FISHERIES RESEARCH & DEVELOPMENT CORPORATION

DRAFT

Informing development of the 2020-2025 FRDC RD&E plan

Qualitative Mathematical Models to Support Evaluation of Alternative Futures

FRDC Project No **2018-197**
CSIRO Contribution – Part 2

Jeff Dambacher, Alistair Hobday, Fabio Boschetti, Chris Moeseneder, Linda Thomas

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2020

Researcher Contact Details

Name:	Alistair Hobday
Address:	GPO Box 1538
	Hobart TAS 7001
Phone:	03 6232 5222
Fax:	
Email:	Alistair.Hobday@csiro.au

FRDC Contact Details

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

In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

Contents

Executive Summary

This project contribution extends the use of the information that was assembled on two of the possible futures. Our results show how the FRDC can test the effect of different perturbations on elements of the seafood system, and to determine what indicators are most useful as predictors of trajectories of change.

This report covers the second of two CSIRO contributions to the project FRDC 2018-197. This project was reviewing FRDC research objectives through a process that developed alternative scenarios of possible futures relevant to Australian fisheries. The first contribution is included as **Appendix 4** of this report, but is not discussed further.

The second contribution discussed here was development of a quantitative model to explore future seafood scenarios developed elsewhere. The purpose of this modelling exercise was to support the project FRDC 2018-197. The development of these possible future scenarios was undertaken in a process that ran in parallel to the CSIRO contribution. This process involved a series of stakeholder workshops and follow-up discussions, to which CSIRO staff were occasional observers, and is referred to hereafter as Stage 1.

Two of these scenarios were chosen in Stage 1 as a central focus for analysis, and the CSIRO team then developed qualitative mathematical models to complement these scenarios. Our qualitative models can account for past, present and potential future dynamics of Australian aquaculture and wild-caught fisheries.

The qualitative models developed to describe present day dynamics were then tested to see if they could account for previously observed shocks or perturbations the Australian aquaculture and fisheries system. This involved a face-to-face workshop and teleconference with representatives of the Stage 1 expert group.

Based on external input to management, employment and environmental variables, the **qualitative models produced a set of predictions that were highly consistent with previously observed impacts** in Australian fisheries and aquaculture.

The models were then tested to see how well they compared to the dynamics described in the future scenarios, and here **model predictions were found to be highly consistent with the dynamics played out in the two future scenarios – that is, both worlds are likely**.

The models were then analysed **to identify informative indicators** for a range of possible perturbations to the system, with the intent that such indicators could be of use to inform monitoring programs and management of fishery and aquaculture systems in Australia. These indicators associated with some of the scenarios that were explored are:

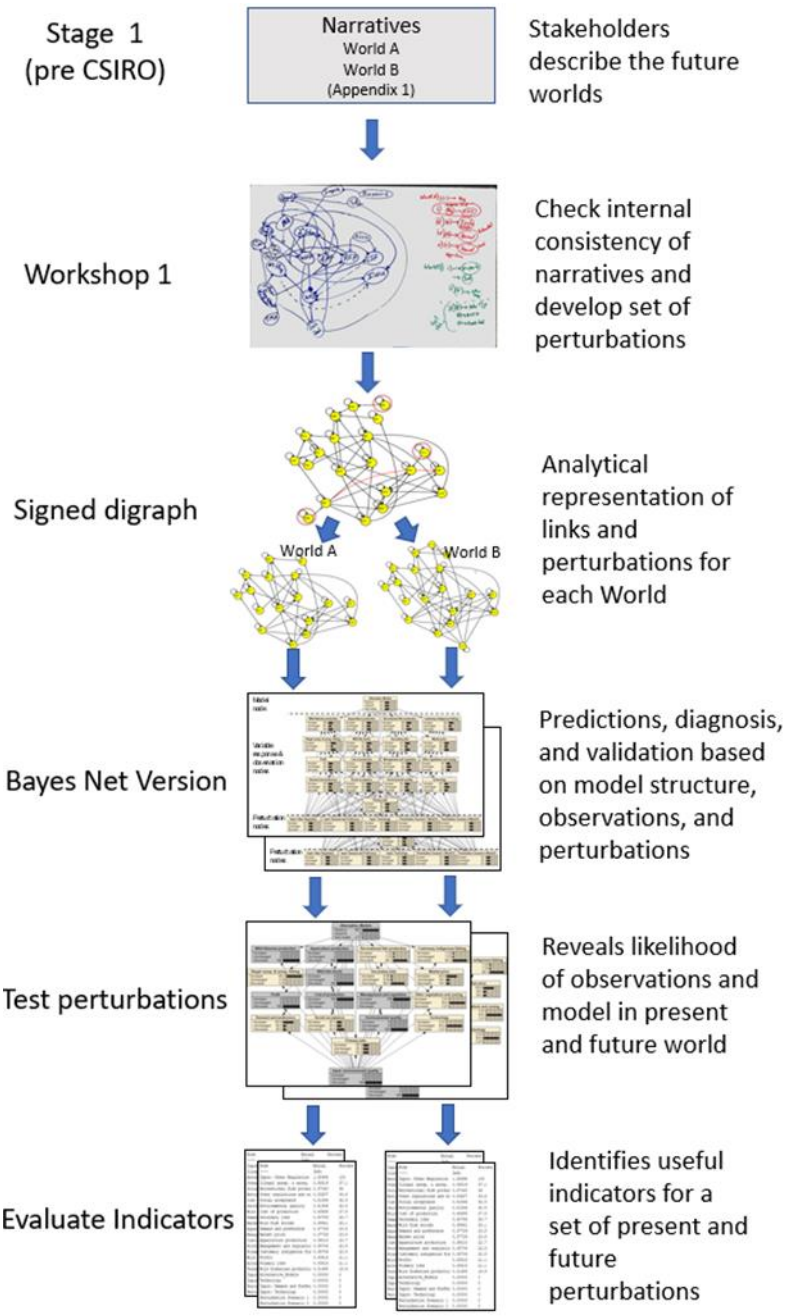
- For an input to other regulations the two most informative indicators for World A were illegal unreported and unregulated fishing and recreational fishery production, while for World B wild fish stocks and other regulations were the top two indicators. For an input to demand and preference both models had a cluster of top indicators that included wild fisheries production, social acceptance and environmental quality. For an input to technology, besides technology itself, there were no other indicators that were highly informative.

These indicators should be the focus of efforts to determine which world is emerging and could be used by FRDC to proactively understand the emergence of a future seafood world.

This project contribution extends the use of the information that was assembled in Stage 1 and allows the FRDC to test the effect of different perturbations on elements of the seafood system, and to determine what indicators are most useful as predictors of trajectories of change. This level of detail is not included in the draft FRDC 2020-25 strategy but can inform execution of the strategy.

With ongoing support from CSIRO, these models can now be used to explore alternative perturbations, identify the informative indicators, and to determine when these models of the future (World A and B) are no longer realistic representations of real situation. If insufficient information is being gather on these indicators, the efforts could be made to collect such data, or if the information is too expensive, the alternatives can also be investigated to determine how many alternative indicators provide the equivalent conformation.

The flow of activity is summarised in the schematic below.



Keywords: *Qualitative models, foresighting, shocks, strategic planning*

Introduction

This project sought to undertake a future-scanning process to provide insight on future trends, risks and opportunities facing Australia's aquaculture and fisheries sectors towards 2030 that considers likely changes in geopolitical, social, economic, environmental and/or technical aspects, drivers of those changes, and implications for fisheries production/targeting, trade, pricing, fishing participation, expenditure, and the environment.

Background

In preparing for the next FRDC RD&E strategy, rapid change must be included in strategic planning exercises. Australia's fisheries and aquaculture are facing large and rapid change due to many interacting factors including changing climate, markets, consumer attitudes and management systems, all occurring in an increasing crowded marine space. It is desirable to work collaboratively with industries, managers, and relevant others in developing a strategic plan that includes specific attention to the future pressures. That strategic plan can be informed by a process of foresighting: envisaging alternative future scenarios with the intent of pro-active choice of most advantageous strategies for informed decision-making (e.g. Cook et al 2014; McDonald et al 2019).

The ability to consider the future is essential to strategic planning. Our CSIRO Ocean Futures team has worked for three years to develop and test methods to guide futures thinking, and to develop capability in this area. Our project team uses foresighting approaches to prepare for alternative marine futures, and to contribute to over-the-horizon strategic planning. Foresighting is concerned with futures that are usually at least 5-10 years away. Foresighting draws on approaches used in long range and strategic planning, horizontal policymaking and democratic planning, and participatory futures studies. Many of the methods that are commonly associated with Foresight (e.g. Delphi surveys, scenario workshops, etc.) – are based on approaches in the Futures field. In our approaches, we examine alternative pathways, not just what is currently believed to be the most likely future. Foresighting exercises may lead to development of multiple scenarios. These may be an interim step on the way to creating positive visions, success scenarios, and aspirational futures for marine systems. Foresighting seeks outcomes such as:

- improved critical thinking concerning long-term developments,
- facilitating debate and effort to create wider participatory processes, and
- shaping the future, especially by influencing strategic policy making.

Our team sought to assist the FRDC in developing the next strategic plan. In a recent publication (McDonald et al. 2019), we reported on one aspect of our work – the pathways that scientists and scientific institutions can take in a world with a rapidly changing climate. This approach will be well suited to the seafood sector that is the focus of this research.

References

Cook, CN, Inayatullah S, Burgman MA, Sutherland WJ, Wintle BA (2014) Strategic foresight: How planning for the unpredictable can improve environmental decision-making. Trends Ecol Evol 29(9):531–541.

McDonald, K. S., A. J. Hobday, P. A. Thompson, A. Lenton, R. L. Stephenson, B. D. Mapstone, L. X. C. Dutra, C. Bessey, F. Boschetti, C. Cvitanovic, C. M. Bulman, E. A. Fulton, C. H. Moeseneder, H. Pethybridge, E. E. Plagányi, E. I. v. Putten and P. C. Rothlisberg (2019). Active, reactive and inactive pathways for scientists in a changing world. Earth's Future **7**: https://doi.org/10.1029/2018EF000990.

Objectives

As a supporting project, this contribution did not have formal objectives, rather a set of deliverables (contribution 1 and 2). The final deliverables, and hence associated objectives were different from those initially proposed. These changes were discussed and agreed with the overall project lead from the FRDC.

Final objectives

1. Compile available information (using interdisciplinary CSIRO internal knowledge and other available reports, including results from Australia's National Outlook reports, https://www.csiro.au/en/Research/Major-initiatives/Australian-National-Outlook) in a discussion paper on obvious trends to date including those related to climate change, management trends, seafood markets, and anticipated major issues. We will draw on a comprehensive Ocean Futures review (unpublished) that we have recently drafted to consider the influence of global megatrends on Australian marine industries. See **Appendix 4** – not covered again in this report.

2. Develop qualitative models and quantitative predictions for the two future scenarios developed by the FRDC expert and stakeholder groups. This report.

Original objectives

1. Compile available information (using interdisciplinary CSIRO internal knowledge and other available reports, including results from Australia's National Outlook reports, https://www.csiro.au/en/Research/Major-initiatives/Australian-National-Outlook) in a discussion paper on obvious trends to date including those related to climate change, management trends, seafood markets, and anticipated major issues. We will draw on a comprehensive Ocean Futures review (unpublished) that we have recently drafted to consider the influence of global megatrends on Australian marine industries.

2. As needed, work with FRDC to define an appropriate stakeholder consultation group in the first weeks of the project.

3. Using the discussion paper as background, we propose to hold at least one 'foresighting' workshop followed by targeted focus group discussions in major centers, supplemented by on-line polling using our website tools, involving a broad representation of aquaculture and fisheries sectors and relevant others (selected in consultation with FRDC), to
    a. Compile ideas and evidence to enable consideration of likely future geopolitical, social, economic, environmental and/or technical changes likely to occur over 2020- 2030, and drivers of those changes;
    b. Generate individual foresights relating to supply and demand for seafood products as well as conservation, energy, transport, cultural, and recreational marine uses that are likely to impact on Australia's aquaculture sector, and commercial, recreational and indigenous fishing sectors in a changing global environment towards 2030; and
    c. consideration of implications for fisheries production/targeting, trade, pricing, fishing participation, expenditure, and the environment.

Workshop results will be developed into a draft report ('draft future scan') for consideration by workshop participants and relevant others (selected in discussion with the steering committee) and interim briefing of FRDC.

4. Work collaboratively with the Principal Investigators for the other two stages in the strategic plan development and the FRDC Project Manager to ensure harmonisation of consultative processes, and timely integration of the outputs of into strategic planning outputs.

Method

The purpose of this modelling exercise (Contribution 2) was to support FRDC 2018-197. This project was reviewing FRDC research objectives through a process that developed alternative scenarios of possible futures relevant to Australian fisheries. The development of these possible future scenarios was undertaken in a process that ran in parallel to the CSIRO contribution. This process involved a series of stakeholder workshops and follow-up discussions, to which CSIRO staff were occasional observers, and is referred to hereafter as Stage 1.

Two of these scenarios were chosen in Stage 1 as a central focus for analysis, and the CSIRO team then developed qualitative mathematical models to complement these scenarios. Our qualitative models can account for past, present and potential future dynamics of Australian aquaculture and wild-caught fisheries.

The qualitative models developed to describe present day dynamics were then tested to see if they could account for previously observed shocks or perturbations the Australian aquaculture and fisheries system. This involved a face-to-face workshop and teleconference with representatives of the Stage 1 expert group.

Narratives and scenarios for Worlds A and B

Two scenarios were selected based on Stage 1 of the project for development into qualitative mathematical models:

World A: Divided we fall—*dominant motivation is fear, social influencers are polarising and divisive*.

World B: *Wisdom of the masses—government policy is integrated, environmental impacts are known, measured and managed*.

Detailed narratives that underpin these scenarios (Appendix 1) were interpreted by a group of seafood experts in a workshop setting (Appendix 2). Model development proceeded by asking participants to describe the current state and structure of Australian aquaculture and wild-caught fisheries, such that the components and elements of the present-day system would likely contain or could encompass those of the future World A and World B systems. Following construction of this model, participants were asked to describe emergence of Worlds A and B from the present-day system either as a change in graph structure or as a set of external drivers or inputs to the system acting on specific model variables.

Following the model-building exercise, a subsequent workshop was convened by teleconference to record observations from experts on the previous behaviour of the Australian aquaculture and wild-caught fisheries system due to perturbations from economic and environmental sources. These observations of the experts were recorded and later compared to qualitative model predictions as a means of hind-cast model validation. Next a set of “observations” were recorded based on the expected future behaviour of the system encoded within the narratives underpinning Worlds A and B. These observations were then used as a means of forecast model validation.

Model building and analysis

Qualitative mathematical models, encoded as signed directed graphs, or signed digraphs were used to describe the general dynamics of Australia's aquaculture and wild-caught fisheries. Here participants were asked to describe essential components, processes and factors associated with aquaculture and fisheries production and consumption within Australia. These descriptions were encoded into sign directed graphs, or signed digraphs (Box 1, Appendix 3) which provide a qualitative depiction of variable in a socio-economic or ecological system and the structure of the relationships by which they are linked. Positive effects and processes that cause the increase of a variable (e.g., a rate of reproduction or profit or a rate of addition) are depicted by a link ending in an arrow: ←; negative effects (e.g., a rate of mortality or degree of suppression or a rate of removal) are shown by links ending in a filled circle: •—.

Based on the structure of the signed digraph, one can assess if the model has the potential to be stable after a pulse perturbation, such that it can return to equilibrium following a short-term shock or disturbance to the system. The models can also be analysed to predict how the equilibrium levels of the system variables will respond to a press perturbation, which is a sustained change to internal or external conditions (Box 1).

Results

The expert elicitation workshop led to the development of a single signed digraph model that described the components and process of the present-day Australian aquaculture and wild-caught fisheries system (Figure 1). The workshop also developed a set of press perturbations that were thought to underpin the development of Worlds A and B. This information was added to Figure 1 and translated into the signed digraph shown in Figure 2.

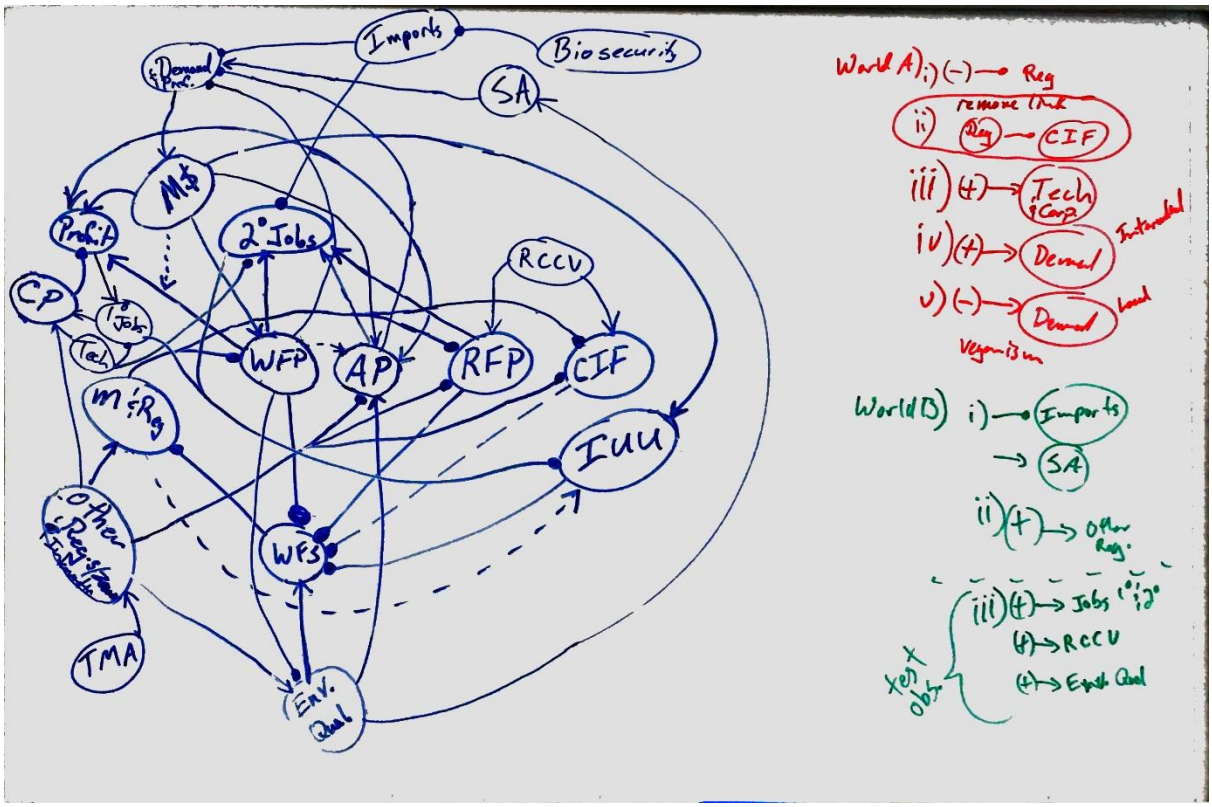


Figure 1. Whiteboard image of signed digraph of present-day Australian aquaculture and wild-caught fisheries. Perturbation scenarios underpinning development of Worlds A and B described set of inputs denoted in red and green, respectively; model variable—1^{o} jobs: primary job, 2^{o} jobs: secondary jobs (i.e., tourism), AP: Aquaculture production, CIF: customary (Indigenous) fisheries, CP: cost of production, IFP: Indigenous fishing production, ITMA: international trade and market access, IUU: illegal, unregulated and unreported fishing, M$: market price (domestic), M&Reg: management and regulations (government agencies), Other regulations & interventions: non-agency policies and procedures, RCCV: recreational, community and cultural values, RFP: recreational fisheries (extractive and non-extractive), SA: social acceptance & norms, Tech: technology and corporatization, TMA: trade and market access, WFP: wild fisheries production., WFS: wild fish stocks.

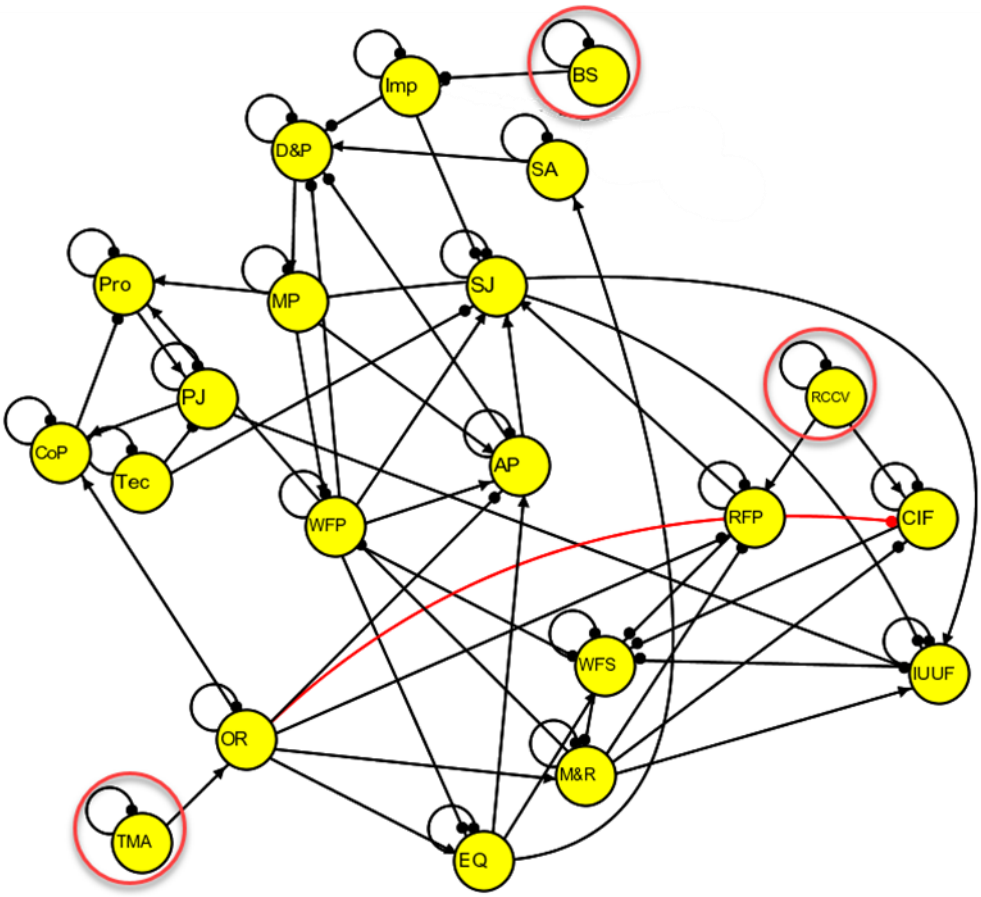
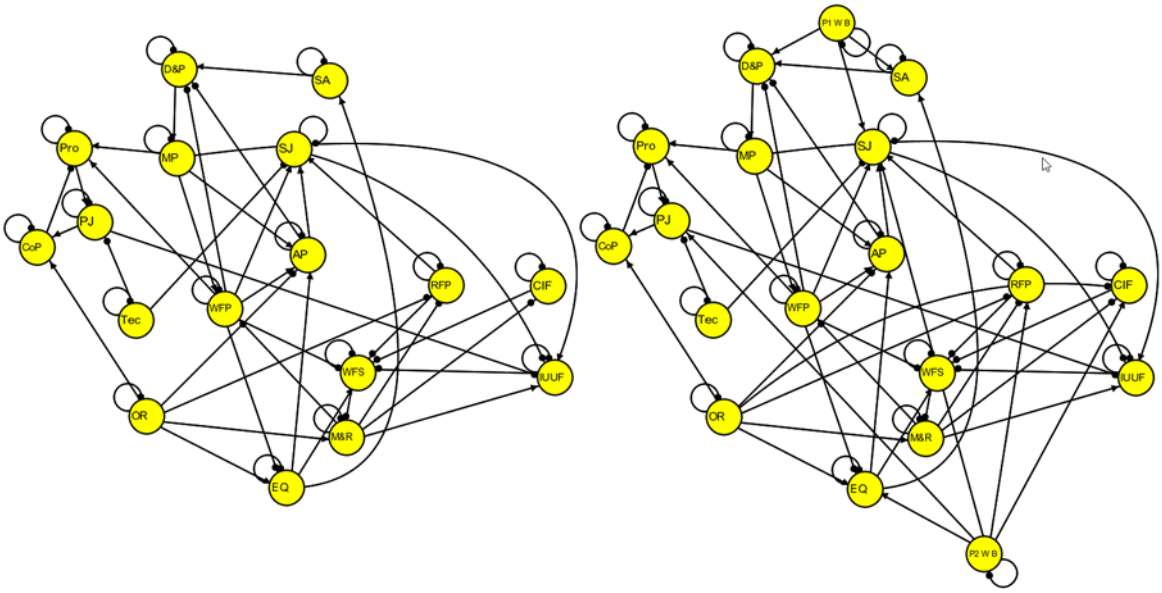


Figure 2. Signed digraph models of Australian wild caught fisheries and aquaculture systems developed from the elicitation workshop (Figure 1). For the present-day system the red coloured link from OR to CIF is absent, and the absence (presence) of this link is basis for World A (World B) model in Figure 3, and red coloured circles denote variables that were omitted or aggregated into adjacent variables to reduce model dimension; system variables: AP: aquaculture production, BS: biosecurity, CIF: customary indigenous fisheries, CoP: cost of production, D&P: demand and preference, EQ: environmental quality, Imp: imports, IUUF: illegal unreported unregulated fishing, M&R: management and regulation, MP: market price, OR: other regulation and zoning, PJ: primary jobs, Pro: profit, RCCV: recreational community cultural values, RFP: recreational fisheries production, SA: social acceptance, SJ: secondary jobs, Tec: technology, TMA: trade and market access, WFP: wild fish production, WFS: wild fish stocks.

In the model system of Figure 2 the demand and preference (D&P) for Australian fish products control the market price (MP), and market price acts to increase profit (Pro), effort in wild fish production (WFP), aquaculture production (AP) and illegal, unreported and unregulated fishing (IUUF). Production from wild fish and aquaculture act to suppress demand and social acceptance acts to increase preference. NB: to minimize model dimension demand and preference were included as a single variable, where fisheries production suppresses demand, and preference, which is sensitive to social acceptance, increases it. Biosecurity pressure acts to decrease imports and imports act to suppress demand for domestic production and secondary jobs (SC). Secondary jobs increase as a function of the levels of wild fish and aquaculture production and recreational fisheries production (RFP). Social acceptance is shown to be driven by environmental quality (EQ), which is negatively affected by levels of wild fish production and protected or increased by intensity of non-fishery agency regulations (i.e., OR: other regulation and zoning). Environmental quality acts to increase levels of aquaculture production and stocks of wild fish (WFS). Other regulation and zoning (OR) is increased by the levels of trade and market access, and also acts to suppress levels of aquaculture production and recreational fishery production, and to increase the cost of production (CP) and the intensity of fishery agency management and regulation (M&R). NB: the negative effect of other regulation and zoning on customary Indigenous fisheries (CIF) shown in red Figure 2 is not a feature of the present-day system, but is included in the future model of World B. Wild fish stocks decrease as a

function of the levels of wild fish production, recreational fisheries production, customary Indigenous fisheries and illegal, unreported, and unregulated fishing. The level or intensity of management and regulation of all fisheries (M&R) is a negative function of the monitored levels of wild fish stocks (i.e., management agencies act to suppress catch when stocks are low in abundance). The levels of recreational and customary Indigenous fishing is driven by recreational community cultural values (RCCV). The adoption of technological advances (Tec) leads to a decrease in primary and secondary jobs. Finally, the cost of production decreases profits and is increased by number of primary jobs.

To reduce the dimension of the signed digraph model of Figure 2, three variables (TMA, RCCV, and BS) were either omitted or aggregated into adjacent variables to create the models for World A and Work B (Figure 3). The link from other regulation and zoning (OR) to customary Indigenous fisheries (CIR) was added to the model for World B, as were two perturbation variables (P# WB) that were used to represent a combination of multiple of perturbations underpinning the dynamics describe for World B.



World A World B

Figure 3. Signed digraph models for present day system, and Worlds A and B derived from Figure 2; system variables: AP: aquaculture production, BS: biosecurity, CIF: customary indigenous fisheries, CoP: cost of production, D&P: demand and preference, EQ: environmental quality, Imp: imports, IUUF: illegal unreported unregulated fishing, M&R: management and regulation, MP: market price, OR: other regulation and zoning, P# W B: World B perturbations 1 and 2, PJ: primary jobs, Pro: profit, RCCV: recreational community cultural values, RFP: recreational fisheries production, SA: social acceptance, SJ: secondary jobs, Tec: technology, TMA: trade and market access, WFP: wild fish production, WFS: wild fish stocks.

Bayes Net Representation of Worlds A and B

The signed digraph models for Worlds A and B were incorporated into a Bayes net representation (Box 3) containing an alternative model node that includes models for World A, World B and a null model (Figure 4). Seventeen nodes are included in the Bayes net to represent responses or observations for the signed digraph variables, and five perturbation nodes provide the means to control press perturbation inputs for single variables or combinations of variables.

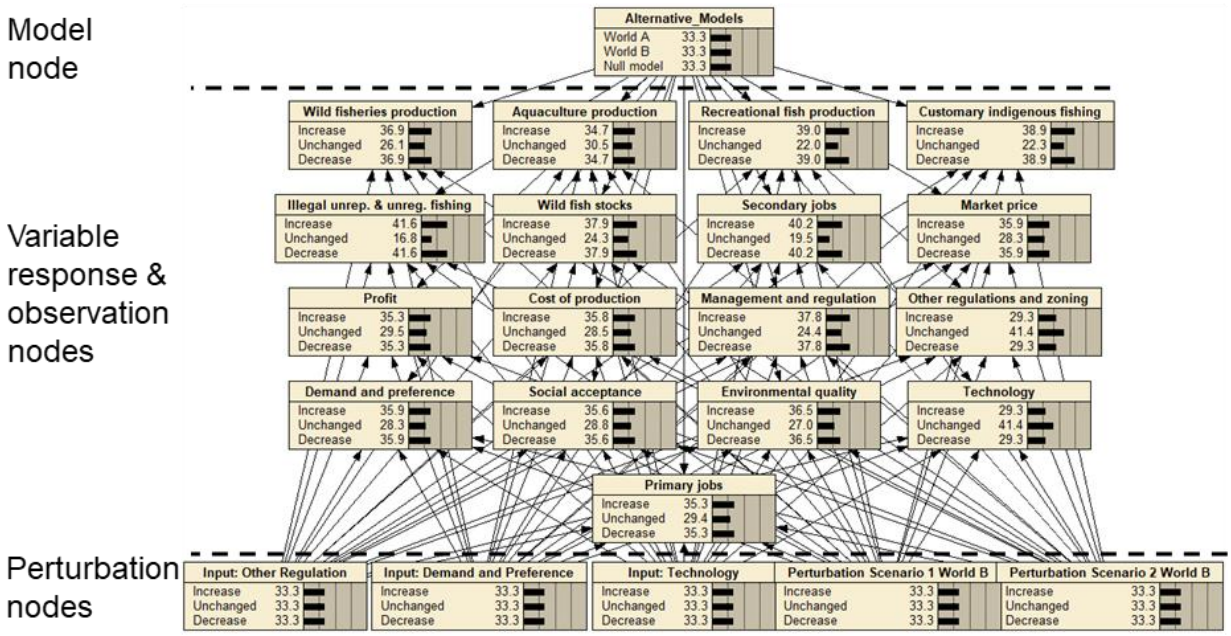


Figure 4. Bayes net structure for representing signed digraph models of Figure 3.

Model Testing from Historic Perturbation Scenarios

A test of the signed digraph model to account for past perturbations to the Australian aquaculture and wild-caught fisheries system was made by creating perturbation scenarios where there was a spilling or decrease of primary jobs couple with an increase in the intensity of other regulations and zoning—i.e., economic rationalization of the Australian fisheries sector (Figure 5). These inputs were applied only to Model A, which represent the present-day system, and to the null model. Thus, this is a hind-cast test of Model A against the null model for relative consistency of model predictions against historic observations, as given by the experts in the elicitation process. Historic observations were entered for a decrease in wild fish production and profit and primary jobs, and an increase in cost of production, management and regulation, and other regulation and zoning.

The Bayes net results indicate that model for World A had a likelihood of 83% against the null model (with model for World B excluded from the comparison).

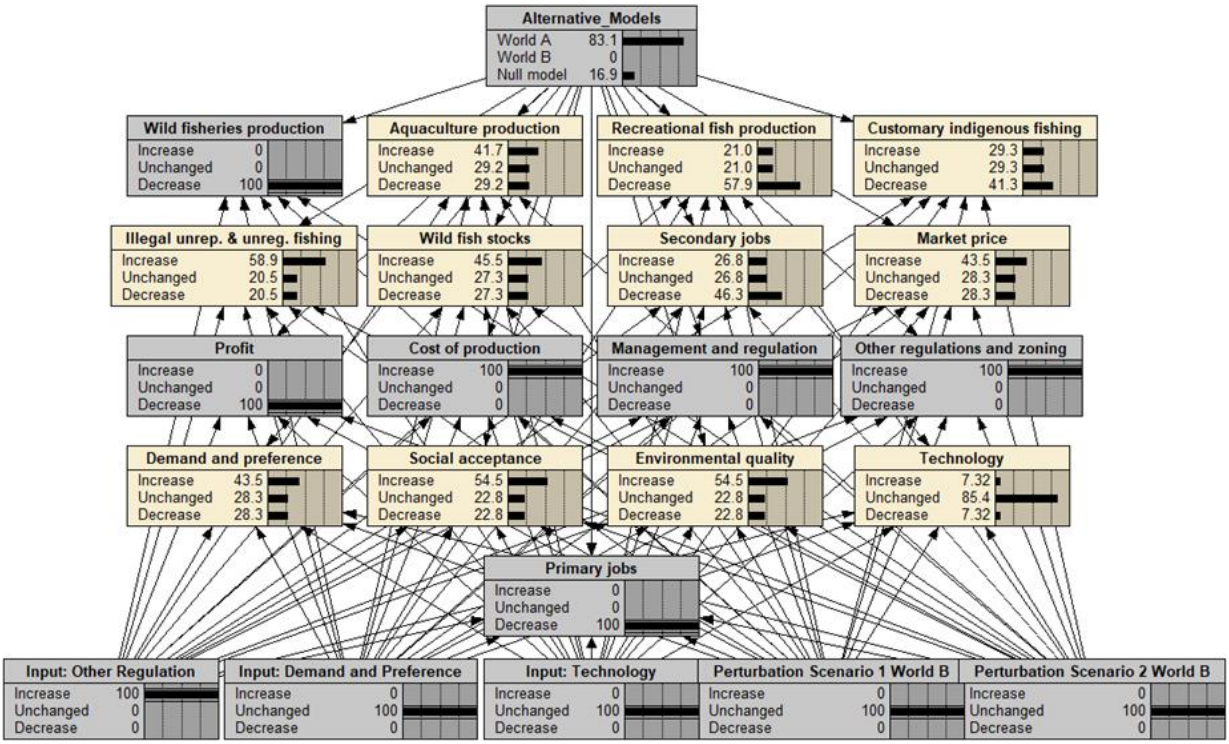


Figure 5. World A model test from historic press perturbation scenario where there was a loss of primary jobs and an increase in the intensity of other regulation and zoning.

An additional test of the model for World A was made in Bayes net that included a single perturbation node to assess an input due to a decrease in environmental quality (Figure 6). NB: the Bayes net in Figure 6 was needed only for this historic comparison, as this mode of input was not included in other scenarios, thus keeping the number of input nodes in the other Bayes nets to a workable minimum of 5 nodes. Observations were entered for decrease in wild fisheries and aquaculture production, wild fish stocks, profit and environmental quality, and an increase in cost of production and management and regulation.

The results indicate a likelihood of 96% for World A model against the null model.

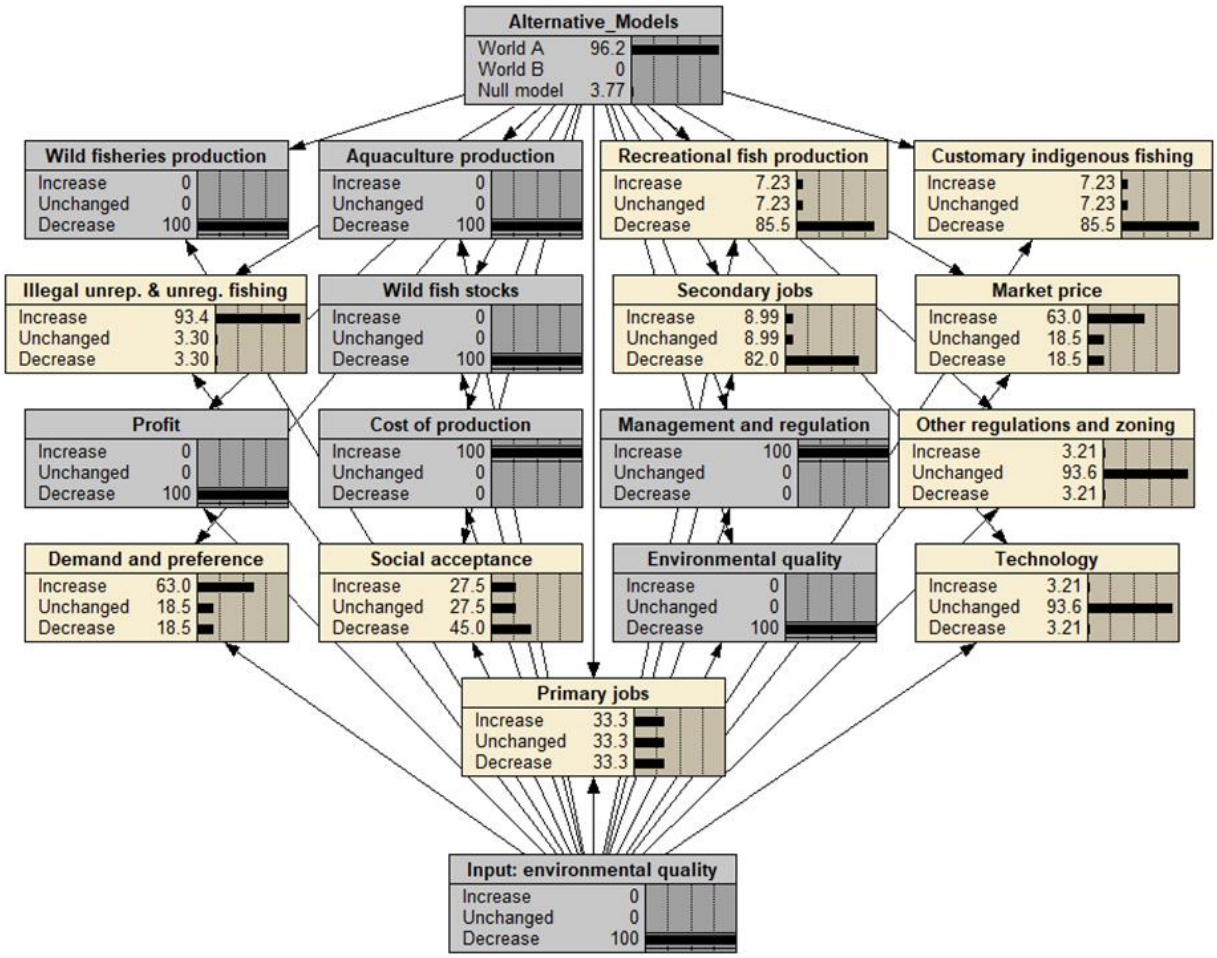


Figure 6. World A model test from historic press perturbation scenario where there was a decrease in environmental quality.

We combined the results of the two perturbation scenarios through the use of Bayesian priors, whereby the likelihood obtained from the second test (input to environmental quality) was applied as a prior to the World A model.

Here a combined likelihood of 99% was obtained for the World A model against the null model (Figure 7).

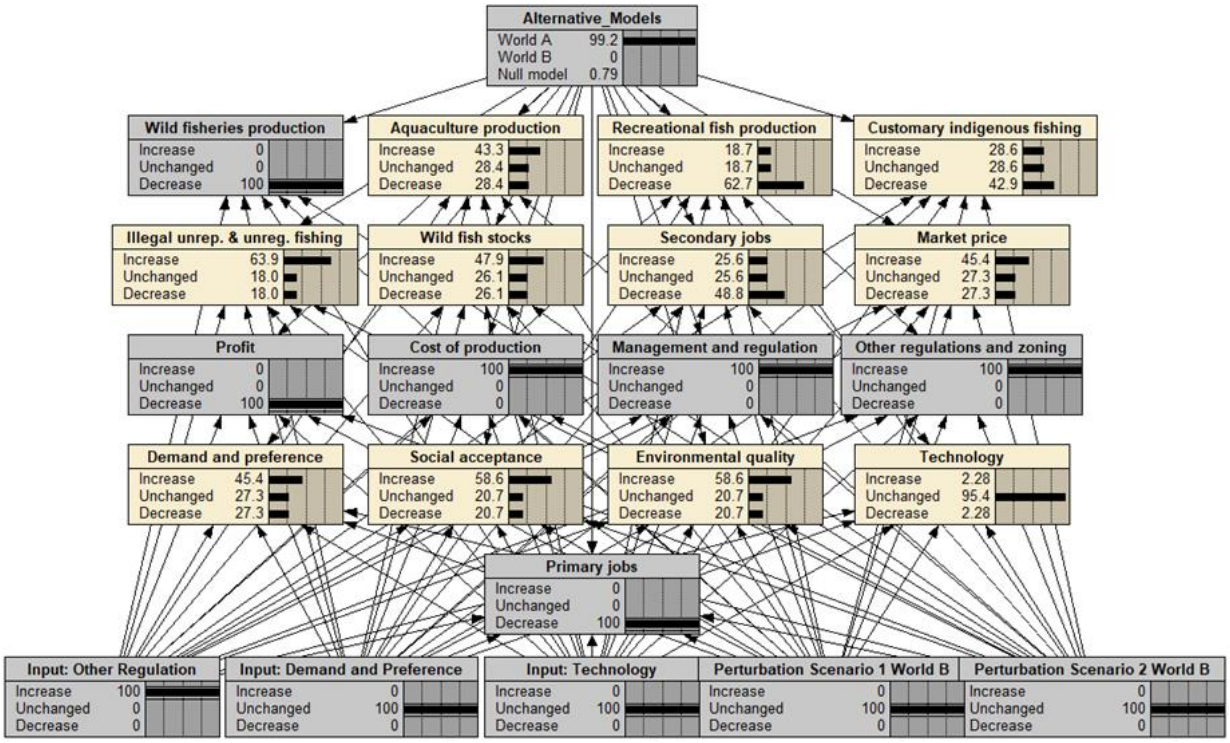


Figure 7. World A model test for two separate historic press perturbation scenarios of Figures 5 and 6, where likelihood for World A model from Figure 6 was used as prior in perturbation scenario presented in Figure 5.

Model Testing from Alternative Future Forecast Scenarios

To evaluate the consistency of the signed digraph models for Worlds A and B with the two possible futures, we tested them against a set of "observations" derived the written narrative underpinning the two future scenarios (Appendix 1).

From the workshop elicitation (Figure 1) World A, *i.e*., Divided we fall, was described as evolving from the present-day state of the system through a set of external perturbations that included a decrease in other regulations and zoning and an increase in demand and preference and adoption of technology (Figure 8). Observations derived from the narrative underpinning World A (Appendix 1) included a decrease in recreational fish production, wild fish stocks, secondary jobs, cost of production, demand and preference, social acceptance, environmental quality and primary jobs, and an increase in customary Indigenous fishing, illegal, unreported and unregulated fishing, market price, profit and adoption of technology. In this test the World A model had a likelihood of 97% (Figure 8).

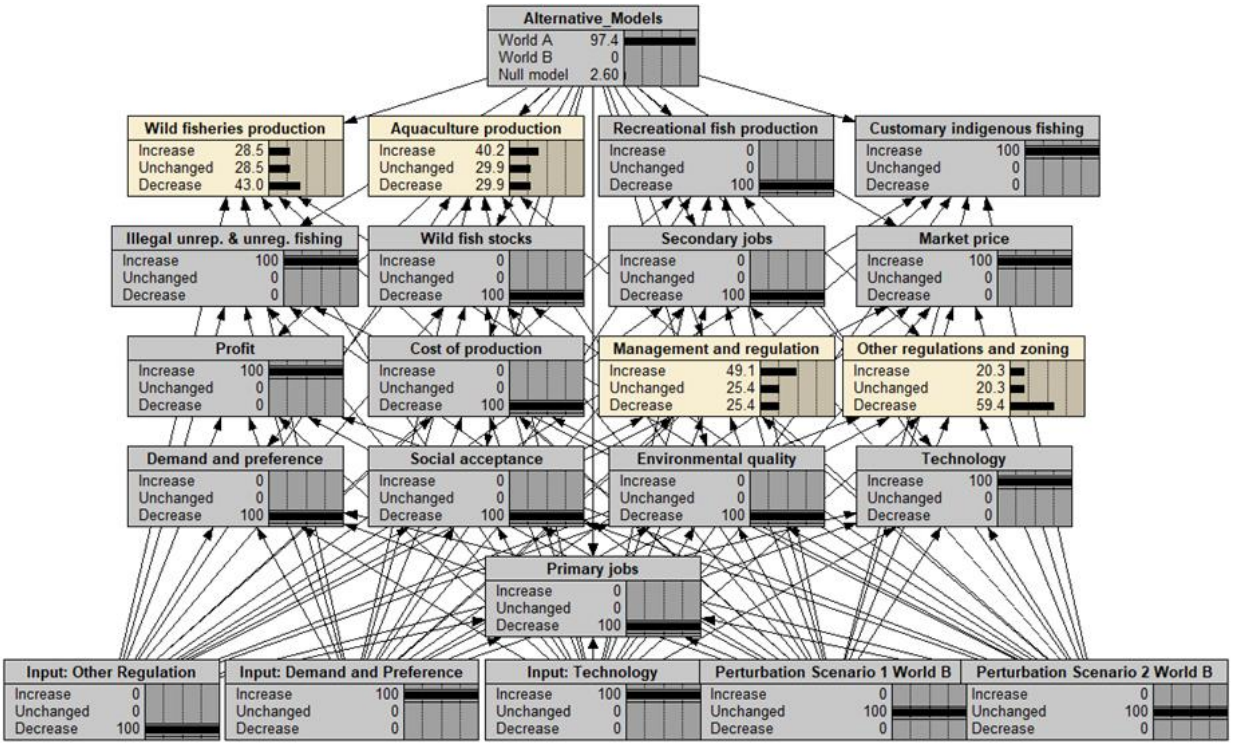


Figure 8. World A model test from forecasted press perturbation scenario.

From the workshop elicitation (Figure 1) World B, i.e., Wisdom of the masses, was described as evolving from the present-day system by the inclusion of an additional link from other regulation to customary Indigenous fishing (Figures 2 and 3) and an increase in other regulation and zoning, adoption of technology, demand and preference, social acceptance secondary jobs, environmental quality, primary jobs, recreational fisheries and customary Indigenous fisheries. Observations derived from the narrative underpinning World B (Appendix 1) included an increase in wild fish, aquaculture, recreational and customary and indigenous fishing, wild fish stocks, secondary jobs, market price, profit, management and regulation, demand and profit, social acceptance, environmental quality and adoption of technology, and a decrease in illegal unreported and unregulated fishing. This test returned a likelihood of 99.8% for World B model against the null model.

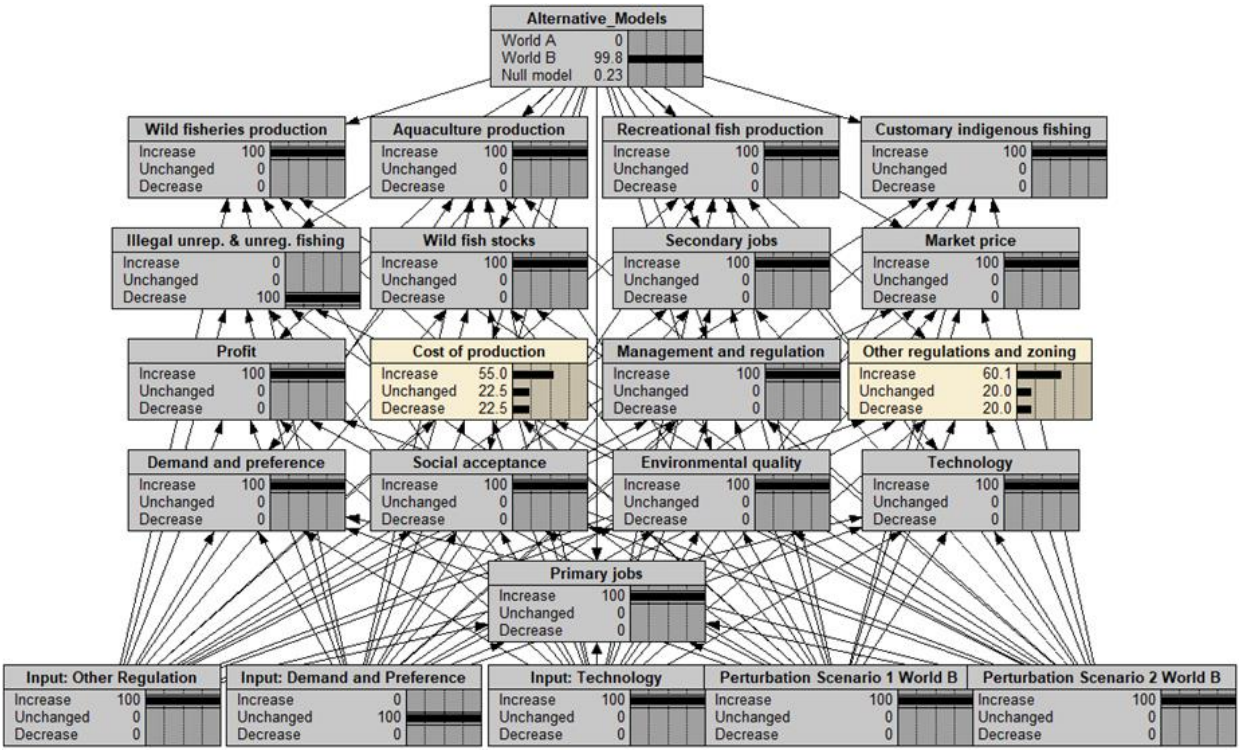


Figure 9. World B model test from forecasted press perturbation scenario.

Informative Indicators

Informative indicators for Worlds A and B models were identified based on a series of analyses based on inputs to other regulations, demand and preference and adoption of technology (Table 1).

For an input to other regulations the two most informative indicators for World A were illegal unreported and unregulated fishing and recreational fishery production, while for World B wild fish stocks and other regulations were the top two indicators. For an input to demand and preference both models had a cluster of top indicators that included wild fisheries production, social acceptance and environmental quality. For an input to technology, besides technology itself, there were no other indicators that were highly informative.

These indicators should be the focus of efforts to determine which (if either) World is emerging and could be used by FRDC to proactively understand the emergence of a future seafood world.

Table 1. Informative indicators for three input perturbations for World A and World B models.

Input to Other Regulations

World A

Node	Mutual Info	Percent
Input: Other Regulation	1.58496	100
Illegal unrep. & unreg.	0.58819	37.1
Recreational fish produc	0.57060	36
Other regulations and zo	0.53287	33.6
Social acceptance	0.51544	32.5
Environmental quality	0.51544	32.5
Cost of production	0.43588	27.5
Secondary jobs	0.40784	25.7
Wild fish stocks	0.39861	25.1
Demand and preference	0.37729	23.8
Market price	0.37729	23.8
Aquaculture production	0.36010	22.7
Management and regulatio	0.35704	22.5
Customary indigenous fis	0.35704	22.5
Profit	0.33515	21.1
Primary jobs	0.33515	21.1
Wild fisheries productio	0.31485	19.9
Alternative_Models	0.00000	0
Technology	0.00000	0
Input: Demand and Prefer	0.00000	0
Input: Technology	0.00000	0
Perturbation Scenario 1	0.00000	0
Perturbation Scenario 2	0.00000	0

World B

Node	Mutual Info	Percent
Input: Other Regulation	1.58496	100
Wild fish stocks	0.53903	34
Other regulations and zo	0.53287	33.6
Cost of production	0.43191	27.3
Social acceptance	0.41432	26.1
Environmental quality	0.41432	26.1
Recreational fish produc	0.40268	25.4
Customary indigenous fis	0.39515	24.9
Wild fisheries productio	0.39365	24.8
Management and regulatio	0.35269	22.3
Primary jobs	0.33417	21.1
Profit	0.33417	21.1
Secondary jobs	0.31557	19.9
Illegal unrep. & unreg.	0.31462	19.9
Market price	0.31171	19.7
Demand and preference	0.31171	19.7
Aquaculture production	0.30982	19.5
Technology	0.00000	0
Input: Demand and Prefer	0.00000	0
Input: Technology	0.00000	0
Perturbation Scenario 1	0.00000	0
Perturbation Scenario 2	0.00000	0
Alternative_Models	0.00000	0

Input to Demand and Preference

World A

Node	Mutual Info	Percent
Input: Demand and Prefer	1.58496	100
Wild fisheries productio	0.51221	32.3
Social acceptance	0.51221	32.3
Environmental quality	0.51221	32.3
Cost of production	0.48362	30.5
Profit	0.48362	30.5
Primary jobs	0.48362	30.5
Demand and preference	0.44471	28.1
Market price	0.44471	28.1
Secondary jobs	0.44235	27.9
Illegal unrep. & unreg.	0.44235	27.9
Aquaculture production	0.37049	23.4
Wild fish stocks	0.30096	19
Customary indigenous fis	0.30096	19
Recreational fish produc	0.30096	19
Management and regulatio	0.30096	19
Alternative_Models	0.00000	0
Technology	0.00000	0
Input: Other Regulation	0.00000	0
Input: Technology	0.00000	0
Perturbation Scenario 1	0.00000	0
Other regulations and zo	0.00000	0
Perturbation Scenario 2	0.00000	0

World B

Node	Mutual Info	Percent
Input: Demand and Prefer	1.58496	100
Wild fisheries productio	0.51221	32.3
Social acceptance	0.51221	32.3
Environmental quality	0.51221	32.3
Cost of production	0.48362	30.5
Profit	0.48362	30.5
Primary jobs	0.48362	30.5
Demand and preference	0.44471	28.1
Market price	0.44471	28.1
Secondary jobs	0.44235	27.9
Illegal unrep. & unreg.	0.44235	27.9
Aquaculture production	0.37049	23.4
Wild fish stocks	0.30096	19
Customary indigenous fis	0.30096	19
Recreational fish produc	0.30096	19
Management and regulatio	0.30096	19
Alternative_Models	0.00000	0
Technology	0.00000	0
Input: Other Regulation	0.00000	0
Input: Technology	0.00000	0
Perturbation Scenario 1	0.00000	0
Other regulations and zo	0.00000	0
Perturbation Scenario 2	0.00000	0

Input to Technology

World A

Node	Mutual Info	Percent
Input: Technology	1.57379	100
Technology	0.46128	29.3
Social acceptance	0.02285	1.45
Perturbation Scenario 1	0.02082	1.32
Illegal unrep. & unreg.	0.01996	1.27
Market price	0.01844	1.17
Demand and preference	0.01844	1.17
Recreational fish produc	0.01348	0.857
Customary indigenous fis	0.01347	0.856
Perturbation Scenario 2	0.01078	0.685
Primary jobs	0.01062	0.675
Secondary jobs	0.01040	0.661
Alternative_Models	0.00161	0.102
Other regulations and zo	0.00055	0.0352
Environmental quality	0.00000	0
Profit	0.00000	0
Input: Other Regulation	0.00000	0
Input: Demand and Prefer	0.00000	0
Wild fisheries productio	0.00000	0
Aquaculture production	0.00000	0
Wild fish stocks	0.00000	0
Management and regulatio	0.00000	0
Cost of production	0.00000	0

World B

Node	Mutual Info	Percent
Input: Technology	1.57132	100
Technology	0.55002	35
Illegal unrep. & unreg.	0.02897	1.84
Social acceptance	0.02666	1.7
Perturbation Scenario 1	0.02479	1.58
Market price	0.02231	1.42
Demand and preference	0.02231	1.42
Recreational fish produc	0.01795	1.14
Customary indigenous fis	0.01786	1.14
Secondary jobs	0.01420	0.904
Perturbation Scenario 2	0.01420	0.904
Primary jobs	0.01266	0.805
Profit	0.00000	0
Cost of production	0.00000	0
Other regulations and zo	0.00000	0
Environmental quality	0.00000	0
Alternative_Models	0.00000	0
Input: Other Regulation	0.00000	0
Input: Demand and Prefer	0.00000	0
Wild fisheries productio	0.00000	0
Aquaculture production	0.00000	0
Wild fish stocks	0.00000	0
Management and regulatio	0.00000	0

Conclusion

The workflow (Figure 10) explains how the narratives developed by the FRDC stakeholder groups can be converted into predictive and informative decision-support tools. This level of detail is not included in the draft FRDC 2020-25 strategy but can inform execution of the strategy.

With ongoing support from CSIRO, these models can now be used to explore alternative perturbations, identify the informative indicators, and to determine when these models of the future (World A and B) are no longer realistic representations of real situation.

If insufficient information is being gather on these indicators, the efforts could be made to collect such data, or if the information is too expensive, the alternatives can also be investigated to determine how many alternative indicators provide the equivalent conformation.

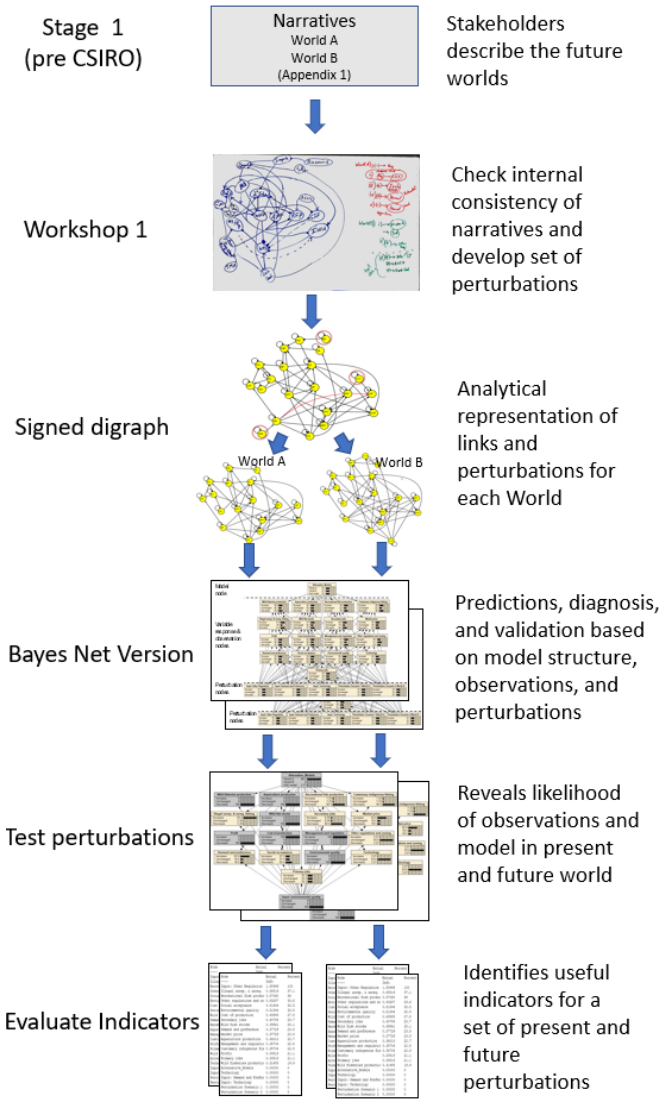


Figure 10. Project workflow, indicating the stages and outcomes of each stage, described in the main body of the report.

Implications

This project contribution extends the use of the information that was assembled in Stage 1 and allows the FRDC to test the effect of different perturbations on elements of the seafood system, and to determine what indicators are most useful as predictors of trajectories of change. This level of detail is not included in the draft FRDC 2020-25 strategy but can inform execution of the strategy.

With ongoing support from CSIRO, these models can now be used to explore alternative perturbations, identify the informative indicators, and to determine when these models of the future (World A and B) are no longer realistic representations of real situation. If insufficient information is being gather on these indicators, the efforts could be made to collect such data, or if the information is too expensive, the alternatives can also be investigated to determine how many alternative indicators provide the equivalent conformation.

Recommendations

These indicators from each of the model perturbations could be the focus of efforts to determine which world is emerging and could be used by FRDC to proactively understand the emergence of a future seafood world.

These changes could then be used to proactively work with the seafood sector in Australia to grow the opportunities and limit the negatives that may arise in the future world.

Further development

While not a specific element in this project, we also have the experience and capability to model all the futures explicitly with Atlantis in a follow-up project.

We could continue to evaluate the probability of different futures emerging with these model tool, and could also update the model structure with new information every few years.

Extension and Adoption

We plan discussions with the FRDC to illustrate the value of this work, and to consider how to use the products of the extensive stakeholder consultation process.

These model results are available for exploration at https://research.csiro.au/oceanfutures/frdc-futures/

Project coverage

Nil

Appendix 1. Narratives underpinning alternative future scenarios developed into World A and World B qualitative mathematical models

These narratives were developed in Stage 1 of the project and supplied to the CSIRO team. They are included here to show the information base used to construct the qualitative models.

World A: Divided We Fall

Dominant motivation is fear, Influencers are polarising and divisive

The year is 2030. People are afraid. Of the unknown, and each other. In times of fear people look for someone to guide and protect them. Leaders. Influencers. But influencers understand the power of fear and harness this base human motivator, through polarising and divisive behaviour, in effort to preserve their power.

Looking back, you can see how it started. What caused it. All the fear. Decades of the corrosive impact of big industry, driven by a need to deliver profit for their shareholders, enabled by blind confidence and corrupted power took its toll on fragile ancient landscapes. Growing extremes of temperature… Destructive climate violence ripping across the globe, to which Australia has not been immune… As rising oceans slowly began devouring the land. Despite these obvious signs of environmental distress, leaders and influencers continue to provide information and arguments justifying polar opposites in terms of cause, leading to no action.

Climate slowly became the major dictating force in terms of primary industries to 2030, with far reaching impacts on how many Australians lead their day-to-day lives. Australia continues to experience storms, floods, fire and drought with increasing frequency. These environmental events increasingly displaced and harmed Australians during the '20's. Eventually insurers began to refuse to insure coastal properties. Given the enormous proportion of Australia's population that live on the coast this fuelled tremendous uncertainty in the housing market, sparking the recession in the early 20's.

Arguments over whether humans and human impacts were the cause of the changing climate raged on. This argument, whether intended or not, reduced the chances of action being taken and things changing. Regardless of what caused it, the swelling caravan of climate refugees at our northern shores eventually made it impossible for Australian politicians to continue to sell climate change as someone else's problem. Natural resources progressively became scarce and highly contested during the 20's. Contested among those seeking to harvest and produce them, and increasingly from the hungry mouths fighting to consume them as we continue to be told on one hand we are in the midst of a food security crisis and the next that we do not.

Sensing opportunity, political influencers began using the climate refugee situation to their advantage. Championing an 'Australia First' rhetoric, which was underpinned by a view that Australia must conserve its resources for Australians, and not deplete them by sharing with the growing displaced population. Establishing a narrative in which 'we' needed to save ourselves from 'them', they sought to depict the refugees fleeing their sinking homelands as somehow deserving of this outcome. Somehow less than equals.

The power of confusion

Despite a Labour government forming a majority government (just) in 2022, extreme right wing and deep green fringe parties are the major beneficiaries from the current environment, largely using digital platforms as their megaphone and character assassination tactics over sound policy. The surgical targeting of different groups, and granular monitoring of results enabled through social media was better than a better mousetrap. It was now perfect. Governments were impotent in attempting to control the influence of these tech giants, who are only interested in their balance sheets. The result has been an unabated digital tidal wave of lies, hate and division.

Sensing the growing ineffectiveness of centrist, evidence-based politics the larger parties have also taken to the new supercharged form of personality politics. Use of covert footage to capture opponents in compromising situations has become commonplace, however increasing use of deep-fake technology, including through regular state-sanctioned cyber interference from growing international economic superpowers means that voters don't know if what they are seeing, and/or their political leaders are saying is real any more. The only successful people in politics are those that can align themselves with a populist influencer, and in general this needs to be done secretively and by manipulation; the public don't know of the alliance, they just hear the message from their favourite sports celebrity or reality tv star.

There have been very, very few examples of major policy being enacted during recent times. Since the Emissions Trading Scheme was enacted in 2023 after Labour came into power in the 2022 election there has been very few further developments of policy on climate change. Even the ETS is not fit for purpose and is not achieving what it set out to do, being constantly fiddled with in efforts to appease the big end of town.

The extensive knowledge of 'ancient time' that exists in coastal Indigenous communities remains an untapped and valuable resource that has the potential to be highly beneficial in natural resource management but Western interactions and approaches to mapping, researching, dividing and allocating resources remains challenging. The Australian public voted against Constitutional recognition of Indigenous people in 2022 in fear of what this might mean. Despite this, and perhaps as a 'runner-up prize', Indigenous communities were allocated fishing rights for a number of inshore fisheries in 2025. This was a knee-jerk decision by the Australian Government, made in response to growing public discontent over commercial and recreational fishing practices, which were the focus of devastating campaigns during the early 20's by powerful and extreme Environmental Non-Government Organisations (ENGOs). Initially, the recreational fishing sector thought they would be spared in the campaigns… Perhaps even benefit, having built what they thought to be an alliance with some of the extreme green groups during 2010-2019 as they worked in lockstep to eject commercial fishers from fisheries such as Westernport Bay in Victoria, to stop the Supertrawler, and to enact the still apparent moratorium on Atlantic Salmon farming in Tasmania. However, this was all part of a strategy by deep green groups who saw no place for fishing of any type in Australia. It was actually much easier to shift public sentiment against recreational fishing when the time came… The rec fishers had no data to demonstrate the minimum impact on the environment of substantial social benefits they claimed to have, and the live baiting practice was a near guaranteed trump card to whatever recreational fishers, managers or scientists had, it tugged at heart strings. And with nearly 90% of Australians now living in major cities, very few people bother to battle traffic for the hours required to get to a fishing location that is not ruined by habitat loss and contamination anyway.

When the anti-fishing campaigns began to wash over the Australian public, representatives of the recreational fishing sector immediately saw the error in their single-minded pursuit of an estimate of their economic importance during 2019-20. In a world where the everyday Australian was sick of money ruling everything, nobody cared what your economic contribution was. The Indigenous fishing community was the only sector whose 'brand' was not perceived as entirely focussed on self-interest and greed. The political response was easy, and the re-allocation was swift.

The re-allocation resulted in significant clashes between recreational, commercial and indigenous fishers throughout 2026, catalysing accusations by the growing white nationalist movement that indigenous communities were trying to exclude non-indigenous people from enormous swathes of coastline in order to limit availability to affordable and healthy food and recreational pursuits. This has been a trigger point since the seafood shortage in 2022 that was caused by a novel virus causing mortality events in wild fisheries and aquaculture farms alike, but more importantly significantly impacting export of seafood products with widespread bans on Australian products. The undescribed virus is thought to have been introduced to impact and kill carp. It is hypothesised that this move was in response to some groups dissatisfaction that the Federal Government rejected the National Carp Control Plan in 2019/20 and refused to revisit the idea of controlling carp. The rejection was on the back of strong campaigns by international academics together with ENGOs and capitalised on genuine angst from sections of the Australia's rural communities (these people were used in the same way that recreational fishers were).

These events fed the unprecedented adoption of cell-based seafood protein during 2024 & 2025 and meant that unfortunately the allocation of fishing rights to Indigenous communities was not a success, even for those who were beneficiaries of the decision. The re-allocation decision was made in haste and without consultation by the Labour party as an election commitment in 2025 and was not accompanied by sufficient follow up policy and legislation by the States to allow for the establishment of functional business structures or governance. Similar political decisions have seen allocation of areas from the commercial fishing sector to recreational fishers, commercial and recreational fishers to marine parks and vice versa. Most instances are not achieving the optimal outcome for the management of the resource, or optimised outcomes from an economic, social or environmental perspective, but do continue to drive a wedge between the different user groups of aquatic resources, and pit them as the bad guys in terms of the left leaning urban population of Australia.

Currency is still king, and the beast is getting bigger. Giant mining conglomerations and intensive agriculture firms are winning access to huge swathes of land and sea. Whilst around these affluent empires, everything else is collapsing. Forgotten by the systems, more people are living on the knife edge of subsistence. The living wage decimated with the collapse of global economies – work/life balance has become non-existent.

The political system does not implement the will of the people anymore. Many question if it ever really did. This is largely due to large-scale changes in global trade in the form of binding Free Trade Agreements that were implemented in 2023, enabling international corporations to take nations to court for loss of income if their aspirations for growth and trade are impeded.

Indigenous people challenged the Australian government over the tragic predicted pollution of the ground water with a successful land right claim in 2023. This resulted in a surprising out of court settlement between Indigenous groups and the Australian government, involving the purchase of quota from high value fisheries on their behalf.

From then Indigenous people continued to focus on the future of Sea Country, equity for all that interact and the ongoing use for future generations. This resulted in dramatic changes to affluence, but emergence of a spiritual crisis as many people were no longer living on Country, having traded it away, forcing closure of traditional homelands, loss of cultural practice and identity, making people unwell. 'Another stolen generation'. Whilst efforts to 'close the gap' were successful from an economic perspective, the mental health and wellbeing chasm is widening.

The Australian Bureau of Statistics report steadily increasing concern among Australians for their future, driven in a large regard by the ever-increasing cost of living, and growing insecurity of employment. A survey in 2025 revealed that 7 in 10 Australians reporting they are now under-employed, in no small part driven by the sweeping adoption of automation that occurred across various industries in the early 20's. This technological revolution was enabled via investment from the ten multi-trillionaires who now own 70% of Australia's corporations and share 99% of the national earnings. Completely reliant on the political

donations provided by the ten trillionaires, no competitive party is willing to advance bold policy reform to effectively mitigate climate change. Even if they did, it would never win sufficient support from the community, who are struggling under present *known* conditions to make ends meet, and continue to be swayed by the fearmongering campaigning of the Australian Coal Party

Under-privileged people have started going off the grid out of necessity. Unable to compete in the high cost, low employment world. Living in shanty cities and attempting to live off the land in places, these forgotten communities do what they can to survive. This shift out of society brings with it exacerbated ecological problems, without infrastructure and means to process waste and emissions. However, there is also a glowing ember of humanity, as people start re-connecting in order to survive. Bartering products. Protecting each other. Recreational fishing – once a pastime, is now a means for securing food.

Speed of innovation has increased dramatically, particularly over the last 6 yrs. however this has been of little benefit for most, feeding a growing expectation of perfection and consistency of supply which has squeezed out the smaller operators, and resulted in significant amalgamation across a variety of industries.

The way we consume information, and the style of information we crave, is different now. The eventual death of free-to-air TV in 2024 was a result of the fact that people increasingly sought personalised content, and the internet was ready to pounce. The few remaining online independent news outlets report a growing homelessness epidemic, with 12% of Australia's public now without steady accommodation. This growing trend can be attributed to sweeping foreclosures that were implemented under a package of strict austerity measures imposed on the Australian government in response to accepting a bail out from an emerging international economic superpower after the Australian Financial Crisis in 2022. The major news networks refuse to cover the continuing decline in living standards after the outbreak of civil unrest in Sydney's Western Suburbs in 2025, which was sparked by de-staffing of the 20th large manufacturing facility in West Penrith in three years. This may be out of a desire to reduce societal friction but is more likely a measure by the trillionaire media mogul to ensure ongoing compliance and preserve the conditions, from which he and his (largely male) trillionaire compatriots derive great benefit.

Society is changing, and this is caused by a variety of factors. People venture out less. This is in part because of continuing poor lifestyle balance as those who still work feel compelled to do so longer in effort to demonstrate their indispensability, but also in response to the growing crime rates, high costs of entertainment, unpredictable weather and significant travel time. Also, the incentives to go out just aren't there anymore. The digital revolution that swept through just before the 2022 financial crisis has meant that most of the work that remains can be done from home (spurred on thanks to technology to ensure optimal productivity). All the ingredients required to 3Dprint each week's meals are delivered. Finding a partner is done most efficiently online… That's for those who bother with a human partner. The divorce rate topped 62% back in 2027, a sure sign of our increasingly solitary existence. The AI giant 'solone' took advantage of this trend, launching their hugely successful new range of 'techno-friends' in 2026 with sweeping adoption of their products that were reported to be "the perfect antidote for those fearful of being hurt, scammed, or let down by flesh-and-blood "loved ones"

There are some changes such as the larger scale roll out of electric cars my most manufacturers. Unfortunately to date there has been little in the way of significant policy or Government investment/leadership on activities such as these. While the level of private investment is good, the free market is only working on the already converted and changing behaviour more broadly proves more difficult. Especially in an age where community values are driven largely by fear and the polarizing landscape of social influencers.

Water security continued to be an enormous issue until the mid-20's, when the great desert drought presented catastrophic security risk for South Australia, the Northern Territory and Perth, and resulted in implementation and activation of a network of desalination plants able to meet 80% of Australia's consumptive needs. This had an unexpected positive outcome for the health of Australian rivers (once the drought broke), as the reduced reliance on natural flows enabled a significant re-allocation to the environment. The significant demands for compensation by water holders – at a time that coincided with

the Australian Financial Crisis – resulted in an unprecedented revocation of rights without compensation. This resulted in significant friction between urban and rural communities, leading to the second significant case of civil unrest in 2025 (within a month of the Western Sydney fighting that took place).

The huge transition to desalinated water has presented a new problem: how to dispose of the three million metric tonnes of salt generated each year. But also, a new opportunity: the Australian Government found a way to turn the waste product into an asset, burying the alt deep underground, and using it as a giant battery to store energy generated by renewables. Scientists also identified an opportunity for salt waste to be diluted into rising sea levels which are largely a result of melting freshwater polar icecaps.

Consumer behaviours is largely broken into three categories: those who form their eating habits around what they believe to be 'sustainable', those who fetishize food, treating it as an escape, and those who have largely abandoned eating altogether in favour of increased productivity, via the new pill-based diet that delivers all nutritional needs in three daily pills.

Dogmatic pursuit of ecological sustainability by powerful ENGOs has contributed to dangerous levels of global poverty. The Industry is divided, deeply divested. Among the sustainability-focussed consumers there is distinct fragmentation within food trends, with almost equal percentages of people identifying as various groups: vegans, vegetarians, pescatarians, traditional etc. Nearly all food outlets (especially ones tailoring to niche diets) are owned and faced by celebrities and influencers in the community (apparently deriving a nice tan from a Bali holiday with 20 of your best friends which derived 2.5bn likes from 16 posts paid for by Uber makes you an expert on gut health). The food trend continues to state the idea of sustainability, however in many cases this is mostly based on values and less on science or data. Bespoke products are very trendy still but are often interlaced with lab-produced and 3D printed food stuffs presented in a single dish.

The largest food trend of the last decade has without a doubt been the rise and plateau of 'meatless meat', with both the rise and plateau being equally dramatic. Meatless meat began to make its way in to mainstream food supply chain around 2019, enabled by the growing population of people concerned about sustainability and animal welfare. It quickly took off, penetrating the supermarkets, fast food chains and even making it on to middle class restaurant menus. As quickly as it rose and was touted as the saviour of all environmental sustainability issues caused in food production. This however, quickly plateaued as a number of influencers in the food world discussed the impact that single plant production industries can have. There remains a strong consumer base for meatless products, but the expansion has somewhat abated.

Among the feed-fetishizes sustainability is not a bad word: it's meaningless. Over the last ten years the word has been often used as a catch-all term to deal with environmental impacts, and social benefits and impacts, with varying degrees of accuracy. Unable to discern truth from market spin without significant investment of time, this group has written off the concept of sustainable purchasing entirely. However, the advent of in-home 3D food printing in 2024 had an unexpected conservation outcome. The ability to produce the tastiest meal of any desired combination of flavours from a mixture of synthetic ingredients and protein filler has seen consumption of red meat and seafood go down by 66%, and the significant rationalisation of the food industry that resulted has also had a good impact on reducing waste associated with food packaging. Advent of the pill-based diet also delivered improved sustainability outcomes by those who subscribed to it.

For Australian primary products there is still a strong wave of high profits for products exported to wealthy Asian countries. These products include red meat, horticultural products like cherries, blueberries and some apples, wine and seafood.

The digital revolution that swept through just before the 2022 financial crisis has meant that most of the work that remains can be done from home (spurred on thanks to technology to ensure optimal productivity). Many led us to believe that failure to utilise technology would see the nation fail, the

government followed this with significant injection into research, development and innovation specifically targeted at avoiding being the “analogue country in a digital world” (Scott Morrison speech to accompany the $500m technology innovation fund announcement, 10 October 2020, coined from an online post made by Henry Jacobson a technological influencer hailing from Sydney’s northern beaches and has 300M twitter followers). This has meant that those who work are able to conduct this remotely. This has seen a resurgence in the regional populations of Australia. Some 30% of the population now lives in regional areas, a huge swing from 10% in 2020. Unfortunately, due to the way in which the community sources food and resources (all the ingredients required to 3Dprint each week’s meals are delivered by drone to anywhere within 1000km of a major centre) there is little to no benefit to regional communities as a whole. People are too scared to source food locally for fear it will be unsustainable.

And the demand for nutraceuticals has exploded, both as a supplement targeting 3Dfoodprint and pill-based diet consumers, and to help offset poor lifestyle of the food-fetishized community. This has been the largest area of growth in the seafood industry in the last decade.

The major fisheries are owned wholly by individual corporations. They utilise very few boats and other capital but maximise the use of technology and automation, meaning that the cost of production is much reduced. This allows them to produce to market. Products that received $50 - $100 per kilo ten years ago are now fetching between $1,000 and $5,000 per kilo. Post the economic downturn in the mid-20s exports reduced significantly. Seafood and some other specialist proteins (Wagyu beef, aged meats etc) have fared extremely well from the extreme high-end restaurant scene that has blossomed in the late 20’s in response to the opportunity to source high end products from primary production in Australia. This high-end experience comes at a cost of between $3,000 and $10,000 per head. Obviously only the extremely wealthy can access this kind of experience.

World B: Wisdom of the Connected

Government policy is integrated, environmental impacts are known, measured and managed

The recession that transformed Australia’s political, economic and social system

Dysfunction, inequity and disharmony reached a tipping-point during the Mother-Of-All-Recessions which shook the foundations of Australia in 2020 – 2022. Economic commentators reported it to be the most significant economic perturbation in Australia’s history since the Great Depression. Fuelled by the trade wars of 2019, this event was unlike the Global Financial Crisis, in that Australia was not immune this time. Without a buoyant mining sector to shield the economic body-blows, there were dramatic job losses particularly across manufacturing, retail and agribusiness sectors. Unemployment reached 15%, and home foreclosures exceeded 12%, hitting hardest in rural and regional areas, and leading to a strong property market decline. Ineffectiveness of government policy to stave off the spiralling crisis, beyond a series of measures serving mainly to prop up large corporations considered ‘too big to fail’ and the banking sector ensured that those worst affected were people occupying lower socio-economic strata.

Government implemented an aggressive stimulus package in 2023 in attempt to quell unrest, restore confidence and spark industry recovery. Certain industries were prioritised for reinvigoration, including Australia’s agriculture system. This was in part due to the food security risks revealed as a result of our historical reliance on imports during the 2019 trade wars. Coupled with substantial changes to fiscal policy, these measures slowly, steadily began to take effect. The stimulus package resulted in a lot of money flowing into the agriculture system, and aquaculture sector in particular, as capital from the impact investment and superannuation sectors started looking for ‘safer bets’, and areas that would deliver a good outcome. Over time this catalysed Australia’s rebound and setting it on a trajectory to thrive.

The dynamics of this period catalysed a range of significant changes throughout Australia's political, societal and economic landscape. Much of the outrage associated with the Recession was directed at the systemically short-sighted, populist politics fuelled largely by corporate self-interest, and consequent poor outcomes for Australian society in 2022 that led to that event. The sentiment of the time was best captured by the headline banner of the leading fact sharing site of the time ("*The Whole Truth*"), which read "*The system is broken, the people have spoken*". The collective holding of political leader's "feet to the fire", coupled with the growing trend of economic activism as the community developed a deeper sense of their own power, sparked significant and unavoidable reform across the parliamentary process in an effort to address the significant dysfunction in decision-making. Key areas of reform included changes to the party process more aligning to Scandinavian systems. The result was a significant improvement in the functionality of the political process during 2022-2025, and quality of decision-making. In 2030 the political discourse now is largely evidence-based, respectful and progressive, wherein evidence is presented and evaluated, solutions are identified and debated, bills are drafted, and debated, and voted upon based on the facts.

This new area of respectful discourse and the associated redefinition of Australia's culture and character was a key factor in Australia returning to explore the process of becoming a republic. This promoted an era of reflection. Taking stock of our national culture, sociological and ecological condition after the mother-of-all-recessions, and looking around the world for inspiration, this period would be marked in history as a key stage in the evolution of Australia's awareness. A stage of enlightenment. But it was not without challenges.

Climate change, population growth and the revenge of ecological systems

Australia's human population began concentrating increasingly into urban population centres. This concentrated anthropogenic impacts to urban areas. The high urbanisation of Australian communities would have resulted in continued dislocation of Australians from their food source, were it not for the introduction of a mandatory process wherein all Australian schools, students were required to being exposed for two weeks per annum, to the primary production sector to understand the origin of food, and build empathy with those who produce it.

Continued massive global population growth, coupled with strongly episodic climate change events throughout the South Pacific and South-East Asia over the past 5 years, awakened forced migration in 2026. This has placed environmentalism and social responsibility mainstream. With 20 million climate refugees now knocking on the door of northern Australia, the Australian Government could no longer pretend this was someone else's problem. The urgency felt by growing risk of ecological crisis, coupled with the very real economic crisis of 2020-2022 fresh in the minds of the public, spawned national recognition of a need to change, matching the raising global consciousness of the time. Enabled by the improved decision-making at a political level, this paved the way for bilateral drafting of an ambitious bill called 'understanding costs and distributing benefits bill', passed in February of 2026. The bill sought to address growing social inequality and ensure holistic accounting in the delivery of products and services.

Central to the reform was implementation of a progressive taxation system to improve accessibility to key services (education, healthcare, housing) strengthening the safety net for Australia's most vulnerable, whilst still rewarding and incentivising effort and achievement. Overall people paid more taxes, but the system *worked*. The collection and reporting of verifiable data on the impact of this economic reform clearly demonstrated its effectiveness, improving the harmonious nature of society, enabling a greater sense of shared understanding, common purpose, and ability to recognise and respond to issues as a society.

The media taking a healing role in society

Traditional media had taken its last loops of its death spiral in 2023. The broad reform in media laws in 2022 was largely ineffective, lagging behind market, whose changes were driven by an era of 'information

enlightenment'. An unquenchable demand for verifiable facts, rich education, and balanced reportage. This, coupled by widespread disaggregation of media and the fierce competition in this digital sector that ensued, resulted in a dramatic change in tone from the historically polarising, sensationalist narrative of media. Over time this had a key role in healing societal cohesiveness, as demonstrated in the annual *National Holistic Accounting Framework* which reports trends in societal trust and wellbeing (among other variables) that was implemented in 2023.

Evidence-based and holistic decision-making in government

With the political system operating as it should (acting on behalf of the people, on the basis of evidence) governments at federal and state levels were liberated to deliver their function more effectively: to undertake analysis and advise ministers on optimal approaches, and development of policy on how best to achieve desired outcomes. No longer were political advisors seeking to enforce an outcome upon the highly trained and well experienced public servants that operated their departments. A fundamental shift occurred wherein decision-making at a political level, and policy developed by government was on the basis of robust, verifiable evidence. Adaptive management, Triple bottom line and ecosystem-based management are no longer trinkets or mirages on the horizon. They are business as usual, enforcing a level of systems thinking, integration, and active and evidence-based adjustment of policy settings never seen before.

In parallel with the increasingly evidence-based government function, was a natural evolution towards a higher level of structural integration across government policy and structures in Australia. This was borne out of a clear recognition that complex interconnected systems (whether societal or ecological) do not lend themselves to a reductionist form of management into disconnected silos. The growing climate crisis reinforced on a daily basis that we cannot consider our food production systems (or any other) in isolation from the underpinning environment. This resulted in the establishment of the 'Environment & Humanity" (E&H) Mega-Department and radical re-prioritisation, with this portfolio now considered the most important under Treasury. All government departments which rely upon 'leasing' of environmental resources to produce food, fibre, wood and other valuable commodities - including fisheries - were then subsumed into the E&H Department, with a simultaneous re-ordering of policy so that all uses of ecological systems were considered secondary to their health, connectivity and functionality.

The power of information and data

Robust, audited systems were put in place to measure and report on a broad suite of metrics under the *National Holistic Accounting Framework*. The framework covered accounting all aspects of Australia's natural environment and the impacts of human intervention on it. This included the standard economic variables, but also social wellbeing aspects (under-employment, satisfaction, trust, cohesion), and a range of environmental variables (soil salt levels, soil carbon, water quality, temperature, sea-level, contaminants and their cumulative impacts). The data now being received has dramatically affected decision-making in many of the food and agribusiness sectors.

For example, fish numbers are now tracked for various life-stages. Monitoring has also extended beyond target species to also include other ecosystem elements not historically monitored due to lack of economic value. Monitoring has also been expanded spatially to include areas outside of those traditionally monitored, which historically only focussed on places of high conservation value and/or where development is planned. These diverse data streams are not only being collected, but more importantly, *shared* and *used*. A variety of digital tools and platforms have come to life that everyone can play on. This has resulted in a breaking down of the data 'fiefdoms' that emerged among scientific institutions in the early 2000's. The Science sector has been comprehensively disrupted. But far from spelling the demise of science as an institution: it spawned its re-birth, as data and scientific publications became open source, paving the way for us to begin to understand our world in previously unimaginable ways.

Interestingly, the open-source nature of data and information sharing has meant that the cost of this heavily data-driven system is not dramatically more than in prior decades. It turns out that a lot of the information required to ensure that key aspects are known, measured and managed was already being collected in the past, just not shared.

The environment is now taken seriously

The environment was now explicitly the dominant driving force behind Australia's social and economic wellbeing. All forms of investment are now evaluated with respect to their return in three dimensions: environmental, social and economic.

Implementation of a carbon tax occurred in 2025, and this catalysed the renewable revolution across industry, domestic use and transport.

This holistic accounting, of course, came at a cost. There was a massive correction in pricing of food, products and services derived from the natural environment in 2026. This was because under the *Understanding Costs and Distributing Benefits Act of 2026*, a full accounting process was put in place to enable all costs associated with manufacturing and production – including social, economic and environmental – to be quantified and passed onto the consumer. This significant change occurred on 7 July 2026 – the same time equivalent changes were also made across all G20 nations under a binding global agreement. These changes have dramatically changed the international trade landscape, Quantification of full cost of production means that products and materials produced overseas are quite expensive. But working in conjunction with government efforts to stimulate industry invigoration in 2023 this has reinvigorated regional manufacturing and production in Australia and helped re-connect Australian consumers with the high-quality natural resources and products produced in Australia, which in turn, are now enjoying renewed support from Australian consumers.

The marine environment and the fishing sector angle for success

There were also some surprising winners in the reform that took place:

- Australian oyster farmers discovered a new revenue source, through the ecosystem services (water purifying, habitat) offered by their farming systems. This, in conjunction with innovative changes to cultivation techniques with science driven environmental monitoring resulted in a rush of interest from impact investors and saw propagation of oyster farming throughout most Australian estuaries that could support businesses.
- Throughout 2026 and 2027 the National Fish Habitat Strategies were released by the recreational fishing sector, followed by First Nations, and commercial and aquaculture sectors.
- By 2028 the Ministerial Task Force on Aquatic Infrastructure of existing programs and habitat conditions was completed. The review led to the adoption by all levels of Government of its key recommendation of a wide-reaching Aquatic Habitat Stewardship Program which used existing and new levies on shipping, boating and tourism as well as local state and Federal funding to underpin a massive growth in restoration activity.

As a result of these changes, we see today a healthy marine ecosystem. Such an ecosystem is characterised by re-established shellfish reefs, seagrass beds, kelp forests and coastal wetlands. These efforts were dramatically enhanced through buy-in from the recreational fishing community. Though initially acting out of self-interest to improve the quality of fishing in restored locations and maintain social license (fishing is now less favourably viewed due to strong community concerns about animal welfare), the fishing community quickly came to appreciate the wellbeing benefits of being heralded as stewards, and that feeling was addictive.

Data, information and AI support the fishing industry

In the fisheries world, enabled by this data-rich environment, harvest strategies are now all highly interconnected and multi-species. This is the nerve-centre of the current system of ecosystem-based fisheries management and has been further enabled by more integrative management under the E&H Department. Natural resources including fisheries are now managed according to their biological stocks and ecological systems – now invisible jurisdictional boundaries. The new open source nature of information sharing has also laid the foundations for all forms of valuable information to be considered and used. Traditional Indigenous knowledge is now also integrated into management of natural resources including fisheries.

This technological breakthrough has been heralded as a tremendous success story, with fisheries management now being recognised as world-leading by the Food and Agriculture Organisation. Far from being seen as a competitive point of difference though, Australia is seeking to share what it has learned with other countries and particularly developing nations, to encourage global adoption of best practice. The motivation is clear and not altogether altruistic: global improvement makes their products cheaper, and so increases the diversity of choice in Australia. And the outcome is a global spirit of collaboration and shared learning.

The growth of aquaculture, the use of AI, automation and the adoption of new technologies

The food production system is now totally different, with farmers in Australia diversifying away from beef, and lots of movement into Aquaculture. The promise of the growing middle class of Asia came true, but global changes in the pricing of products and services under the binding G20 global agreement means that red meat is now a super-premium product, and aquaculture product is now centre-of-plate. There is a tonne of tech now being used. An international collaboration between Norway and Australia has resulted in broadscale adoption of best practice in recycled aquaculture systems, automation, and Ai, with technology creep into wild harvest fishing production systems.

This has happened in parallel with an explosion in the market share enjoyed by lab-grown meat, enabled by the modest footprint of this form of food production. Lab-grown seafood is still in development, having received less investment compared to other forms of meat as a result of the smaller material footprint associated with seafood production.

Though investment and adoption of new technology has dramatically increased since 2023 across the entire food production system, adoption of robotics and Ai has been carefully regulated by the E&H Department under the *Understanding Costs and Distributing Benefits Act of 2026*, to ensure that employment and quality of life metrics reported in the Annual *National Holistic Accounting Framework* do not fall below agreed targets.

The holistic accounting system implemented under the *Understanding Costs and Distributing Benefits Act of 2026*, enabled by the *National Holistic Accounting Framework,* and consistent with the G20 binding agreement has also helped us to address the plastics crisis that crept in from the shadows in 2019. Traditional plastics are now extremely expensive to produce and have been almost entirely replaced with keratin-based biological analogues. The high cost of plastic production has increased plastic value, establishing a market for harvest and recycling which has helped supercharge removal from the natural environment. Despite this, projections indicate natural systems will continue to suffer a hangover of historical carelessness for at least another 50 years.

Of course, every structure and process of governance has its drawbacks, and the process now in place in Australia under the *Understanding Costs and Distributing Benefits Act of 2026*, and internationally under the G20 binding agreement and other equivalent treaties is no exception. The holistic accounting process that has become central to ensure compliance comes at a significant burden to industry and consumers

alike. However, this has been partially offset in the fisheries and aquaculture sectors by rationalisation of management under the E&H Department.

A process of review and re-allocation of access to natural resources (including fisheries) was also undertaken under the *Understanding Costs and Distributing Benefits Act of 2026*, in recognition of historical utilisation. Australia's indigenous community was a particular beneficiary and is now has fishing rights allocated for all major freshwater and inshore fisheries. Historical use by recreational fishers has also been acknowledged through formal allocation.

The dominance of the consumer and the demand for traceability and transparency

The building of consumer awareness in terms of where their food comes from has also been significantly enhanced through the introduction of a national food traceability system in 2027 under the *Understanding Costs and Distributing Benefits Act of 2026*. The system was designed to inform consumer behaviour around true costs of each product, and as a result everything is now block-chained, tracked and traced. Consumers can now scan QR codes on every product and know where it comes from, how it was collected, and the material footprint to produce it. Mislabelling has been eradicated as a result as well. This has fundamentally changed the way we produce and consume products in Australia. We are now largely eating seasonally and locally, preferentially choosing items produced with lesser impact – because they are better aligned with stakeholder values, and cheaper. This has led us back to reinvigorating our smaller artisanal production systems, including fisheries. Having largely lost smaller operators in 2022 as a product of legislative conditions that promoted corporatisation, since implementation of the *Understanding Costs and Distributing Benefits Act of 2023* there has been a re-emergence of family fishing and farming operations, which are now once again abundant. The marketplace is now more distributed – with fish processed and sold through regional centres to reduce food miles, rather than funnelled through a small number of large processing facilities, as was done prior to 2022.

In fishing, the traceability revolution has also supercharged innovation in production systems and methods. Through significant investment in R&D we have worked out how to modify the catching system to largely exclude non-edible species.

The traceability revolution since 2023 extended beyond the food production sector and played a key role in revolutionising the political decision-making system as well. Adoption of technology enabled full traceability and transparency of political donations, with every dollar tracked in real time. In combination with the reform in political process this dramatically re-shaped economic dimensions of the political process, with corporate and international donations dropping by 70% over three years. The financial incentive of political donations largely evaporated, with political parties and leaders focussed now on representing the political will of the people.

Appendix 2. Agenda of expert elicitation workshop where World A and World B qualitative models were developed

22 October 2019
Cove room, CSIRO Marine Laboratories
Castray Esplanade, Hobart

TIME	TOPIC
09:00-09:30	The model process Model example: Aquaculture model
09:30-10:00	Review of scenarios What are the intrinsic components, processes and narratives?
10:00-10:30	*break*
10:30-12:30	Model creation
12:30 – 13:00	*lunch*
13:00-15:00-	Model creation
15:00-15:15	*break*
15:15-15:45	Analysis of model
15:45-16:00	Future work and close

Attendees

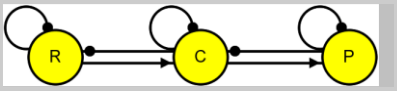
NAME	ORGNAISATION
Brett Cleary	Australian Recreation Fishing Foundation, TAS
David Smith	Research Provider Network, TAS
Emily Ogier	Social Science (UTAS)
Colin Buxton	National Fishery Advisory Council Chair, TAS
Wayne Hutchison	Aquaculture, Adelaide
Mike Gilby)	Indigenous, Melbourne
Matt Barwick	FRDC
Alistair Hobday	CSIRO
Jeff Dambacher	CSIRO
Fabio Boschetti	CSIRO
Chris Moeseneder	CSIRO
Linda Thomas	CSIRO

Appendix 3. Overview of qualitative models

The following pages provide a summary of model development theory.

Box 1. Qualitative mathematical models and their analysis

Qualitative modelling proceeds from the construction and analysis of sign-directed graphs, or signed digraphs, which are depictions of the variables and interactions of a system. Here we are only concerned with the sign (*i.e.*, positive, negative, zero) of the direct effects that link variables. The below signed digraph is a straight-chain system with a basal resource (R), consumer (C) and predator (P). There are two predator-prey relationships, where the predator receives a positive direct effect (*i.e.*, nutrition, shown as link ending in an arrow (→)), and the prey receives a negative direct effect (*i.e.*, mortality, shown as link ending in a filled circle (●—); included also are self-effects, such as density dependent growth.



Stability.—Based only on this qualitative structure, it can be determined that this model is stable, which is a result, in part, of it having only negative feedback cycles. The paths leading from the predators to their prey and back to the predator are negative feedback cycles of length two, and there are no positive (destabilizing) cycles. Thus, if this system were to experience a sudden disturbance it would be expected to return relatively quickly to its previous state or equilibrium.

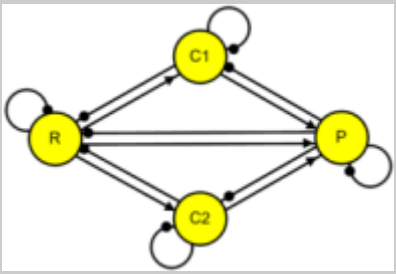
Prediction of perturbation response.—One can predict the direction of change in each variable (*i.e.*, increase, decrease, no change) due to a sustained input or pressure to the system. Consider a pressure on the system in the way of food supplementation to the predator that increases its reproductive capacity. The predicted response of C is determined by the sign of the link leading from P to C, which is negative (denoted P —● C). The predicted response of R will be positive because there are two negative links in the path from P to R (P —● C —● R), and their sign product is positive (*i.e.*, − x − = +). In this system there is complete sign determinacy for all response predictions, as there are not multiple pathways between variables with opposite signs.

Press perturbation analyses of signed digraph models commonly reveal ambiguity in model predictions. Such ambiguity is based on there being a mixture of both positive and negative effects contributing to any given prediction of a perturbation response. These ambiguities are resolved by either a detailed analysis of the algebraic details of a response or through a statistical approach (Box 2). By taking the latter approach, one can embed the qualitative dynamics of a sign digraph into probabilistic framework through a Bayes net (Box 3).

Box 2. Ambiguous response predictions and sign determinacy

Compared to the system in Box 1, the signed digraph below is a more complex system with an additional consumer and a predator that feeds on more than one trophic level; this added

complexity creates multiple pathways with opposite signs between the predator (P) and resource (R).



Here the predicted response of R due to an input to P is ambiguous, because there are now three paths leading from P to R, two positive (P —● C1—● R, P —● C2 —● R) and one negative (P —● R). The abundance of the resource can thus be predicted to either increase or decrease. This ambiguity can be approached in two ways. One is to apply knowledge of the relative strength of the links connecting P to R. If P was only a minor consumer of R then the R would be predicted to increase. Alternatively, if R was the main prey of P, and C1 and C2 amounted to only a minor portion of its diet, then R would be predicted to decrease in abundance.

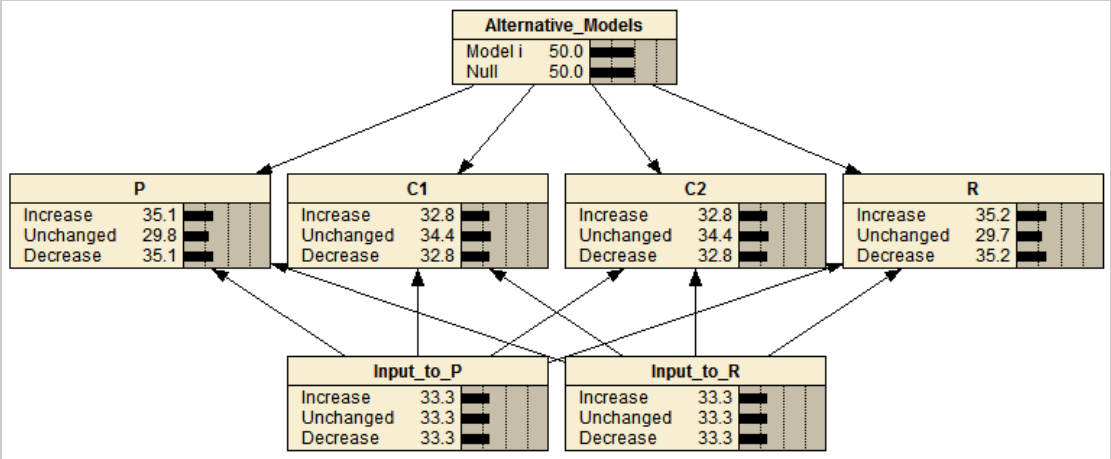
It is often the case, however, that we lack sufficient knowledge of the strength of the links involved in a response prediction. In these instances, we can use a statistical approach developed by Dambacher *et al.* (2003a) and Hosack *et al.* (2008) that provides a probability of sign determinacy for response predictions. Through computer simulations, path strengths can be randomly allocated to qualitative models, and the signed determinacy of responses predictions compared to the relative balance of positive and negative paths. If there are an equal number of positive and negative paths between variables, then an increase or decrease in a variable is equally likely. In the above example with two positively signed paths and one negatively signed path, there is a net of one positive path (*i.e.*, it is considered that a negatively signed path cancels a positively signed path) out of a total of three paths. Based on computer simulations by Dambacher *et al.* 2003a and Hosack *et al.* 2008, R can be expected to increase roughly three out of four times, but also decrease one out of four times; accordingly, one can assign a level of reliability, or ambiguity, to the prediction for a positive response in R.

The ratio of the net to the total number of paths in a response prediction has been determined to be a robust means of assigning probability of sign determinacy to response predictions. These probabilities of sign determinacy can then be used as conditional probabilities for Bayes nets.

A Bayes net provides a convenient and flexible tool to analyse the qualitative behaviour of complex systems, permitting one to 1) portray predictions from press perturbations, 2) diagnosis of likely causes of an observed change in a system, 3) validation of a model against observed system behaviour, and 4) identification of informative indicators for management and monitoring programs (Box 3).

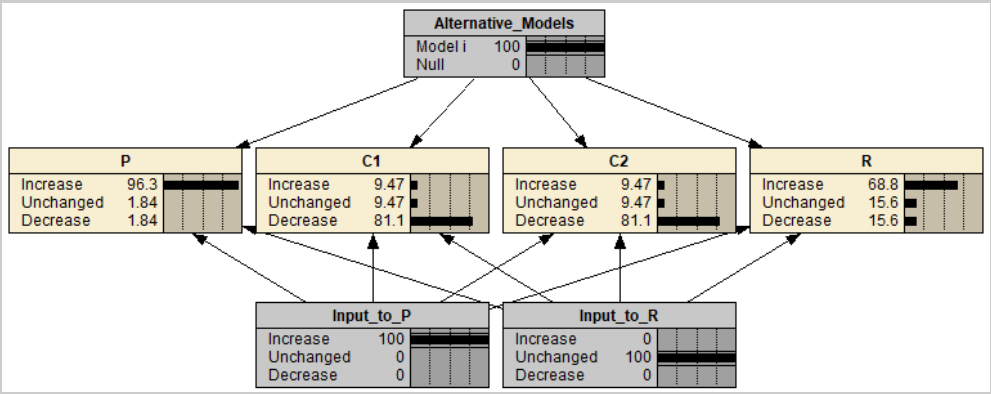
Box 3. From signed digraph to Bayes net

A significant limitation to standard applications of Bayes nets is that there is not a practical means of incorporating feedback cycles into the network's acyclic graph structure. Thus, in practice, feedback processes common to ecological systems cannot be explicitly included in a Bayes net. Hosack *et al.* (2008) addressed this limitation by providing the means to incorporate the consequences of feedback processes within an acyclic Bayes net, which is accomplished by embedding probabilities from qualitative model predictions within the Bayes net's conditional probability tables. Below is the resultant Bayes net for the signed digraph in Box 2.



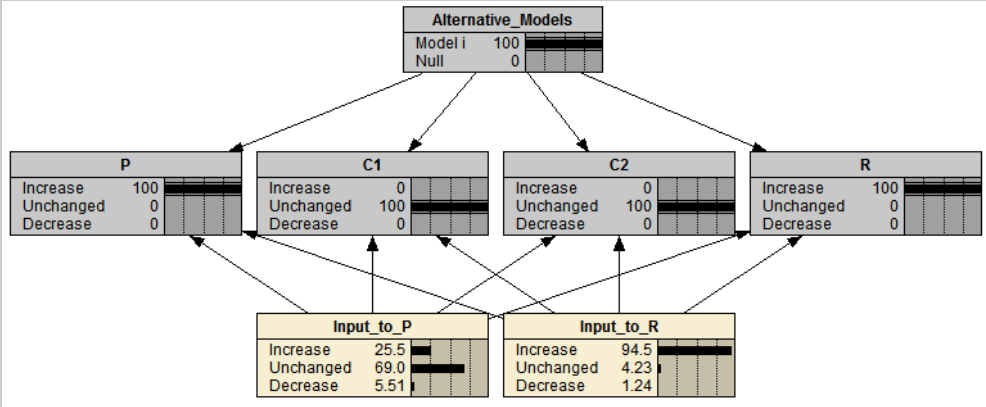
The general structure for a Bayes net derived from signed digraphs starts with a single parent node on the top that represents the probability for alternative models. There is at least one or more alternative model that is compared to a null model, which is a qualitative model that predicts all responses (+, −, 0) for variables with equal probability. In the middle row are child nodes that give the probabilities for qualitative predictions of responses to inputs to the system. These inputs are driven by one or more parent nodes on the lower row of the network. The above Bayes net is shown in a state with no probabilities attributed to parent or child nodes. The Bayes net allows for four basic analyses of the qualitative models: prediction, diagnosis, validation and sensitivity.

Prediction.—What is the probability that the equilibrium level of a variable will change given an input to the system? These probabilities are conditional upon the likelihood of an input to one or more of the system's variables and prior belief in the alternative models. In the below scenario, we are fully confident in our choice of Model (i), and that there has been an input to variable P and no input to variable R, thus each of these nodes receives a 100% likelihood for the chosen state. The resulting probabilities for qualitative response predictions are observable along the middle row of nodes. In this work predictions are used to compare the likely consequence of a pressure. In the below example, a pressure that has a positive input to P would be judged to most likely be a benefit to P and R, and a detriment to C1 and C2.

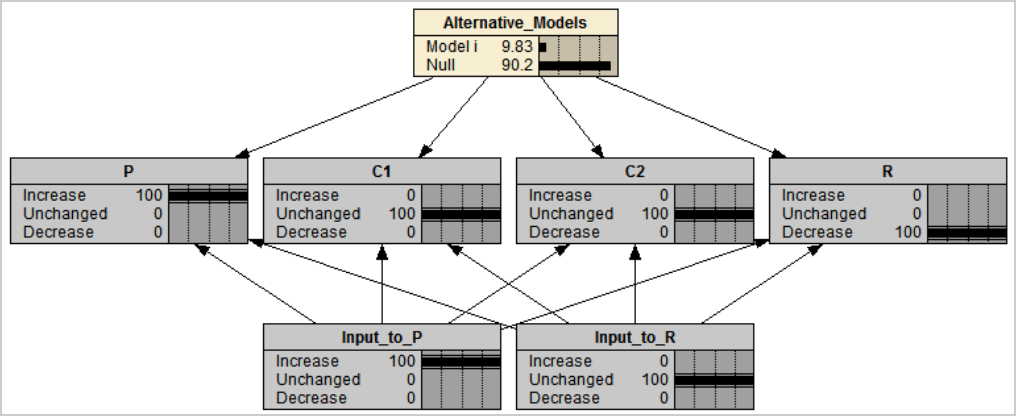


Diagnosis — What is the most likely cause of input to the system? Given a prior belief in the correct model structure, and observations of change in the system variables, levels of likelihood are

attributed to each of the possible input variables. In the below example an input to R receives a relatively high likelihood (*i.e.*, 94.5%), while only a relatively small likelihood for change (<31.1%) is attributed to P. In this work, we employ the logic of diagnosis to identify potential management interventions. For instance, if one wished to affect an increase in both P and R, but not in C1 and C2, then the below analysis suggests that an effective intervention would be through a positive input to R.



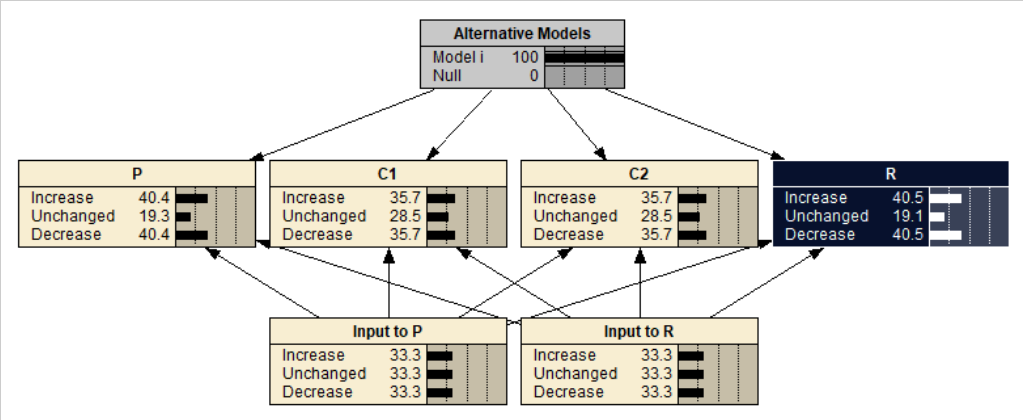
Validation — How consistent with empirical evidence are the predictions of alternative models? Given our confidence that a perturbation to a system has occurred, and our level of certainty in qualitative responses of the variables, we can judge the relative consistency of model predictions with observations, thus allowing model testing and falsification. In the below example, there is complete certainty in the source of input and the direction of change of each variable. Here Model (i) is less consistent with observations than a null model, indicating that it performed worse than pure chance. This function is most useful for judging system understanding and the conceptual model(s) that underpin an integrated monitoring and management program.



Sensitivity — Which variables are most sensitive to perturbations of other variables? Sensitivity analyses deduce the influence of one variable on another through a measure of mutual information. This analysis is especially useful in deciding which variables to measure or observe to identify the most informative variables for monitoring and to diagnose the most likely source of an input, thus it is especially important for identifying potential ecological indicators for monitoring programs.

For the example system, if we accept Model (i) as the most likely model and we are interested in identifying what would be the most informative part of the system to predict the dynamics of R,

then in the Bayes net the node R is selected, shown below as darkened node, and the remaining observation and input nodes are left unconstrained. The resulting sensitivity analysis suggests that the two most informative indicators that will inform and predict R's behaviour is Input to R and P, with the remaining variables having comparatively much less information. Measuring inputs of R to the system and the state of P would thus be logical candidates and priorities for monitoring, while variable C1, C2 and input to P would not.



Sensitivity of 'R' to a finding at another node:

Node	Mutual Info	Percent
R	1.51243	100
Input to R	0.48844	32.3
P	0.40687	26.9
C2	0.09258	6.12
C1	0.09258	6.12
Input to P	0.08652	5.72
Alternative Models	0.00000	0

Appendix 4. - Informing development of the 2020-2025 FRDC RD&E plan

(FRDC 2018-197)

CSIRO Contribution Part 1

An analysis of medium to long-term impacts on the Australian Oceans

Fabio Boschetti[1], Cathy Bulman[2], Alistair J. Hobday[2], Stephanie Contardo[1], Hector Lozano-Montes[1], Lucy Robinson[1,3,4], Joanna Strzelecki[1], Ingrid van Putten[2], Tony Smith[2]

[1] CSIRO Oceans and Atmosphere, Crawley, Western Australia, Crawley, WA, 6009
[2]CSIRO Oceans and Atmosphere, Hobart, Tasmania, 7000, Australia
[3] Oceans Institute, The University of Western Australia, Perth, WA, 6009
[4] Oceans Graduate School, The University of Western Australia, Perth, WA, 6009

Introduction

This document describes three tools which can help develop a shared understanding of the overall system in which Australian fishing and aquaculture operate, how it works and its main drivers at global, national and regional scales:

- a conceptual model of the stressors and drivers of changes affecting the Australia oceans (Section 0). This conceptual model includes the sectors directly or indirectly interacting with the Australian oceans (fishing, aquaculture, shipping, tourism, oil and gas, etc.) their regional and national drivers (Australian Population growth, Australia GDP, Energy requirements, etc.) as well as global drivers (global population growth, global GDP growth, climate change, etc.).
- four scenarios for these global drivers (Section 0) as produced by the Great Transition Initiative [1]. These specific scenarios were chosen because they were simulated numerically via the PoleStar model [2] and thus provide numerical projections for a large number of social, economic and environmental indicators at the global and continental scales.
- A set of projections for future development for a number of industry sectors, processes and regional and national drivers (Section 0).

These tools can inform the development of the narratives underlying the four scenarios identified by the Leadership Group. In addition, the combined analysis of the conceptual model, global scenarios and sector projections allows us to assess:

- what inter-sectorial interactions are described or explicitly acknowledged within each sector;
- to what extent sector and process projections are compatible with one another;

- whether these projections align with any of the global scenarios.

This combined analysis is a work in progress but some preliminary observations are of significance for the task at hand:

- the sector projections are based on a number of underlying assumptions or scenarios which are not necessarily shared among sectors. This is understandable because each sector developed its projections according to its own specific needs. However, this makes it difficult to jointly analyse multiple sector projections and care must be taken when doing so.
- Some sector projections span several decades while others span only a few years. Care must be taken when different time scales are jointly analysed because both the methodology and the motivation behind these projections may differ significantly. Cognitive attitudes towards the close and the far future also differ significantly and may be at play behind both the development and the interpretation of the projections [3].
- In the development of the projections, some sectors acknowledge interactions with other sectors or processes currently not included in the conceptual model in Figure 1. These additional interactions can be included in the conceptual model if a need is recognised during the workshop.
- Scenarios are narratives, while projections are numerical estimates (see definitions in Table 1). In addition, both can represent either expectations of what may happen (looking *forward* to what may happen given what we know) or desires in the form of visions (looking *backward* from a future we desire to consider what we should do to reach it). How scenarios, projections and visions can be jointly analysed depends on the task at hand. For example, as a first pass, projections may be considered as initial rough indicators of likely system behaviour under specific assumptions. In all cases, care needs to be taken in recognising the assumptions and in discriminating between assumptions, desires and visions.

Table 1. Suggested definitions for approaches commonly used in the Future Studies literature.

Approach	**Definition/use**
Scenarios	Alternative narratives of how the future might unfold.
Projections	A numerical estimate (time series, plots, trends, growth rates, etc.) of the likely or possible future values of one or more indicators of a system's behaviour.
Foresighting	An informed analysis of some aspects of a future reasonably far from now, which arises from intellectual speculation requiring both broad and expert knowledge.
Forecasting	A prediction about a future usually next to now, requiring expert knowledge.
Visioning	A statement about a desirable future and commitment to create it

A conceptual model of impacts on the Australian Oceans

Our conceptual understanding of the main drivers impacting the Australian Oceans is shown in Figure 1. It includes four types of processes, which we label as Global Processes, National Processes, Blue Economy Sectors and Oceans Processes, respectively:

- Global processes (top row) are those whose control and scope lie outside Australia but are the main drivers controlling the global context in which Australia as a system needs to operate. These are international trade, global GDP trends, climate change, and energy and food requirements. Trends in international trade and global GDP will affect the Australian economy both directly and indirectly.

This in turn will have both direct and indirect effects on Australian oceans in terms of transport and resource extractions (mineral and fishing). Energy technology has so far had a crucial impact on economic production and growth [4, 5] and it is likely to have an even stronger impact in a world of declining energy resources. It is likely to affect the Australian economy through its impact on transport costs and the attractiveness of Australian mineral resources. Food technology can have an impact on what resources will feed an growing global human population and on the balance between land versus marine food production [6]. Finally, the climate change will directly or indirectly affect all processes al various time scales. Here we assume that Australia has little impact upon these global variables either through policy or feedback effects; in other words, we treat these processes as drivers of the system.

- National processes (second row from the top) are those with control or scope within Australia whose impact on the Oceans is mostly indirect. These include mining, energy generation and national GDP and population growth. Their impact on Australian oceans is mediated mostly by transport, environmental impacts of land-based resource extraction, and requirements for different ecosystem services. In principle, there is scope for control and policy intervention on these processes. However, this may be limited in practice for a number of reasons. First, the complexity of the political processes may render some of these intervention options less likely to occur. Second, regulation for these sectors is in the hands of bodies different from the ones tasked to manage marine matters. Finally, their management is strongly coupled with other national and international issues of larger social and political scope.
- Marine Sectors and Processes (third row from the top) directly relate to uses of Australian oceans. These include sea transport, tourism, fishing and aquaculture and possibly other future ecosystem services. Tourism is likely affected by trends in both local and international GDP but also by other factors like environmental quality and the cost of transport; in turns it can affect fishing as well as other ecosystem services and Australia's GDP itself. Australian population growth is likely to be a key driver, possibly the main driver, of most processes in this category.
- Oceans processes and some of their core ecological components (blue box) include population dynamics of marine species and trophic relations, ecosystem services and biodiversity. While we acknowledge these processes, they are not explicitly discussed in this work, since our focus is on the processes impacting the oceans, rather than oceans processes per se or ocean responses to pressures.

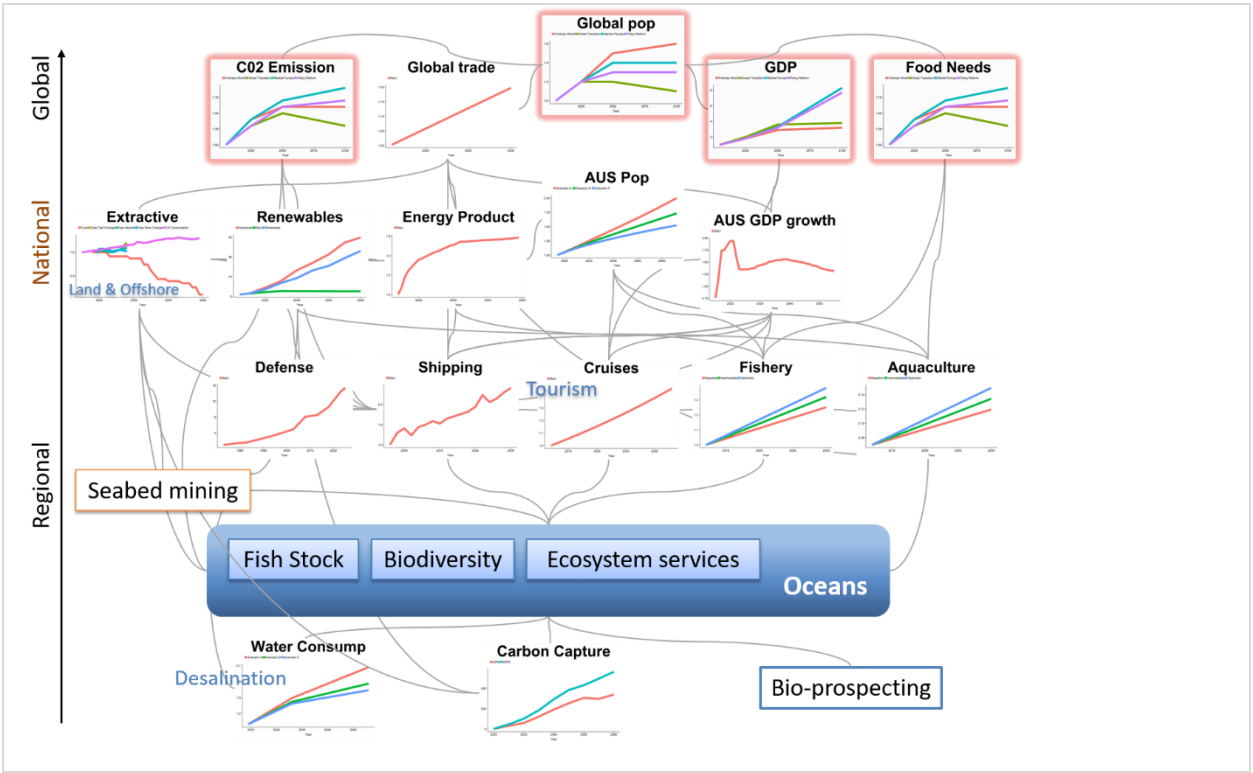


Figure 1. The conceptual model of the stressors and drivers of changes affecting the Australia oceans.

The global context – Future scenarios

In order better understand the global context in which Australia as a system needs to operate, we employed the global scenarios from the Great Transition Initiative [1] which aimed to explore pathways of long-term development and their implications for global sustainability. These scenarios are shown in Table 2.

The Foresight literature describes a long tradition, going back at least to the early 70s [7, 8], on how to explore 'probable, plausible, possible and preferable futures' [9]. With some variations, this accumulated experience has converged towards a fairly well-established approach according to which a practitioner guides a group of experts, stakeholders or members of the public who, working as a team in a workshop setting, explore scenarios of possible future system trajectory. We recall that scenarios are alternative narratives of how the future might unfold (see Table 2) and do not necessarily include numerical projections. One of the most important insights from this literature is the observation that scenarios developed in a wide range of foresight exercises, addressing disparate issues, in different contexts and arising in different cultural backgrounds, share features which allow them to be clustered into 5-6 common themes [10-12]. These common themes, referred to as scenario archetypes in the literature [10, 13, 14], explore what the future may look like if development is principally determined by either i) markets, ii) institutional reforms, iii) social and moral transformation at a global scale, iv) local rather than global focus, v) ecological and social decline or vi) technological innovations. While some variations and slightly different terminology can be found in the literature, the core ideas are fairly well established. This observation has in turn provided a useful framework for further foresight exercises by suggesting using these themes as starting point for developing scenarios specifically suited to the problem at hand. As a result, most scenario exercises now focus on what these broad themes mean for a specific issue at stake[1].

Within this tradition, the Great Transition Initiative [1] developed four scenarios (Market Forces, Policy Reform, Great Transition and Fortress World) which focus on markets, institutional reforms, social and moral transformation and local nationalistic priorities as main drivers of change. The assumptions underlying these scenarios are then used to initialise the PoleStar model [2] and simulated numerically. This generates numerical projections to the year 2100 for a large number of social, economic and environmental indicators.

It is important to emphasise that the purpose of a scenario exercise is rarely to assess the most likely future, rather to explore ranges of possibilities. This means that the role of business-as-usual or most likely scenarios is usually to frame the context against which alternative scenarios are explored. This allows us to highlight which underlying assumptions, possibly unquestioned, are core to the business-as-usual developments and how alternative economic drivers, power relations and psychological or social attitudes [15, 16] may lead to alternative, either feared or preferred, outcomes. As a result, how the projections for different national and sectorial processes compare to the trends implied in the projections of these global scenarios, may say something on which directions the Australia processes and sectors affecting the Australia ocean imagine as more likely or more desirable.

Table 2. The four global scenarios discussed in [1].

Scenario	Focus/assumption	Description
Market Forces	Markets drive progress	Economic growth-oriented globalization dominates. Population grows 40% and the economy 300% by 2050. The availability of sufficient resources, bio-physical sustainability and social inequalities are the main challenges to this future.

[1] Because the literature also suggests that 3-5 scenarios are used in workshops (usually four scenarios are chosen), not all themes may be explored in a single exercise.

Policy Reform	Institutions drive progress and influence human values	Governments lead the way toward sustainability goals without major changes to existing institutional structures and social values. Economic incentives and technological innovation result in strong gains in poverty reduction, climate stabilization and ecosystem preservation.
Great Transition	Human values drive progress	While Policy Reform focuses more on changing institutions than values, the opposite happens in Great Transition. Driven by the necessities of deepening crises and the desire for a just and sustainable society, the focus moves to human solidarity, ecological resilience and quality of life over economic growth.
Fortress World	Crises lead to force which exacerbates crises	Global crises lead to local authoritarian solutions. This is a future of protected enclaves with poor masses outside. Social conflict and mass migration lead to emergency measures of higher priority than sustainable development.

Numerical projections for national and marine sectors and processes

Projections for each of the national and marine sectors and processes included in the conceptual model in Figure 1 were collected by searching the literature for scientific publications or industry reports. Only documents containing numerical projections were considered. The outcome of this process, in the form of one short document per process or sector is included in the Supplementary Material. In addition, the projections are included as small plates in Figure 1. In order to simplify the visual comparison, the projections are plotted as ratio over the value in the year 2019 (i.e., a value of 2 mean doubling the sector performance compared to its value in 2019). A few observation can be drawn from analysis the set of projections in Figure 1. First, with the only expectation of coal use for energy generation (in the National Extractive sector on the top left) all projections show a growth (notice that this also applies to Australian GDP, since it plots GDO *growth*, with is always positive in the projection). This aligns with the Market Forces and Policy Reforms Scenarios as can be seen by the corresponding projections on the top row of Figure 1.

Second, some processes and sectors provide alternative projections, underlying alternative scenarios, while some provide a single projection, supposedly reflecting a single, business-as-usual scenario. This may be the result of our literature search not been exhaustive and may require further analysis. Third, the processes and sectors which provide multiple projections, have based these projections on different sets of scenarios. Some employ the IPCC scenarios, others the International Energy Agency scenarios, oher the ABS population growth scenarios, but most use sets of scenarios designed for their specific needs. All together more than 10 different sets of scenarios form the basis of the projections in Figure 1. In addition, further analysis highlights that these scenarios can be grouped in two types. The first type is *forward* looking: it is based on taking the state of the sector or process as it is now and considers how it may develop into the future. The second type is *backward* looking: it takes an aspirational state of the sector at some time in the future (as set by the Paris Agreement or Sustainable Development Goals) and considers how it can be reached by starting from the current state of the system. Finally, the time horizons of the projections vary considerably, from a few years for some business and economic sectors to a century scale for climate change and ecological projections.

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Appendix 5 Project Staff

Jeff Dambacher	CSIRO Data 61, Hobart TAS
Alistair Hobday	CSIRO Oceans and Atmosphere, Hobart TAS
Fabio Boschetti	CSIRO Oceans and Atmosphere, Crawley WA
Chris Moeseneder	CSIRO Oceans and Atmosphere, Brisbane QLD
Linda Thomas	CSIRO Oceans and Atmosphere, Hobart TAS