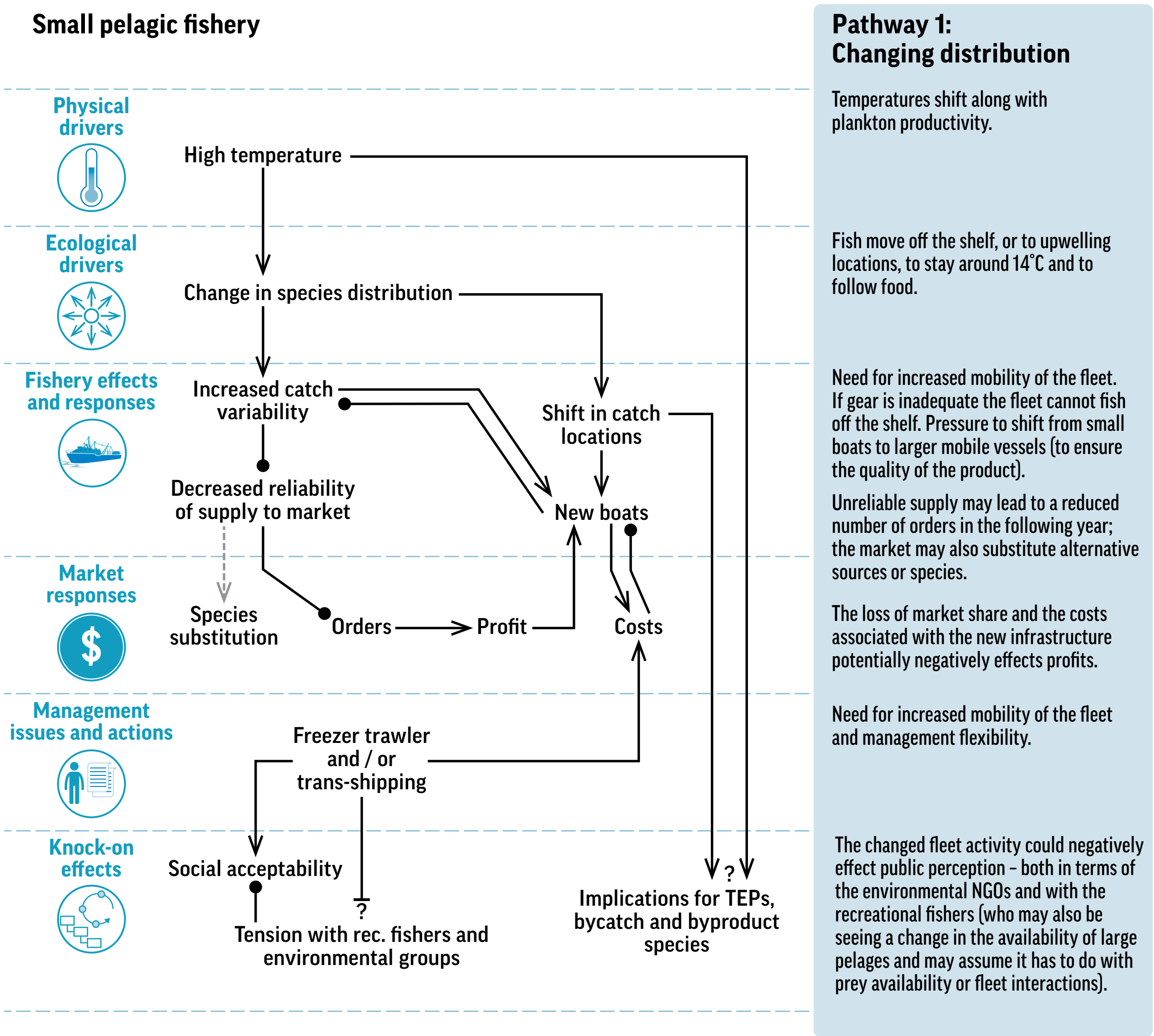


Image: **David Clode**

How to analyse impact pathways

Impact Pathways are representations of how participants perceive how the fishery works, including the relationships between climate change, physio-chemical variables and fisheries outcomes (e.g. catches, price), and which interventions can be used to make a positive difference in the outcomes. It includes the underlying assumptions and causal pathway to understanding how interventions are expected to cause the desired results. The presentation of the impact pathway in a group setting used as supporting documentation describes the underlying assumptions in the representation and "what has to happen for the causal linkages to be realized", or a theory of change (Mayne 2005).

Appendix K

Qualitative models

Information from existing documents and fisheries knowledge and expertise (e.g. as capture in an impact pathway) can be used to construct conceptual models of how the various parts of a fishery are interconnected, that is, what the key components are and how they influence each other. Alternatively, conceptual models can be drawn up separately, to act as a cross check on the other methods. However, it is often easier to draw up the linear impact pathway chains first and then fill those out with feedbacks and extra details to create the conceptual models. As a result, conceptual models can sometimes look quite similar to the impact pathways, but can bring in other factors (e.g. feedback loops including issues not directly related to climate, such as management approaches, markets, connections to home ports, social perceptions etc). It is also possible to use conceptual models to consider alternative scenarios of change (especially where multiple things change at the same time) or to qualitatively explore how different management options may play out in the fishery under those scenarios of change.

Impact pathways and the articulation of underlying assumptions of what needs to happen for interventions to work are important to identify which interventions are likely to work and why. Impact Pathways can be translated into qualitative models to expand mental models by testing changes in key drivers (e.g. from climate change) and unexpected impacts of interventions by analysing feedback loops.

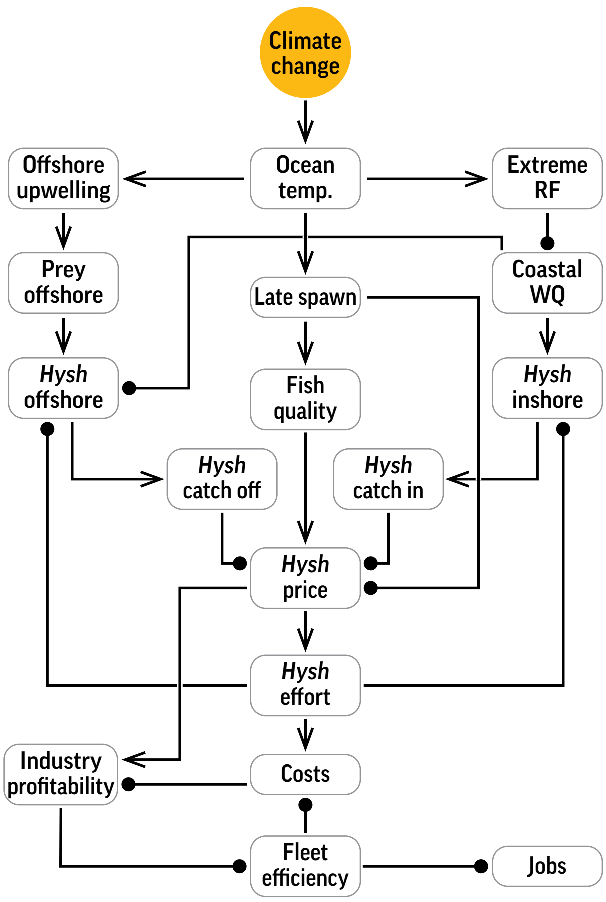
Qualitative models represent a more structured approach compared to impact pathways to drawing conceptual models of how a system works. Information from experts (or other sources) can be used to construct conceptual models of how the fishery system is interconnected – what are the key components and how do 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.

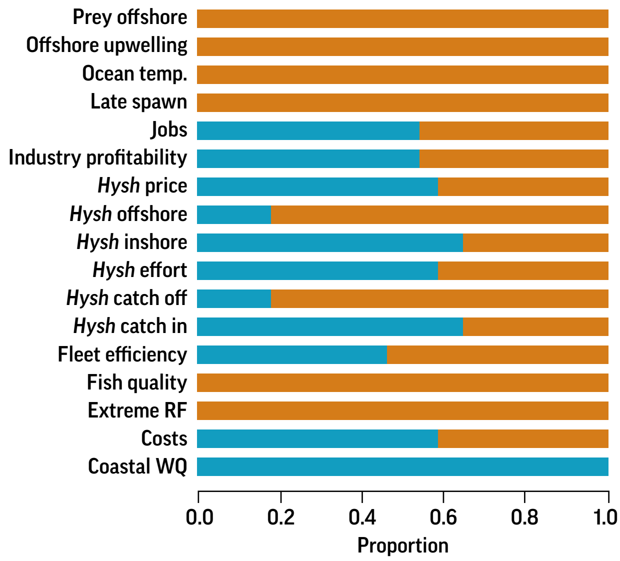
In the example shown here (Figure A-11) temperature increases offshore upwelling and abundance of prey offshore, which has a growth effect on offshore stocks of Hysh. More extreme rainfall events decreases water quality pushing Hysh offshore. Fishers 'follow the fish' catching more fish offshore. However, higher ocean temperatures pushes spawning later in the year resulting in catches later in the season, negatively affecting prices.

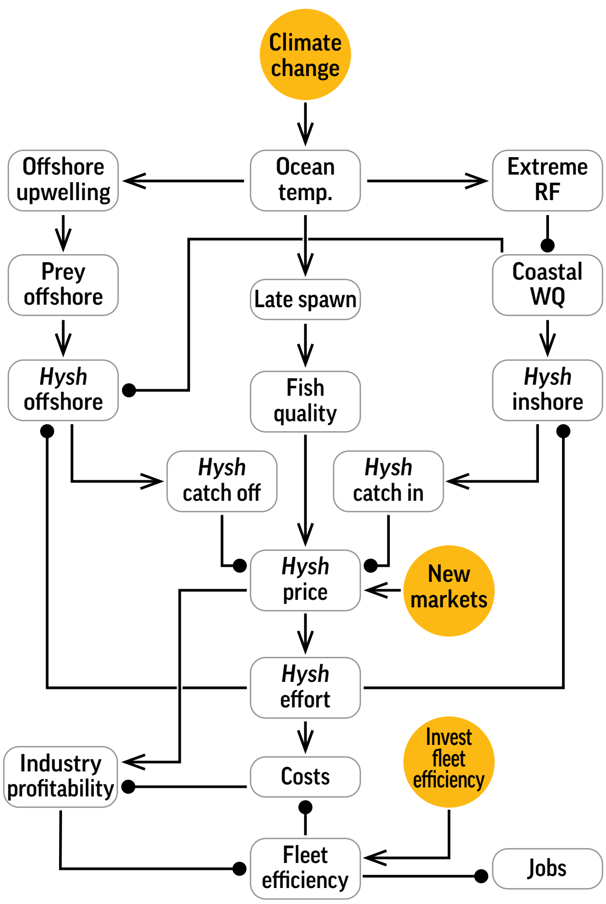
Figure A-12 shows that developing new markets, changing the fishing season to accommodate later best quality catches (removal of negative link between late spawn and Hysh price), and investing in fleet efficiency will increase fish prices and industry profitability but at the expense of jobs.

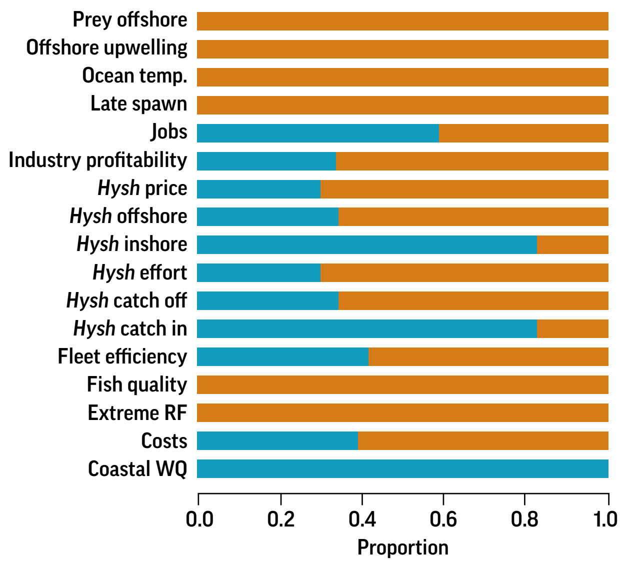
FIGURE A-11 (top right) Qualitative model diagram showing impacts of climate change on hypothetical fishery. The links ending in a dot (—●) indicate a negative interaction (e.g. extreme rainfall (RF) negatively affecting coastal water quality (WQ)) and links ending with an arrow head (➔) indicate a positive relationship (e.g. fish quality contributes to a higher price). The bars show response types, orange indicates a growth response and blue indicates shrinkage responses (laying out the nature of the links in this way makes it clear whether a factor has an overall negative or positive effect on the system).

FIGURE A-12 (bottom right) Qualitative model diagram showing management options to deal with impacts of climate change on hypothetical fishery. The arrows, lines and colours of the response types is as defined in Figure A-11.


Climate change
Ocean temp.
Offshore upwelling
Extreme RF
Prey offshore
Late spawn
Coastal WQ
Hysh offshore
Fish quality
Hysh inshore
Hysh catch off
Hysh catch in
Hysh price
Hysh effort
Industry profitability
Costs
Fleet efficiency
Jobs


Prey offshore
Offshore upwelling
Ocean temp.
Late spawn
Jobs
Industry profitability
Hysh price
Hysh offshore
Hysh inshore
Hysh effort
Hysh catch off
Hysh catch in
Fleet efficiency
Fish quality
Extreme RF
Costs
Coastal WQ
0.0
0.2
0.4
0.6
0.8
1.0
Proportion


Climate change
Ocean temp.
Offshore upwelling
Extreme RF
Prey offshore
Late spawn
Coastal WQ
Hysh offshore
Fish quality
Hysh inshore
Hysh catch off
Hysh catch in
Hysh price
New markets
Hysh effort
Industry profitability
Costs
Invest fleet efficiency
Fleet efficiency
Jobs


Prey offshore
Offshore upwelling
Ocean temp.
Late spawn
Jobs
Industry profitability
Hysh price
Hysh offshore
Hysh inshore
Hysh effort
Hysh catch off
Hysh catch in
Fleet efficiency
Fish quality
Extreme RF
Costs
Coastal WQ
0.0
0.2
0.4
0.6
0.8
1.0
Proportion

The qualitative models complement impact pathways as they represent a structured way to check on whether a factor may have an unrecognised role. It is possible that a factor thought to be trivial by experts may have a key role due to system feedbacks which can be too complex to keep track of.

In reality, whichever way you tackle the problem, it is usually good to iterate between impact pathways and conceptual models to make sure all major mechanisms and feedbacks are captured somewhere.

How to elicit qualitative models

Qualitative models can be created almost entirely from the description of processes and narratives by people expert on a system (either academically or because they live/work within the system). The scope and bounds of the fishery system of interest are defined in the pre-assessment scoping and then the specific components of interest are identified (i.e. the parts of the system important to the influence of climate on fisheries). As this is an almost identical process to what needs to be done when drawing an impact pathway, it is often easy to run the processes in parallel. In establishing the relationships between the components, one asks 'what is the direct influence of one component on another', and 'what else in the system determines the creation/growth or destruction/shrinkage of a component'. This same approach can be taken with physical, chemical, biological and ecological components, as well as social and economic processes. Additionally, we need to depict the influence of a component on itself, for example, its own rate of growth, such that as its abundance increases its rate of growth is self-limiting (the most common case) or (more rarely) self-enhancing.

Qualitative models can be obtained during a workshop setting similarly to impact pathways (see Corney et al., 2019). The only difference is that the formal representation of qualitative models requires a positive or negative effect from one model variable to another.

Workshops with experts is the most common means of drawing together a qualitative model, but it can be done based on any source of information – such as a literature review.

Qualitative models can be drawn based on a literature review (Constable et al., 2014) , or using a standard framework (e.g. the Institutional Analyses and Development Framework; Ostrom, 2009, 2011) to construct qualitative models (Dutra et al., 2018) and through the use of facilitated workshops, sitting with those who live in and now the system well (Ostrom 2009; Metcalf et al., 2014; Ostrom 2011).

As model systems include cause-effect relationships between interacting components of social, economic and ecological systems, a systems-thinking framework can assist in thinking through the many connections. A commonly recommended one is the Driving Forces – Pressures – State – Impacts – Responses (DPSIR) framework (Elliott et al., 2017). The selection of variables under the DPSIR framework allows the identification of relevant system indicator variables as a function of system impacts.

Once each component of the model system has been specified then you can represent it as a signed digraph (i.e. identifying which links lead to growth or shrinkage of the connected components) where only positive and negative effects are considered in the model. While most people will be most comfortable with narrative based model construction the method derives from a field of science called dynamical systems theory. Meaning it is possible to write the system as a set of equations, as a matrix of connections, or as a digraph (the formal name for the qualitative model) (Levins, 1974). Sometimes considering the model in the different ways (e.g. for those who are mathematically minded, thinking through how you might write the processes surrounding a particular component as an equation) can help clarify interactions that are not clearly defined via narrative descriptions – such as self-damping of a component – or identify alternative pathways or processes missed in the narrative.

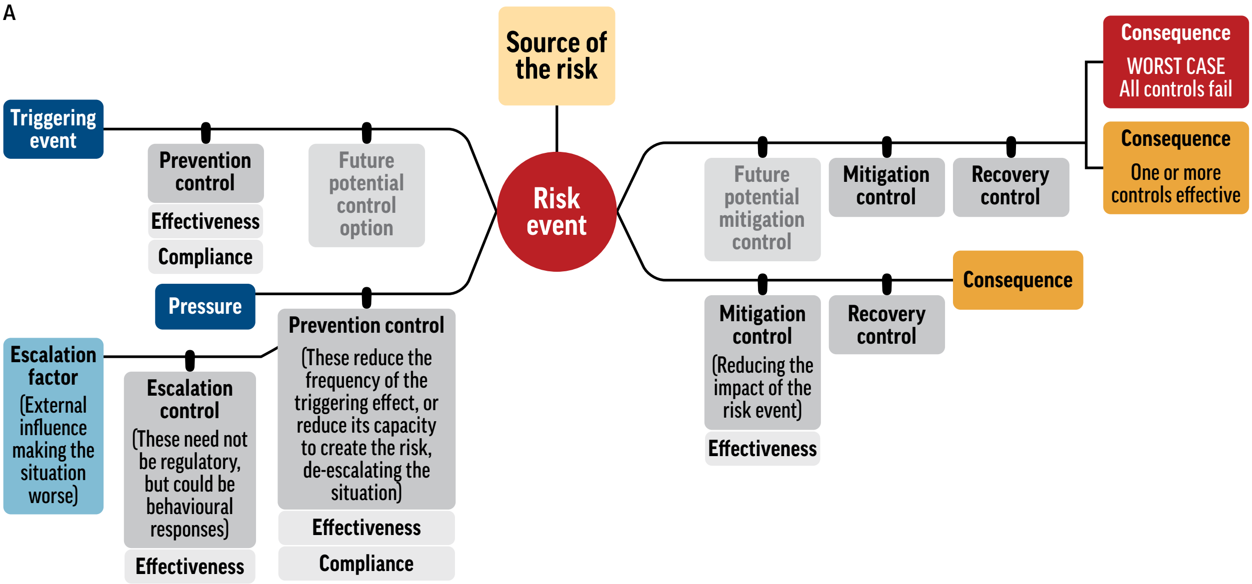
Appendix L

Bow-tie method of understanding risk

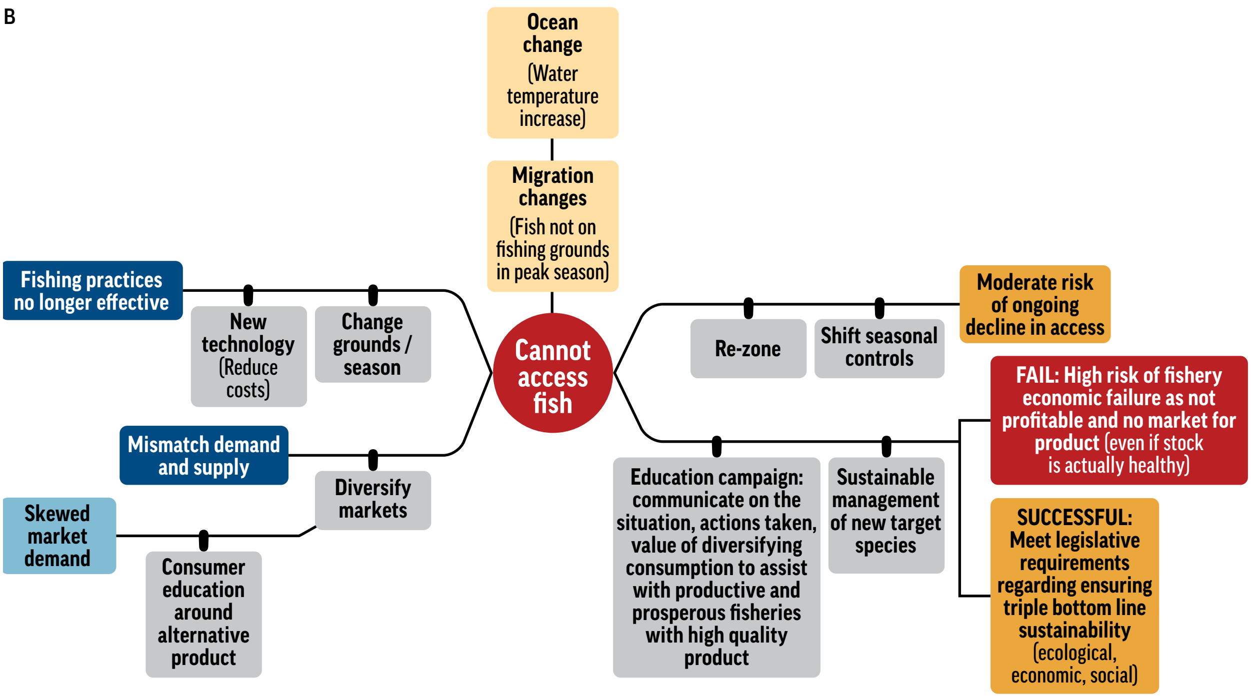
The ISO 31010 Bowtie Risk Management Assessment Tool (Figure A-13) provides a framework for structured analysis of the hazard and potential responses.

FIGURE A-13 Schematic of the Bow-tie risk tool, which is helpful for clearly laying out the risk and potential responses: (A) formal layout and explanation of components; (B) worked example for the hypothetical fishery.

A



B



The risk (event) is put in the central knot. From the left to the right of the risk event are cause/pressure-effect-impact pathways. If a causal event exists (or more often as a pressure increases) there is an increase in the likelihood of the risk event taking place, an increase in effects and ultimately an increase in the likelihood of impacts/consequences. Along the pressure-effect-impact pathways sit adaptation responses (e.g. fleet behaviours), which might control the degree of escalation (e.g. changing behaviour might prevent the pressure really playing out to a level that creates risk), and management measures. These management measures might be preventive (to avoid the risk event from occurring) or they may be aimed at mitigating the effects or helping recovery if a risk event does occur. Additional influences (external factors) that may undermine the effectiveness of the management measures can also be added to the figure.

Laying things out in this way provides a structured approach to thinking about risk. The diagrams clearly display the links between the potential causes, what can escalate the risk any preventative or mitigative controls, and consequences of a major incident. The arrangement of the diagram is there to help show the relative emphasis between the “preventative” left-hand side compared to the “mitigative” right-hand side. This can highlight the strength of the legislated and non-legislated frameworks in place for prevention, avoidance, and mitigation of threats to sustainable management. The diagrams also provide an overview of multiple plausible incident scenarios and show what barriers may exist in trying to control these scenarios.

Appendix M

Attributes building resilience

Figure M-1 summarises the many ways that climate change can impact a fishery or ecosystem and the aspects of the biological and human part of the system that can resist change or ease adaptation (i.e. provide adaptive capacity).

FIGURE A-14 Schematic diagram of the system attributes influencing vulnerability and adaptive capacity of ecological and human dimensions of fished ecosystems (based on Marshall et al. 2013).

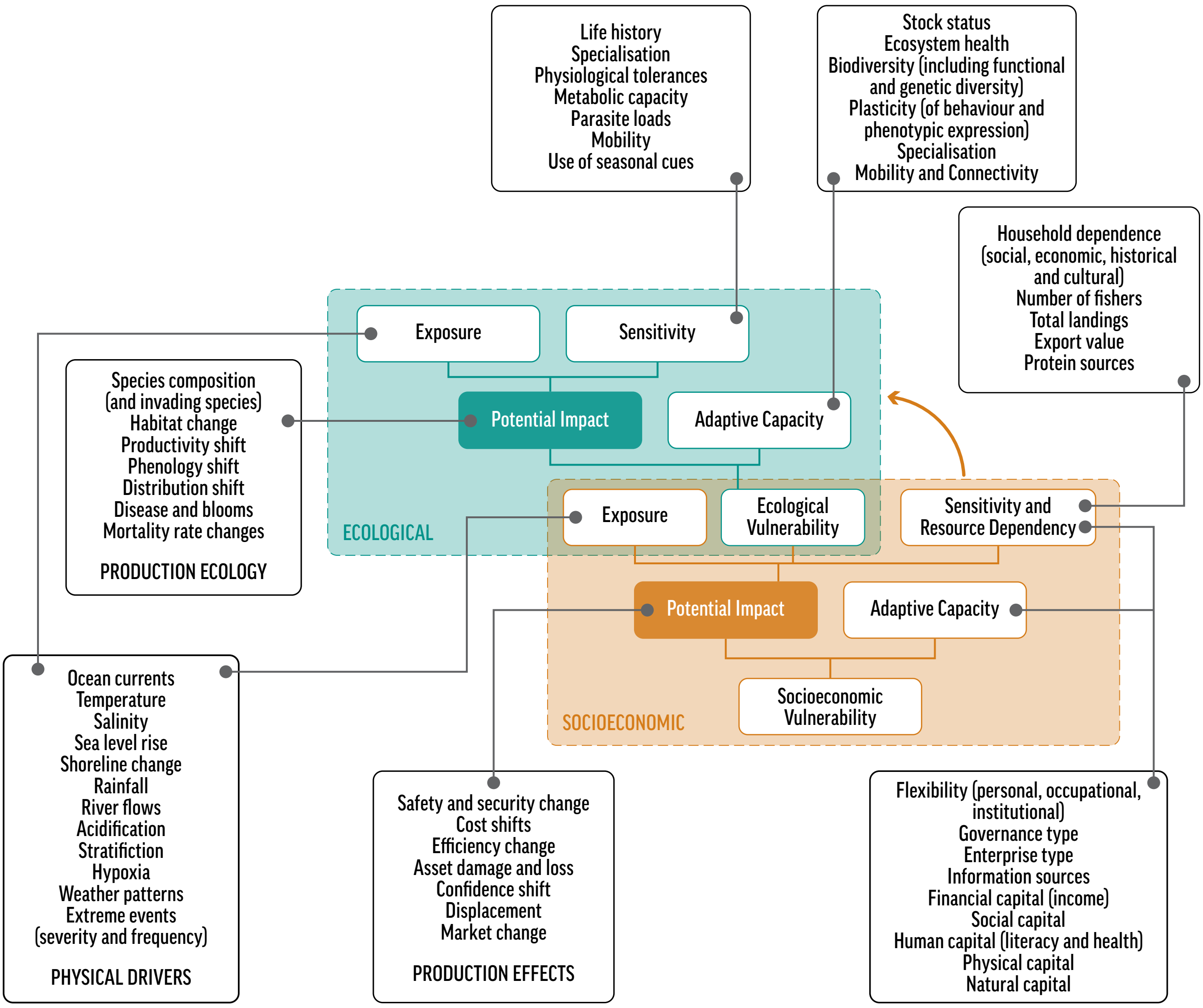


Image: Chris King

There are many attributes of a system – whether ecological, economic, social, institutional etc – that can influence how robust that system is under climate change. Those attributes may influence the capacity of the system to resist or buffer change or they may affect the capacity to adapt. Table M-1 lists and describes attributes contributing to adaptive capacity that are most commonly discussed in scientific literature. Additional factors appropriate to the system of interest should be added to the list.

TABLE M-1 Ecological, economic, social and governance attributes influencing system robustness and adaptive capacity (based on references from the suggested reading listed below and discussions with the SNAPP Working Group on Climate Resilient Fisheries, https://snappartnership.net/teams/climate-resilient-fisheries/).

Attribute	Discription
BIOLOGICAL	
Stock status	Fish stocks (populations) that are more abundant and with more complete age structure have more capacity to cope with short term environmental variability. Long term capacity is influenced by the biological categories listed in Table 4-2.
Ecosystem health	The more intact the ecosystem structure and function the more robust it is to environmental variation.
Biodiversity	Biodiversity of all kinds increases adaptive capacity. Functional diversity provides depth in the capacity to deliver ecosystem functions (such as habitats or nutrient cycling). Similarly, species and genetic diversity expand the chances that some species (or genetic variant) has the plasticity to cope with any environmental changes and that there is redundancy in the options available to the fishery (e.g. giving fishers the chance to switch target species if needed).
Plasticity	Flexibility in terms of behaviour change, acclimation or phenotype expression under different conditions all provide species with a greater capacity to adapt to environmental change.
Degree of specialisation	Species that are more specialised (whether in terms of habitat needs, diet composition, physiological tolerances etc) are less able to cope with changing conditions.
Degree of mobility	Species that can move if conditions become unfavourable have more capacity to survive and adapt. From a community perspective, however, it can leave "gaps" in the biological communities if all species of a particular functional type leave the system.
Connectivity	A higher degree of inter-connectedness of sub-populations, habitats and the like means that there are places mobile species can go to if conditions change, or sources of new larvae if a sub-population or habitat patch is lost due to an extreme event. Higher connectivity improves the chance to adapt to or even resist climate change as there is a rich capacity to respond and recover (it is very difficult to destroy the entire network of connected areas all at once).
ECONOMIC	
Employment or other economic opportunities (economic security)	Individuals who are struggling to meet day-to-day needs have little capacity to prepare for or avoid negative consequences of climate change impacts. Economic assets, wealth, success to credit and insurance can all provide economic security and greater opportunities.
Economic diversity	Operators with diversified earning options (regions with multiple employment options) are more robust to climate impacts as it is more likely that not all sources of income will be lost at once, as not all sectors/employers will be affected in the same way (i.e. there is a portfolio effect).
SOCIAL	
Access to information/knowledge	Greater pools of available information (ideally drawn from multiple diverse sources) provide greater potential for adaptation (as there is existing understanding of how best to respond or there is information on what is occurring). Adaptation is not guaranteed, but it is made easier.
Learning capacity	Those who know how to use available information can make better evidence-based decisions, increasing their likelihood of a positive outcome.
Capacity to act	The greater the capacity for individuals to act (make choices on how to respond) the more robust the system will be – as individuals can respond when needed, are more motivated to respond, and there is the potential for innovation to create new opportunities.
Flexibility	Individuals and organisations who are more flexible, who can change when change is needed increases the capacity to adapt. If flexibility can be built into planning processes (by allowing for uncertainty or planning for variability and extreme events) the more robust and successful the fisher/fishery.
Degree of mobility	Fishers that can move if conditions become unfavourable have more capacity to adapt. This may require access to appropriate/new technological options and sufficient economic capacity to respond in a timely manner. Social ties and place attachment can reduce mobility.

Attribute	Discription
SOCIAL	
Community cohesion (social capital)	Networks of relationships and cultural connections in a healthy community enable society to function and facilitate the kind of collective actions that may be required to respond to some large-scale changes (e.g. via transforming company operations or the suite of management instruments applied).
Cultural diversity	Communities with diverse cultural composition and viewpoints have an increased chance of containing knowledge around how to respond. However, extremely high diversity can lead to fragmentation if there are no shared goals; and strong tensions between groups can erode large scale social capital.
INSTITUTIONAL	
Secure funding arrangements	Similarly to individual/organisational economic security, adequate and ongoing funding of agencies increases adaptive capacity providing the resources required to gather information, contribute to both immediate management/enforcement and long term planning.
Leadership	Systems with community or organisational leaders/teams who show initiative are often better prepared for change or can respond more quickly (see responsiveness). Good leaders can also motivate others to act and create cohesion (deepening social capital).
Responsiveness (adaptive)	Institutions with the capacity to act quickly (with short time frames from receiving information to acting) and flexibly (so actions can be modified as needed) have a greater capacity to adapt so long as responses are anchored in terms of delivering on longer term strategies (e.g. via structured adaptive management frameworks that include explicit monitoring evaluation and adjustment); simply reacting to each new event without some supporting framework or thought can exhaust resources and personnel and be maladaptive.
Equitable and inclusive	Fair, equitable and inclusive approaches can benefit from greater sense of stewardship, engagement and access to diverse knowledge bases. However, they can also have significant inertia (especially if consensus based).
Accountable and transparent	Decision making that is clearly laid out, defensible – in terms of being efficient, effective and based on clear lines of logic or pre-agreed rules and procedures – and with clear (and effective) grievance processes increase trust and compliance and ultimately the robustness of the fishery.
Integrated	Management and planning regimes that account for connections within and across a system are less likely to lead to unintended consequences (as adverse actions are more likely to be realised and avoided ahead of time). This makes such systems more robust to climate change, as buffers and allowances have typically been built into management procedures and there are much lower levels of cumulative effects (this is because their potential is realised and action is taken to minimise them).

Suggested reading list

For those who want more details on how the attributes in Table M-1 contribute to resilience. This is not an exhaustive literature review, rather a taster to give insights into what aspects of an ecosystem and fishery (or natural resource and environmental management more generally) can assist or undermine resilience.

Adger, W., Barnett, J., Brown, K. et al. (2013) Cultural dimensions of climate change impacts and adaptation. Nature Climate Change 3: 112–117	Discussion of how culture of communities and groups can influence adaptation
Anderson, C., Hsieh, Ch., Sandin, S. et al. (2008) Why fishing magnifies fluctuations in fish abundance. Nature 452: 835–839	Explains how removing older individuals in a population destabilises population buffering reducing resilience
Armitage, D. (2005) Adaptive Capacity and Community-Based Natural Resource Management. Environmental Management 35: 703–715	Describes what can build adaptive capacity for natural resource management situations
Cinner, J.E., Adger, W.N., Allison, E.H. et al. (2018) Building adaptive capacity to climate change in tropical coastal communities. Nature Climate Change 8, 117–123	Describes what aspects of society can build adaptive capacity
Clarke, D., Murphy, C., Lorenzoni, I. (2018) Place attachment, disruption and transformative adaptation. Journal of Environmental Psychology 55: 81-89	Discusses how place based attachment of community can slow down or derail the best intentions of adaptation
Cvitanovic, C., Hobday, A. J., McDonald, J. et al (2018). Governing fisheries through the critical decade: the role and utility of polycentric systems. Reviews in Fish Biology and Fisheries 28: 1–18	Discusses features of governance that may provide opportunities for improved adaptation to climate change
Duncan, M.I., Bates, A.E., James, N.C. et al. (2019). Exploitation may influence the climate resilience of fish populations through removing high performance metabolic phenotypes. Scientific Reports 9: 11437	Describes how fisheries can selectively remove physiological and behavioural phenotypes that are more robust to climate shifted environments
Folke, C., Carpenter, S., Walker, B. et al (2004) Regime Shifts, Resilience, and Biodiversity in Ecosystem Management Annual Review of Ecology, Evolution, and Systematics 35: 557-581	Explains how a loss of biodiversity can undermine ecosystem resilience in terrestrial and marine ecosystems
Garmestani, A. S., Allen, C. R., Cabezas, H. (2009). Panarchy, adaptive management and governance: Policy options for building resilience. Nebraska Law Review 87: 1036-1054	Discusses how laws can prevent flexibility, adaptation and resilience, and how adaptive management approaches can help
Hixon, M.A., Johnson, D.W., Sogard, S.M. (2013) BOFFFFs: on the importance of conserving old-growth age structure in fishery populations, ICES Journal of Marine Science 71: 2171–2185	Discusses the importance of preserving large females in fish populations because they produce proportionally more offspring than smaller females
Mumby, P.J., Hastings, A. (2008), The impact of ecosystem connectivity on coral reef resilience. Journal of Applied Ecology 45: 854-862	Explains how connectivity between habitats and sub-populations improves overall resilience
Pinsky, M.L., Mantua, N.J. (2014) Emerging adaptation approaches for climate ready fisheries management. Oceanography 27: 146–159	Describes opportunities to make fisheries management more climate ready and what may stand in the way of that, such as funding security
Sunday, J.M., Pecl, G.T., Frusher, S. et al (2015), Species traits and climate velocity explain geographic range shifts in an ocean-warming hotspot. Ecology Letters 18: 944-953	Discusses how traits, such as the mobility of a species, influences how fast it can move to more desirable locations as climate change influences the environment
Taylor, BM, Choat, JH, DeMartini, EE, et al. (2019) Demographic plasticity facilitates ecological and economic resilience in a commercially important reef fish. Journal of Animal Ecology 88: 1888– 1900.	Describes how life history can make a species more robust to climate change influences
Waters, E., Barnett, J., Puleston, A. (2014)Contrasting perspectives on barriers to adaptation in Australian climate change policy. Climatic Change 124: 691–702	Describes potential barriers to adaptation, which shows access to information, financial resources and the like can undermine adaptation and thus resilience

Image: **David Clode**

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