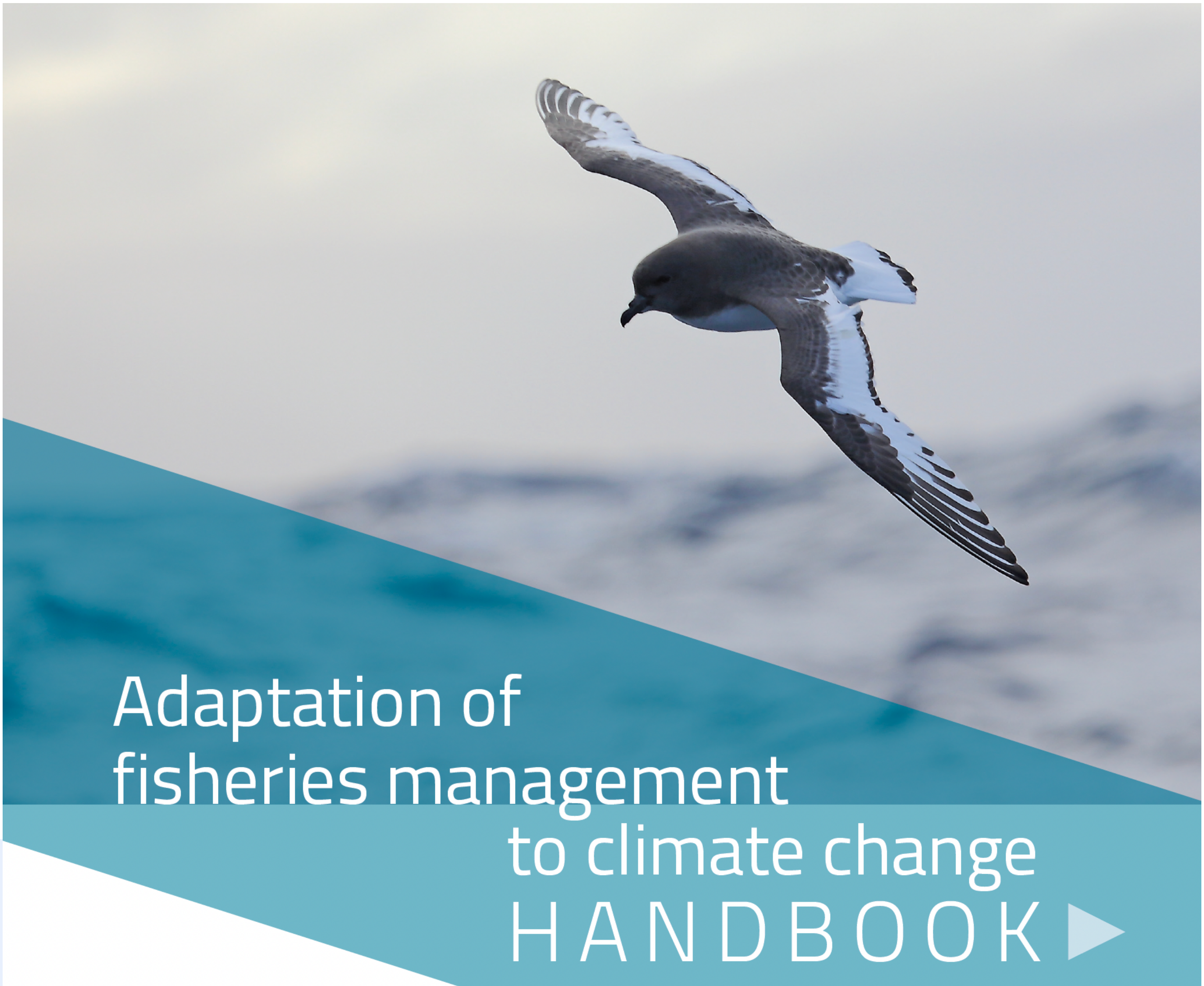
CSIRO

Australia's National
Science Agency

Training materials for the Adaptation of Fisheries to Climate Handbook



Introduction

Introduction & Roadmap

Adaptation handbook training

2022

Australia's National Science Agency

Acknowledgement of Country

Wilfred Nawirridj

Roadmap

- Handbook background
- Thinking through impact pathways
- Risk (peoples' perceptions)
- Online handbook app
- Step 1 – Ecological Vulnerability
- Step 2 – Fishery Activities
- Step 3 – Management Options
- Discussion (& Next Steps)

Handbook Scope

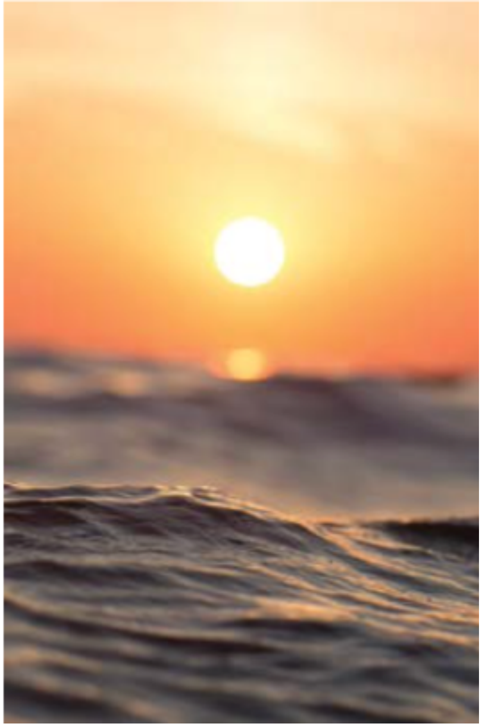
IISD 2016

SCAG 2020

Adaptation has many component steps, from conceptualisation to planning and finally implementation. This project and handbook process only dealt with the conceptualisation, vulnerability assessments and identification of options. Final plan drafting and implementation remains the purview of the individual jurisdictions (as it is subject to agency and policy considerations beyond the scope of the project).

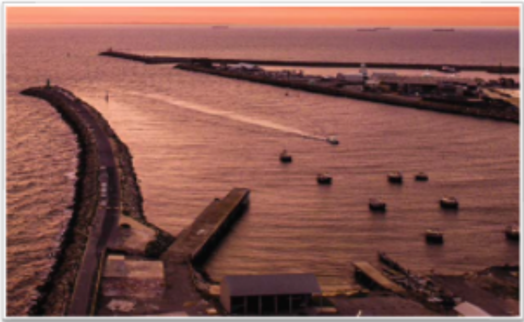
Handbook Development

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



Application

Inclusive – designed to involve committees of industry, management and other stakeholders to come to a more shared understanding of climate risks and develop more robust adaptive management options



Scalable – designed to be applied with differing degrees of detail so that it can be adjusted for the available information and the resources available

Flexible – not limited to the climate-driven risks to ecological components of Commonwealth fisheries, could be applied to other sectors and/or other types of risks

The handbook was created to be inclusive – drawing together researcher, management agency personnel, representatives of the fishing sectors (commercial, recreational, customary as appropriate) and any other interested groups. As the method is largely qualitative (or semi-quantitative) it is easily scalable (it can be used for small scale as regional or nation-wide scales) and can be modified for local contexts or even for use beyond long term climate change to other pressures or shocks (such as extreme events, the pandemic or market shifts).

Co-design and user testing with case studies

1. Northern Prawn Fishery
2. Southern Bluefin Tuna
3. Heard Island & MacDonald Islands fishery

The method was originally designed and trialled with three AFMA managed fisheries. This helped make it useful for operators and managers.

Reaching Recommendations

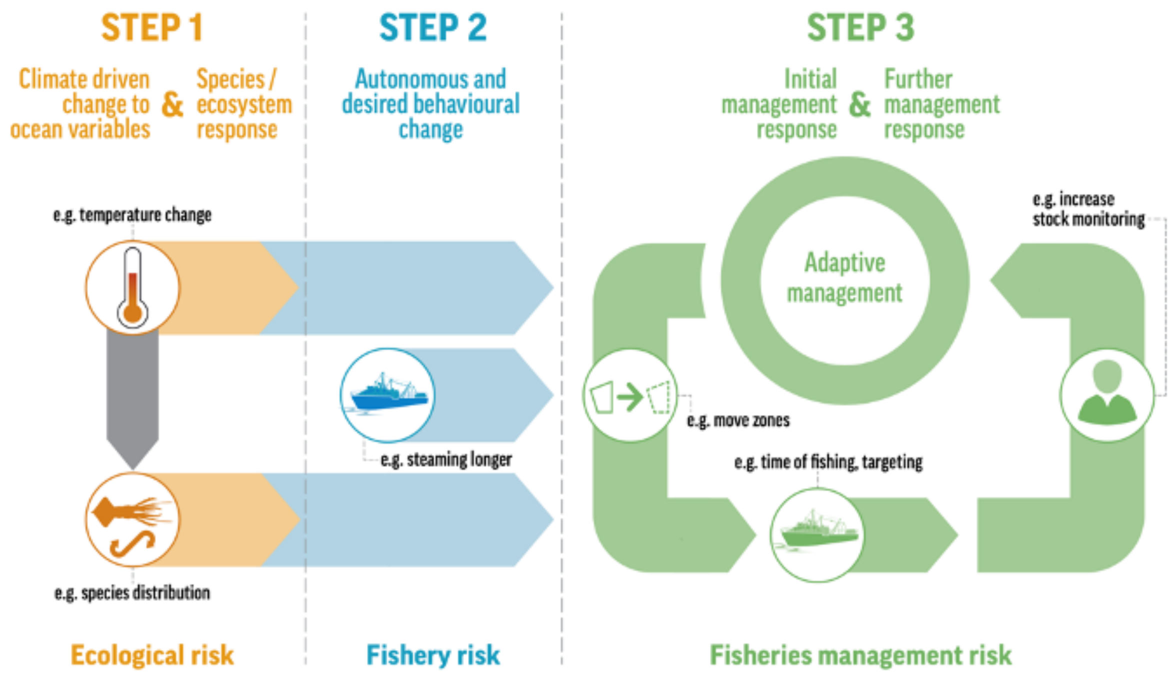
- Recognise hazards (risk factors)
- Identify intervention points (and whether that helps)
- Prioritise options (based on risk/reward/cost)

CONSEQUENCE
How severe could the outcomes be if the risk event occurred?

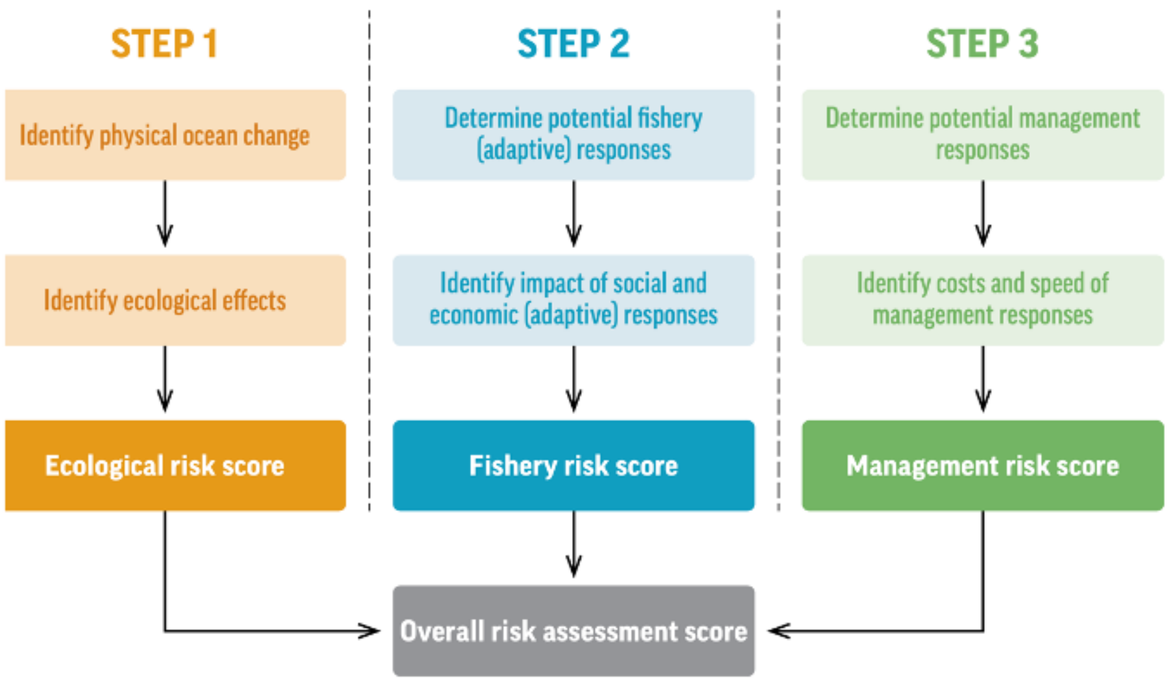
LIKELIHOOD
What's the chance the of the risk occurring?

	INSIGNIFICANT 1	MINOR 2	SIGNIFICANT 3	MAJOR 4	SEVERE 5
ALMOST CERTAIN 5	MEDIUM 5	HIGH 10	VERY HIGH 15	EXTREME 20	EXTREME 25
LIKELY 4	MEDIUM 4	MEDIUM 8	HIGH 12	VERY HIGH 16	EXTREME 20
MODERATE 3	LOW 3	MEDIUM 6	MEDIUM 9	HIGH 12	VERY HIGH 15
UNLIKELY 2	VERY LOW 2	LOW 4	MEDIUM 6	MEDIUM 8	HIGH 10
RARE 1	VERY LOW 1	VERY LOW 2	LOW 3	MEDIUM 4	MEDIUM 5

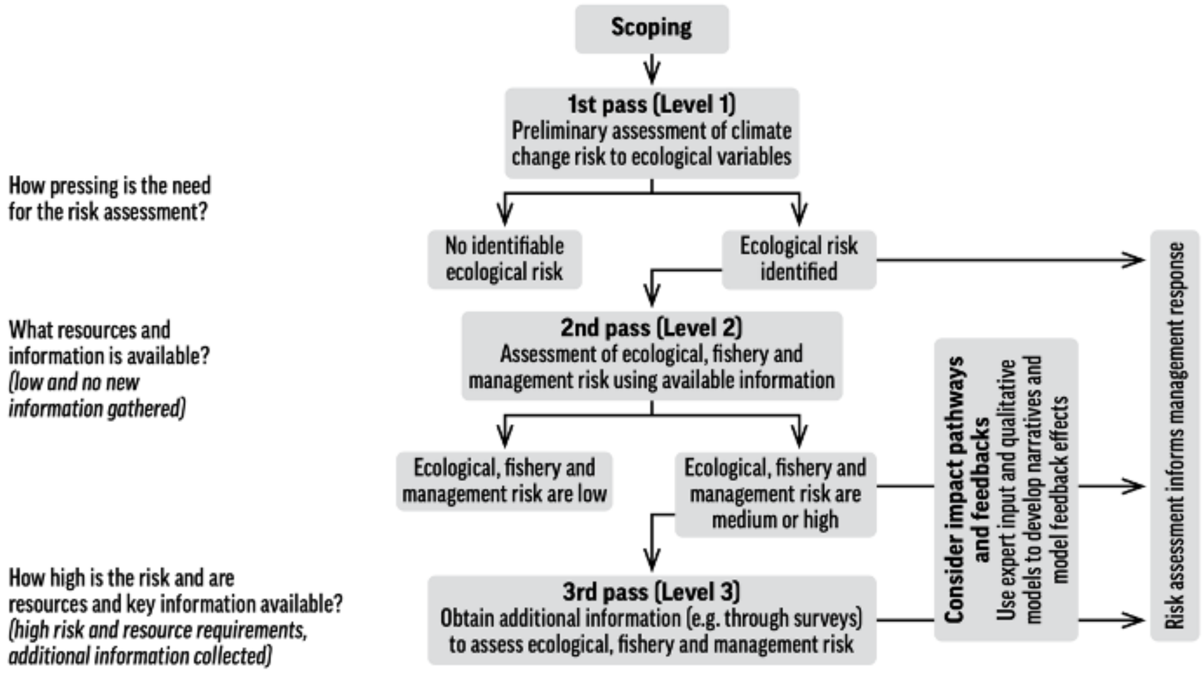
The handbook intentionally stops short of plans and policy because they have many jurisdictionally specific aspects. What it does do is help recognise risk factors, levels of vulnerability and to prioritise possible responses (or gaps to be filled for options to be realised).



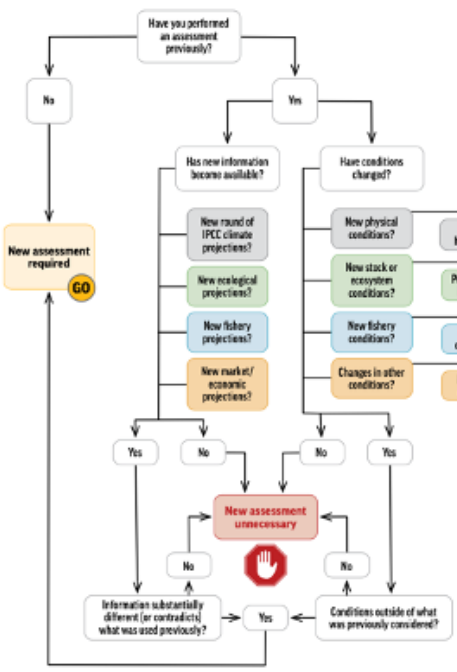
The method involves 3 steps – physical change and how that expresses itself for vulnerable species; what fishers can do operationally to cope with or respond to the change; and what management can do to ensure ongoing sustainability without constraining adaptation options unnecessarily.

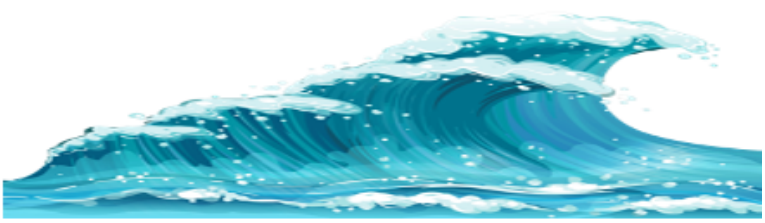


Those three steps are guided via a structured set of questions and conversations.

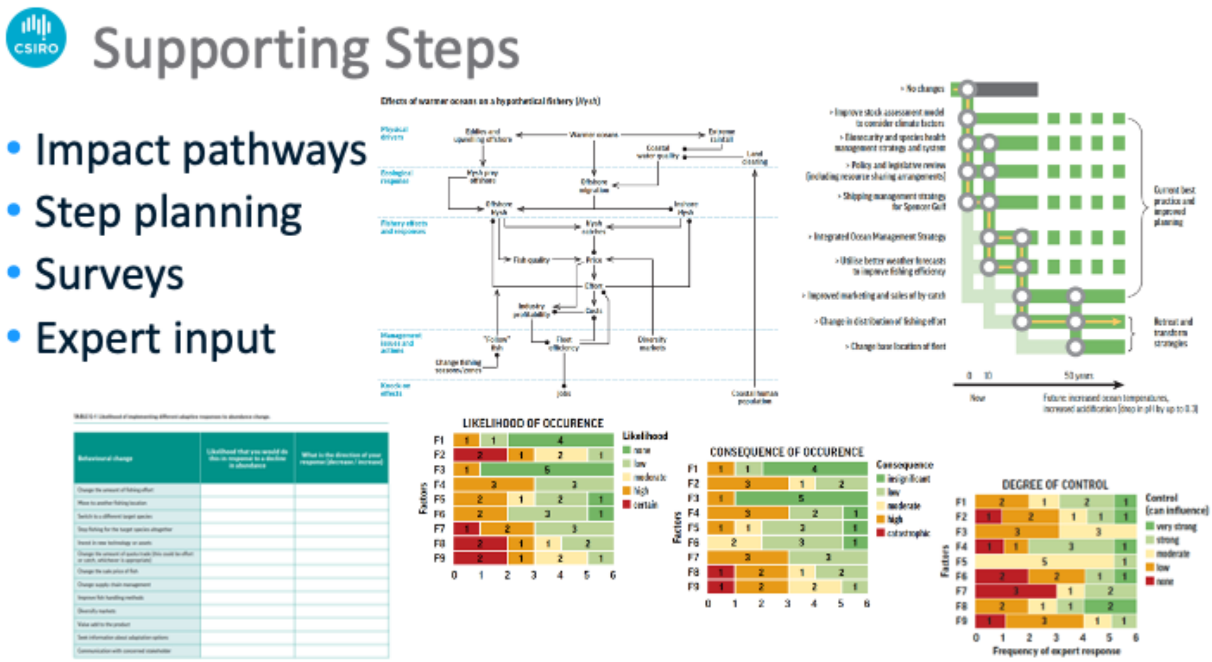


Like Ecological Risk Assessments for the Effects of Fishing (ERAEF) or other best practice risk assessments it takes a triage tiered approach, only progressing to more quantitative approaches for species or systems under the most pressure where very clear quantitative information is needed. The project only deals with the first and second passes. The individual jurisdictions could progress their most high value or at risk species to a full quantitative assessment if they feel the Level 2 assessment completed in the project workshops was insufficient for their needs.





Once an assessment has been completed once, it is not necessary to repeat the exercise until new information comes to light or conditions change. This flow diagram helps identify when a new assessment would be advisable.



There is no one right way to gather the information needed. The handbook describes some of the most useful commonly used tools – including: impact pathways; stepped planning (what can be done in the short term, what has no future, what steps are promising but have a lead time due to requiring preparatory development); surveys or other forms of expert input.

What we learnt

- All AFMA fisheries contain valuable species sensitive to climate change (some of the most valuable showing the greatest sensitivity)
- All fisheries (especially short lived species and invertebrates) likely to become more variable
  - affecting when, where and how much is caught
- Bycatch and TEP species are likely to be highly sensitive to climate change
  - will need to understand how that interacts with any fishing effects

What we learnt

- Shifting ecosystem state (over decades) may go unnoticed, eventually undermining sustainability of fisheries and dependent businesses & livelihoods
- Cross jurisdictional management coordination will be required to improve adaptation & minimise the risks from cumulative effects
- Monitoring & forecast capacity will become key to understanding system change, supporting evidence based decision making, fishery sustainability & business profitability
- Significant implications, both positive and negative, for fisheries (extending from operational issues to community impacts & economic consequences)

Each session would end with a description of the project plan and would welcome any questions on the approach or project.

Conceptual Models and Impact Pathways

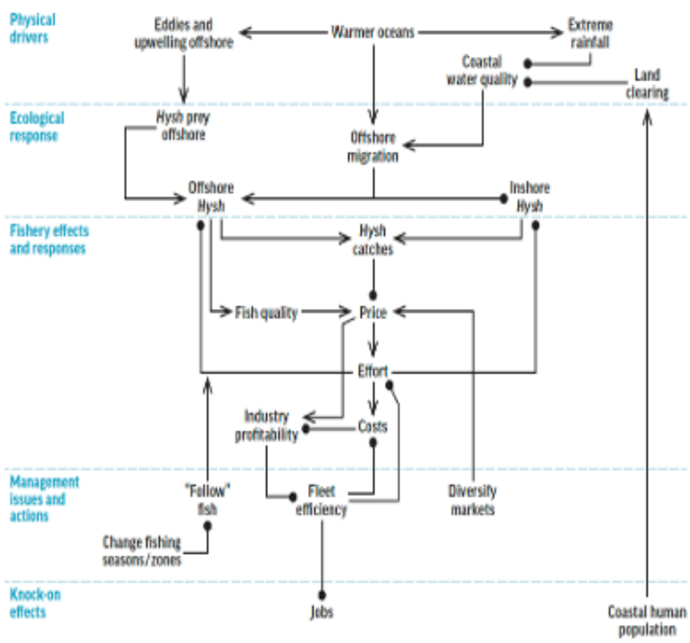
Example conceptual models of generic impact pathways from climate change driven environmental shifts through the fishery were shared to help inspire the trainees before they were asked (as a group) to draw their own conceptual model for their fishery using https://www.mentalmodeler.com.

Conceptual models

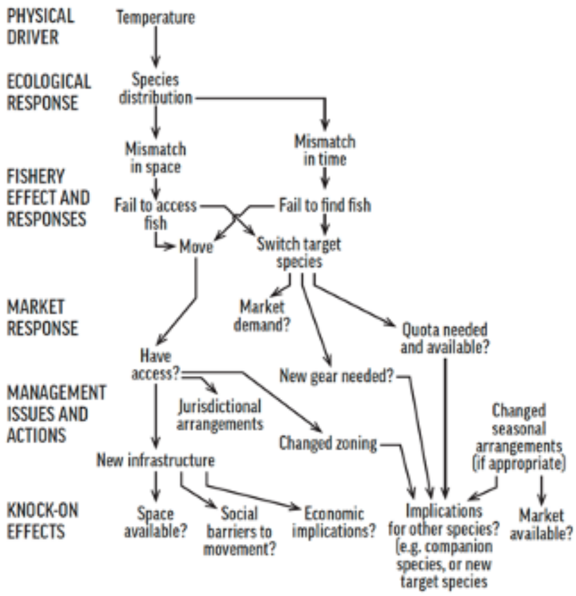
2022

Australia's National Science Agency

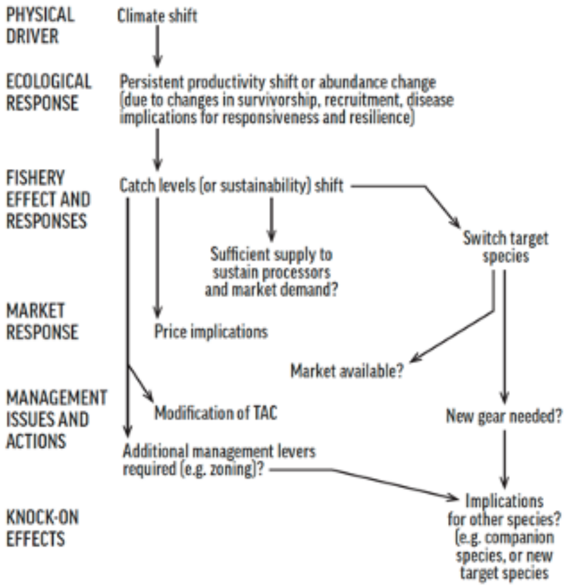
Effects of warmer oceans on a hypothetical fishery (*Hysh*)



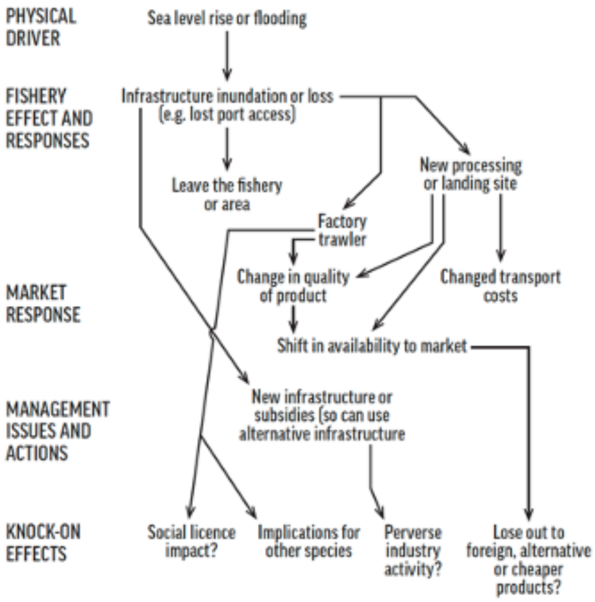
Example (Generic Pathways) - Temperature

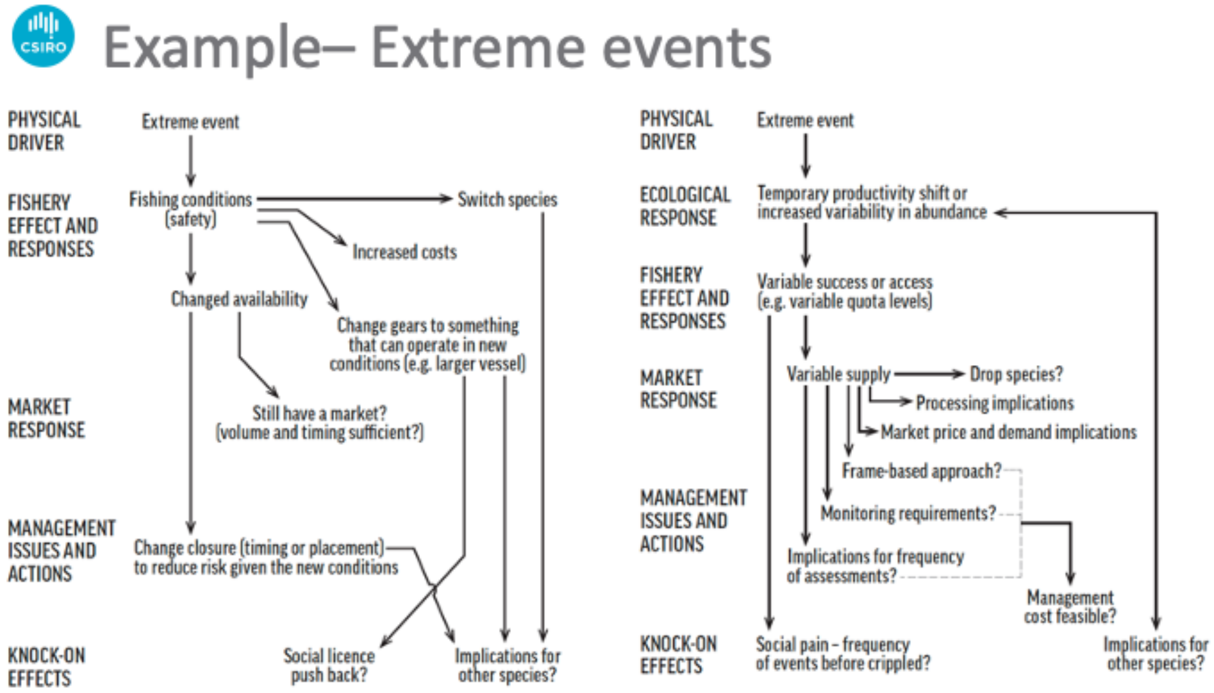


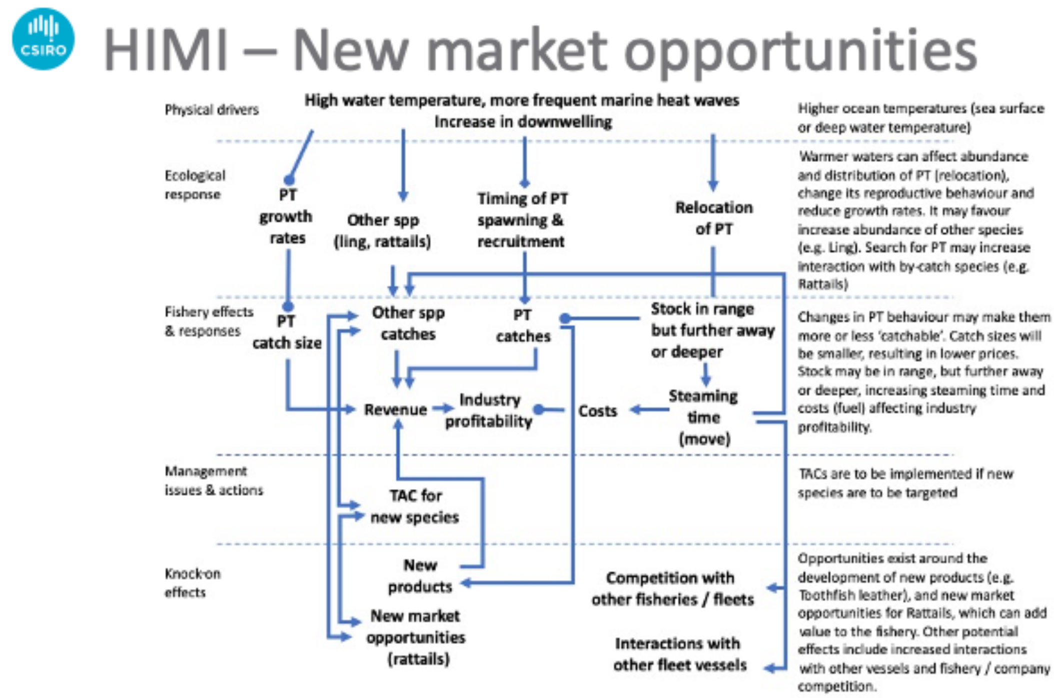
Example – Productivity Change



Example – Sea level Rise







Impact pathways

Another name for these conceptual models is impact pathways

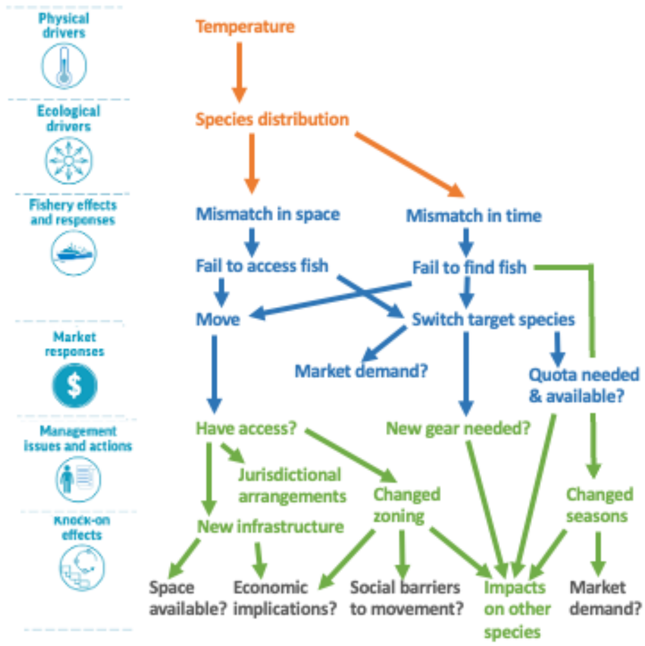
What we will cover in this session

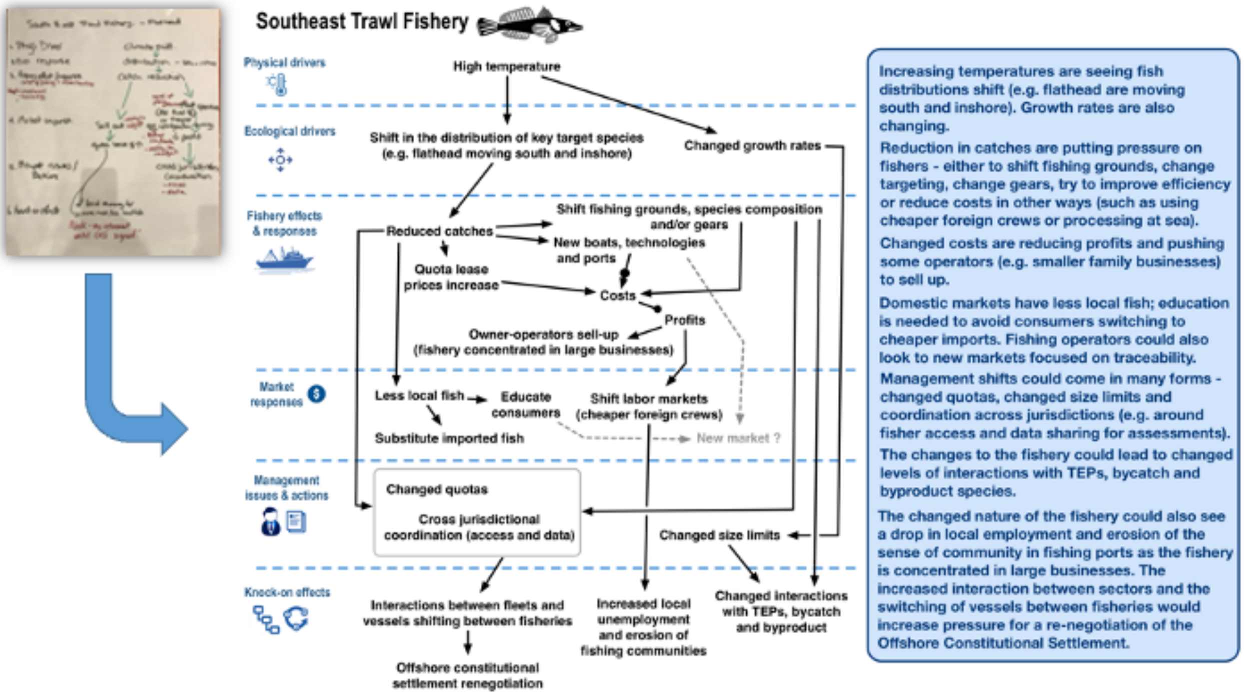
- How is a **fishery** impacted by climate change?
- What are the pathways between **changing climate** and impact on a **fishery**?
- How to identify **pathways**?
- How **impact pathways** relate to this **risk assessment**?

Northern Prawn Fishery - Adaptation of fisheries management to climate change Handbook, CSIRO, 2020

An expert view on how fisheries are impacted

- **Impact pathways** are chains of potential impacts which can tell us about the **full impact of climate change**





How we use impact pathways

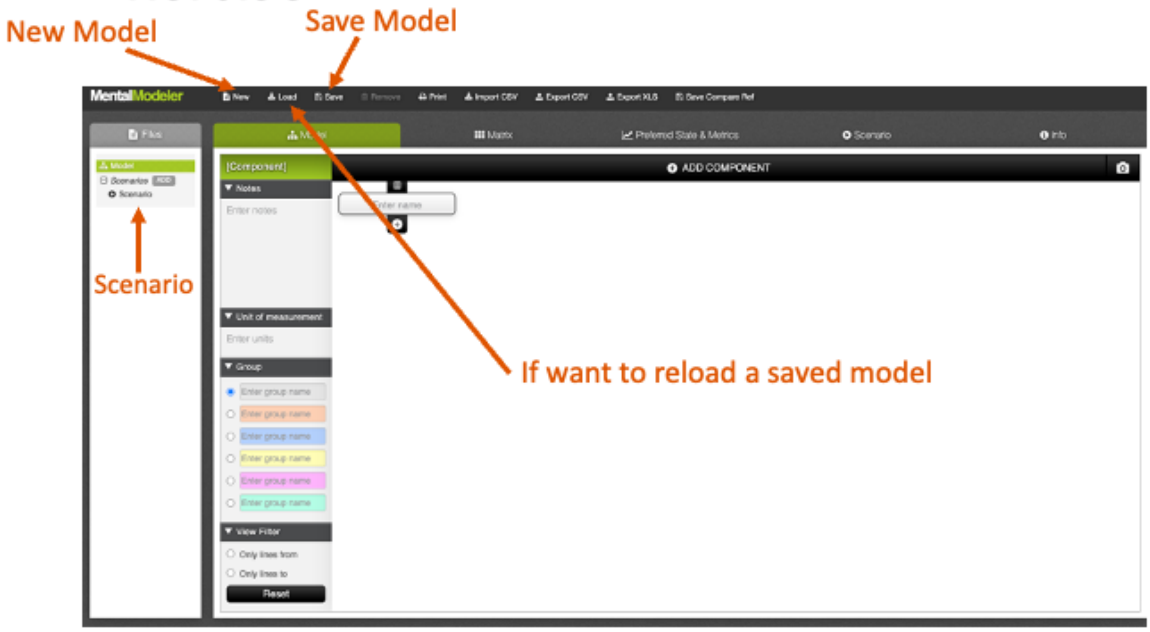
- Real world understanding and degree of consensus among stakeholders
- Develop shared understanding of how climate changes link to different **ecological drivers** effecting fisheries
- Starting place to identify **autonomous adaption responses** by fishers

Adaptation of fisheries management to climate change Handbook, CSIRO, 2020

What kind of materials can be used to create impact pathways or conceptual models? It can be done using pen and paper (or any other writing materials, whiteboard, butchers paper even large “mud maps” literally drawn on a sandy surface). However, as more and more interactions are undertaken online or with digitial infrastructure online tools can also be used. Mental Modeler is one such tool that is freely available.

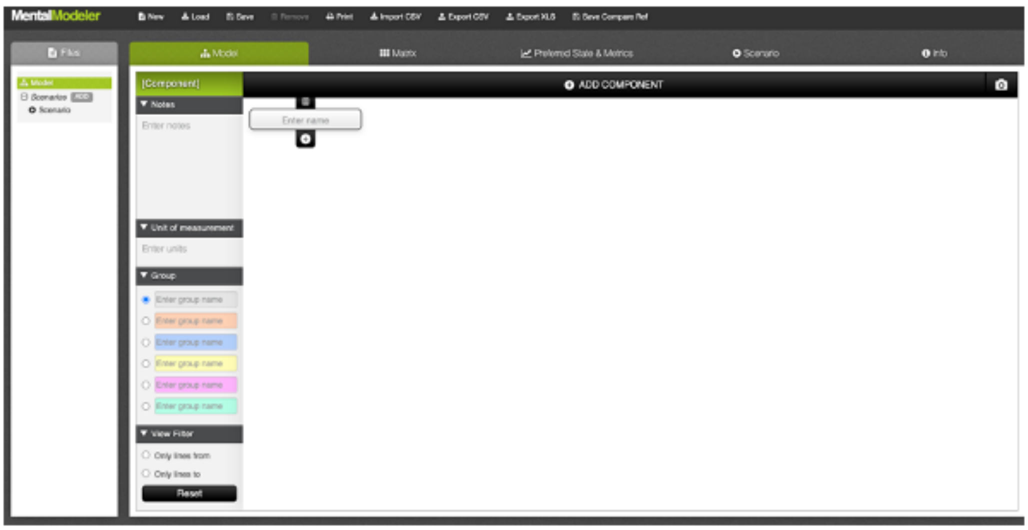
Exercise

https://www.mentalmodeler.com/



Exercise

https://www.mentalmodeler.com/



This is what a blank sheet looks like on mental model – click “Add component” for a new box (variable). Click in the box to name it. The note section and colours on the left of the canvas can be used to take notes on sources of information, uncertainty etc.

Exercise

https://www.mentalmodeler.com/

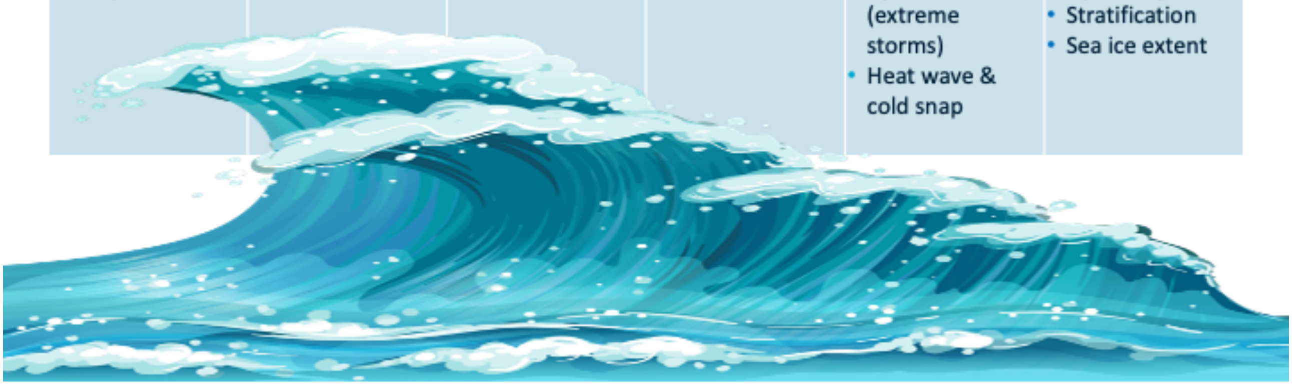
Drag arrows from one box to another and set their weight (from +1 positive to -1 negative) to explain the nature and strength of the connection between the variables. To figure out what those weighting should be image standing on the sending box (let's call it box A) looking at the receiving box (let's call it box B). When the sending box grows (in abundance, magnitude, level of activity) what happens to the receiving box. If the receiving box grows it is a positive weighting, but if it declines (or shrinks etc) then it is a negative weighting. Also think about whether there is a reciprocal response – i.e. repeat the process by standing on what was the receiving box (box B) and looking back at the original sending box (box A), does that box change as a result of a change in the receiving box? If yes create a link and repeat the process, this time standing on box B and looking at box A. For example, imagine a predatory shark and its prey fish, if the number of fish increase there is more food for the shark and it can also increase (a positive sign response). However, as sharks increase they eat more and the prey species are consumed and decline in abundance (a negative sign response).

The matrix of connections can be found on the Matrix table of the mentalmodeller website. Save this matrix and it can be used explicitly in qualitative modelling (as described in the handbook).

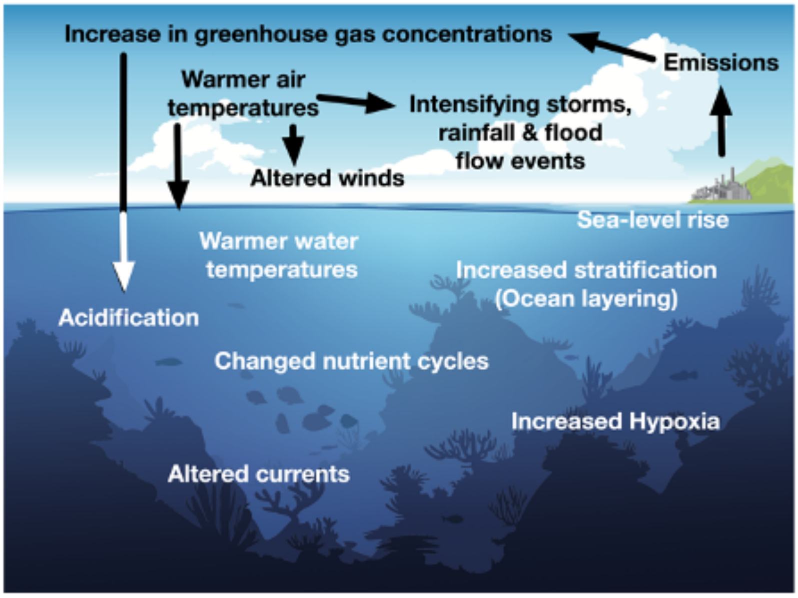
What kind of drivers should be considered in these models?

Drivers: Ocean properties changing

Temperature	Chemistry	Physical	Atmosphere	Extreme Events	Timing & Nature Events
• Sea surface temperature • Deep water temperature	• pH (acidification) • Salinity • Dissolved oxygen	• Sea level • Wave height & direction	• Alongshore wind speed • Air temperature • Rainfall & runoff	• Drought • Flood • Fire • Cyclones (extreme storms) • Heat wave & cold snap	• Seasonal shift • Ocean circulation • Upwelling • Stratification • Sea ice extent



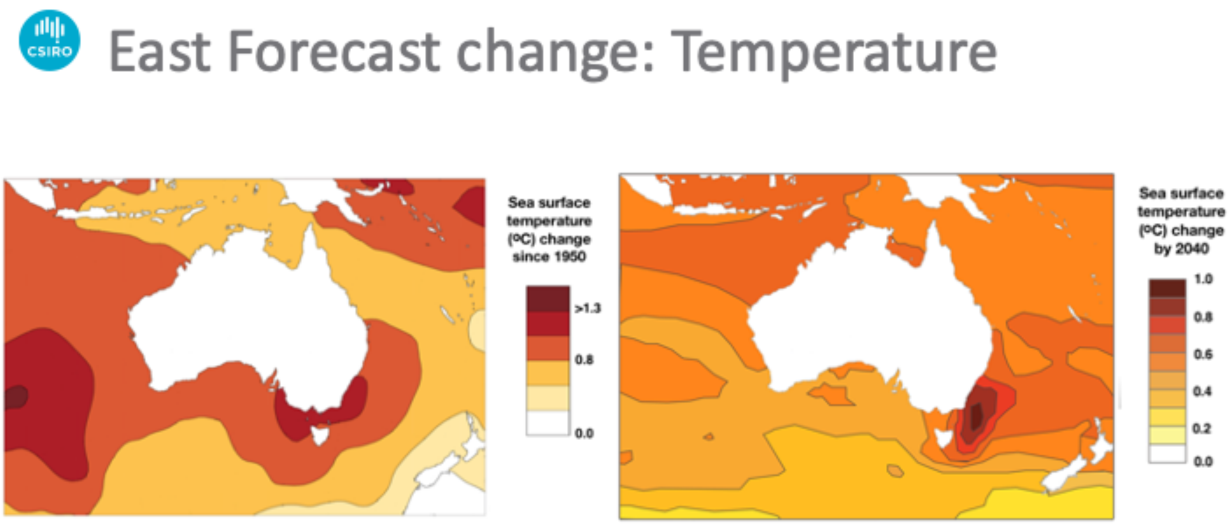
Forecast change



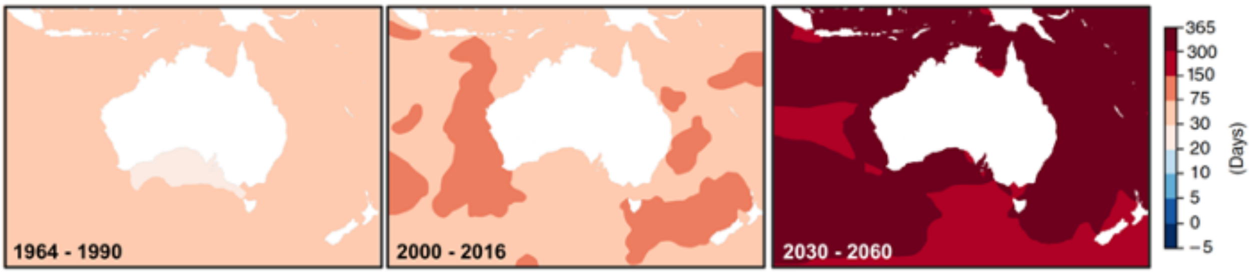
A summary of observed change and forecasts for each region are available on the handbook website (https://research.csiro.au/cor/research-domains/climate-impacts-adaptation/climate-adaptation-handbook/), but are also summarised here for convenience. As these will be updated in future as more information becomes available, please check for more recent information before running your own workshops/processes. For example the fisheries intermodal comparison (FISHMIP) is a source of projections created via a global collaboration. They must be used with care as the models used are not as well focused on Australia as models developed within Australia, but if nothing else is available they are a useful start. An FAO report summarising that work is available at https://openknowledge.fao.org/items/ae42f17d-4685-4c7e-8e3d-424cea16c8d4 with online exploratory tool at https://rstudio.global-ecosystem-model.cloud.edu.au/shiny/FAO_report_shiny/.

A climate change explainer is also available in Appendix C.7 and on you tube https://www.youtube.com/watch?v=A4OIlrEI2R8.

East coast

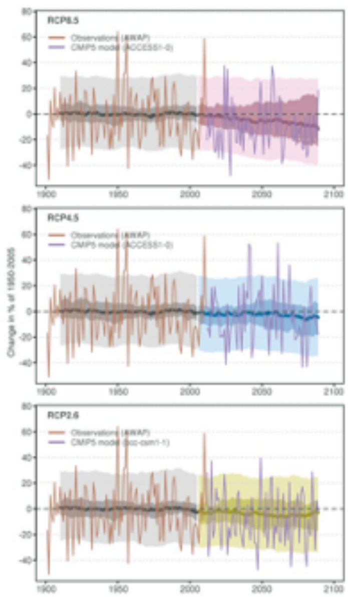


Forecast change: Extreme Events

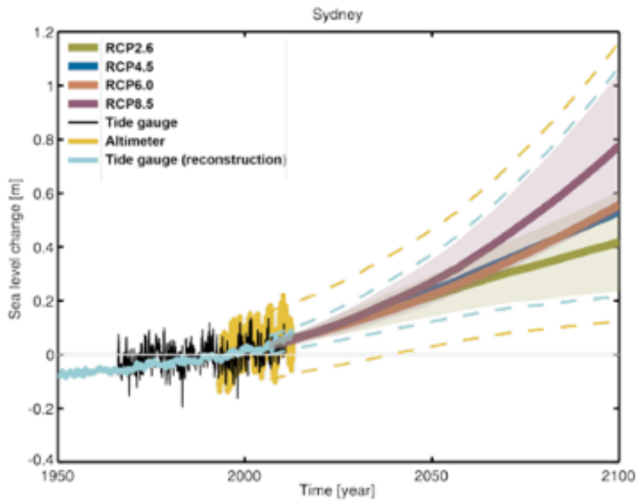


The number of days per year where water temperature exceeds the top 10% of historical temperatures.

Rainfall



Sea level height



Forecast change

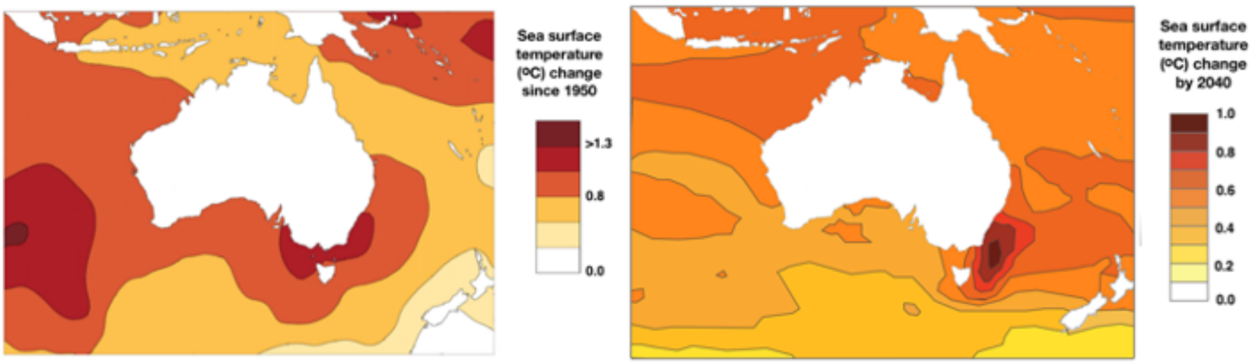
	Observed change (vs 1950)	Future change (vs today)
OCEAN TEMPERATURE	1.0°C increase	0.3 - 1.4°C increase
MARINE HEATWAVE	20 - 35 day increase	>200 day increase
STORMS	Conflicting information	More intense, but fewer
DROUGHTS	Increasing	Longer, twice as frequent
RAINFALL	Roughly steady	3% decrease
SEALEVEL RISE	15cm increase	10 - 20cm increase
OXYGEN	Approx 2% decrease	5% decrease
ACIDIFICATION	26 - 30% increase	20 - 50% increase

Species Vulnerability & Potential Future Change

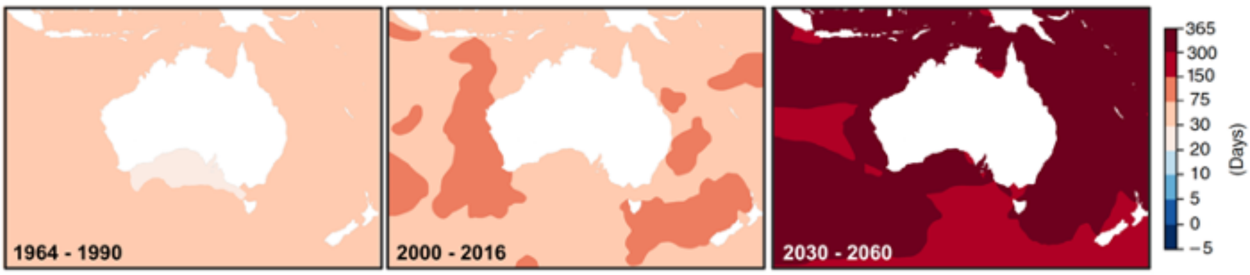
SPECIES CLIMATE SENSITIVITY	22% highly sensitive, 78% moderately sensitive
TARGET SPECIES	Abundance of many key target species decline 20%, Bonnie Upwelling may be more productive

South coast

South Forecast change: Temperature

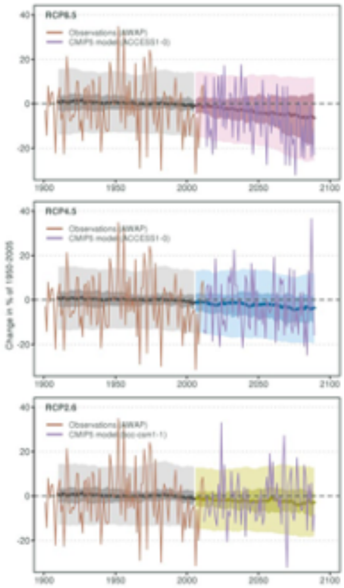


Forecast change: Extreme Events

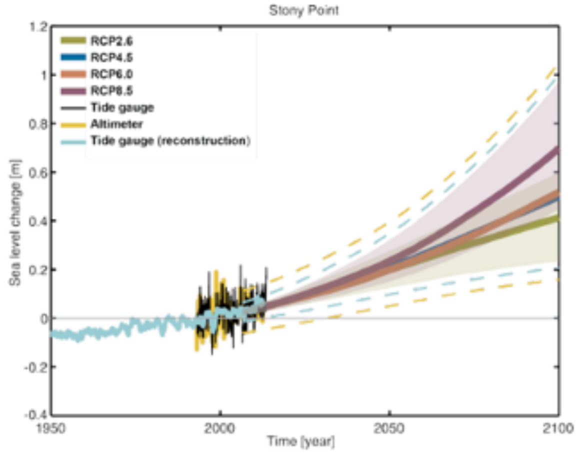


The number of days per year where water temperature exceeds the top 10% of historical temperatures.

Rainfall



Sea level height



Forecast change

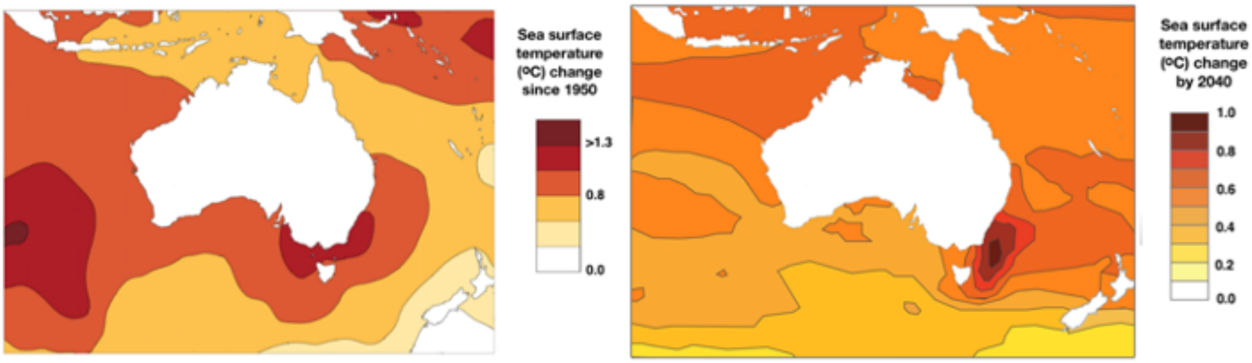
	Observed change (vs 1950)	Future change (vs today)
OCEAN TEMPERATURE	1.2°C increase	0.3 - 1.2°C increase
MARINE HEATWAVE	20 - 35 day increase	>200 day increase
STORMS	Conflicting information	More intense, but fewer
DROUGHTS	Increasing	Longer, twice as frequent
RAINFALL	5% decrease	3% decrease
SEALEVEL RISE	15cm increase	10 - 20cm increase
OXYGEN	Approx 2% decrease	5% decrease
ACIDIFICATION	26 - 30% increase	30% increase

Species Vulnerability & Potential Future Change

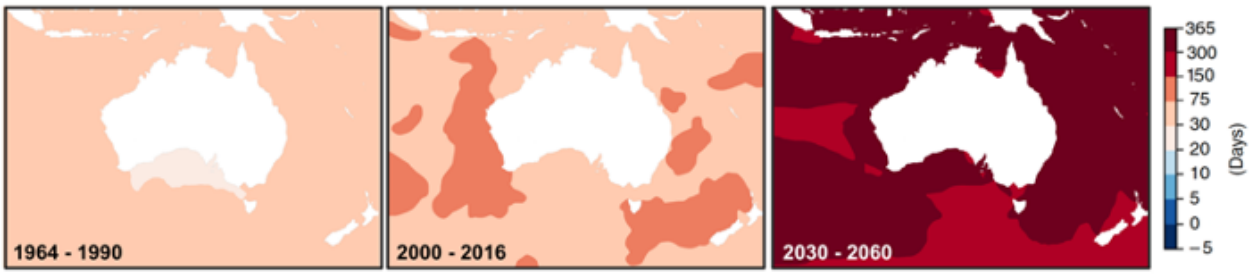
SPECIES CLIMATE SENSITIVITY	20% highly sensitive, 80% moderately sensitive
TARGET SPECIES	Abundance of key demersal target species decline 20%, pelagic species may increase

West coast

West Forecast change: Temperature

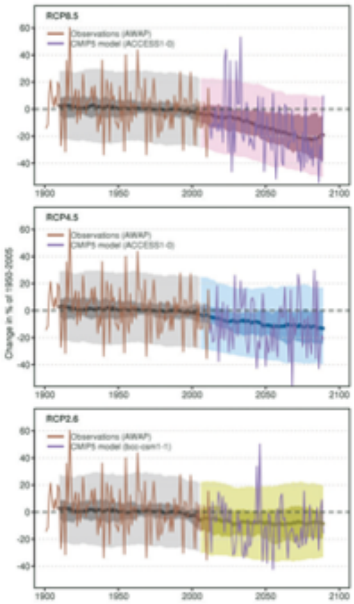


Forecast change: Extreme Events

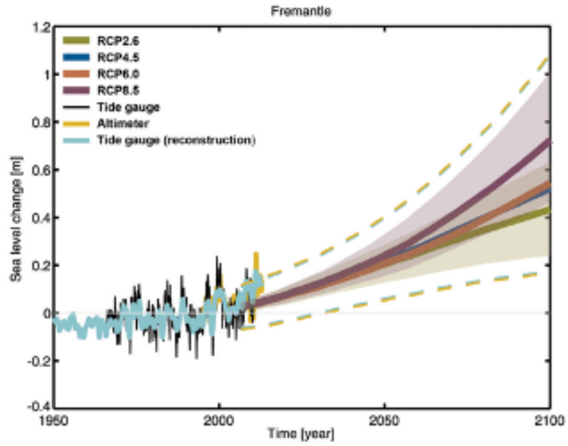


The number of days per year where water temperature exceeds the top 10% of historical temperatures.

Rainfall



Sea level height



Forecast change

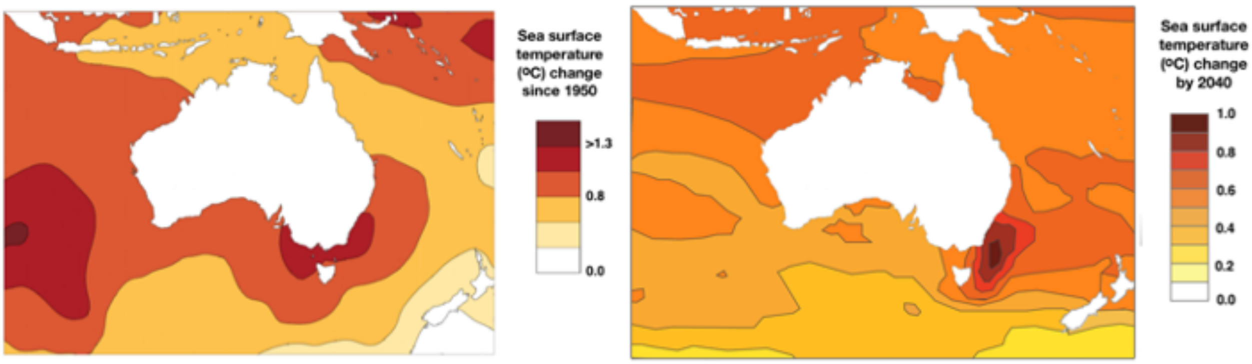
	Observed change (vs 1950)	Future change (vs today)
OCEAN TEMPERATURE	1.0°C increase	0.5 - 1.0°C increase
MARINE HEATWAVE	20 - 35 day increase	>200 day increase
STORMS	Conflicting information	More intense & variable
DROUGHTS	Some increase	Longer, twice as frequent
RAINFALL	9% decrease	3 - 5% decrease
SEALEVEL RISE	20cm increase	10 - 20cm increase
OXYGEN	Approx 2% decrease	5% decrease
ACIDIFICATION	26 - 30% increase	20 - 30% increase

Species Vulnerability & Potential Future Change

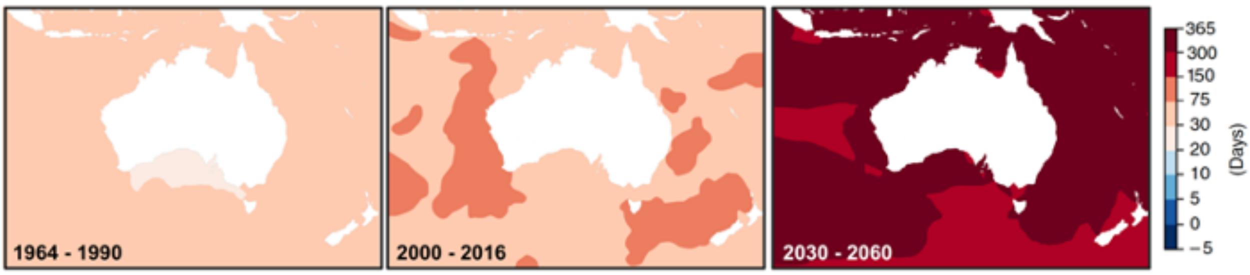
SPECIES CLIMATE SENSITIVITY	35% highly sensitive, 65% moderately sensitive
TARGET SPECIES	Abundance of key demersal target species decline 10-20%, pelagic species may increase

North coast

North Forecast change: Temperature

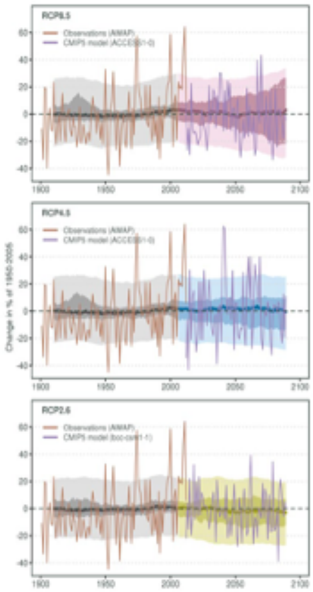


Forecast change: Extreme Events

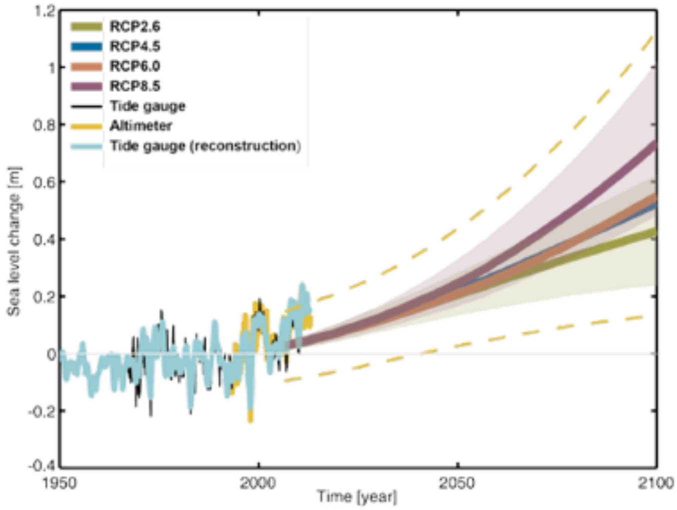


The number of days per year where water temperature exceeds the top 10% of historical temperatures.

Rainfall



Sea level height



Forecast change

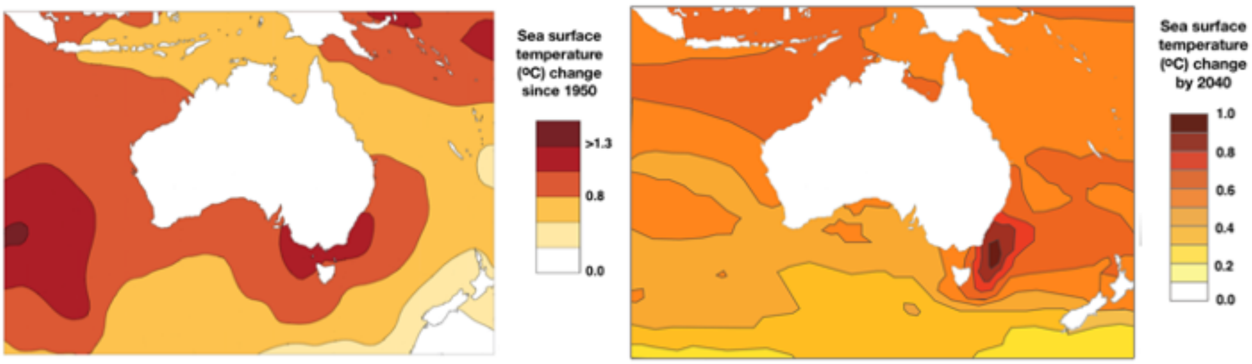
	Observed change (vs 1950)	Future change (vs today)
OCEAN TEMPERATURE	0.6 - 0.8°C increase	0.6 - 1.0°C increase
MARINE HEATWAVE	15 - 20 day increase	>200 day increase
STORMS	Conflicting information	Stronger & more variable
DROUGHTS	Shorter, more intense	Longer, twice as frequent
RAINFALL	Roughly steady	Roughly steady
SEALEVEL RISE	20cm increase	20 - 40cm increase
OXYGEN	Approx 2% decrease	5% decrease
ACIDIFICATION	30% increase	20 - 120% increase

Species Vulnerability & Potential Future Change

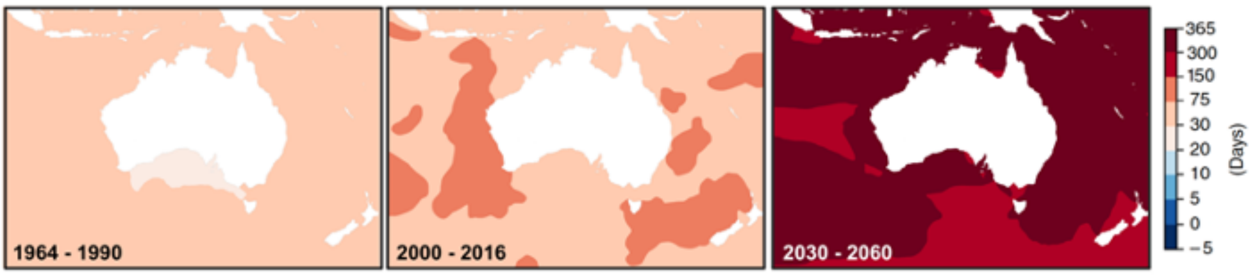
SPECIES CLIMATE SENSITIVITY	>35% highly sensitive, 55% moderately sensitive
TARGET SPECIES	Abundance of key target species decline 10-20%

Northeast coast

Northeast Forecast change: Temperature

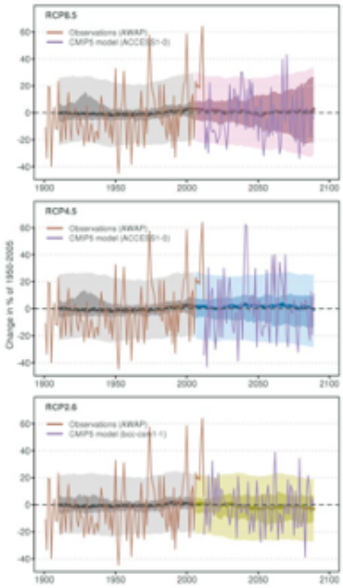


Forecast change: Extreme Events

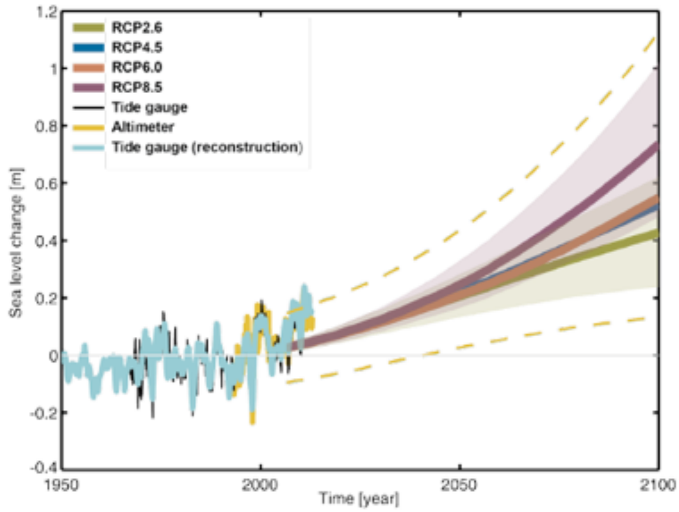


The number of days per year where water temperature exceeds the top 10% of historical temperatures.

Rainfall



Sea level height



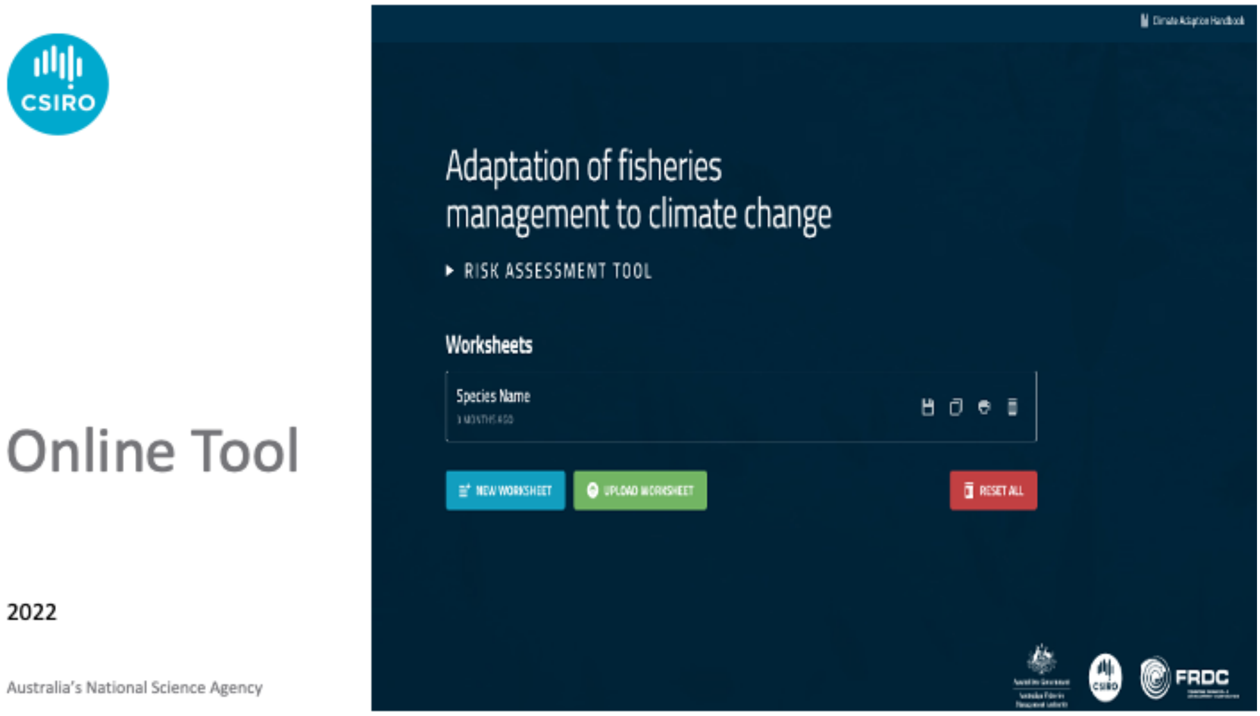
Forecast change

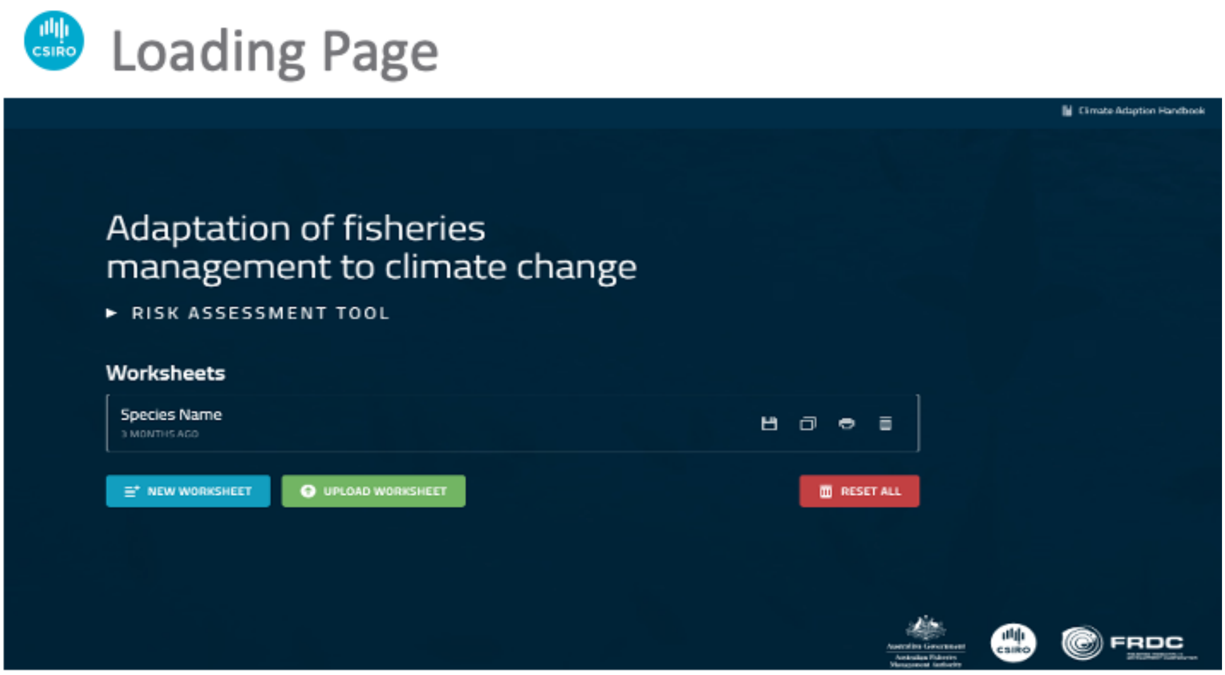
	Observed change (vs 1950)	Future change (vs today)
OCEAN TEMPERATURE	0.6 - 0.8°C increase	0.6 - 1.0°C increase
MARINE HEATWAVE	15 - 20 day increase	>200 day increase
STORMS	Conflicting information	Stronger & more variable
DROUGHTS	Shorter, more intense	Longer, twice as frequent
RAINFALL	Roughly steady	Roughly steady
SEALEVEL RISE	20cm increase	20 - 40cm increase
OXYGEN	Approx 2% decrease	5% decrease
ACIDIFICATION	30% increase	20 - 120% increase

Species Vulnerability & Potential Future Change

SPECIES CLIMATE SENSITIVITY	>35% highly sensitive, 55% moderately sensitive
TARGET SPECIES	Abundance of key target species decline 10-20%

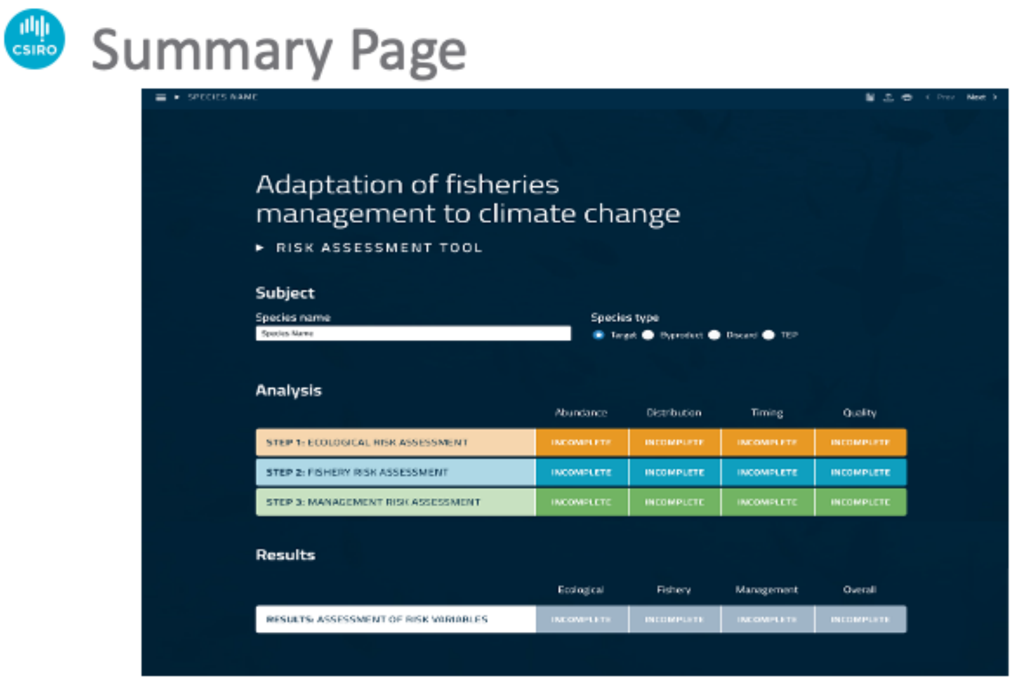
Introduction to the Online Tool





Note that nothing is stored on the site, it is only in your browser so to keep it for the future please save the file (using the save button) so you can reload (using the upload button) in future if needed. There is also a delete option for unwanted worksheets. Typically a worksheet will remain active (accessible) until the browser cache is cleared.

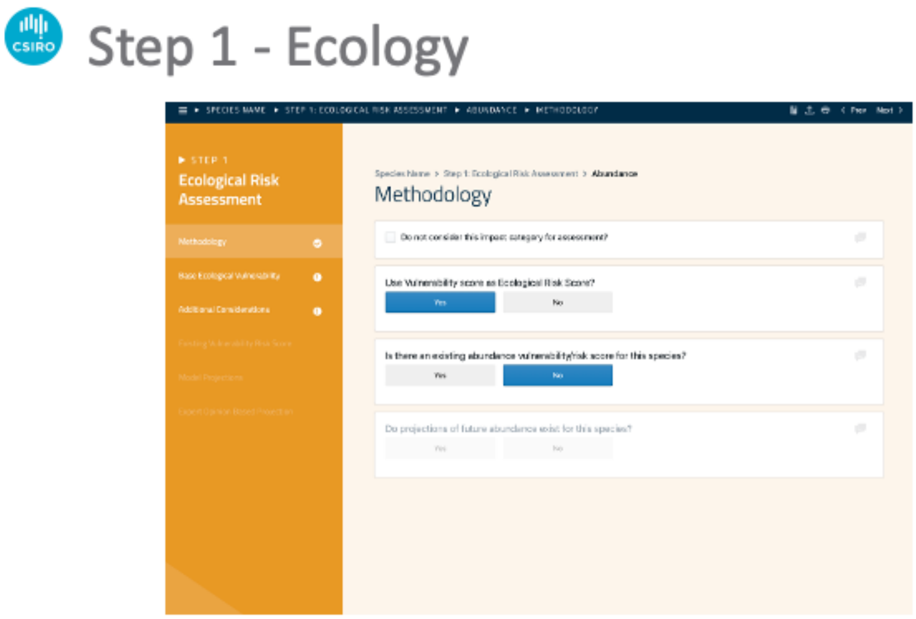
A link to the handbook website is also included for quick reference.



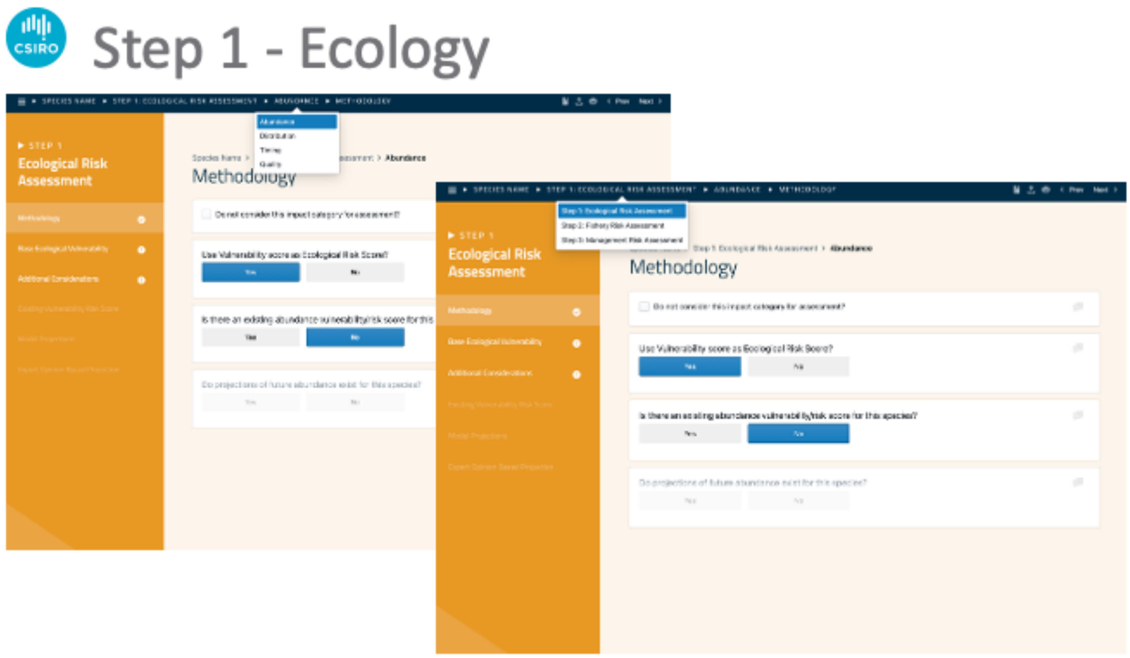
Please enter the name for your species. Select what kind of species it is for your fishery (e.g. target) and then click on each step and answer the questions until each panel reads complete. The resulting risk will be summarised on the results panel.

A pdf report version of the questions, answers and results can also be generated using the report button in the top right.

A link to the handbook website is also included for quick reference.

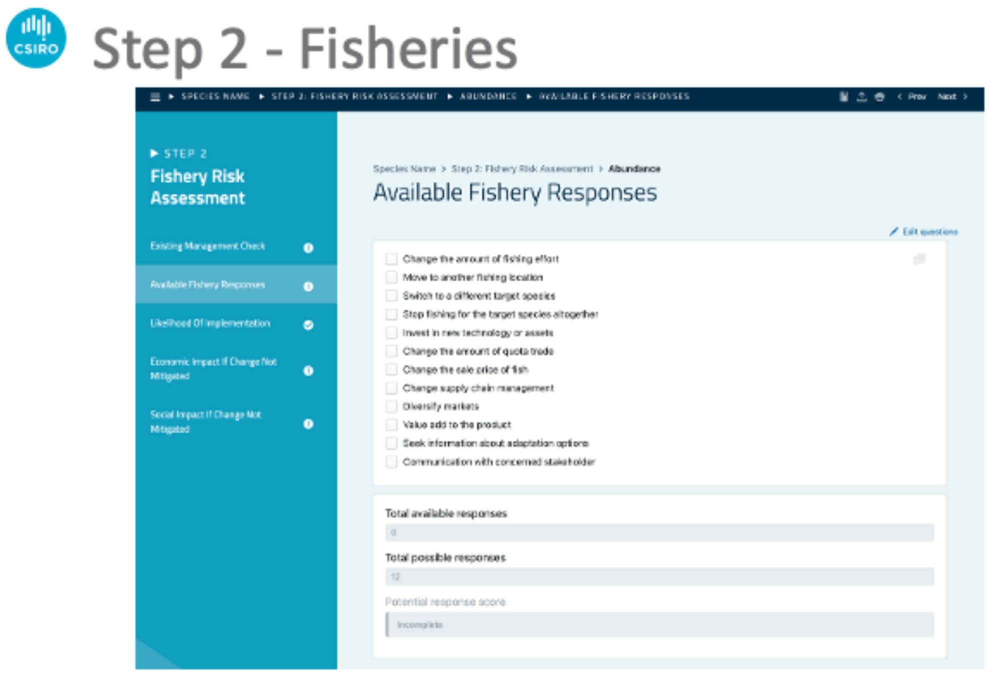


If an there already exists a vulnerability assessment or quantitative projections you can simply enter the results of that previous work. You only have to answer all the vulnerability questions in step 1 if no previous assessment exists. Notes on responses at any step of the tool can be stored by clicking on the speech bubble/comment icon (which opens up a comment dialog box).

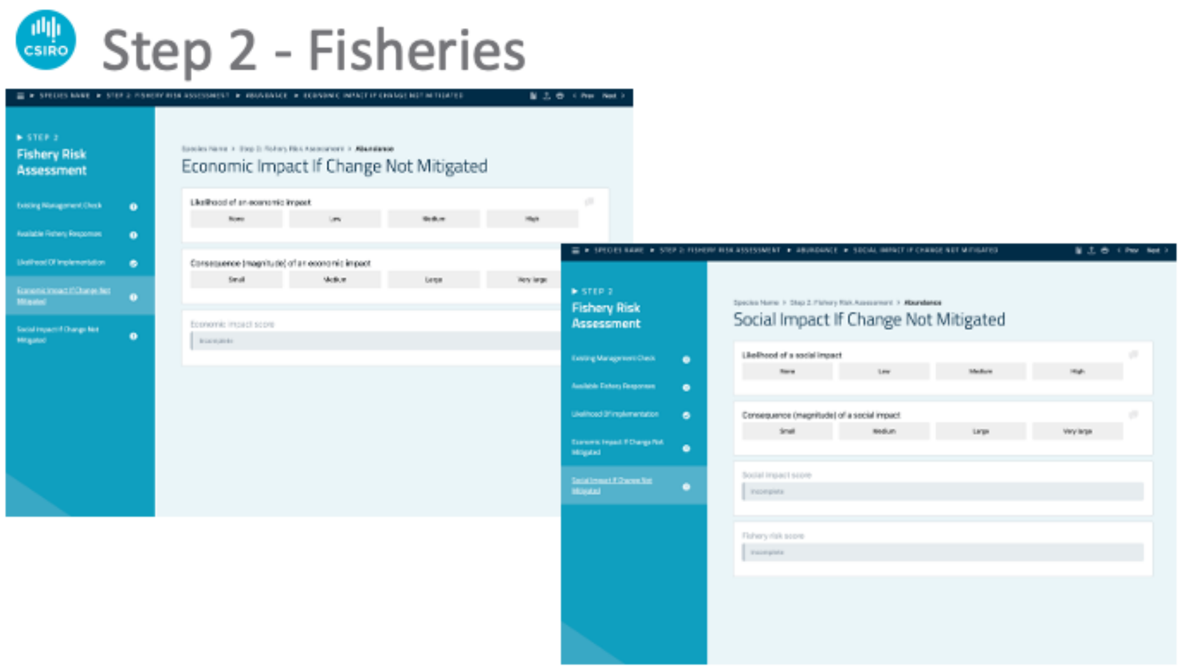


You need to answer questions relating to factors influencing abundance, distribution, phenology (timing of life history events like reproduction or migration) and quality (condition of the species).

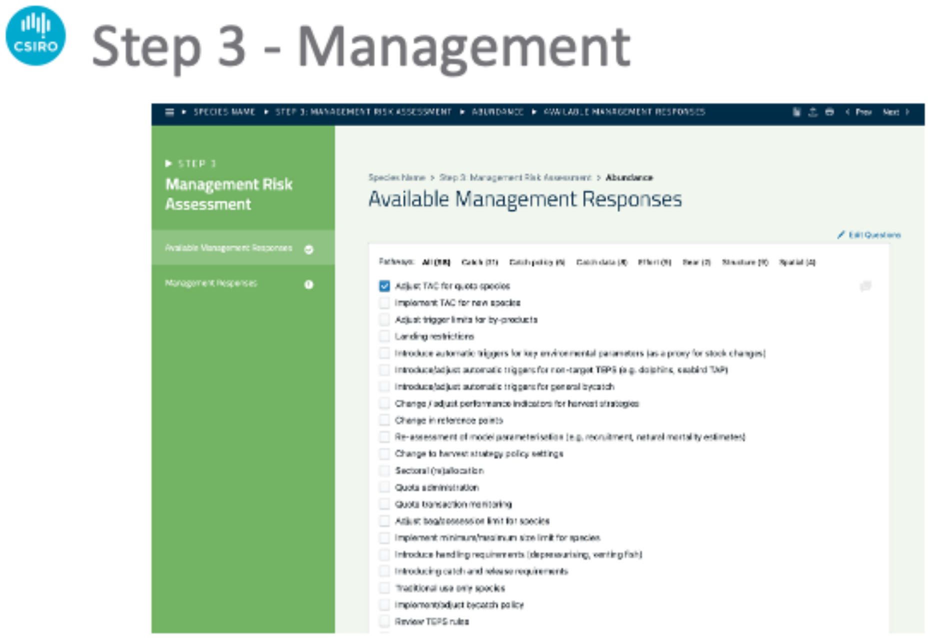
As a section is completely answered a tick will be shown on the left hand panel. Use the next buttons or tab links to move through the assessment.



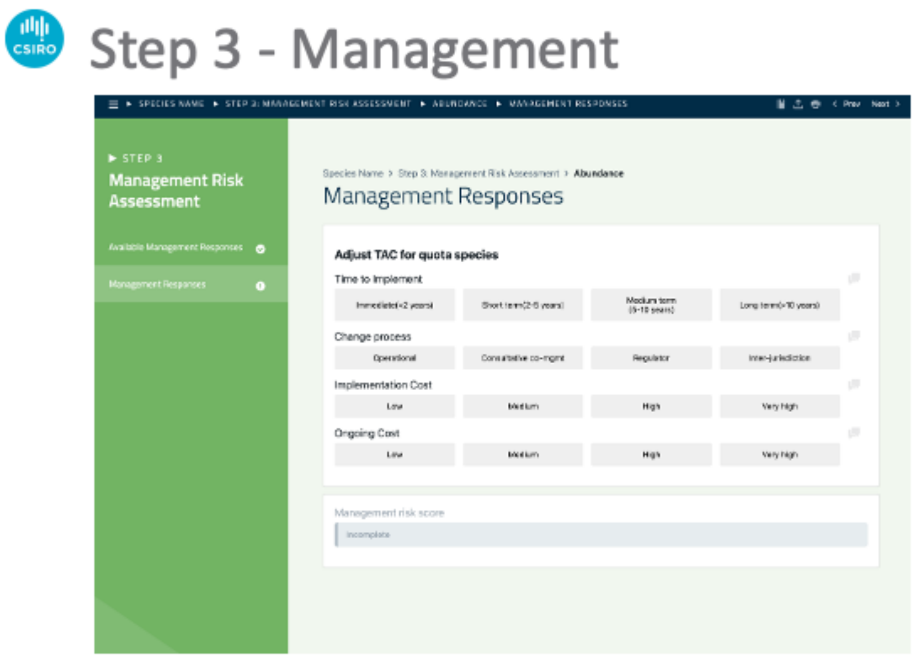
There are also sheets for fisheries operations (not that additional options can be added using the edit button and these will flow through the entire set of questions). Only remove an option if it is absolutely impossible. If its just difficult please leave it as having an idea of what proportion of options are difficult is important for determining a more faithful risk score.



Economic and social implications also need to be recorded

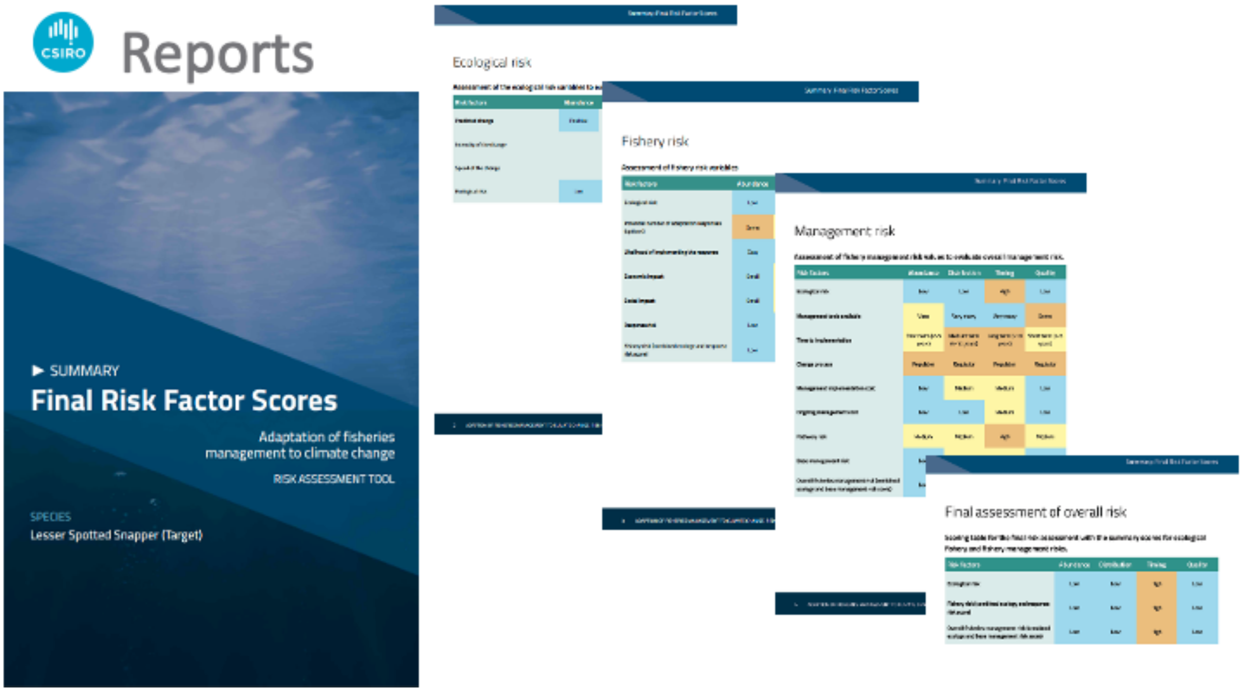


As for the fisheries options, management options can be added (or removed if impossible or not appropriate for that kind of fishery). Because there are so many management options these have been grouped by theme to make them easier to navigate and consider.



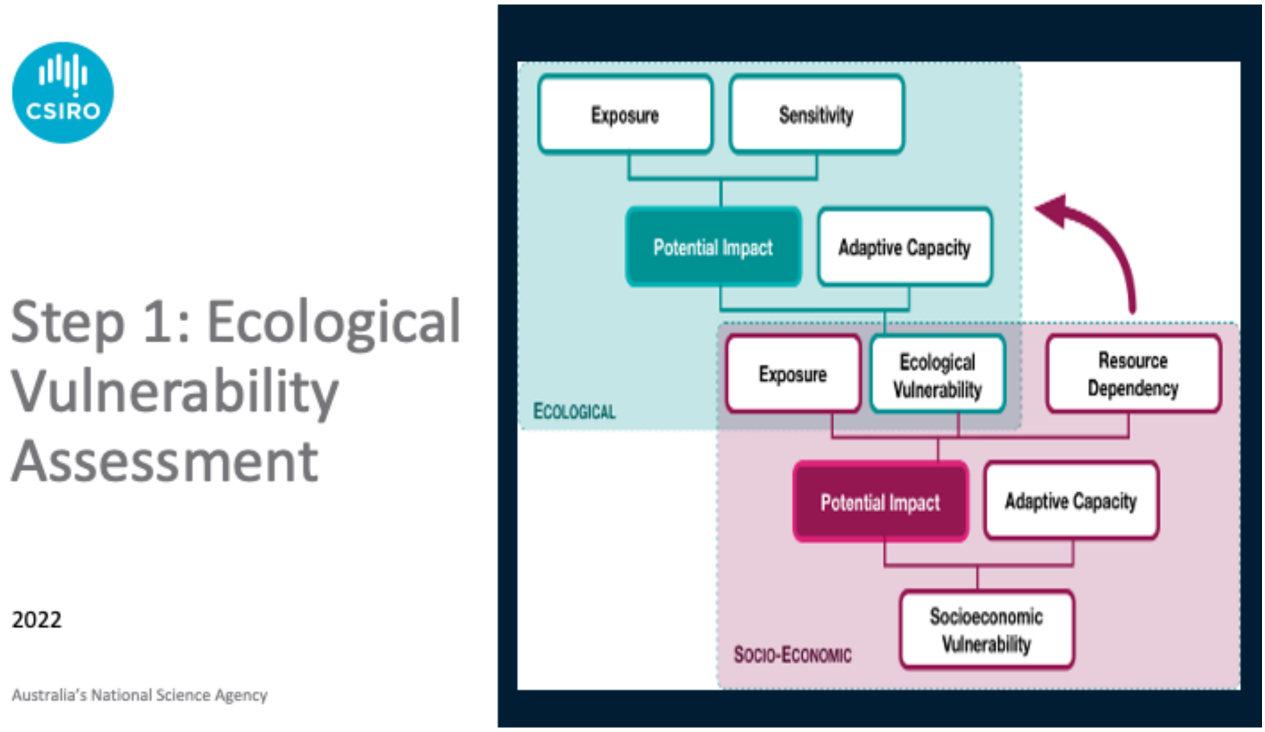
For each management option please rate the time to implement, the costs and policy steps involved in achieving that kind of management or management change.

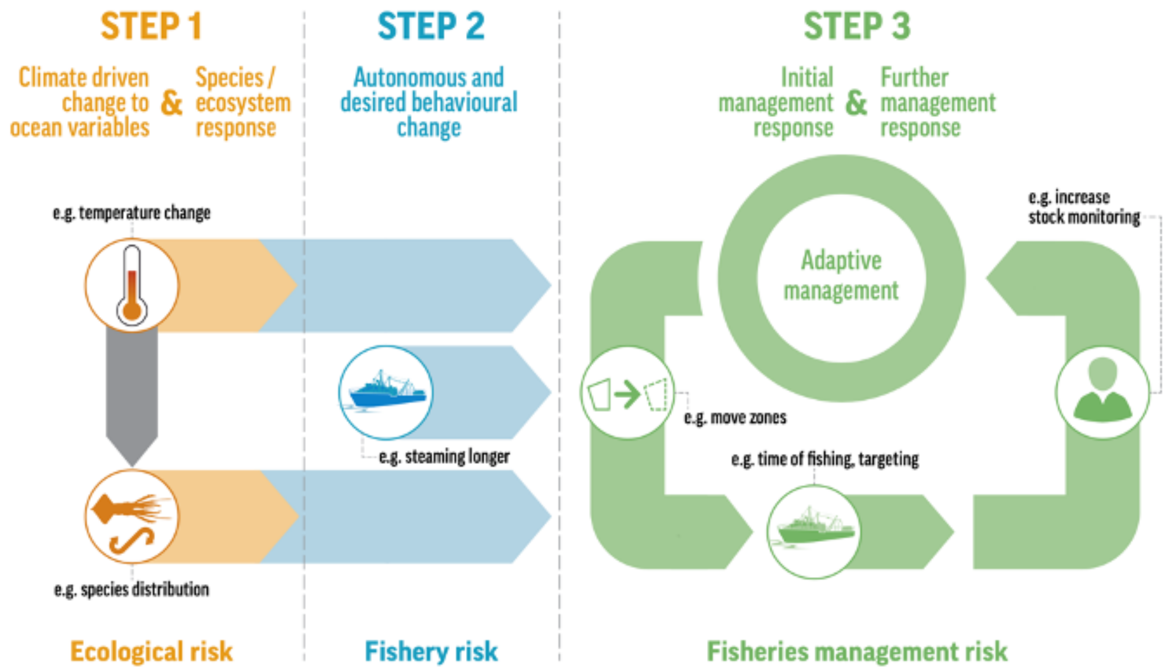
Reports



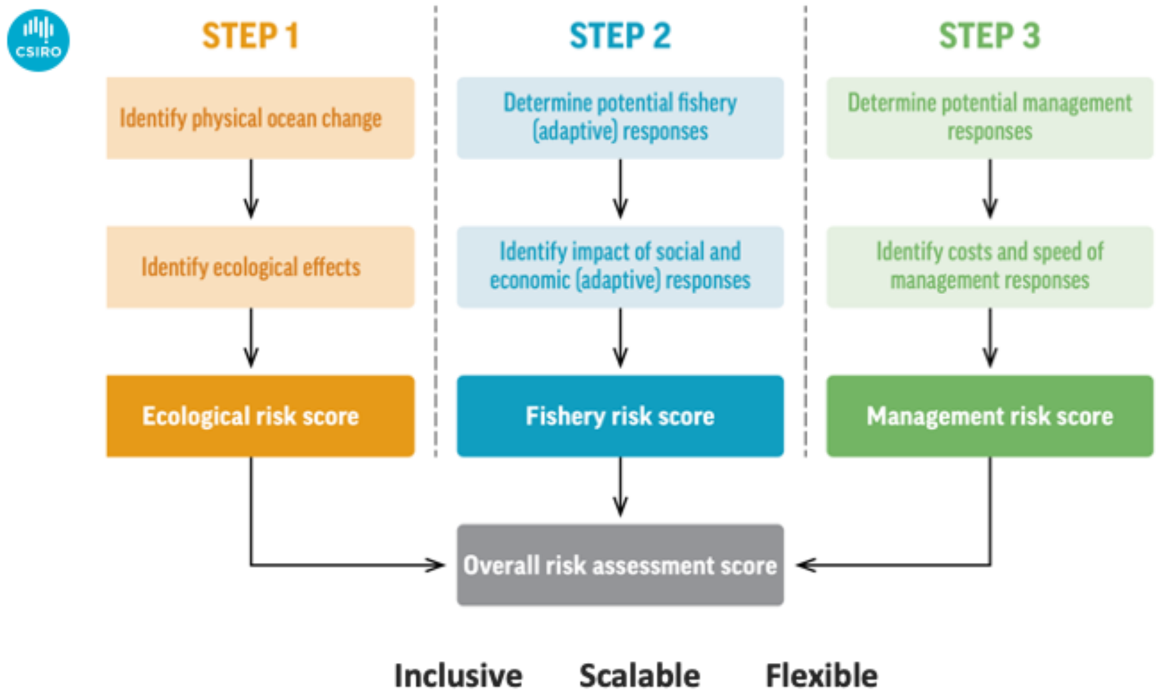
PDF formatted reports can be generated for the entire assessment or individual steps. These will include any comments made in the comments dialog boxes. It is possible to generate combined reports across species by generating the report from the loading page (which will give you an option to select the species to include).

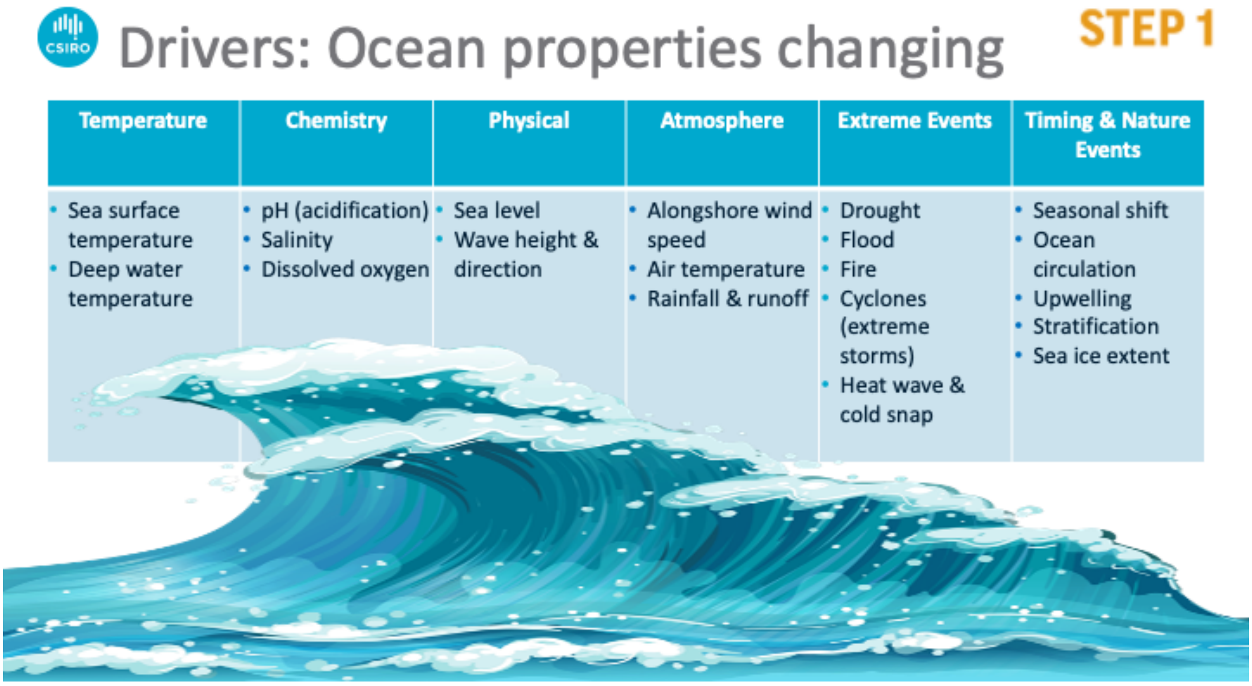
Appendix C.4 – Ecological step





This presentation begins with a brief introduction to the concept of exposure, sensitivity, adaptive capacity and ultimate vulnerability. It also reminds people of the structure of the handbook process.





Step 1 is to gather information on physical changes anticipated for your system.

Ecological responses

STEP 1

Abundance	Distribution	Phenology	Physiology/Quality
• Fecundity • Recruitment period • Average age maturity • Generalist vs specialist	• Larval dispersal • Juvenile/adult movement • Tolerance (preferred conditions) • Spatial availability of habitat	• Enviro. as cue for reproduction • Enviro as cue for settlement • Temporal mismatch (e.g. with food) • Migration	• Fat and muscle content • Body size • Metabolic capacity • Physiological tolerance & response curve • Activity level • Metabolically costly activities • Efficiency of uptake & energy conversion • Disease/parasite load

Ecological responses to be considered cover things that can influence abundance, distribution, phenology (timing of life history events) and physiology (which sets the condition of the spcies and its product quality).

Abundance

Based on Pecl et al 2011

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

For each factor score the species based on which category best matches the characteristics of that species (e.g. low sensitivity if it has >20,000 eggs, high if it has <100 eggs etc.)

Based on Pecl et al 2011

Distribution

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)
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

Based on Pecl et al 2011

Phenology

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)
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

New aspect

Physiology/Quality

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)
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)

Most of the factors considered have been included since vulnerability assessments began (over a decade ago), but more recently physiology has been added as it influences product quality (important in a fisheries context).

Risk factors	Levels	Abundance	Distribution	Phenology/ timing	Quality
Predicted direction of change	Positive (good) Negative (bad) Absent				
Intensity of the change	Very large Large Medium Small				
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				

STEP 1

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

If an assessment already exists note what kind of change that is on the risk table. Otherwise note the overall response from answering the questions in Step 1, with the time frame matching the speed of expected physical change.

Then the results for a hypothetical fishery are presented to demonstrate the process

Abundance

A_D Watching brief as currently abundant

A_B Observed trend = increasing

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 (A_B)	100-20,000 eggs per year	< 100 eggs per year (A_D)
		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 (A_B)	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

A_T Have a direct population estimate (from assessment model) so skip the table
Projection: No abundance change within the next 2 decades

Where T = target species, B = bycatch species, D = discard species

Example - Hypothetical

D T Q

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 (A_T)

Distribution

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)
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 D_T	2 - 8 weeks	< 2 weeks or no larval stage
		Capacity for adult/juvenile movement	> 1,000km D_B D_D	10 - 1000 km	< 10 km
		Physiological tolerance	>20° latitude D_B	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

Example - Hypothetical

T Q

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 D_T	Low	None A_T

Phenology

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)
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 T_B T_D	Weak correlation of spawning to environmental variable	T_T 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

Example – Hypothetical

Q

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 T_T	Medium	Low	Low	None
More than 10 years	High	High	Medium	Low D_T	Low	None A_T

Physiology/Quality

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)
Physiology'	Changes in the quality of the species.	Fat and muscle content (capacity for energy storage)	High fat and muscle content (capital breeder)	Intermediate (Q_B)	Low energy storage (income breeder)
		Body size	Large (> 100 cm) (Q_D)	Medium (between 20 and 100 cm)	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 (Q_T)	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)

Q_T Observed increasing quality of product

Example - Hypothetical

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 (Q_T)	None
Next 5-10 years	High	High (T_T)	Medium	Low	Low	None
More than 10 years	High	High	Medium	Low (D_T)	Low	Non (A_T)

Example – Hypothetical (Target species)

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

Questions on the process are then taken to make sure everyone is comfortable with the approach.

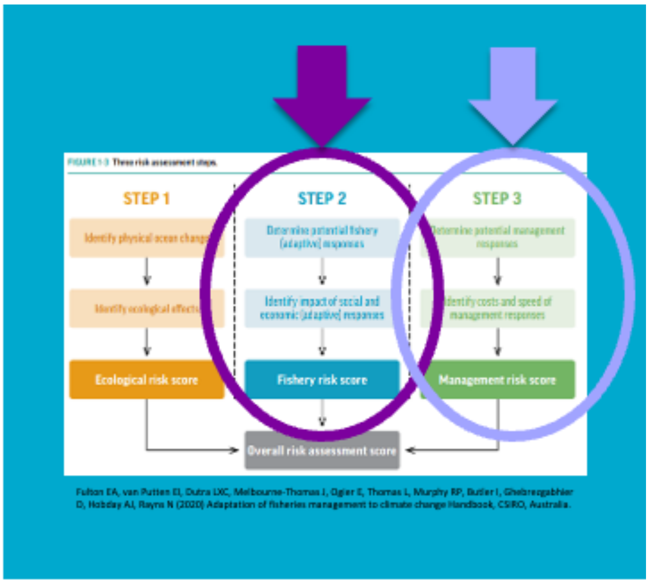
Fishery and Management Responses

CSIRO

Climate change risk to fishery and management

Prepared by:
Emily Ogier & Ingrid van Putten

Australia's National Science Agency



Australian Government
Australian Fisheries Management Authority
UNIVERSITY of TASMANIA
IMAS
FRDC
CMS

What we will cover in this session

- What is the climate change risk to the **fishery**?
- What is the risk made up of?
- How to assess the risk
- How to record the risk
- Repeat the above for **management** risk

Adaptation of fisheries management to climate change Handbook, CSIRO, 2020

Link to the ecological risk assessment

Ecological risk assessment tells us the risk that climate change poses to a species
The species might be affected in terms of changes in
Abundance **Distribution** **Physiology (quality)** **Phenology**

Ecological risk was assessed in term of three aspects of change

1 - Direction
2 - Intensity
3 - Speed

Direction → / Intensity → / Speed ↓	Negative				Positive	Absent
	Very large	Large	Medium	Small		
Next 2 years						
Next 2-5 years						
Next 5-10 years						
More than 10 years						

Link to the ecological risk assessment

What **can** fishers actually do?

What are the available adaptive response?

Lets say we have a large negative change in the next 2-5 years

Adaptive responses for a fishery

What are adaptive responses (that are allowed)?

- Initial adaptation responses can take place within the **bounds of the current regulations** and are referred to as **autonomous** adaptations.
  - For example – change in distribution might mean that fishers will follow the fish to this new location (not breaking any rules)
- These **behavioural adaptations** can take place prior to, and **independently** from, any management actions

Available adaptive responses

From the literature & other studies we found that fishers have done the following:

- Change in fishing effort
- Move to another location
- Switch species
- Stop fishing
- Invest in new technology
- Etc

Not all responses are going to apply across change in **abundance**, **distribution**, **timing**, and **quality**

But there are likely to be others that we have missed

In the App:

Four risks aspects of adaptive responses

Available responses

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

Implementation

If it is **more difficult** to implement the **risk is assumed to be higher**. 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.

Economic impact and Social impact

Higher costs are assumed to pose **higher risks** 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. Socially an example might be a loss of social licence and employment impacts.

To really know the response – ask the fishers

Determine adaptive responses

To really know the response – ask the fishers

Not easy because of survey fatigue!!

Handbook has three example surveys that gather increasing levels of information

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

Survey A gather information on the possible and **likelihood** of *adaptive responses*.

Survey B is like A but also provides a basic indication of the **likelihood** of *economic* and *social impacts*.

Survey C (is intended to be implemented in addition to survey A or B) 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).

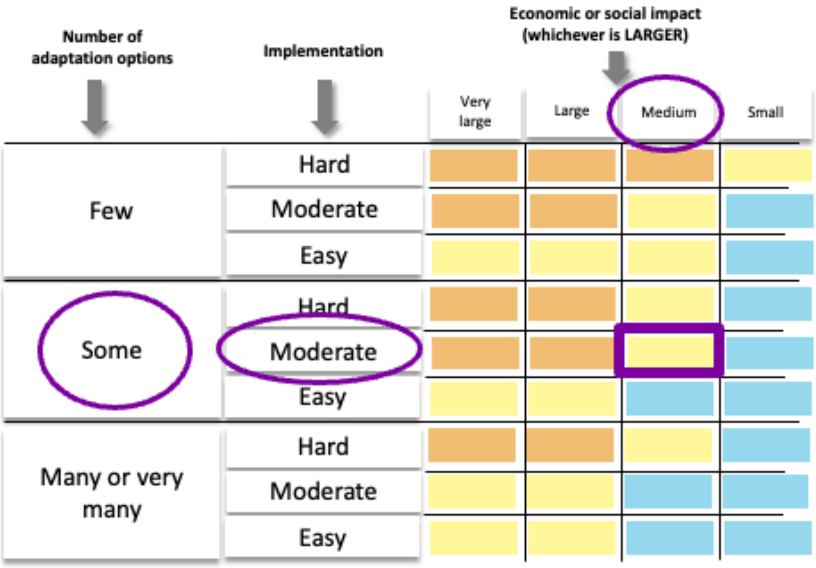
Risks associated with adaptive responses

= Response risk

There might be many or few **ways in which a fisher can respond** (if you have few that means higher risk)

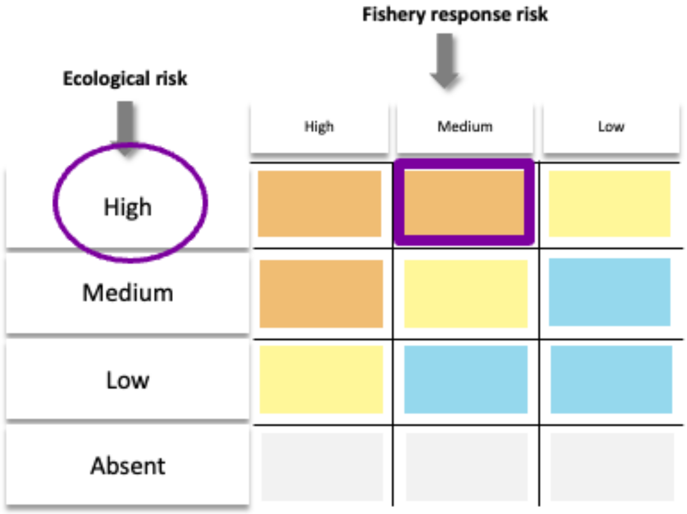
Even though there is a way to respond the fisher might not be likely to do it because it is difficult to **implement** (this means higher risk)

The **economic** and **social** impact of the ecological change might be very large or small



Combine fishery risks and ecological risk

= Fishery risk



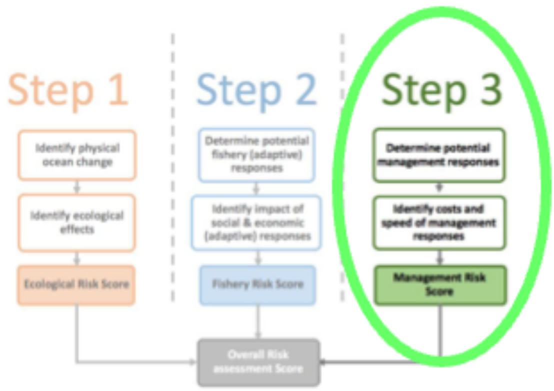
Response options for a fishery – role of management

Some adaptive responses might not be allowed but are desirable?

This means that some **management aspects** might have to be changed

For example – change in distribution might mean that fishers are no longer allowed to catch the fish that have moved into another management zone

For this reason we also want to look at **management risk**



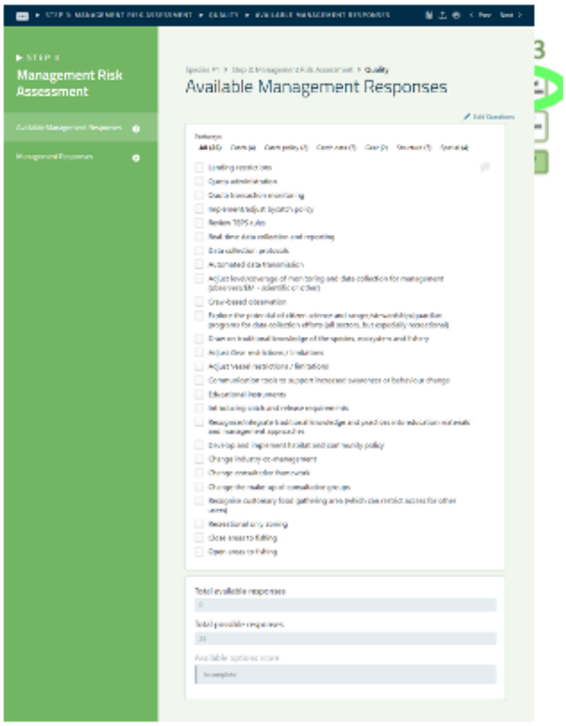
Response options for management

What does management have in the toolbox?

- Operational management
- Performance management
- Communication and information
- Strategy and policy
- Cross cutting

There is a long list of things

In the App.:



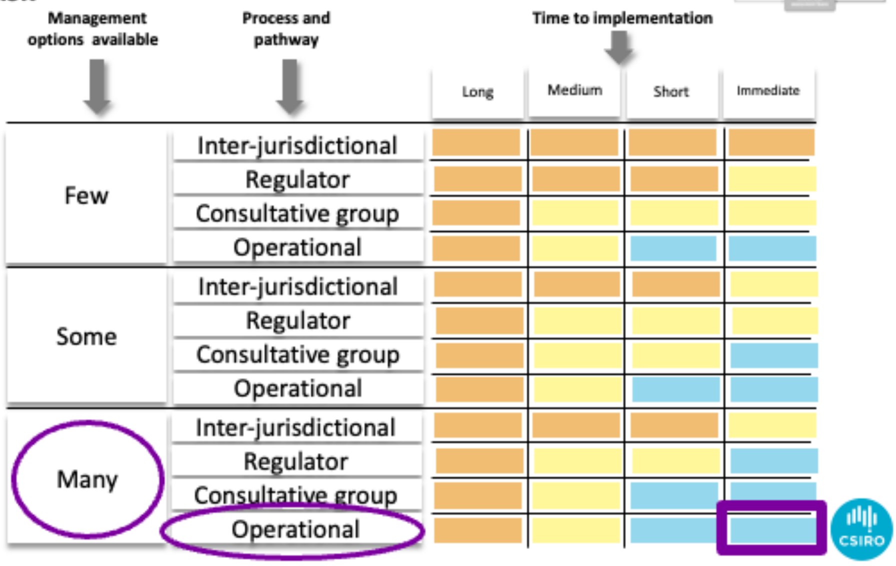
Five risk aspects of management options

Management tools available	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**
Time to implementation	The **more time required** until the management change can be implemented to address ecological change **the greater the fishery management risk**. Changing regulatory processes is likely to take longer than change using operational instruments.
Change process	The **more complicated or large scale the process**, the more levels of administration involved, the **higher the perceived management risk.** There are four levels of change process – operational, consultative (co-management) groups, regulatory or inter-jurisdictional; each has a different consultation process. Changes to regulations will have to go to public consultation and will risk being delayed or not gain social licence. Inter-jurisdictional is most risky as it involves many steps and potentially quite large numbers of people.
Management implementation cost	The **higher implementation costs** are associated with **higher levels of management risk**. Some implementation costs may, for instance, be very high because they require a large investment in staff and resources (or large R&D programs).
Ongoing management cost	Like implementation cost, the **higher the relative ongoing cost** the **greater the management risk**

Response risk for management options

Two steps in determining the management risk

= Management Pathway risk



To asses the **Management Pathway risk:**

- Management options availability
- Change process (Process and pathway)
- Time to implementation

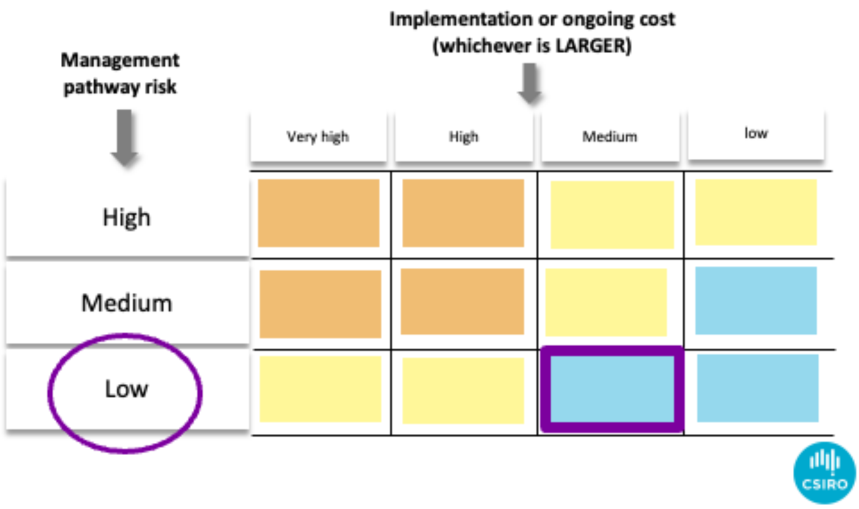
Response risk for management options

= Management cost risk

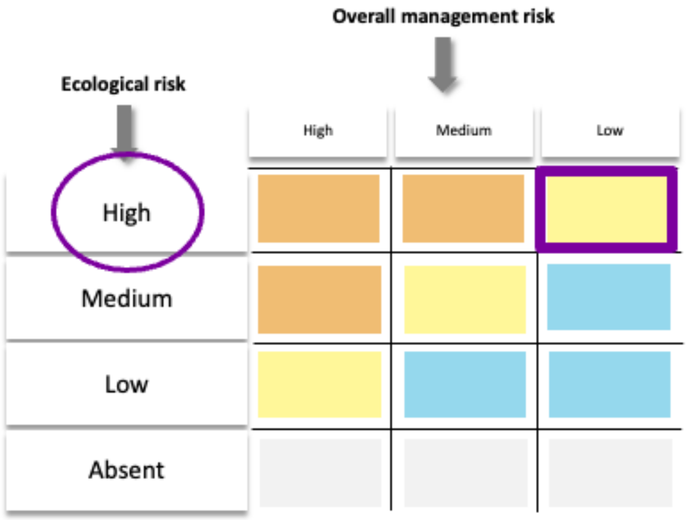
Two more management risks (taken together as **Management Cost Risk**):

- Management implementation cost
- Ongoing management cost

Then, combine pathway risk and management cost risk



Combine management risks and ecological risk



Risk Perception

Talking about risk and risk perception

Prepared by:
Ingrid van Putten

Australia's National Science Agency

Something a bit different in this session

- How people perceive risks
- Risk appetite
- Risk profile
- What influences risk

Adaptation of fisheries management to climate change Handbook, CSIRO, 2020

Risk perceptions (what influences it)?

Affective factors
- Emotions
- Feelings
- Moods

Cognitive factors*
- Gravity of the event
- Biases**

Individual factors
- Experience/ familiarity
- Culture & demographics
- **Risk profile**

Contextual factors
- Risk framing
- Information availability
- Responsible authorities
- Trust factors
- Nature of the risk

→ **Risk perception**

* Related to e.g. attention, memory, and reasoning

* Cognitive biases such as, for example, *availability bias* (placing more weight on things that come readily to mind) or *anchoring bias* (relying too heavily on one trait or piece of data verses others) can play a role in the way we perceive and deal with risk. There are literally hundreds of different biases that can emerge at every stage and they exist for professionals / experts as well!

Risk perception & appetite

A **risk profile** is an evaluation of an individual's general **willingness** (appetite & tolerance) and **ability** (capacity) to take risks

Risk appetite is the degree of risk that an individual is willing to take (endure)

Risk capacity is the ability to take on the risk (will depend on e.g. income)

Risk tolerance: is the limit of someone's capacity for taking on risk

Risk perception is the **subjective** decision-making process that an individual uses to evaluate risk and the amount of uncertainty

Risk profile (that the test will give us)

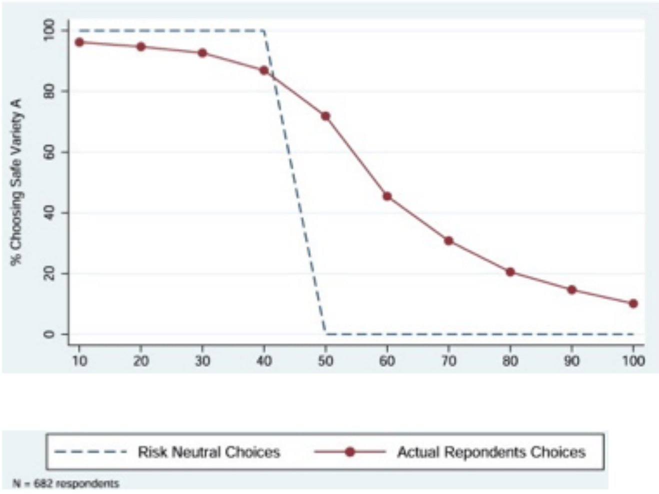
Risk seeking	Refers to an individual who is willing to **accept greater uncertainty** in exchange for the potential of **higher returns**
Risk neutral	A mindset where an individual is **indifferent** to risk (but it does not mean they are not informed about the risk)
Risk averse	Describes an individual who **chooses certainty** and **dislikes risk** (and is willing to accept lower returns)

The dominant risk profile

In economic theory it is generally accepted that most individuals are not risk-neutral

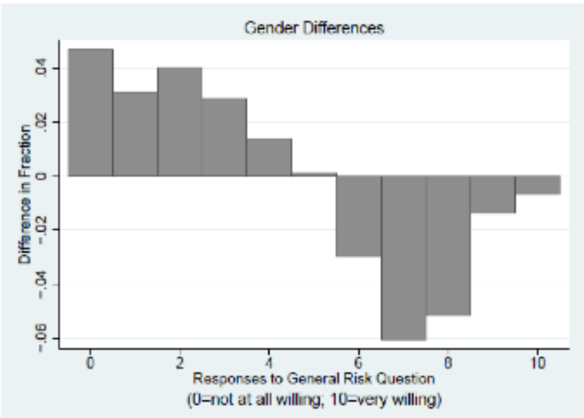
People tend to prefer safer choices to riskier ones, meaning they are risk-averse

Risk aversion is one of the most widely observed behaviours in the animal kingdom; hence, it must confer certain evolutionary advantages



de Brauw, Alan and Eozenou, Patrick, 2014 Journal of Development Economics, 111
Ruixun Zhang, Thomas J. Brennan, Andrew W. Lo Proceedings of the National Academy of Sciences Dec 2014, 111 (50) 17777-17782; DOI: 10.1073/pnas.1406755111

Willingness to take risks varies (gender)



Difference between the fraction of females and males choosing each response category.

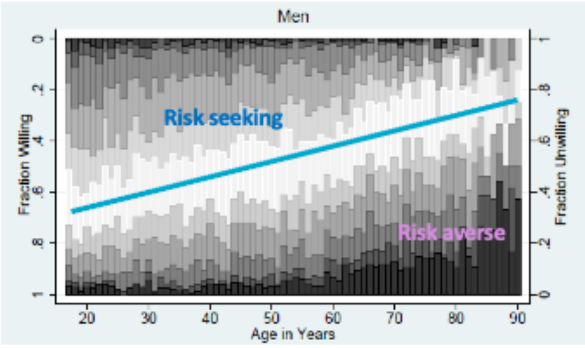
A positive difference for a given category indicates that relatively more females choose that category

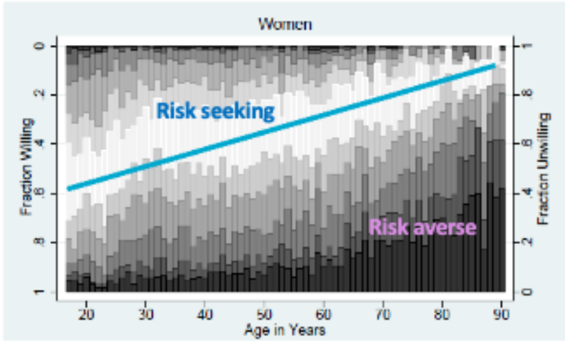
Some paper say that it is just 'males showing off' that explains the gender difference

Environmental (rather than biological) reasons for this

Pawlowski et al 2008 Evolutionary Psychology 6(1): 29-42

Willingness to take risks varies (gender and age)



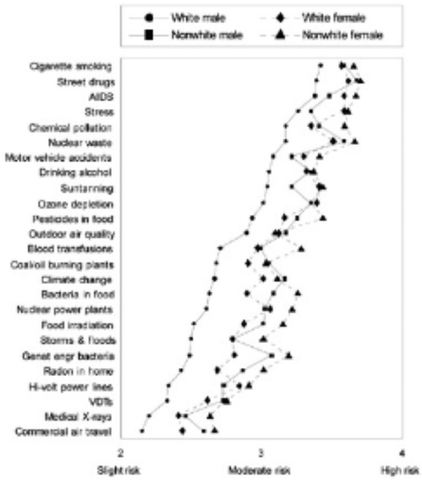


Willingness to take risks varies by race (or does it)?

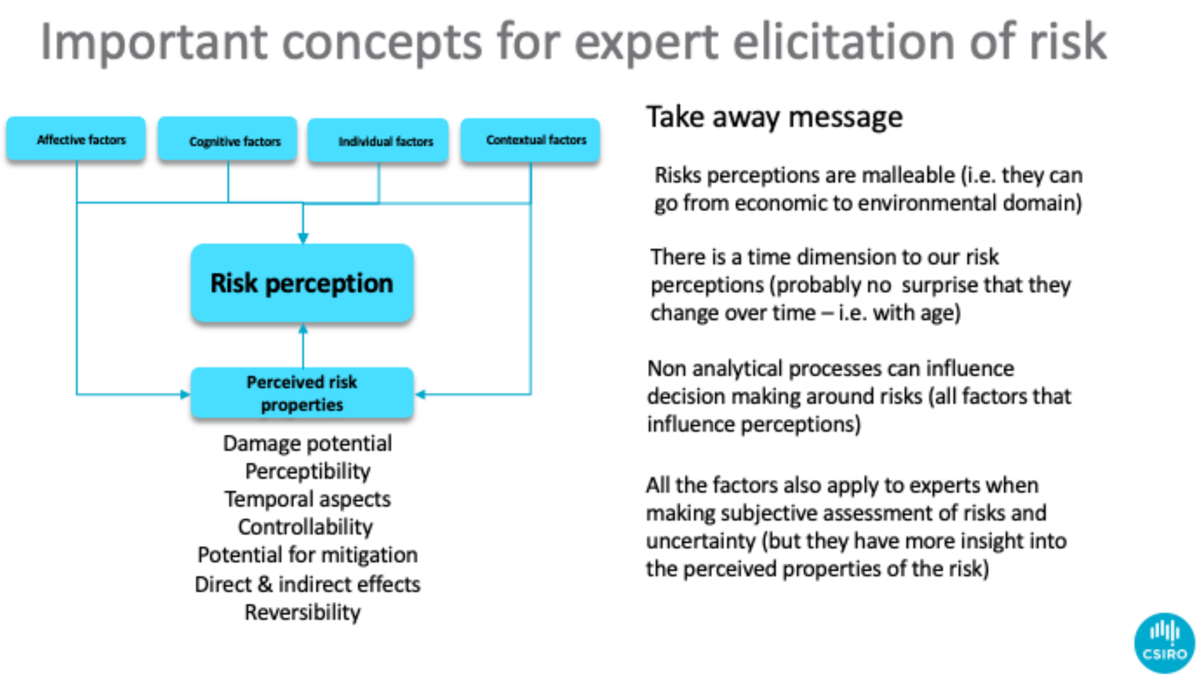
White males produced risk-perception ratings (willingness to take risks) that are consistently much lower than the means of the other three groups.

The "White-male effect" appeared to be caused by about 30% of the White-male sample who judged risks to be extremely low. The remaining White males were not much different from the other subgroups with regard to perceived risk.

The subgroup of White males who perceive risks to be quite low can be characterized by trust in institutions and authorities and by anti-egalitarian attitudes, including a disinclination toward giving decision-making power to citizens in areas of risk management.



FLYNN, J.; SLOVIC, P.; MERTZ, C. K. Gender, race, and perception of environmental health risks. *Risk Analysis*, New Jersey, v. 14, n. 6, p. 1101-1108, 1994.



An example of the kind of the Holt and Laury survey that can indicate risk perception is as follows

Gender:

Female

Male

Other

Prefer not to say

Indicate your domain of expertise, you can pick multiple:

Environment

Fisheries

Economics

Society (inc. Policy)

Other:

For each of the following pairs of options please pick the one you prefer

Q1

10% chance of $100 and 90% chance of $80

10% chance of $190 and 90% chance of $5

Q2

20% chance of $100 and 80% chance of $80

20% chance of $190 and 80% chance of $5

Q3

30% chance of $100 and 70% chance of $80

30% chance of $190 and 70% chance of $5

Q4

40% chance of $100 and 60% chance of $80

40% chance of $190 and 60% chance of $5

Q5

50% chance of $100 and 50% chance of $80

50% chance of $190 and 50% chance of $5

Q6

60% chance of $100 and 40% chance of $80

60% chance of $190 and 40% chance of $5

Q7

70% chance of $100 and 30% chance of $80

70% chance of $190 and 30% chance of $5

Q8

80% chance of $100 and 20% chance of $80

80% chance of $190 and 20% chance of $5

Q9

90% chance of $100 and 10% chance of $80

90% chance of $190 and 10% chance of $5

Q10

100% chance of $100 and 0% chance of $80

100% chance of $190 and 0% chance of $5

An R script can be found on the handbook webpage to plot the results, along with an example survey results file (download and unzip the Holt_Laury_Survey.zip file).

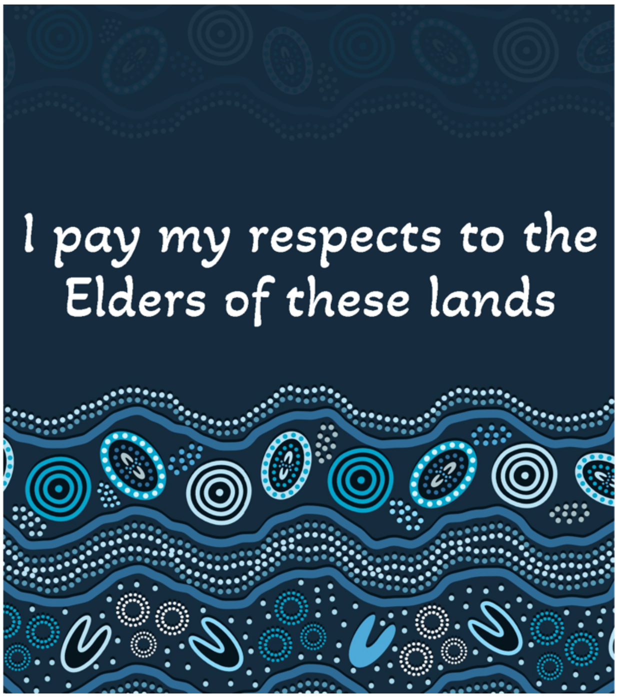
Climate Explainer

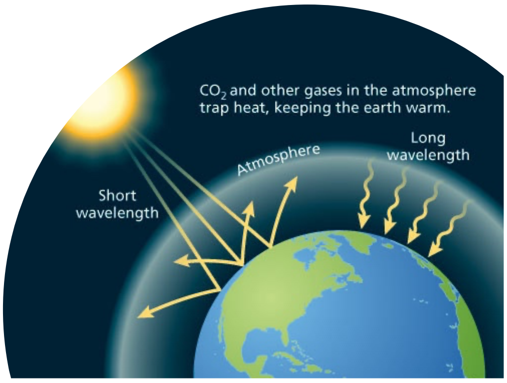
CSIRO

Climate Change & Fisheries

Beth Fulton | 2024

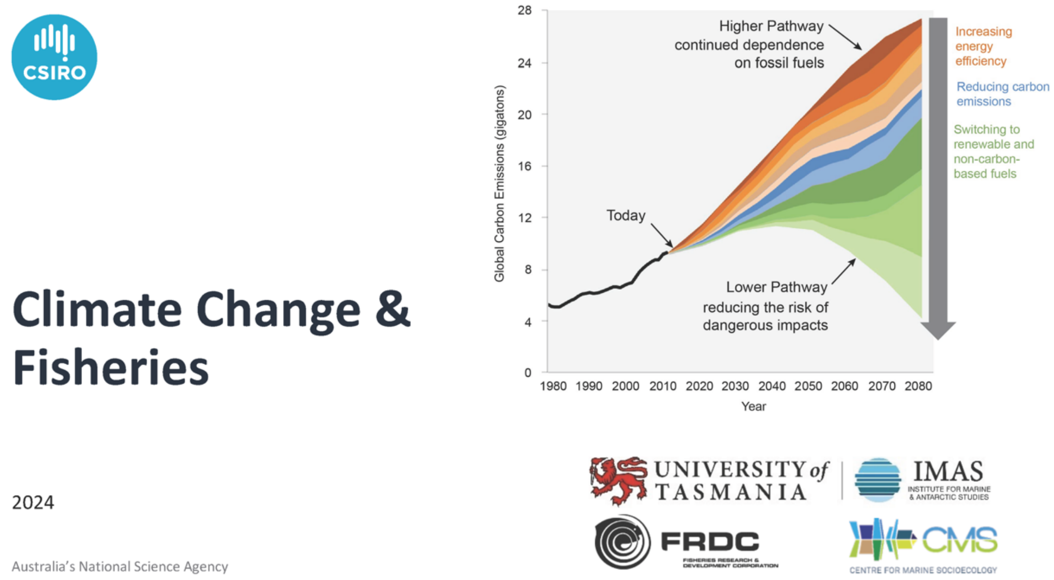
Australia's National Science Agency

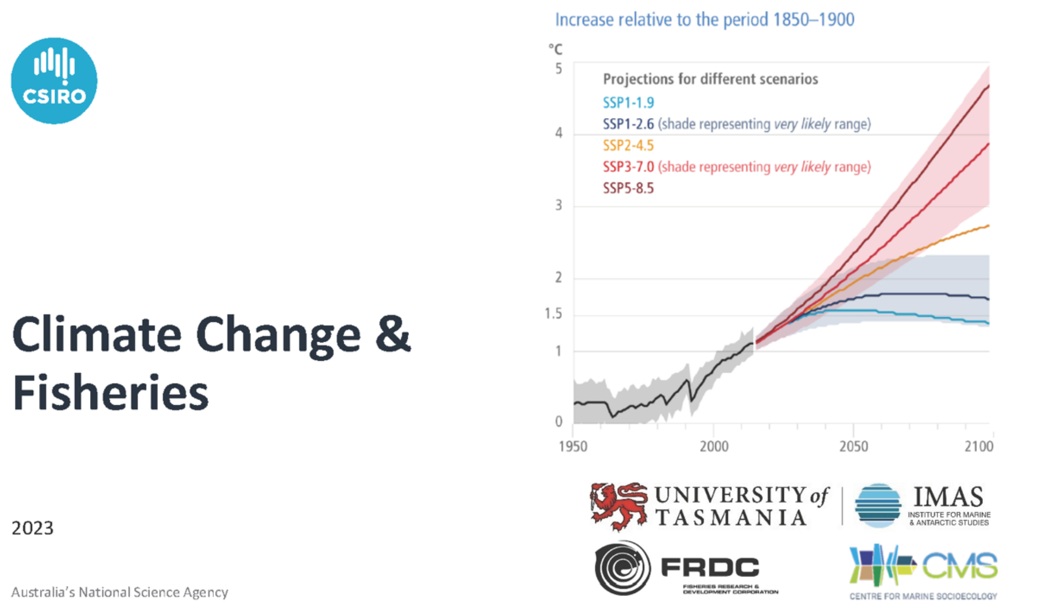




You might have heard of climate change, but do you know what it is?

Climate change is driven by changing composition of the atmosphere. As humans use fossil fuels (fuels sug as oil, petrol, diesel, coal – all of which use fossil carbon stored underground beginning millions of years ago) it releases the fossil carbon into the atmosphere. That carbon acts to increase the blanket created by the atmosphere, trapping in more heat. This change in heat causes climate change.

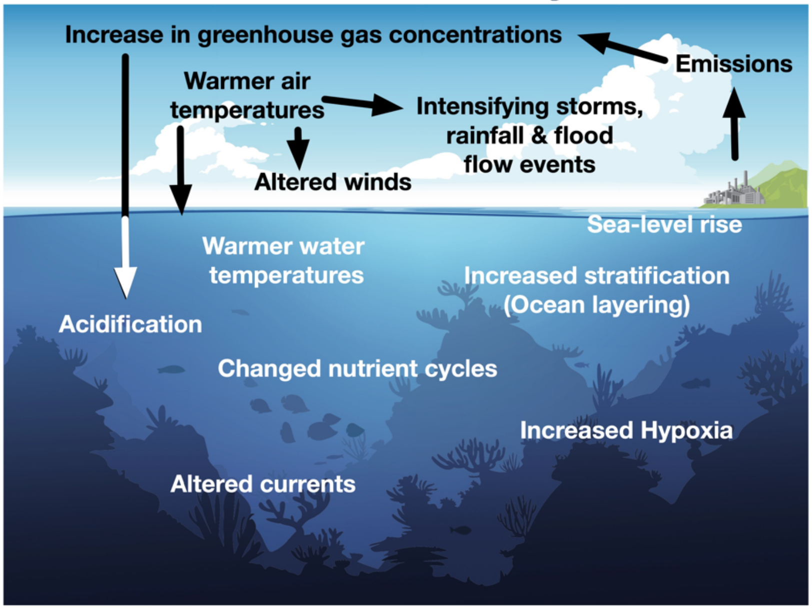




Over time the amount of carbon released (the emissions) has accumulated. It will continue to do so into the future as more fossil fuels are used and as other sources of greenhouse gases (gases like carbon that increase the heat trapping blanket of the atmosphere to intensify) also increase. Green house gases can be directly released by human use but also because human activities (like land clearing uncap other sources so they also enter the atmosphere).

We can measure how emissions (and correspondingly the global temperature) has increased to date since the start of the industrial revolution. Looking forward atmospheric scientists, mathematicians, economists, technologists, political scientists and others have discussed future scenarios. At the upper end if the world had done nothing to respond to climate change and had continued emitting as quickly as in 2000 (the red curves above) then the world would have been heading for about a 5°C increase in temperature compared to temperatures at the start of the industrial revolution (i.e. before climate change begun, also known as the preindustrial baseline). Given pledges regarding a move to net zero (blue areas in top curve above) cumulative emissions are likely to see global temperatures reach 2-3 °C above the pre-industrial baseline. However, if current technological projects that are building big machines to pull carbon dioxide out of the atmosphere work at scale (prototypes already exist) then. Emissions will drop (the green curves) and temperatures will remain below a 2 °C increase. Scientific evidence suggests it would be best to stay below 1.5-2 °C to ensure ecosystems can cope.

How climate effects ecosystems

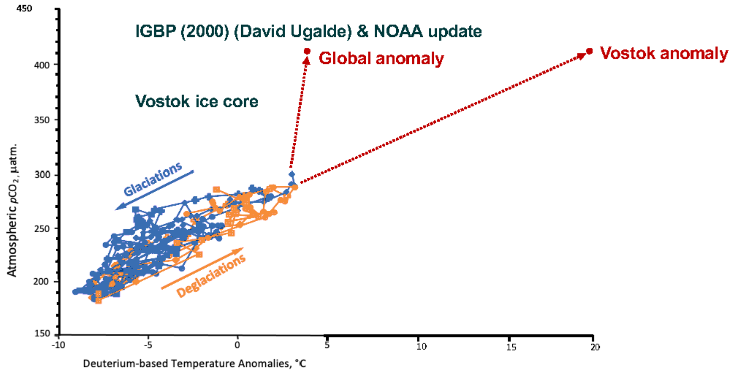


Climate change influences the weather and oceans in many ways. It intensifies winds, chains rainfall (e.g changing when and how much, but typically making storms and bursts of rainfall more intense even if overall levels of annual rainfall remain the same or drop in some locations). In the ocean the heat strengthens the layering (stratification) making nutrient mixing more difficult and leading to a reduction in plankton (fish food). Oxygen in some parts of the ocean can decrease to dangerously low levels. Habitats can also change or die. Large scale current patterns can also change, as has occurred off eastern Australia, where the major currents that flow north to south have extended more than 250km further south, shifting ocean temperatures, eddy patterns and larval fish population distributions.

In addition, the extra carbon dioxide in the atmosphere enters the oceans. This causes a change in the chemistry of ocean water – it creates pacification. Animals with external skeletons (shellfish like mussels and oysters, or crustaceans like prawns and lobster) find it harder to form those shells, so cannot grow as easily, or the shells may be brittle and break more easily (increasing the chance of disease or death).

How much change has occurred?

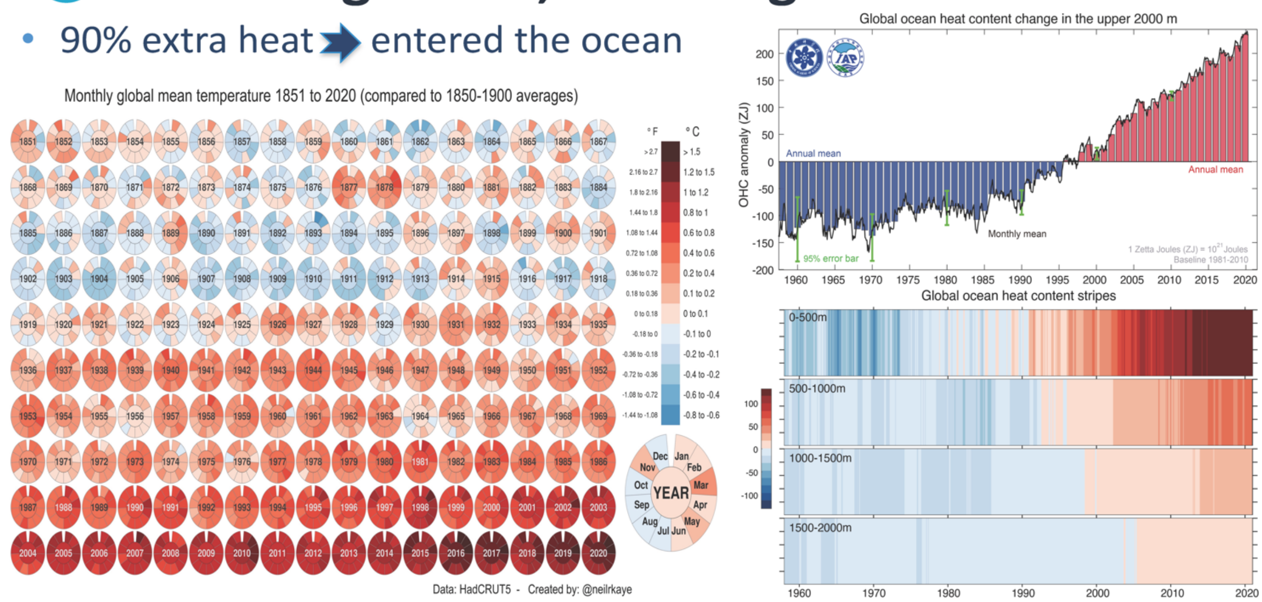
- 800,000 year time series



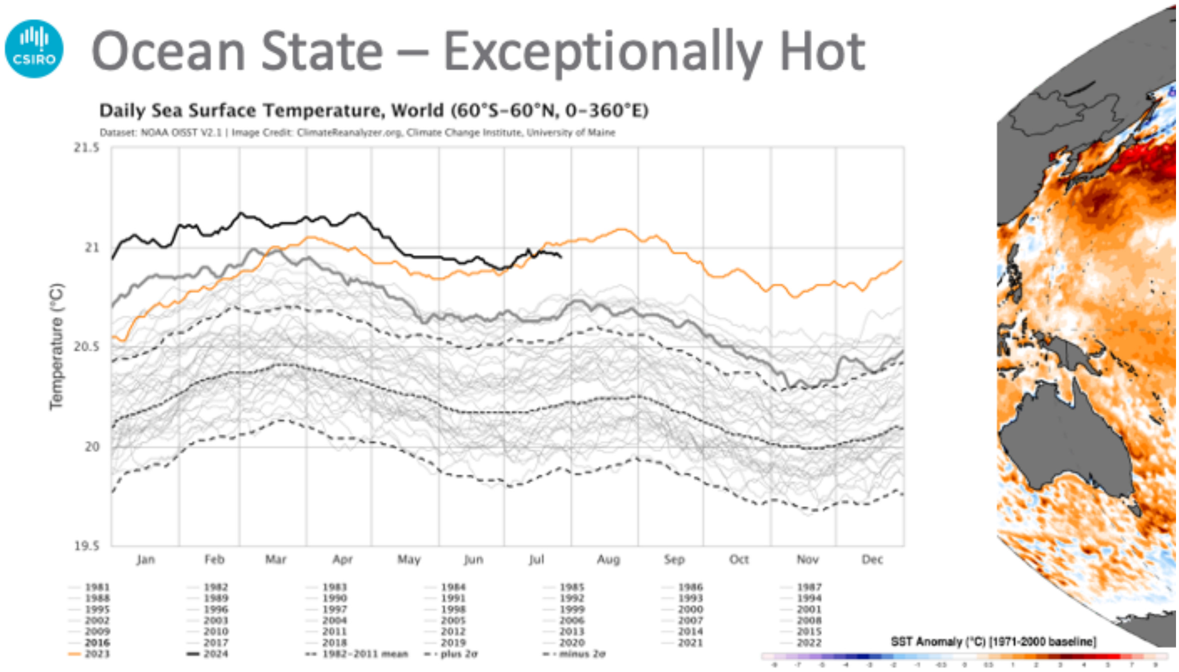
How does this change compare historically? Bubbles of atmosphere trapped in layers of snow in the Antarctic show that for the last 800,000 years the Earth has oscillated between conditions similar to the the start of the industrial revolution through to very cold states – Ice Ages. Atmospheric make up (and temperatures) now are outside that envelope both globally and in the region where the snow cores are taken (the Antarctic Vostok site).

Warming world, warming ocean

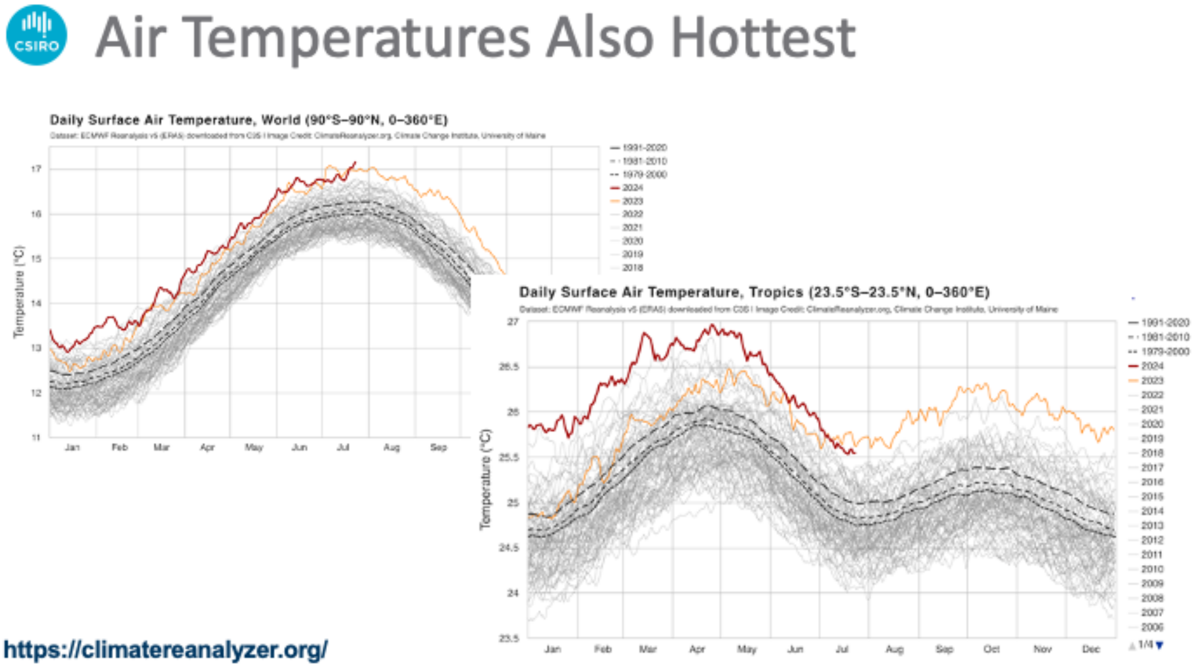
- 90% extra heat ➔ entered the ocean



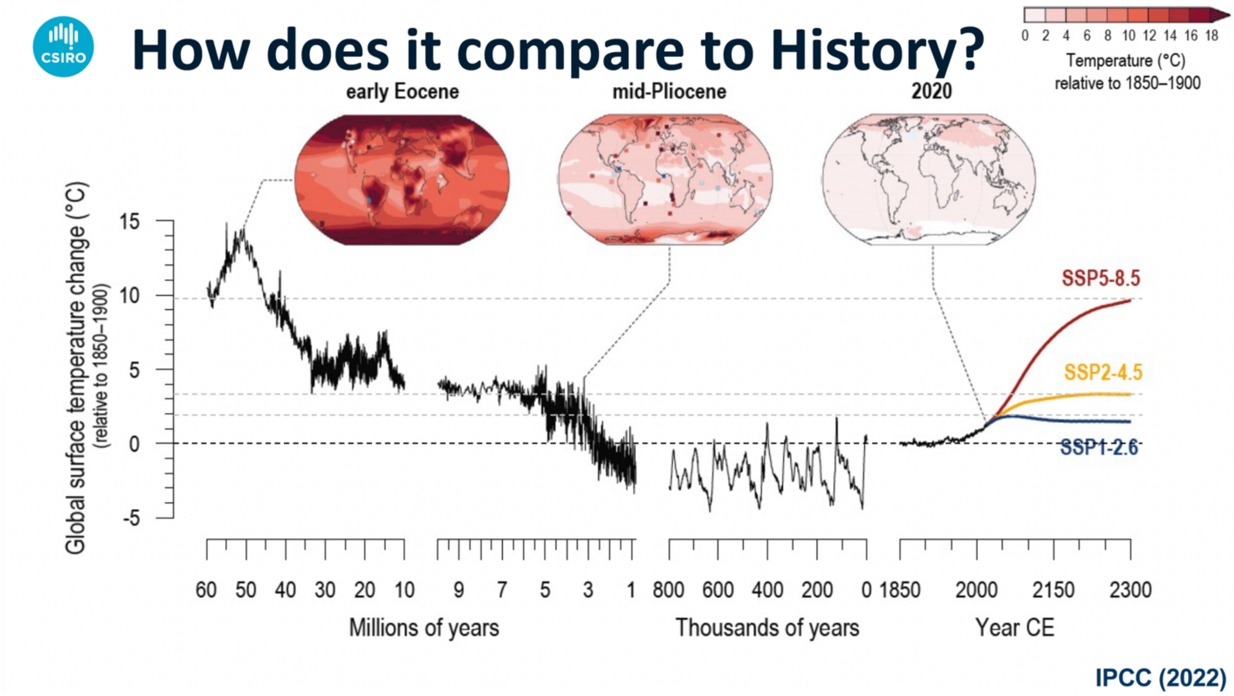
Comparing air temperature to what was the average before the Industrial revolution scientists have plotted up every onth of every year (the circles) with blue being a cool period and red a warm. At the start of the 1900s both cool and warm years occurred. Since the 1930s the years have just been getting warmer and warmer. The ocean takes longer to heat up but it has also been warming and since the 1980s has been quite steadily warming (top right, look at the line, the blue and red in that plot are because the average date being used is the 1990s when remote sensing was first becoming more common, but the line shows the increase started before the 1990s). This is strongest in the surface ocean (top bar of four on the right, the different bars being the different depths). Most fish are caught in the surface ocean. However, the deep ocean has also heated up – in fact >90% of the extra heat form climate change has been captured by the ocean It's immense size and thermal mass has meant it has warmed slowly (and in the deep ocean by only a little), but that is a huge amount of energy. Even if we stopped emissions today that heat would take decades to dissipate – the ocean has a long memory. It is why we need to look ahead and also try to avoid adding extra emissions, as it just makes the issue larger.



Looking at the satellite record (the many lines above). Until recently 2016 was considered the hot year for the ocean – top of the grey lines – as there were marine heatwaves and mass bleaching across the global ocean. However, last year (the orange bar) was even hotter than 2016 and the start of this year hotter still. It has only been since mid 2024 that 2024 came down to 2023 temperatures (still exceptionally warm). This has caused marine heatwaves and impacts on marine life and weather.



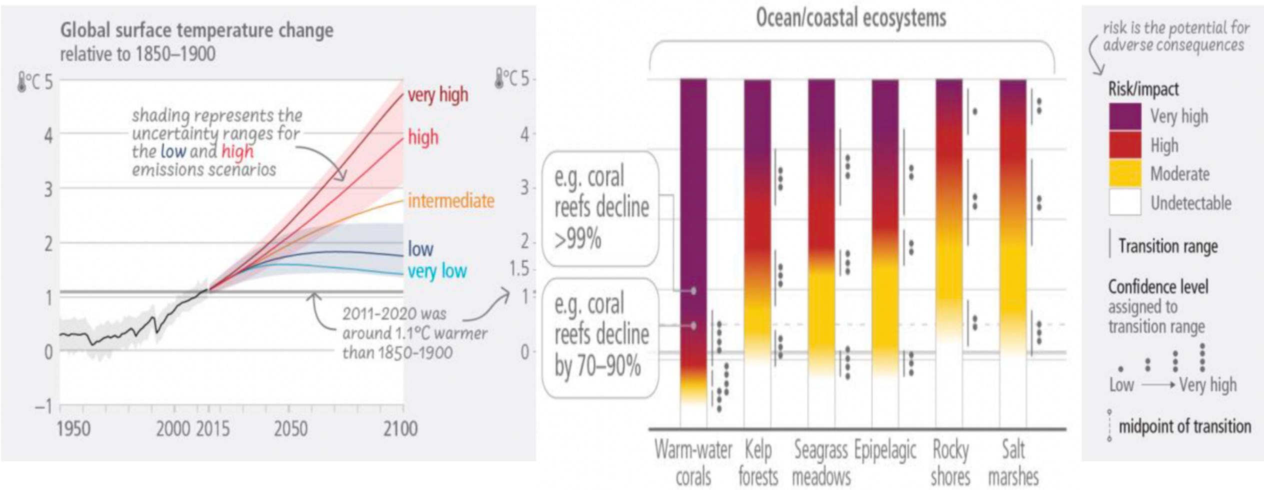
Air temperatures globally and especially across the tropis (and at the poles) have also been the hottest recorded.



Using temperature signals from tree rings, ice cores and rocls scientists can recreate past temperature time series going back 60 million years (to just after the mass extinction that marks the end of the age of dinosaurs). If you run your eye backward aling the dashed lines starting form the bottom line you can see that temperatures in the pre-industrial were about the same level as other inter-glacials, this is why scientists in the mid 1900s discussed how Earth was due to begin descending into another Ice Age. Instead temperatures by 2020 (where the red, blue and yellow line split) will be higher than any period except the last interglacial. Only one group of people have a cultural memory of that long ago – the First Nations of Australia, who have stories of how the change they witnessed since then, the ecosystem shifts (like the formation of the Great Barrier Reef) and how the wirld around them and their practices had to change also. Going back further temperatures in 2050 won't have been common on Earth for around 1-3 million years ago (these temperatures will persist for some time even if those large carbon reduction machines come on line). Temperatures for the most likely future (the yellow curve in this plot) will reach levels by the end of the century not seen for around 5 million years. Thankfully action on climate change means the global temperatures will avoid the levels likely under high emissions – temperatures not seen for 40-50 million years.

This is important because on average individual species only exist for around 1 million years (ver linger periods they either die off or evolve into new things, perhaps only slightly different but not exactly the same). There were no Homo sapiens (modern man) 3 million years ago. Many of the species back then were a bit different too. That is not to say everything will die out (or that we will all die out) under climate change, but species will change as conditions change. Meaning we will need to change what we do too.

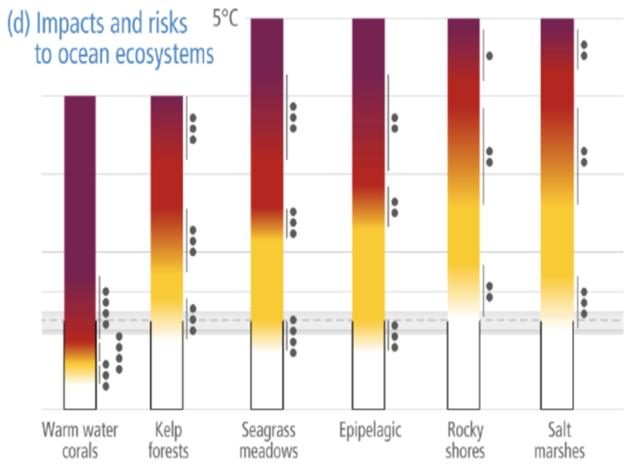
Implications of change?

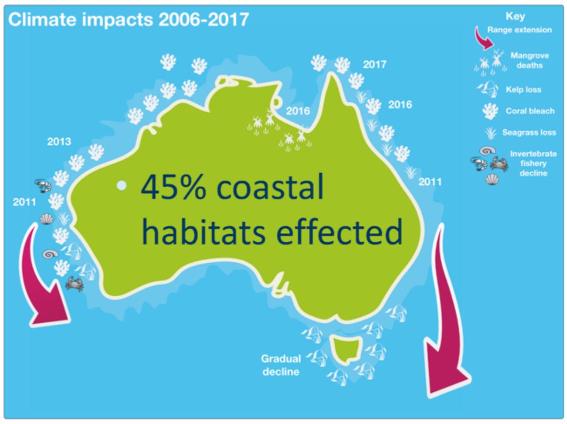


IPCC (2022)

Different species will be impacted at different rates. Corals are already feeling the pressure – that's why we are seeing mass bleaching events. Other habitats, like seagrass and macroalgae only start to be more negatively effected as temperatures rise further, but it is likely most marine habitats globally will be effected by the middle to the end of the century under projected levels of climate change.

How much change?



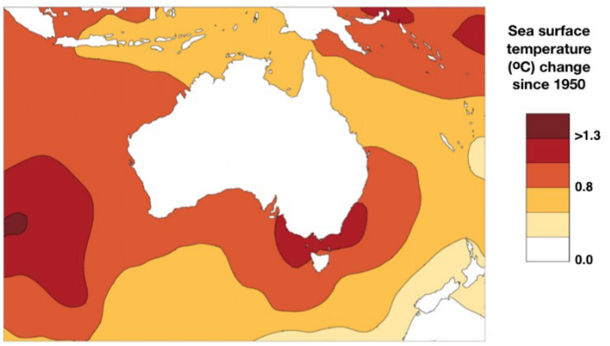


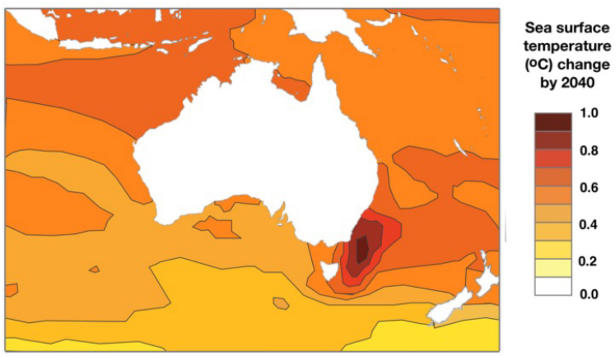
IPCC (2022)

Babcock et al (2019)

As climate change advances at different rates in different regions, some lcoations are already seeing these effects. Australia is a continent already seeing major change. Indeed since 2010 mire than 45% of Australia's coastal marine habitats have seen episodic or longterm decline or change. Most of Australia's marine life is rated as vulnerable to climate effects. Hundreds of species have shifted their distribuition – as can be seen on the https://www.redmap.org.au/ website.

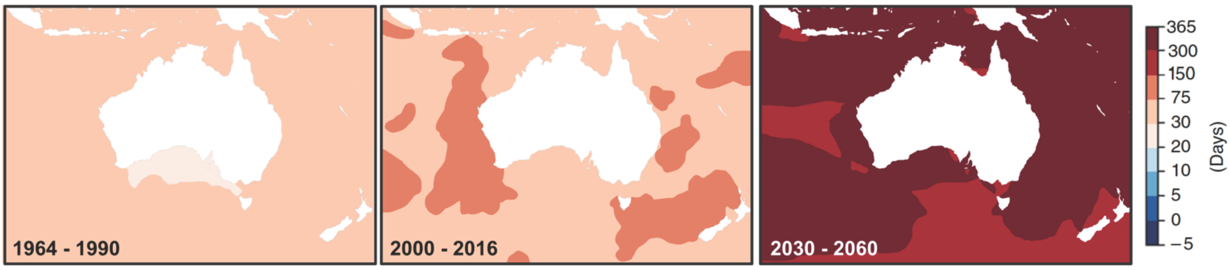
Forecast change: Temperature





The observed ecosystem impacts are because ocean temperatures around Australia have already increase, in some areas by close to 1ºC (many times the global average) with about the same amount still to come in the next 15-20 years.

Forecast change: Extreme Events

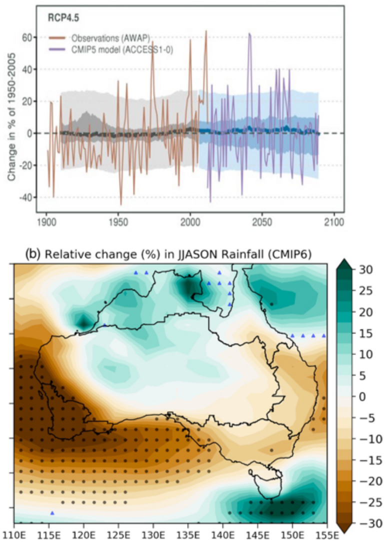


The number of days per year where water temperature exceeds the top 10% of historical temperatures.

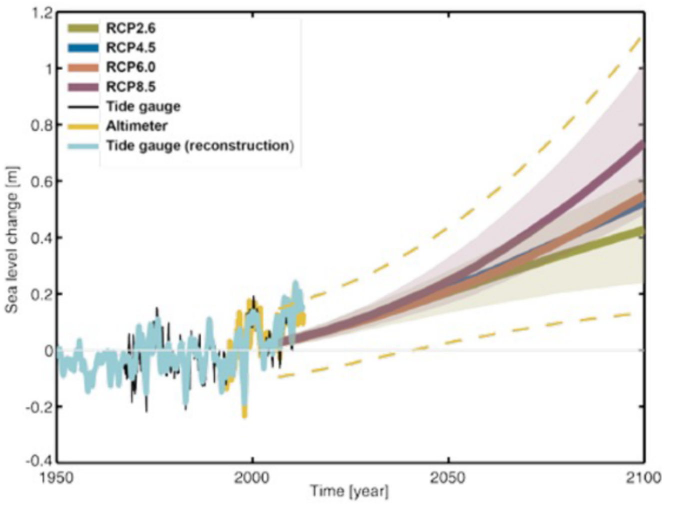
This is pretty clear from the frequency of extreme events. If we look at the number of hot days (top 10% of recorded values compared to 1950s-1950s) about 30 days a year were that hot back in the 1960s-1990s. That makes sense that is the peak of summer. By 2016, hot days were twice as likely (i.e.a round 2 months a year) in some regions. By 2030-2060 the majority of the year will have ocean temperatures as hot as summer temperatures in the 1950s. Air temperatures follow a similar pattern.

Rainfall

Steady overall but site dependent



Sea level height



For Queensland CMIP5 & 6 predictions very similar

Rainfall si also expected to change, increasing in some areas (such as in southern Tasmania or the wet tropics) and decreasing in others (especially in Western Australia).

Sealevel will also rise, fairly consistently around Australia (though again some places will see a little greater/smaller rise than other places). By 2050 most places will see 20-50cm vertical height increase, with at least a metre likely by the end of the century. That vertical rise equates to many metres of horizontal change in coastlines, meaning low lying areas would be inundated or experiencing saltwater intrusion. Storm surges could also cause more wide spread flooding, reaching places not usually directly impacted now.

CSIRO

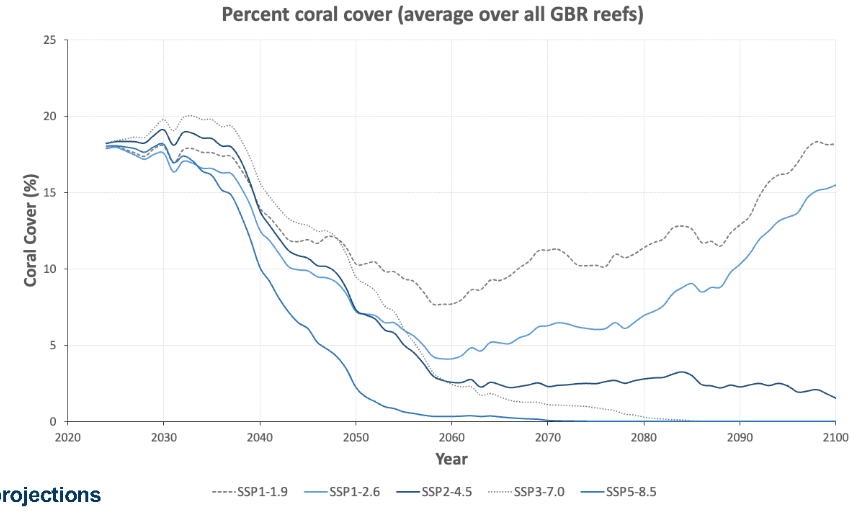
Forecast change

	Observed change (vs 1950)	Future change (vs today)
OCEAN TEMPERATURE	0.6 - 0.8°C increase	0.6 - 1.0°C increase
MARINE HEATWAVE	15 - 20 day increase	>200 day increase
STORMS	Conflicting information	Stronger & more variable
DROUGHTS	Shorter, more intense	Longer, twice as frequent
RAINFALL	Roughly steady	Roughly steady
SEALEVEL RISE	20cm increase	20 - 40cm increase
OXYGEN	Approx 2% decrease	5% decrease
ACIDIFICATION	30% increase	20 - 120% increase

	Species Vulnerability & Potential Future Change
SPECIES CLIMATE SENSITIVITY	>35% highly sensitive, 55% moderately sensitive
TARGET SPECIES	Abundance of key target species decline 10-20%

Scientists have put a lot of effort into recording what has changed and trying to realistic predict what is likely to happen over the next decades. An example for northern Australia is given here. You'll note that the level of observed change since 1950 is about the same amount as the additional change ahead of us over the next 15-20 years. That is another aspect of climate change, it is speeding up. The level of change that has occurred incrementally over the past 50-70 years will take place faster (in less than 20 years) from now into the future.

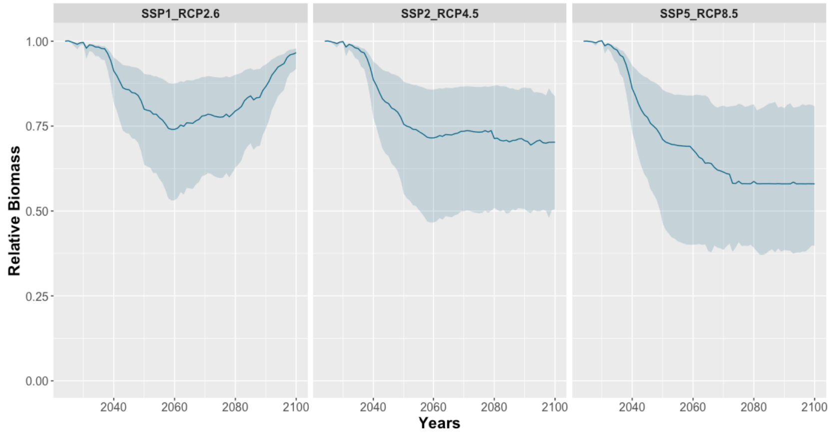
How much change – Coastal Fish (GBR)



REEFMOD projections

So what does that mean? It is likely the Great Barrier Reef (and other reefs such as Ningaloo) will see large scale coral bleaching and mortality, changing reef structure and function. Other habitats (such as the Great Southern Reef's plant and algae based ecosystems) will also change.

How much change – Coastal Fish (GBR)



FISHMIP projections

Thia has the potential to see quite large changes in habitat dependent fish stocks. If they can behavioural adapt (or evolve) changes might be quite small, but if they can't, or if habitat loss is catastrophically large as much as 50% fish biomass loss is possible b y mid century along the Great Barrie Reef (based in best available science models).

A large group of scientists and mathematicians have been collaborating to produce models of specific regional ocean sites as well as the global ocean, with the intent that the outputs of those models run under climate change conditions be used to inform decision makers, fishers and communities about the future. The general form of those models and how they are connected to global climate models is shown below.

Figure 4. Schematic diagram to illustrate the flow of information used by the FishMIP global marine ecosystem model ensemble capturing a range of scenario and model uncertainties.

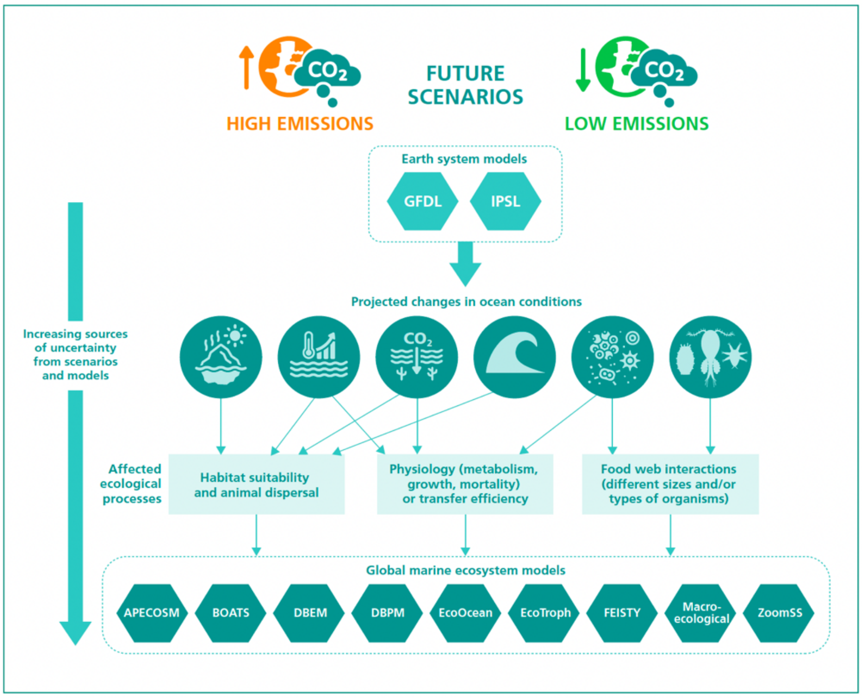
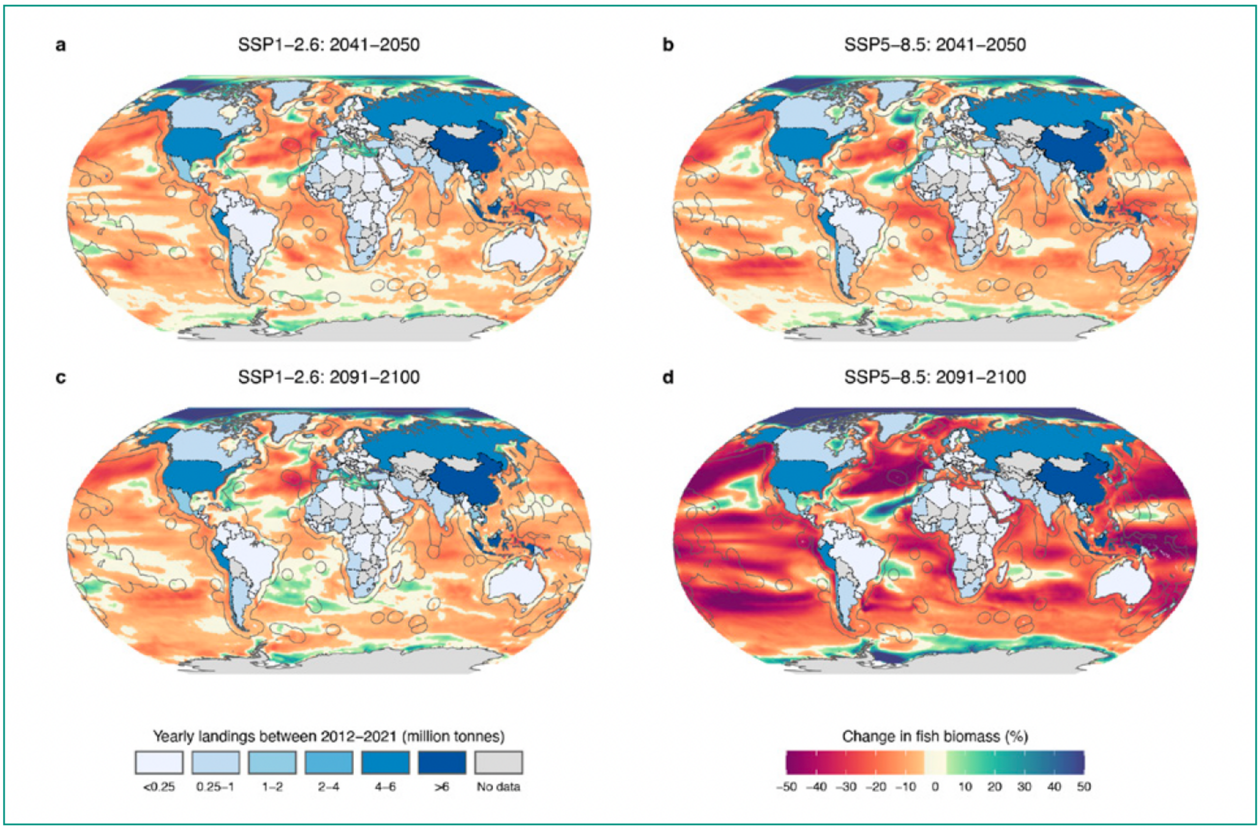
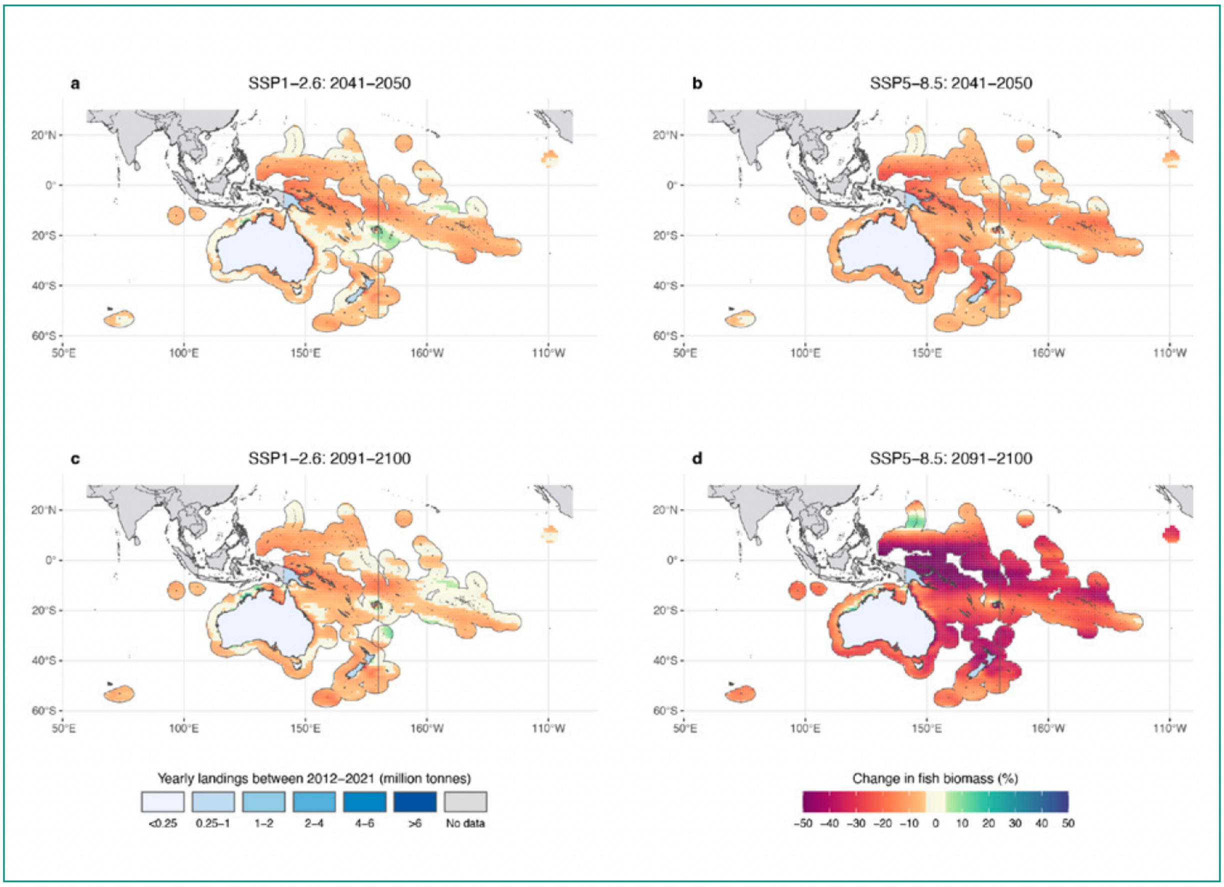


Figure 7. Percentage change in exploitable fish biomass



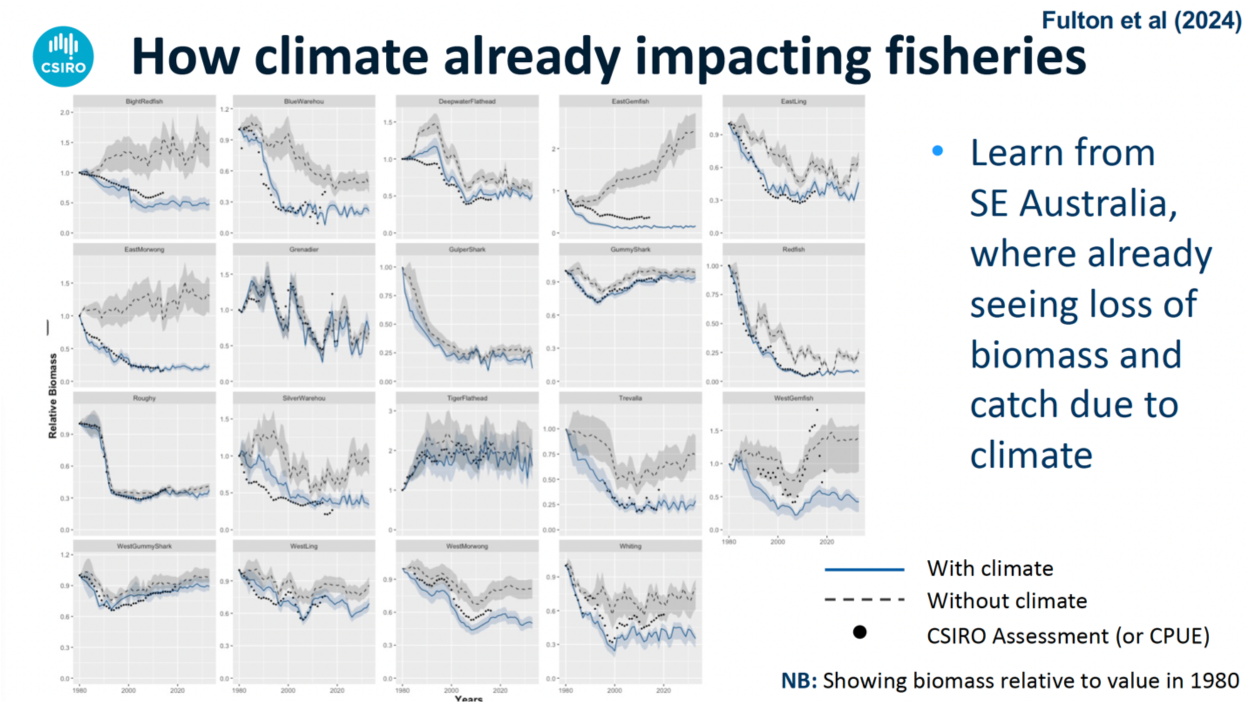
Even under lower emission scenarios, the stored heat of the ocean and "baked in" climate change means that some regions will likely see a drop in fish biomass of 5-10% even in the absence of fishing. The situation is worse with higher emissions. The most likely future sits somewhere between the pictures on the left and the right.

Figure 17. Percentage change in exploitable fish biomass for countries and territories in Oceania

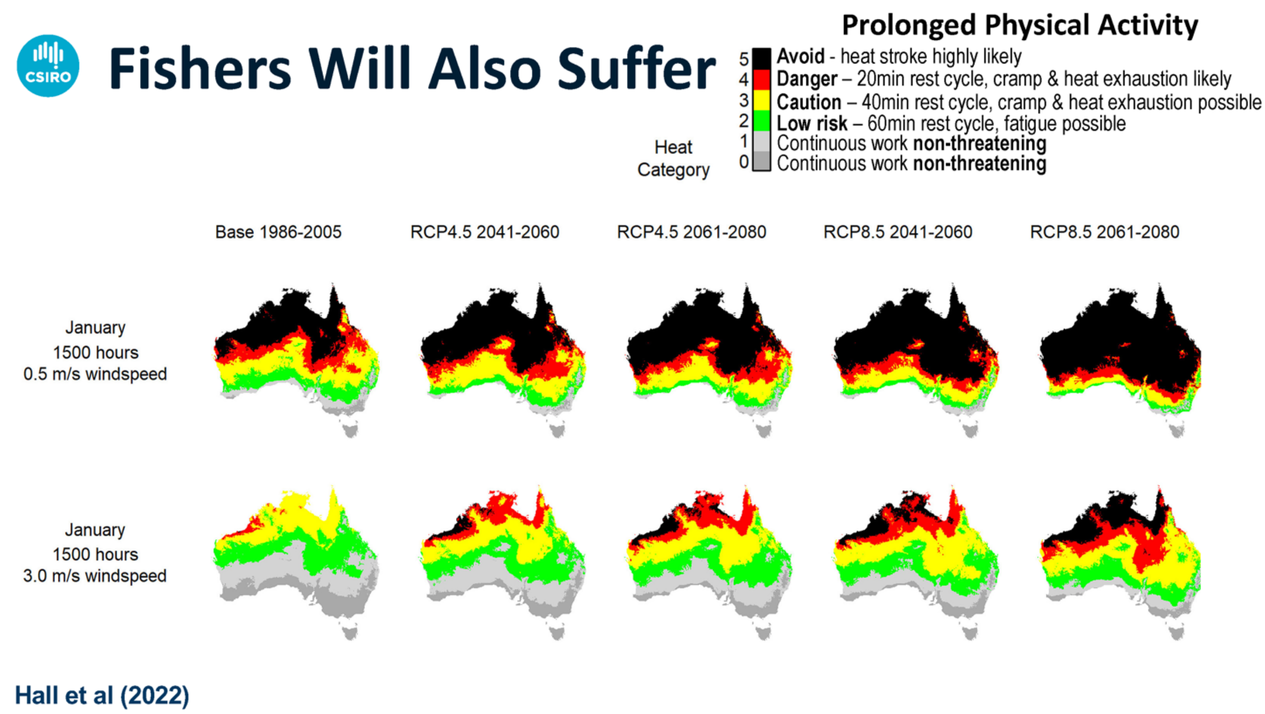


Notes: In the ocean, model ensemble projects mean change (percentage) in exploitable fish biomass between 2005–2014 and 2041-2050 (a,b) or 2091–2100 (c,d) under the low emissions (a,c) and the high emissions (b,d) scenarios for Oceania. Projections capture ecosystems under climate change in the absence of fishing, and therefore represent changes in exploitable fish biomass. On land, mean annual fisheries catches by country over the period 2012–2021 are shown.

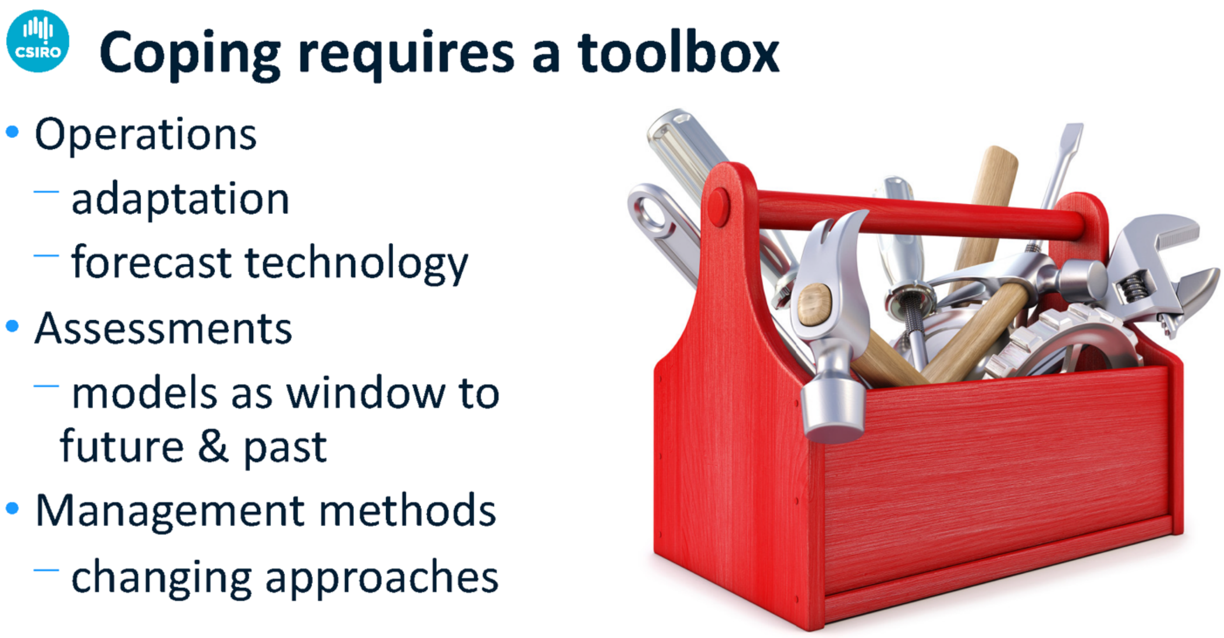
Australia is not immune to that change, Seeing similar levels of change as projected for much of Oceania (or SE Asia). There is a iot of variation around Australia, which is why regionally specific work will be important for local and regional adaptation.



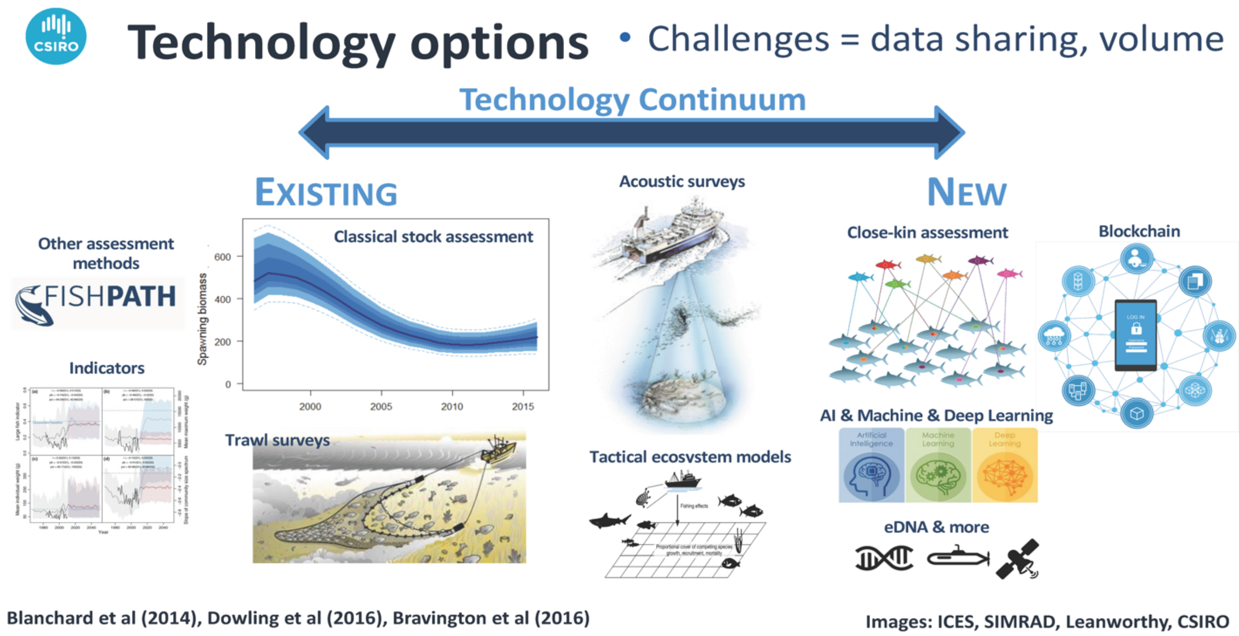
Models are also being used to explain what climate change related impacts are already being felt. In southeast Australia models suggest some species have been heavily influenced by climate change (where the black dots, best estimates of reality, and blue lines, climate influenced projects for the region, overlap) versus others where the species have likely been much less effected (e.g. flathead or other species where the dark grey, no-climate change simulations, and blue lines overlap with each other and the black dots).



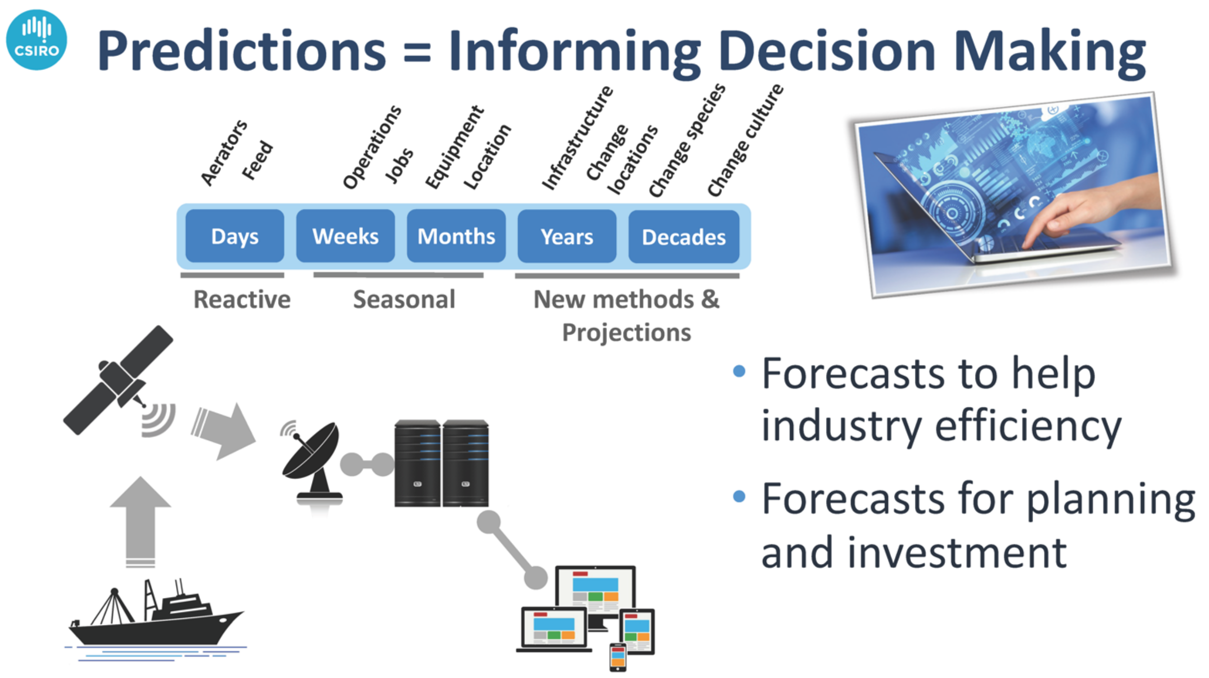
Projections are not only concerned with what the ecosystem will experience, but also what workers will face. When temperature and humidity combine to give an effective ("feels like") temperature of 35°C or higher temperature than heat stroke is a significant risk (the human body can't shed excess heat and organs begin to "cook"). Strenuous work should be avoided in such conditions because it can be lethal. This has implications for farming, fishing, construction etc in the future when summer temperatures could reach such dangerously high levels in some regions, especially where wind is absent or blocked.



Dealing with that level of change will be challenging, but it is possible. Many tools exist or are under development.



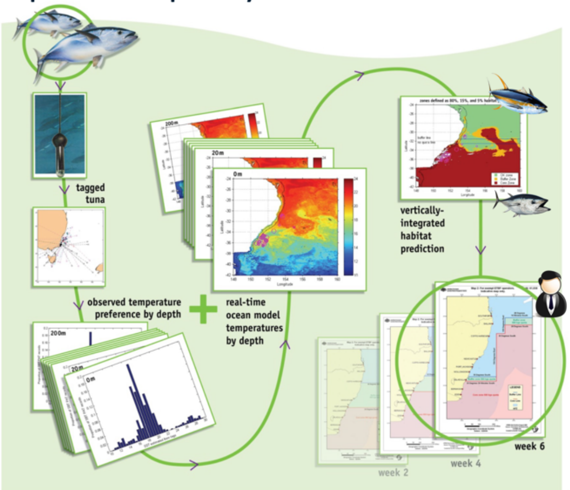
There are lots of ways of collecting information to understand what is changing and how; and whether it is a hot year where extra precaution may be required.

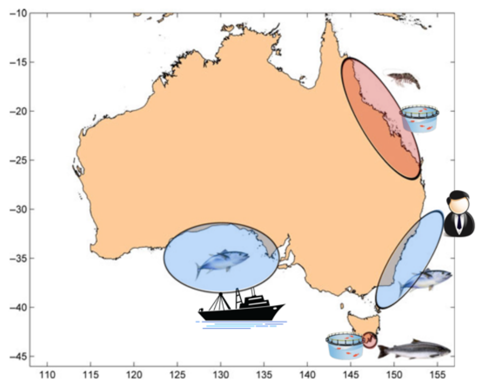


New modelling methods mean that forecasts are becoming better and better at many scales, allowing for planning and responses on those scales.

Forecasts for Industry & Management

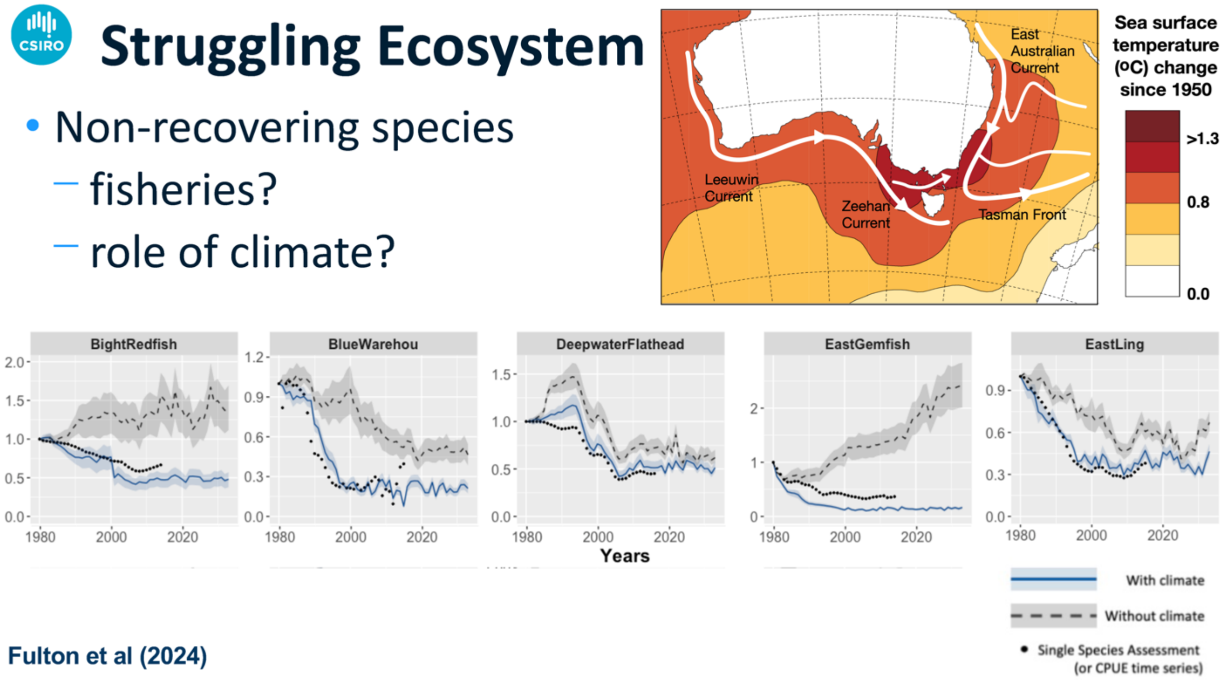
- Climate aware forecasts: Scientific understanding transformed into practical policy advice and tools to support fishing



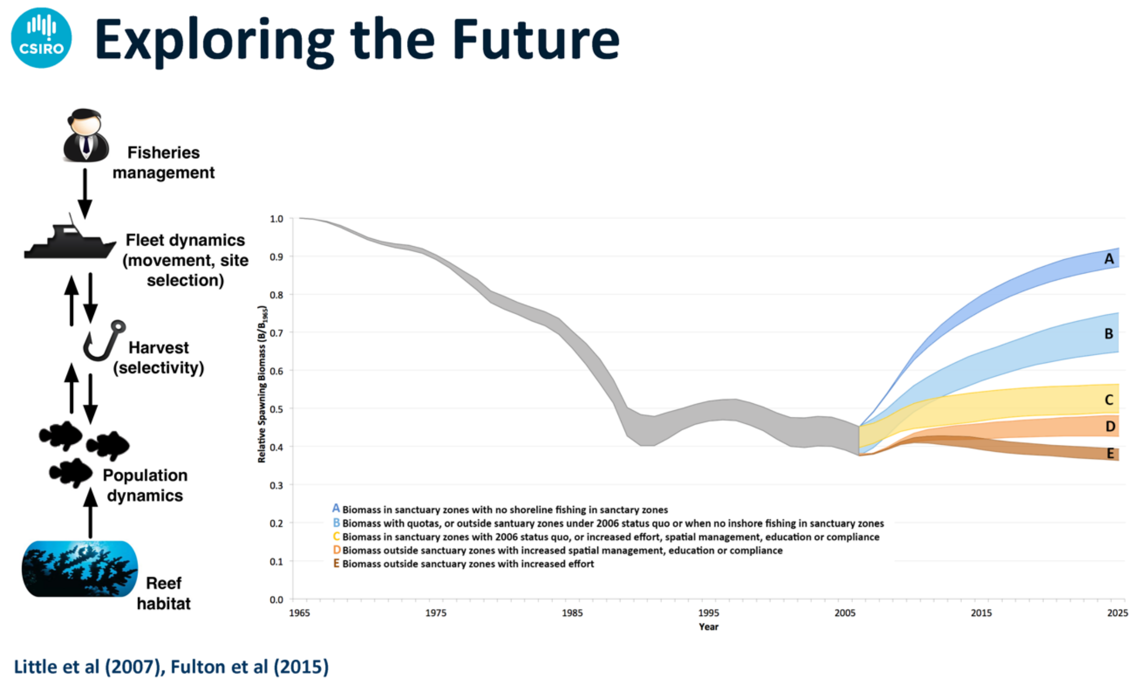


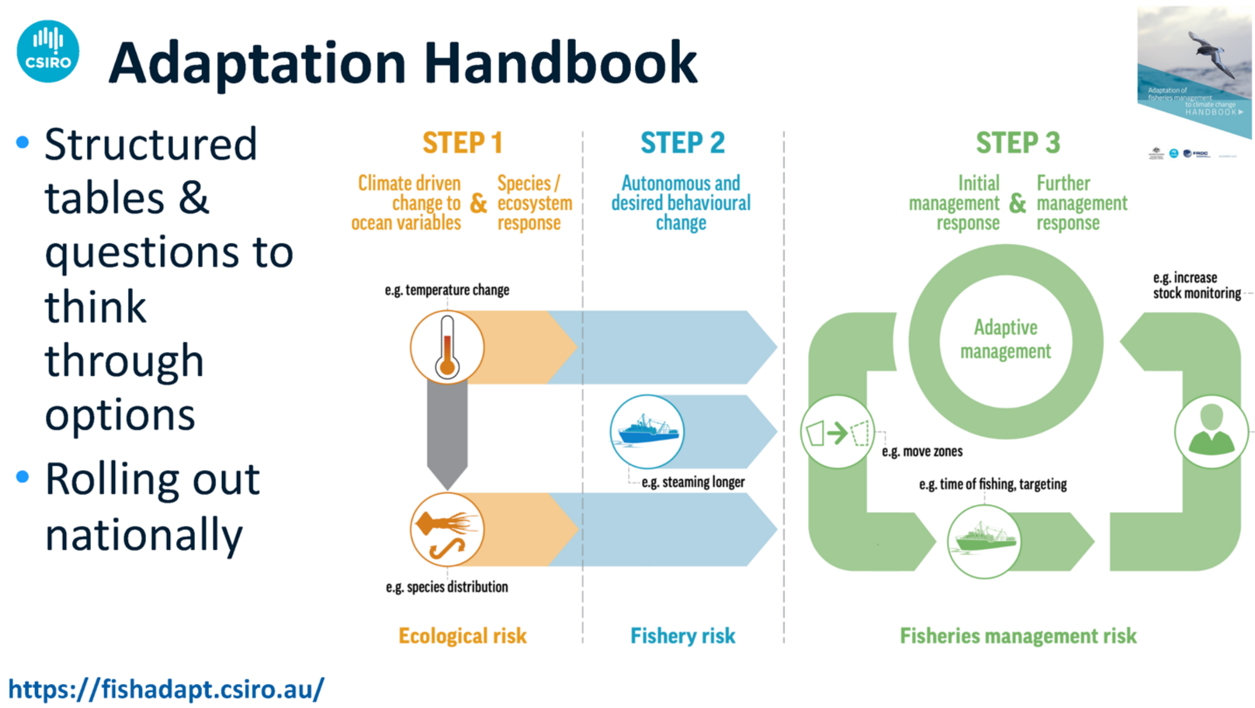
For example near real time forecasts and seasonal forecasts can let fishers and marine farmers operate efficiently and in a way appropriate for the conditions.

Management can even use such projections – to adjust rules within seasons to match specific conditions and minimise undesirable outcomes. Such as using "dynamic ocean management" which ties operational regulations to specific water features (defined on ocean temperature for instance) rather than fixing them in place permanently. This allows for much more responsive management, but also requires data collection at appropriate scales.



As mentioned models can also be used to understanding past or current effects and to look at possible futures (under differing levels of climate change or alternative fisheries operations or management regimes).

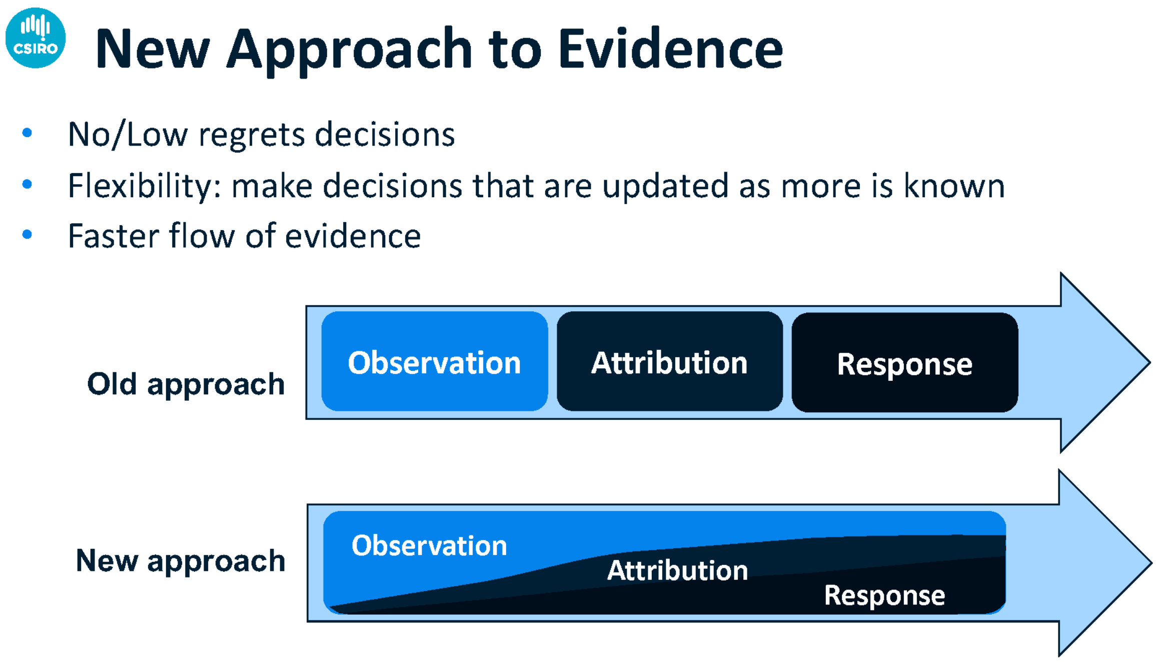




Tools such as the adaptation handbook are being made available to help people look at their exposure and vulnerability and to try to identify options for future operational and management regimes that are more robust to climate effects.

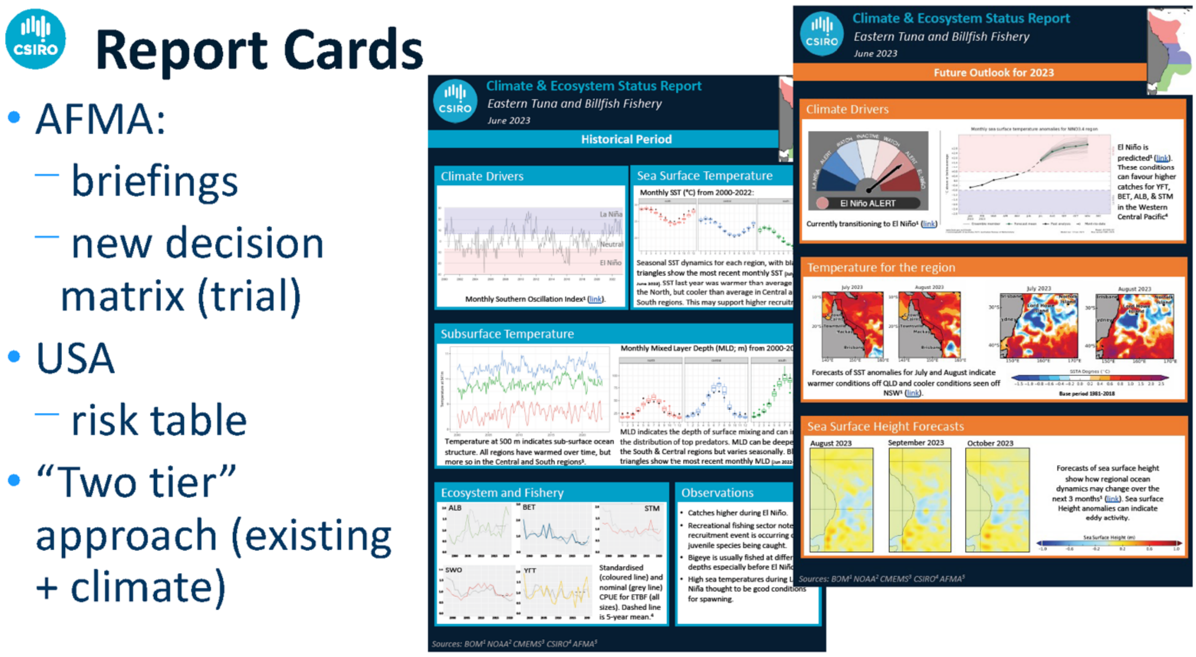
This can require new ways of doing management – either by allowing for dynamic rather than fixed reference points (for judging performance and what's possible) – or by collaborating with, or accounting for other marine industries operating in the same region.

Any new ideas do need careful thought to make sure they help both in the short and longer term, minimising the risk of perverse outcomes or “maladaptation” long term (when something that looks like ti will help ultimately actually makes the situation wose).



One major change is to realise the world is changing so much and so quickly that taking time to come to definitive answers is no longer possible – it takes too long (things will have changed too much and damage will have been done before acting) and the system is changing so much (it will have changed again before the answer is found). Consequently, making best possible (and no regrets) decisions and updating as new information becomes available is the best possible approach.

This is not contrary to the warning to think carefully. This can be done using best available information. It won’t always be 100% right, but doing it will allow for responses that aren’t overly delayed while also avoiding compounding problems generated by superficial assumptions.



One approach already proving useful is simply to provide climate information (report cards) along with stock information when making decisions on catch or effort levels. That way the ecosystem context (good year, bad year) can be taken into account. This kind of approach is beginning to be used in many commercial fisheries in the northern hemisphere and is being trialled in some places in Australia.

All of that can be pretty confronting. It is fine to feel sad or angry, many people do. If you are feeling challenged by it don't be shy in reaching out for help to BeyondBlue (https://www.beyondblue.org.au/), StayAfloat (https://www.stayafloat.com.au/) or other mental health professionals

However, there is hope. Humans are resourceful and more options and tools are becoming available to allow us to prepare and to have sustainable fisheries into the future.

If you are looking for more information on climate change there are a number of good resources out there – such as

https://curiousclimate.org.au/

http://www.bom.gov.au/climate/

https://www.csiro.au/en/research/environmental-impacts/climate-change/climate-change-information

https://research.csiro.au/cor/research-domains/climate-impacts-adaptation/

https://www.climatechangeinaustralia.gov.au/

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