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Revisiting biological parameters and information used in the assessment of Commonwealth fisheries: a reality check and work plan for future proofing

Karen Evans, Elizabeth A. Fulton, Cathy Bulman, Jemery Day, Sharon Appleyard, Jessica Farley, Ashley Williams, Shijie Zhou

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Researcher Contact Details

Name: Karen Evans
Address: GPO Box 1538
Hobart Tasmania 7001
Phone: +61 3632325222
Email: karen.evans@csiro.au
Web: www.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

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Executive Summary

What the report is about

This project was undertaken across 2019-2022 by CSIRO scientists experienced in fisheries biology, stock assessments, ecosystem modelling and novel biochemical and genetic approaches relevant to the determination of biological parameters for use in Commonwealth fisheries stock assessments. They were assisted in achieving the objectives of the project by expert knowledge provided through an extensive consultative process that included numerous interviews and two workshops involving fisheries biologists, ecologists, assessment scientists, fishery managers, and industry experts. They undertook the project in response to concerns on the use of unknown provenance and old parameters used in stock assessments and the impacts of uncertainties created by these parameters on the advice provided to fisheries managers, particularly within the context of a changing environment and the biological responses of species to that change. The project provides, for the first time in 20 years, an evaluation of the provenance of key parameters used in stock assessments. It also provides a qualitative assessment of the uncertainties associated with those parameters; an investigation of the risks associated with the use of outdated and potentially unreflective parameters in assessments; and provides guidance on priority areas for future work on updating parameters. These priority areas include, improving communication of the source of parameters used in assessments; better understanding uncertainties in stock assessments, developing systems and methodologies that streamline sampling and analyses to support the provision and updating of parameters for future-proofing stock assessments to ongoing changes in the marine environment and considerations for implementing change processes into stock assessment and associated management.

Background

Australian waters in the southeast and southwest are recognised as climate hotspots and overall, Australian waters have warmed faster than the global average. Key components of the productivity of marine fish (reproduction, growth, maturity, and mortality) are considered to already be undergoing change or are expected to undergo directional changes under a changing climate in response to changes in ecosystems. It is therefore entirely possible that in addition to fishery induced changes, there have been changes in fundamental productivity parameters for Australian stocks.

Ascertaining the responses of species populations to fishing and to environmental change requires that the biological parameters for species subject to fishing be regularly updated and those updated parameter estimates are incorporated into assessments used to inform management. Not considering changes to population parameters can have implications for management measures that might be based on the outputs of population models, ultimately leading to management practices that might be misinformed and/or inappropriate.

Efforts placed into revisiting and updating the biological parameters that fundamentally underpin stock assessments (e.g., growth rates, age and size at maturity, fecundity, natural mortality rates, dietary information, and stock structure) used for informing fishery management in Australia has varied, with greater effort placed on some species and fisheries than others. As a result, many assessment models now rely on biological parameters derived from information collected during the 1990s, and in some instances information that is borrowed from other regions, stocks or species.

In order to understand what might need to be done to better inform stock assessment processes and associated management of changes to biological parameters and their implications, first an evaluation of the current state of assessment of biological parameters and second an understanding of the impact of any potential change in the biological parameters used in assessments is required.

Aims/objectives

1. Review current biological information used to support Commonwealth fisheries management to identify that information that might be considered as out of date.
2. Qualitatively assess the implications and risks associated with using dated information in assessments currently used for fisheries management.
3. On the basis of the outputs of objectives 1 and 2 and with the assistance of an expert panel, develop a prioritisation guideline for the replacement of information identified as out of date.
4. With input from an expert panel, provide preliminary guidance on work plans that might be employed to update or replace out of data information with contemporary information.

Methodology

Before the work of the project could be started, an important first step was to identify what fisheries and species it should focus on, as it was recognised that the project did not have the resources to evaluate all species caught by fisheries or all Australian fisheries (both Commonwealth and state/territory fisheries). An evaluation of the varying complexity of assessments and the data and information available in association was undertaken as a first step.

Once the set of focal species, fisheries and assessments was identified, the project was then conducted in four clearly identified stages:

Stage 1. Information compilation and review

Using information collated from multiple sources and targeted interviews with experts, key biological parameters used in the most recent assessments for each species were identified. An extensive investigation of the provenance of these parameters was then undertaken.

Stage 2. Qualitative assessment of risk

Two approaches were taken to evaluate the risk associated with parameter uncertainty and the implications of changes in parameters: (i) documentation of any sensitivity analyses undertaken as part of assessment processes and (ii) exploration of the effects of changes in parameters on productivity or biomass using two types of ecosystem models and comparison of these results with the outputs of sensitivity analyses undertaken as part of assessments.

The first assessment qualitatively considered whether assessments included any sensitivity analyses and if that analysis focused on parameters identified as being most uncertain in Stage 1. It also considered the extent of parameter variation included in sensitivity analyses and the magnitude of effects on the assessment outcomes. In addition to any sensitivity analysis, the time since parameters were last estimated, the data used to estimate the parameters and the methodologies associated with data collection and analyses, including the representativeness of the samples/data utilised were considered. Any updated, or novel, methods that superseded the original methods were identified.

The second assessment utilised Ecopath with Ecosim (EwE) and Atlantis models developed, populated, tested and used with confidence on fishery questions for an area of the south-east Australian ecosystem. Focusing on this region was considered a precautionary approach given that south-east Australia is an area of rapid change and most likely to create the greatest pressures on single species assessment capabilities. Changes in mortality (EwE) and changes in size-at-age, growth rate, and reproductive rate (Atlantis) and the resulting effects on biomass or productivity were explored.

Stage 3. Expert review and development of a prioritisation guideline

The project then sought expert feedback on the outputs produced in Stages 1 and 2 and input into identifying what might be key priority areas to focus on for reducing uncertainties in parameters and their estimation. This was facilitated through a two-stage workshop that included fisheries biologists, ecologists, assessment scientists, fishery managers, and industry experts.

Stage 4. Development of guidance on work plans for updating or replacing out of date information

Using the outputs from stage 3 and in consultation with the experts from the stage 3 workshop, preliminary guidance was then developed for the work that would need to be undertaken to update or replace parameters considered to be outdated with contemporary information.

Results/key findings

Using those assessments that were considered to be data rich and had the lowest uncertainty as a starting benchmark, the project team decided to concentrate efforts on those species within Commonwealth fisheries for which tier one assessments were conducted, or where not formally recognised within the Harvest Strategy Policy tier system, could be considered as meeting the criteria for a data rich/tier one assessment. This resulted in a total of 40 stock assessments across 9 fisheries being considered by the project.

Stage 1. Information compilation and review

With the input of expert opinion on those biological parameters that stock assessments were most sensitive to, the following parameters were identified as those that the project would focus on in determining their provenance:

- Growth curve parameters
- Longevity
- Maturity ogives; length and age at 50% maturity
- Fecundity; egg production; litter size
- Sex ratio
- Natural mortality
- Steepness
- Length/weight conversion factors
- Stock/population structure
- Mixing/connectivity

Ascertaining clear provenance of parameters varied across species and fisheries, with provenance unable to be determined in 22.3% of parameters. The largest number of parameters where provenance could not be ascertained from the available literature occurred in assessments of Southern and Eastern Scalefish and Shark Fishery (SESSF) and Northern Prawn Fishery species. Biological parameters that were older than 10 years were found in the assessments of all species assessed in the Great Australian Bight, Heard Island and MacDonald Islands, Macquarie Island, Northern Prawn Fishery, SESSF and Small Pelagic Fishery. Biological parameters older than 20 years occurred in the assessments of all species assessed in the Great Australian Bight, Macquarie Island, and Small Pelagic Fishery and in 11 of the 12 species assessed in the SESSF. Parameters that were older than 10 years occurred to a greater extent in those associated with reproduction (24.3 % of all parameters older than 10 years) and age and growth (20 % of all parameters older than 10 years). Of those parameters that were older than 20 years, those associated with reproduction (26.4 % of all parameters older than 20 years) and conversion factors (24.5 % of all parameters older than 20 years) occurred the most frequently.

Stage 2. Qualitative assessment of risk

(i) Qualitative sensitivity analysis

Biological parameters qualitatively considered as highly uncertain occurred in 27.4% of the total number of parameters assessed and were associated with almost all species in all fisheries. High uncertainty was predominantly associated with steepness values (30.9% of those parameters identified as highly uncertain) used in assessments, followed by mortality values (21.4%) and understanding of stock structure and connectivity (13.1%). Uncertainty could not be assessed in 45 parameters (14.7% of the total number of parameters assessed), predominantly because of an inability to ascertain the provenance of the parameters. High uncertainty was also associated with reproductive, growth and length-weight conversion parameters (all <12%).

Of the parameters identified as highly uncertain, 50% were included in sensitivity analyses. Steepness parameters were most often included in sensitivity analyses (25% of the parameters identified as highly uncertain) followed by natural mortality parameters (17.8%). Parameters associated with other parameters identified as highly uncertain such as stock structure and connectivity, reproduction and growth were rarely included in sensitivity analyses (<4% of highly uncertain parameters) and sensitivity analyses did not include exploration of length-weight conversions.

(ii) Ecosystem model comparisons

Both ecosystem models suggested relatively small changes (<10%) in absolute “all of ecosystem” total biomass levels, which is within already appreciated levels of uncertainty. However, at a species level, more substantial shifts in biomass and catch values were expressed.

The EwE model suggested changed productivities and associated shifts in group biomasses could be quite large for many species targeted by commercial fisheries and their prey. For example, a 75% decrease in the productivity of Redfish (*Centroberyx affinis*), close to 50% in Tiger Flathead (*Neoplatycephalus richardsoni*), 30% in Jackass Morwong (*Nemadactylus macropterus*) and the School Whiting group (*Sillago* spp.) and 20% in Blue Grenadier (*Macruronus novaezelandiae*) was estimated by the model. This resulted in the projections of catches being much lower than those estimated when using parameter values from the 1990s.

Strong variation in the responses of species were observed in the Atlantis model. Some species were estimated to undergo little change, due to compensatory dynamics (such as a reduction in competition for prey), while other species were quite heavily impacted due to changed size-at-age altering predation rates. Many of the main target species declined in line with available evidence that suggests their life history parameters are likely to have declined.

The results per species did not match in magnitude across the two models, but there was overlap. The projections from Atlantis were more conservative than those of EwE because of differences in the implementation of parameter modifications and in the structure and process representations used in the two models. Both models however, highlight that changes in life history parameters considered as plausible can have substantial implications for biomass estimates for key target species. This means that parameter mis-specification, such as due to relying on older parameter estimates that encode predator-prey and other ecosystem processes from a system state that has since changed, could be a real issue for assessments in this region.

When the outputs from Atlantis are compared with the outputs of stock assessment sensitivity analysis, , the range of changes in parameters in just under half of the assessment model sensitivity analysis is larger than those estimated by the ecosystem model. This suggests that sensitivity analyses for stock assessments for some species are already addressing uncertainties estimated in the ecosystem models.

However, this relies on the full range of uncertainty in biomass values provided by the sensitivity analyses being considered in decision-making and the base case is not used as a "one point of truth". In just over half of comparisons parameters were 4-20 % different to those currently assumed in the base case run of assessments and consequently the base case biomass estimate is consistently 10-40% higher than those estimated using Atlantis. This suggests updating parameters in stock assessments, modifying base cases, or more heavily drawing on results from sensitivity analysis in discussion of stock assessment results would be strongly advisable, especially in regions where large environmental shifts are known to be occurring.

Stage 3. Expert review and development of a prioritisation guideline

The workshop participants reiterated that the project had captured those parameters that influenced stock assessments the most and highlighted that lack of knowledge on stock/population structure and population connectivity were major issues for many assessments.

The value of developing a table that provided details on parameters and their estimation was considered as an important tool as this provided an opportunity for rapid exchange of information across species and fisheries and potential cross-learning opportunities for assessment groups particularly in method development and sensitivity analysis approaches.

While it was recognised that the exploration of parameters using the two ecosystem models was useful, it was noted that teasing apart the drivers on productivity and recruitment is not straight forward. It was not clear how to implement consideration of trophic interactions in current stock assessment models, particularly when information on trophic dynamics and interactions is currently universally poorly understood.

In discussing priority areas for better understanding the impacts of changing parameters and what was needed to address these, the workshop participants identified several areas that research could be focused on. These included:

- the need for further targeted exploratory work across several aspects of stock assessment models, if the implications of changing parameters on current stock assessments were to be fully understood;
- the need for further exploratory work to investigate why the Ecosystem Risk Assessment (ERA) process is not currently capturing risks identified via the project and what might be needed to capture risks associated with biological shifts more comprehensively;
- the need to clearly identify the steps (initial exploratory work, sub-projects etc.) needed to design a framework within stock assessments to appropriately capture species-specific changes (i.e., updating of parameters, incorporation of time-varying parameters into assessments) and the most effective ways of achieving those steps (including the costs and benefits);
- under harvest strategies where catch rates are the driver, biological information is not what is currently limiting decision making, so it was important to consider what data might be needed to quantify changes, identify where the greatest sensitivities occur, and capture the implications of parameter uncertainty within the context of harvest strategy frameworks.

In addition, a framework that could be applied to focus efforts at the species and/or fisheries level was identified, noting that it was beyond the scope of the project to definitively identify priority species across each Commonwealth fishery. This framework, if implemented across fisheries could provide a mechanism for identifying which parameters and which species to focus on within a staged approach to addressing current gaps and uncertainties.

Stage 4. Development of guidance on work plans for updating or replacing out of date information

Four thematic areas on which work plans could be focused were identified from stages 1, 2 and 3. These could provide an initial starting point in developing specific work plans that could be implemented to address current uncertainties associated with outdated parameters, potential changes in parameters and their influence on stock assessment outputs. The outputs from these would directly improve advice provided to fishery managers and the industry. These included:

1. Improving information workflows and information accessibility, including ensuring parameters are fully documented in stock assessment reports and improving accessibility to historical information;
2. Better understanding stock assessment uncertainties, including undertaking broader sensitivity exploration (than is currently conducted) and dedicating time to working through those uncertainties with members of Resource Assessment Groups to ensure full understanding;
3. Streamlining parameter determination and improving cost-effectiveness, including developing approaches that include automation or semi-automation of processes and considering where there could be greater involvement of students, which would also ensure ongoing capability development;
4. Improving processes for implementing change into stock assessments, including progressing approaches to the management of change processes that might be associated with introducing updated parameters or expanding exploration of sensitivities and uncertainties in models

Implications for relevant stakeholders

The outputs from this project highlight current issues with the stock assessment process for Commonwealth fisheries and provide a realistic and feasible pathway for identifying a range of activities that can be implemented by Resource Advisory Groups that will futureproof the assessment process.

Implementing the guidance provided by this project will reduce uncertainty around the veracity of information used to manage the fisheries and broader ecosystems, thereby building confidence in the sustainability of management guidance. It will also support clearer understanding of developments needed to progress assessments in accounting for changes occurring in marine systems. This will assist with increasing understanding across stakeholders and avoiding maladaptation as fishers and other ocean users look to adapt practices in response to changes to ecosystems and fish stocks.

Keywords: Biological parameters, fishery stock assessments, assessment uncertainty, biological responses to climate change, future-proofing

Introduction

Background

Marine food-webs and associated trophic interactions are being altered by human activities associated with the harvesting of individuals and changing environmental conditions caused by climate change (Murphy et al. 2021; UN 2021). Life-history changes that may arise as evolutionary responses to intensive, size-selective fishing have been found to destabilize and degrade ecosystems both rapidly and continuously (Garcia et al. 2012, Kuparinen et al. 2016, Zhou and Smith 2017). This destabilisation has been associated with direct reduction of older, larger individuals that contribute the most to reproduction and changes in intrinsic population growth rates resulting from shifts of fish life histories towards young, small, and more quickly maturing individuals (Anderson et al. 2008, Audzijonyte et al. 2013). Similar changes in population growth rates have been associated with changing environmental conditions, and in particular increasing water temperatures (Cheung et al. 2012, Lehodey et al. 2013).

Australian waters in the southeast and southwest are recognised as climate hotspots and overall, Australian waters have warmed faster than the global average (Wernberg et al. 2011, Hobday and Pecl 2013, IPCC 2019). Key components of the productivity of marine fish (growth, maturity, and recruitment) are expected to be undergoing directional changes under a changing climate and it is entirely possible that there have been changes in fundamental productivity parameters for Australian stocks.

Ecosystem modelling efforts have shown that small decreases in the body size of fish species can have large effects on their natural mortality (Audzijonyte et al. 2013), suggesting that induced evolutionary change may alter fish stock productivity (Law et al. 2015). This, in turn, can impact the economic returns those resources might provide to fishers. Further, removal of older, larger fish can result in increased fluctuations in population abundance as a result of evolutionary and ecological side effects associated with overall contributions to reproduction and recruitment (Garcia et al. 2012). This variability increases uncertainty in population assessments and the risks associated with low population abundances. Quantifying and predicting the evolutionary effects of external factors such as fishing and changing environments is therefore important for both ecological and economic reasons (Laugen et al. 2014).

Ascertaining the responses of species populations to fishing and to environmental change therefore requires that the biological parameters for species subject to fishing be regularly updated and those updated values incorporated into assessments used to inform management. Failing to account for such changes in life history parameters such as growth, maturity and recruitment can have implications for management measures that might be based on the outputs of population models, ultimately leading to management practices that might be misinformed and/or inappropriate.

Within Commonwealth fisheries, the regularity with which the biological parameters of species are evaluated varies (see Patterson et al. 2018), with the associated assessment of any change in parameters limited largely to sensitivity analyses. These analyses consist of exploring alternate values of key parameters such as natural mortality and stock recruitment steepness, at values close to those used in the base-case assessment, and generally agreed upon as within acceptable ranges of values.

Need

Much effort has been placed over the last couple of decades into the development of harvest strategies, stock assessments, risk assessments and the strategic use of ecosystem models to facilitate the needs of the Commonwealth's Harvest Strategy Policy. A focus on modelling to improve fisheries management has required effort towards method development. However, this has meant that efforts placed into revisiting and updating the biological parameters that fundamentally underpin such modelling (e.g., growth rates, age and size at maturity, fecundity, natural mortality rates, dietary information, and stock structure) has varied, with greater effort placed on some species and fisheries than others. As a result, many assessment models now rely on biological parameters derived from information collected during the 1990s (e.g., available maturity ogives for blue-eye trevalla were calculated more than 20 years ago), and in some instances information that is borrowed from other regions or species.

Whether such values are now representative for commercial Australian fish species is unknown, but many factors point to major changes occurring in our marine environment (e.g., Last et al. 2011; Suthers et al. 2011; Gervais et al. 2021). Experience shows that small changes in some biological parameters can have significant impacts on assessment outputs; for example, the recent adjustment of the growth curve used in the assessment model used for Bigeye Tuna in the Western and Central Pacific Fisheries Commission area resulted in a substantial change to population biomass estimates (McKechnie et al. 2017). Further, several academic exercises have begun to identify which parameters are being most affected by phenotypic and evolutionary change under climate change (e.g., Ward et al. 2016). The reliance of current assessments on what is likely to be outdated information leads to increased uncertainty, which propagates into management decisions (e.g. see Wayte (2013) for an investigation of mis-specification of recruitment within management strategy evaluation scenarios). Without an understanding of any changes in biological parameters and how those changes might impact assessment outputs, determining the effectiveness of current management measures becomes highly uncertain.

This lack of understanding introduces a degree of uncertainty into assessments of species, thereby limiting the ability to determine if current fishing levels are sustainable. To fully understand the potential for fishery or environmental induced evolutionary change, and what might need to be done to inform management under such change, first an evaluation of the appropriateness of biological parameters and second, an understanding of the impact of any potential change in biological parameters used in assessments is required.

In response to the Fisheries Research Development Corporation (FRDC) call for revisiting the biological parameters used in Commonwealth fishery assessments, CSIRO has conducted several informal meetings and discussions with the Australian Fisheries Management Authority (AFMA), FRDC, and in association the Commonwealth Research Advisory Committee (COMRAC). It was recognized that an integrated project that evaluated the status of biological parameters used in assessments and the implications of any change in parameters on current assessments would assist AFMA in understanding uncertainties in assessments. Such a project was also recognised as highly useful for informing workplans that could be implemented to address any uncertainties.

This project depends on several previous FRDC and AFMA projects, particularly those focused on updating biological parameters for assessment purposes and has relevance to those projects focused on improving yields, increasing sustainability, reporting on stock status, and predicting the impacts of environmental change on stocks and associated fisheries[1]. The project contributes directly to the national priority of continuous improvement to the sustainability of Australian fisheries.

Objectives

1. Review current biological information used to support Commonwealth fisheries management to identify that information that might be considered as out of date.
2. Qualitatively assess the implications and risks associated with using dated information in assessments currently used for fisheries management.
3. On the basis of the outputs of objectives 1 and 2, and with the assistance of an expert panel, develop a prioritisation guideline for the replacement of information identified as out of date.
4. With input from an expert panel, provide preliminary guidance on work plans that might be employed to update or replace out of date information with contemporary information.

Method

The project was carried out in four clearly identified stages, the outputs of which are delivered as a set of four components. This form of structuring allowed for the project, its outputs, and its progress to be assessed at each stage, and if needed, methods reviewed and revised in response to changing circumstances or needs (Figure 1). It also ensured that there was the opportunity for consultation with the broader stock assessment community and provision of advice and feedback on all stages of the project and associated outputs.

Stage 1. Information compilation and review

Step 1: Identification of species and associated stock assessments

Before the work of the project could be started, an important first step was to identify what fisheries and species it should focus on, as it was recognised that the project did not have the resources to evaluate all species caught by fisheries or all Australian fisheries (both Commonwealth and state/territory fisheries).

An evaluation of the varying complexity of assessments and the data and information available in association was undertaken as a first step. Fisheries throughout Australia collect differing amounts of data and utilise differing approaches to assessing stocks. As a result, they incorporate varying information on the biology of focal species into frameworks for determining status. Some collect and incorporate little biological information and so are less relevant to this project than those that incorporate multiple biological parameters into assessment models. Some commercial species are not assessed formally under fisheries management and so again are less relevant to this project than

[1] For example, FRDC funded projects 2021-077, 2021-002, 2019-036, 2017-185, 2017-125, 2017-100, 2016-139

species that are assessed formally (see Status of Australian Fish Stock Reports: fish.gov.au for current information on the varying assessment processes undertaken on Australia's fisheries species).

To assist in identifying those biological parameters that had the most influence on assessments, the original planning for this project involved gathering expert input on biological parameters via a one-day stakeholder workshop. The aim of this workshop was to ensure expert input into the identification of parameters the project would focus on and direct information on the history of assessments.

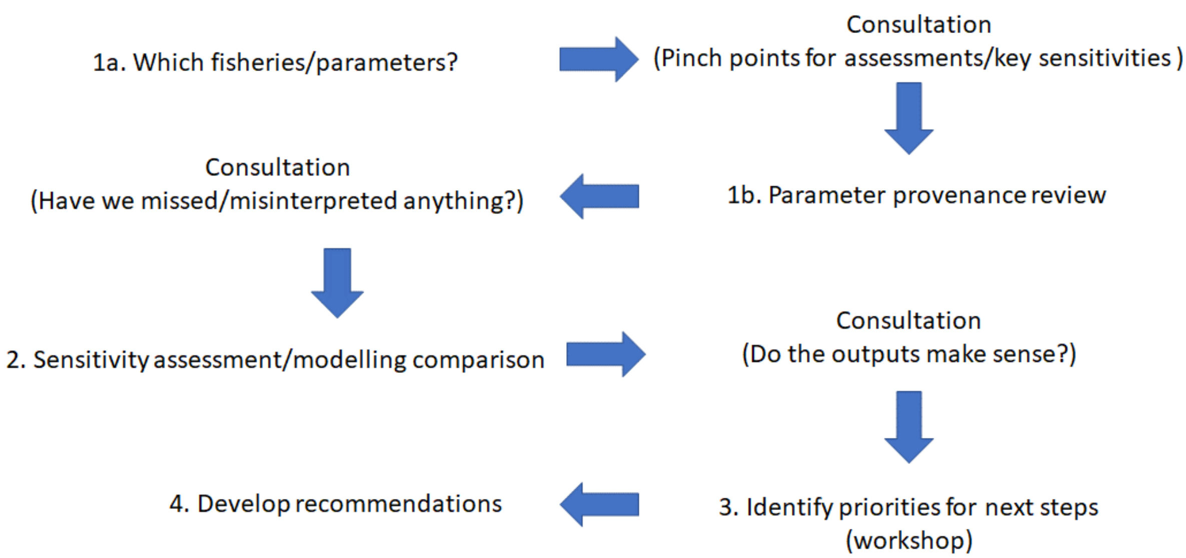

Figure 1. Summary of the four components of the project and consultation at each stage.

With the onset of the COVID-19 pandemic, associated closure of domestic borders and varying degrees of lockdowns across Australia, this workshop was not possible. To address the need to have essential input from stock assessment developers, those carrying out stock assessments within Commonwealth fisheries and those involved in historical assessments, an extensive consultative process based on a series of virtual meetings between project staff and individuals providing key inputs into assessments were scheduled. These direct interviews focused on identifying those parameters that assessments were most sensitive to and therefore of the highest priority in evaluating their provenance, including identifying where parameters were derived from, when parameters were last updated and where the associated literature could be sourced.

Step 2: Establishing the provenance of parameters

Once focal parameters were identified, an extensive literature search was undertaken, facilitated with follow-up meetings with individual stock assessment scientists, to ascertain the provenance of each parameter. This included identifying their origin (where they were derived), when they were last updated, and the associated methodology used to estimate (or in the case of fixed parameters set) the parameter value. Information was collated from: stock assessment scientists; historical archives of stock assessment reports; stock assessment reports available on fisheries management websites, including Commonwealth and regional fisheries management organisation sites.

Commonwealth fishery Resource Assessment Groups (RAGs) and stock assessment researchers were asked to identify any current work focused on updating parameters. In addition, relevant projects were also identified from the listing of projects on the Fisheries Research Development Corporation website[2].

Stage 2. Qualitative analyses of potential impact of changing biological parameters on assessment results

It was important to not only identify those parameters that assessments may be most sensitive to, but also the risks associated with their continued use in assessments across Commonwealth fisheries.

Two approaches to evaluating this risk was undertaken: (i) documentation of any sensitivity analyses undertaken as part of assessment processes and (ii) exploration of the effects of changes in parameters on productivity or biomass using two ecosystem models and comparison of these results with the outputs of sensitivity analyses undertaken as part of assessments.

This two-part approach was undertaken to first evaluate if sensitivity analyses done as part of the assessment process encapsulated uncertainties in parameters determined through Stage 1 (e.g., due to their age, source data and known understanding of uncertainties). Second, ecosystem models were used to investigate if there were other compound uncertainties that could stem from changed parameter values that were not encapsulated by current sensitivity analyses, such as responses mediated through environmental influences and non-stationary mortality. For example, growth can affect size-at-age, which influences both the predation pressure experienced by age groups and the prey available due to the gap-limited feeding mode of most teleosts. In addition, the size at age influences fecundity, with larger fish producing disproportionately more spawn.

Step 1: Assessment of sensitivity analyses

A qualitative assessment of stock assessment processes was undertaken to assess whether existing sensitivity analyses are already sufficiently broad to account for parameter uncertainties and guard against mis-information generated by parameter mis-specification. This included:

i. identifying if there were any sensitivity analyses included in each assessment;
ii. which parameters were included and in association whether the parameters included were those parameters identified as being most uncertain in Stage 1;
iii. the degree of parameter variation considered; and
iv. the magnitude of effects of changes in parameters considered on the assessment outcomes (i.e. biomass estimates).

It was also noted whether documented uncertainties in parameter estimation processes or the methods used for estimating parameters were considered in assessments. This evaluation of the handling of uncertainty in assessments considered uncertainties associated with the time since parameters were last estimated, the data used to estimate the parameters and the methodologies associated with data collection and analyses, including the representativeness of the samples/data utilised. Any updated, or novel, methods that supersede the original methods were identified. Extensive consultations with stock assessment scientists were undertaken to ensure a good understanding of how sensitivities and risks were being handled in assessment processes.

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[2] www.frdc.com.au

Step 2: Uncertainty scenario exploration

As natural mortality is one of the greatest sources of uncertainty in stock assessments, two ecosystem models were then used to explore how changes in natural mortality might influence biomass or productivity. Ecosystem models were chosen for this component of the project, rather than individual stock assessments for several reasons:

i. they allowed for underlying processes to be explored, (e.g. how changes to growth might influence time spent in age groupings and therefore exposure to predation or access to trophic resources); such process driven changes are unable to be explored in single species stock assessment models;
ii. they allowed for changes to be explored across multiple species within the system of focus; in general, multi-species assessment models are not available for Australian fisheries;
iii. interactions between parameters are integrated into models and therefore can be explored intuitively, in comparison to single species stock assessments where interactions between parameters are often unknown and unexplored.

The two ecosystem models utilised were the Ecopath with Ecosim (EwE, Bulman et al. 2006) and Atlantis (Fulton et al. 2004) models. As we wished to take advantage of modelling frameworks already developed, populated and tested, and given the need to have maximal confidence and species-specific relevance in the ecosystem models, the ecosystem models used focused on the southeast region of Australia. This area is an area of rapid change and most likely to create the greatest pressures on single species assessment capabilities. Consequently, focusing on this region was considered a precautionary approach given that the greatest effects are likely to be seen in this region. It should be noted that while ecosystem models exist for other regions, they have not been put through the same rigorous checking and acceptance steps as the two models used (particularly in being applied to the southeast region of Australia) and so cannot yet be guaranteed to have the same rigour. Choosing these models therefore increased efficiencies in the project as there were insufficient resources to gain the same level of confidence in ecosystem model validity in other regions.

During Stage 3 of the project (see below), workshop participants identified areas of exploration in addition to those detailed in this section that would be useful to informing the guidance developed during Stage 4. These included:

i. Comparing the outputs of EwE and Atlantis for individual species to identify if both models were projecting similar changes;
ii. Rather than implementing a step change in parameters implemented in the Atlantis model, incorporate sliding changes to parameters through time to explore the effect of time varying parameters;
iii. Comparing the outputs from both EwE and Atlantis with outputs from sensitivity analyses conducted as part of recent assessments. This would provide insights into whether or not stock assessment sensitivities are broad enough to encapsulate the additional uncertainties raised due to food web and ecosystem scale processes.

These suggestions were incorporated into the project and delivered back to the participants engaged in Stage 3 during the second session of the workshop (see below).

Ecopath with Ecosim

An updated version of an ecosystem model for the southeast region (SEF2020), developed in the EwE modelling software (Bulman et al. 2006), incorporated data obtained from biological surveys of fishery production in the East Bass Strait region in the mid-1990s and fisheries effort data up to 2016 or 2019 depending on the fishery.

To provide some insights into how changes in parameters could influence understanding of biomass levels (and thus where assessment misspecification may be occurring due to changing levels of natural mortality), the model was revised for certain parameters in two ways. First, dietary information for a small number of species was updated (Revill et al. 2016) and the model rebalanced in either of three ways (i) only adjusting biomasses for those groups out of balance; (ii) adjusting natural mortality (M) for groups out of balance; (iii) adjusting Productivity/Biomass (P/B, which typically equates to total mortality), Biomass (B), or diet proportion, but retaining the original biomasses as far as possible (this model was referred to as the "modeller's model"). Second, changes required to rebalance the model were demonstrated, both with the original diet and with the new diet, after replacing the productivity values (P/B) of a selected few species with natural mortalities used in current stock assessment models (Table 1). Changes to long term catches were then projected. Values of M (either those used is the first revision of EwE or those derived from stock assessments) were compared with values derived using Hoenig's formula based on maximum age for comparative purposes (Table 1), with no further fitting of reprojecting of catches.

Table 1. Values of natural mortality (M) input into the EwE model to explore changes in productivity.

Common species name	**Original M value**	**Assessment M value**	**Variant using empirical M estimation method**
Eastern sSchool Whiting	0.9	0.6	0.655 (9y)
Blue Warehou	0.28	0.45	0.386 (16y)
Silver Warehou	0.3	0.25	0.277 (23y)
Blue Grenadier	0.27	0.174 (m), 0.209 (f)	0.224 (29y)
Jackass Morwong	0.22	0.11	0.147 (46y)
Silver Trevally	0.1	0.1	0.139 (49y)
Dories	0.3 (average)	0.288 (weighted average)	
Silver Dory	0.39	0.39	0.568 (10.5y)
John Dory	0.24	0.36	0.386 (16y)
Mirror Dory	0.2	0.3	0.437 (14y)
King Dory	0.19	0.19	0.174 (38y)
Pink Ling	0.22	0.27	0.231 (28y)/0.217 (30y)
Flatheads	0.52	0.23	0.231 (28y)
Redfish	0.31	0.075	0.153 (44y)
Gemfish	0.44	0.44 (not updated)	0.366 (17y)

After rebalancing, the same baseline Ecosim scenario that had been developed for the original model was run in each model version. The baseline scenario was a 50-year simulation comprising the initial 24-26 years of actual fishery effort driving the model and a 24-26 year projection retaining the last actual fishing effort value. All other parameters and vulnerabilities in the original model were retained. Comparisons of biomasses produced by the original model and the “modeller’s” model were undertaken, as were final catches and total biomasses of the system.

Atlantis

The Atlantis modelling framework (Fulton et al. 2004) is an end-to-end model presently being used to support marine ecosystem-based management (EBM) and system understanding. It includes representations of each significant component of the adaptive management cycle (Jones 2009), including the biophysical system, the human users of the system (industry), the three major components of an adaptive management strategy (monitoring, assessment and management decision processes) and socioeconomic drivers of human use and behaviour. Atlantis includes dynamic, two-way coupling of all system components. For further details on Atlantis and its development see Fulton et al. (2011).

To provide some insights into how changes in parameters could influence understanding of biomass levels and sustainable catch levels (and thus potential levels of assessment deviation), the Atlantis model developed for use in management strategy evaluation studies of the Southern and Eastern Scalefish and Shark Fishery (SESSF – see Fulton et al. 2007; 2014; Fulton and Gorton 2014 for detailed specifications of the model) was run for a 25 year period with modified parameters. Parameter variants run were:

- Baseline: the current most common parameterisation already used;
- A 4% decrease in size-at-age based on Audijyontze et al. (2013);
- A 20% decrease in size-at-age based on observations of target species such as Tiger Flathead and in other target species in the North Atlantic (e.g., see Svedäng and Hornborg 2014);
- A 4% decrease in growth rate based on declines observed in temperate regions globally (e.g., see van Rijn et al. 2017);
- A 20% decrease in growth rate based on observations and projections (e.g., see Cheung et al. 2013, Baudron et al. 2014);
- A 4% decrease in reproductive rate based on the minimum expected responses to declines in larval supply (derived from the Integrated Marine Observing System (IMOS) larval time series);
- A 20% decrease in reproductive rate based on the maximum expected responses to declines in larval supply (derived from the IMOS larval time series);
- Diet: modified similarly to diet shifts observed by Revill et al (2016).

These variants were chosen as they bookend what has been observed in other systems and therefore reflect the best available evidence of possible changes in parameters (minimum and maximum) that could have occurred in a fast-changing climate effected region such as south-east Australia. Changes in life history parameters (decline in size-at-age, growth rates and reproductive rates) were run both as flat changes in these parameters (where the original values were replaced with the modified values and the model rerun) and where the change was allowed to occur gradually over a 10 year period before running forward at the new value.

Stage 3. Expert review and development of a prioritisation guideline

Once stages 1 and 2 were completed, the project then sought expert feedback on the table of parameters produced and the assessment of risk, and gathered input into identifying what might be key priority areas that needed to be focused on for reducing uncertainties in parameters and their estimation. This was facilitated through a workshop where fisheries biologists, assessment scientists, fishery managers, and industry experts were invited to participate. With ongoing restrictions because of the COVID-19 pandemic, this workshop was held online over two half days in February 2022.

The first session of the workshop focused on gaining feedback on a series of questions associated with the parameter review and simulation process. These included:

- Does the review encompass the parameters that assessments are most sensitive to? Are there other parameters that should be considered?
- Is the information gathered on parameter values and their estimation correct? Is there information missing? Has the information gathered been misinterpreted?
- Is there information relating to parameter provenance that has been overlooked? Is there information available that could assist in filling current information gaps? Has the information gathered been misinterpreted?
- Is there work planned in updating parameters that has been overlooked?
- Do the outputs from the simulation exercise investigating risk make biological sense? Are there alternative scenarios that should be considered (within the context of the timeline and budget of the project)?

The second session of the workshop involved a series of interactive segments where workshop participants were asked to provide their views on three key areas that would assist in identifying priority areas for reducing uncertainties:

1. Identifying key features that could be used to assist with prioritising the focus of any future work on parameters. For example, should the focus be on individual parameters (across all species in all fisheries), or should it take a species by species or fishery by fishery approach? Should the approach focus on parameters where the methods or data were greater than 10 years old or alternatively, those parameters where updated or new methods for estimation were available regardless of the age of parameters?
2. Identifying possible actions that could be recommended in responding to various uncertainties in parameters such as where provenance was unknown, or the data or methods associated with a parameter were old.
3. Identifying some “low hanging fruit” that could be implemented easily to address parameter uncertainties and what might need more effort. This could assist in developing a staged approach to recommendations that could be implemented as a workplan.

Stage 4. Development of guidance on work plans for addressing current uncertainties

Using the outputs from stage 3 and in consultation with the experts from the workshop, preliminary guidance on what work would need to be undertaken in order to address current uncertainties in parameters. This included consideration of what would be required to better understand and explore uncertainties in stock assessment models, what would be required to better understand changes to biological parameters, and what would be required to fill current knowledge gaps and update assessments with parameters that reflected contemporary biology and addressed current uncertainties. The intent in developing this preliminary guidance was to provide useful information for planning any future work for improving the state of biological parameters and ensuring that changes in parameters through time were better reflected in stock assessments. It also aimed to provide broad advice on the effort required to ensure that uncertainties were better understood and reflected in assessments.

Results and discussion

Stage 1. Information compilation and review

Step 1: Identification of species and associated stock assessments

The first objective of the project identifies that the project will "Review current biological information used to support Commonwealth fisheries management". Given the focus of this objective, assessments conducted with a focus on state or territory fisheries and those that did not incorporate biological aspects of species (i.e. those that are based on catches only) were excluded.

The Commonwealth Harvest Strategy Policy (DAWR 2018) provides for fisheries to identify key commercial stocks, set targets associated with maximising economic returns, determine limits beyond which the risk of negative impacts on the stock are too high and design strategies that allow for the identification of environmentally driven changes to productivity. Implementation of risk limits is recommended through a tiered system based on data availability for the stock (Dowling et al. 2014; Dichmont et al. 2016), with those tiers then guiding approaches that might be utilised for acknowledging uncertainty (e.g. through appropriate testing using management strategy evaluation).

Using those assessments that were considered to be data rich and with the lowest uncertainty as a starting benchmark, it was decided to concentrate efforts on those species within Commonwealth fisheries for which tier one assessments were conducted or where not formally recognised within the Harvest Strategy Policy tier system, could be considered as meeting the criteria for a data rich/tier one assessment. This resulted in a total of 40 stock assessments across 9 fisheries being considered by the project (Table 2).

The project team then compiled and reviewed a full list of parameters for a small number of illustrative examples of assessments, including Brown Tiger Prawn (*Penaeus esculentus*), Eastern School Whiting (*Sillago flindersi*), Patagonian Toothfish (*Dissostichus eleginoides*), Spanish Mackerel *(Scomberomorus commerson*), Tiger Flathead (*Platycephalus richardsoni*) and Yellowfin Tuna (*Thunnus albacares*) to identify the range of parameters used and what might then be considered as priority parameters to concentrate on. An example for Tiger Flathead is provided in Table 3.

Virtual meetings between project staff and individuals providing key inputs into assessments were conducted throughout July and August 2020 and involved those contributing to stock assessments (contemporary and historical) in the following fisheries:

- Eastern Tuna and Billfish Fishery
- Northern Prawn Fishery
- Small Pelagic Fishery
- Southeast Shark and Scalefish Fishery
- Southern Bluefin Tuna Fishery
- Sub-Antarctic Fisheries
- Torres Strait Finfish Fishery
- Western Tuna and Billfish Fishery

The series of virtual meetings identified what parameters and considerations had the most influence on assessments, and where the greatest uncertainties were contributing to assessments.

Table 2. Commonwealth fisheries species assessments considered by the project. *Assessments conducted by a Regional Fisheries Management Organisation. ^Coral trout is assessed as a species complex of four species (*Plectropomus leopardus, P. Areolatus, P. maculatus, P. laevis*). Common species names follow those in the Australian species name database (https://www.frdc.com.au/knowledge-hub/standards/australian-fish-names-standard#toc-download-the-australian-fish-names-database).

Fishery	**Common species name**
Eastern Tuna and Billfish Fishery*	Albacore Tuna Swordfish Bigeye Tuna Striped Marlin Yellowfin Tuna
Heard and McDonald Islands Fishery*	Patagonian Toothfish
Macquarie Island Toothfish Fishery	Patagonian Toothfish
Northern Prawn Fishery	Redleg Banana Prawn Banana Prawn Brown Tiger Prawn Grooved Tiger Prawn Blue Endeavour Prawn Red Endeavour Prawn
Small Pelagic Fishery	Blue Mackerel Common Jack Mackerel
Southern and Eastern Scalefish and Shark Fishery (Commonwealth Trawl and Scalefish Hook Sector)	Blue Grenadier Eastern School Whiting Tiger Flathead Gemfish – east Gemfish – west Jackass Morwong – east Jackass Morwong – west Orange Roughy – east Pink Ling Redfish Silver Warehou
Southern and Eastern Scalefish and Shark Fishery (Great Australian Bight Trawl Sector)	Bight redfish Deepwater Flathead
Southern and Eastern Scalefish and Shark Fishery (Shark Gillnet and Shark Hook Sector)	Gummy Shark School Shark
Southern Bluefin Tuna Fishery*	Southern Bluefin Tuna
Torres Strait Finfish Fishery	Coral Trout^ Spanish Mackerel
Western Tuna and Billfish Fishery*	Albacore Tuna Swordfish Bigeye Tuna Striped Marlin Yellowfin Tuna

Table 3. Summarised evaluation of parameters used in the Tier 1 assessment for Tiger Flathead (*Neoplatycephalus richardsoni*) in 2019 using the model Stock Synthesis version SS-V3.30.14.05 (Day 2019).

Parameter	**Estimation method**	**Year parameter/parameter method updated**	**Key sensitivities/uncertainties**
Age at 50% maturity (A50)	Unknown	Unknown – not documented in stock assessment, the same parameters have been used since prior to Cui et al. (2004)	Estimation method unknown
Length at 50% maturity (L50)	Maturity modelled as a logistic function with L50 fixed at 30cm	1997	Although the source is known the estimation method is not documented
Minimum age	based on age-at-length data available	Age-at-length measurements available for 1998-2018	Age estimation error
Maximum age (plus group)	unknown	Unknown, possibly 2005 as 2004 assessment uses a different parameter value and the 2006 assessment uses the same value as all later assessments	Based on an unknown source of decision making rather than use of direct ages
Growth (CV, K, L_{min}, L_{max})	von Bertalanffy growth parameters estimated by sex within the model fitting procedures from age-at-length data. Three parameters estimated (CV, K, L_{min}) and L_{max} fixed at 56. An offset to K is estimated separately for males, with the others the same. Growth assumed to be time invariant.	2006	Age estimation error, growth fixed (cannot vary through time)
Length-weight relationship	Unknown	Unknown	Estimation method unknown
Sex ratio	Strictly speaking the model is a two sex model with conditional age-at-length data separated by sex. However not all parameters are estimated for two sexes and a sex ratio is not calculated.	Unknown	Does not account for potential ratio biases across age groups
Natural mortality (M)	Likelihood profile of M showed that the assessment model fit was improved by increasing values of M resulting in 0.27 being agreed upon	2010	The likelihood profile suggests that there is little information in the model that can be used to inform this parameter

Parameter	Estimation method	Year parameter/parameter method updated	Key sensitivities/uncertainties
Steepness (h)	Recruitment follows a Beverton-Holt stock recruitment relationship with h estimated within the model for the base case	Possibly 2005	Steepness is not estimated very precisely and often poorly estimated
Sigma R	Expert judgement	Unknown	Unknown
Population structure	Assumed, no assessment of structure undertaken	2005	Population structure based on assumption
Connectivity/mixing	Assumed, no assessment of mixing undertaken	Unknown	Mixing based on assumption

Based on the discussions during the virtual meetings, the following parameters were identified as those that the project would focus on in determining their provenance:

- Growth curve parameters
- Longevity
- Maturity ogives; length and age at 50% maturity
- Fecundity; egg production, litter size
- Sex ratio
- Natural mortality
- Steepness
- Length/weight conversion factors
- Stock/population structure
- Mixing/connectivity

Step 2: Establishing the provenance of parameters

Ascertaining clear provenance of parameters varied across species and fisheries; provenance could not be determined for 70 biological parameters (22.9%) from a total of 306 parameters across all fisheries. A full assessment of the provenance of parameters for all Commonwealth assessments considered is provided in Appendix 1.

The largest number of parameters where provenance could not be ascertained from the literature occurred in assessments of SESSF and Northern Prawn Fishery species, noting that the fishery containing the highest number of species assessed was the SESSF (Table 4). Of species within the SESSF, provenance issues occurred in eight of the 12 species for which parameters were assessed. Of those in the Northern Prawn Fishery, provenance issues occurred in four of the five species for which parameters were assessed. Issues with determining provenance were distributed across parameters associated with age and growth, conversion factors, steepness and stock structure and connectivity relatively equally.

Where the provenance of parameters could be determined, a total of 115 parameters were more than 10 years old and of these, 53 parameters were identified as last being updated more than 20 years ago. Biological parameters that were older than 10 years were found in the assessments of all species assessed in the Great Australian Bight, Heard Island and MacDonald Islands, Macquarie Island, Northern Prawn Fishery, SESSF and Small Pelagic Fishery (noting that only one species is assessed in the Macquarie and Heard and MacDonald Islands fisheries). Biological parameters older than 20 years occurred in the assessments of all species assessed in the Great Australian Bight, Macquarie Island, and Small Pelagic Fishery and in 11 of the 12 species assessed in the SESSF. Of those parameters older than 20 years, more than half (53 %) were associated with the SESSF (Table 4). Parameters that were older than 10 years occurred to a greater extent in those associated with reproduction (24.3 % of all parameters older than 10 years) and age and growth (20 % of all parameters older than 10 years). Of those parameters that were older than 20 years, those associated with reproduction (26.4 % of all parameters older than 20 years) and conversion factors (24.5 % of all parameters older than 20 years) occurred the most frequently.

Newer methodologies were available for 86 parameters, with the main advancements in methods occurring in association with determining the stock structure and connectivity of populations. Genetic/genomic methods have undergone a technical revolution in the last decade and can now achieve much higher resolution than was previously possible, offering fine-scale solutions for investigating connectivity and stock structure of populations (Evans et al. 2021). Work done by the CSIRO has demonstrated that of all methods likely to provide information on the stock structure and connectivity of species, molecular methods are most likely to be (i) cost effective; (ii) logistically feasible and (iii) most likely to robustly provide insights into any spatial structure in populations (Evans et al. 2016; Evans et al. 2021). Despite technological advancements, almost all species in the SESSF had either not been assessed with contemporary genetic methods or where they had, the methodology employed is now superseded by more modern and powerful approaches such as the evaluation of single nucleotides polymorphisms (i.e., SNPs – see Hemer-Hanson et al. 2014).

Overall, very few projects were identified as underway or planned that focused on updating parameters in the assessments included. One project was identified that is determining the stock structure of Eastern School Whiting (see https://www.frdc.com.au/project/2019-030) and once finalised, will provide new information for this species that can be used to update stock assessments. Other relevant projects identified included projects re-evaluating methods associated with age determination, synthesising current information for more effective understanding and utilisation of stock assessment models, investigating the connectivity or identifying the stocks of species other than those the focus of this project or adapting assessment models or harvest strategies to better account for variable shifts in productivity – however none of these were producing outputs that could be used to directly update parameters.

The assessment of biological parameters used in stock assessments indicated that some of the issues identified by Bruce et al. (2002) still remain 20 years later. Information gaps on movement and connectivity, stock structure and stock recruitment relationships remain, documentation of basic biological parameters is still poor and exploration of uncertainties in assessment models is lacking.

Stage 2. Qualitative analyses of potential impact of changing biological parameters on assessment results

Step 1: Assessment of sensitivity analyses

A total of 84 parameters were qualitatively assessed as having high uncertainty (27.4% of the total number of parameters assessed). These biological parameters were distributed across all fisheries and were associated with almost all species within those fisheries. High uncertainty was predominantly associated with steepness values (30.9% of those parameters identified as highly uncertain) used in assessments, followed by natural mortality values (21.4%) and understanding of stock structure and connectivity (13.1%). High uncertainty was also associated with reproductive, growth and length-weight conversion parameters (all <12%). Uncertainty could not be assessed in 45 parameters (14.7% of the total number of parameters assessed), predominantly because of an inability to ascertain the provenance of the parameters. Where provenance could not be ascertained it was also unclear of any sensitivity analyses included these parameters.

Of the parameters identified as highly uncertain, 42 (50%) were included in sensitivity analyses. Steepness parameters were most often included in sensitivity analyses (25% of the 84 highly uncertain parameters) followed by natural mortality parameters (17.8%). Parameters associated with stock structure and connectivity, reproduction and growth were rarely included in sensitivity analyses (<4% of highly uncertain parameters) and sensitivity analyses did not include exploration of length-weight conversions.

Table 4. Summary of provenance determination for parameters used in Commonwealth tier 1 assessments by fishery. ETBF: Eastern Tuna and Billfish Fishery, GAB: Great Australian Bight, MAC: Macquarie Island, HIMI: Heard Island and MacDonald Islands, NPF: Northern Prawn Fishery, SBT: Southern Bluefin Tuna, SESSF: Southern and Eastern Scalefish and Shark Fishery, SPF: Small Pelagic Fishery, TS: Torres Strait, WTBF: Western Tuna and Billfish Fishery.

	No. of parameters (number of species parameter issues occurred in)				
	Unknown provenance	**Methods/Data >10 years old**	**Methods/Data >20 years old**	**Use of generalised parameters from other sources**	**Parameter assumed**
Parameter group (all fisheries)					
Age/Growth	14 (5)	23 (18)	11 (5)	0 (0)	1 (1)
Conversion factors	12 (6)	21 (21)	13 (10)	1 (1)	0 (0)
Reproduction	10 (5)	28 (28)	14 (7)	0 (0)	6 (3)
Mortality	3 (2)	16 (16)	5 (3)	5 (5)	5 (5)
Steepness	14 (11)	14 (13)	4 (4)	3 (2)	9 (9)
Stock structure/ Connectivity	16 (9)	18 (14)	6 (4)	0 (0)	12 (12)
Fishery (all parameters)					
ETBF	3 (2)	9 (4)	2 (1)	1 (1)	1 (1)
GAB	4 (1)	3 (2)	1 (2)	0 (0)	2 (2)
MAC	1 (1)	4 (1)	3 (1)	1 (1)	0 (0)
HIMI	0 (0)	2 (1)	0 (0)	0 (0)	0 (0)
NPF	20 (4)	11 (5)	5 (1)	0 (0)	4 (4)
SBT	2 (1)	1 (1)	1 (1)	0 (0)	0 (0)
SESSF	25 (8)	46 (12)	28 (11)	1 (1)	8 (8)
SPF	12 (4)	20 (4)	10 (4)	3 (2)	2 (2)
TS	0 (0)	10 (1)	1 (1)	3 (1)	1 (1)
WTBF	3 (1)	9 (4)	2 (1)	9 (4)	10 (4)

Approaches to sensitivity analyses varied, but predominantly included either exploring alternative values of the parameter (for example if the base case included a defined value for mortality or steepness, the sensitivity analyses included two alternative values that varied 15- 25% from the base case or it might include applying an alternative growth curve) or utilising an ensemble of models where alternative values of the parameter (e.g., natural mortality or steepness) were drawn from a prior.

Step 2: Uncertainty scenario exploration

Ecopath with Ecosim

Where the model was updated with parameter values from assessments and other more recent data sources and then used to re-estimate biomasses, a 2.3-7.8% increase in total system biomass was required to rebalance the model. Of that additional biomass, 25-37% was derived from fish or squid and the remainder from lower trophic levels (Table 5). If total mortality was re-estimated rather than biomass, then many groups required new total mortality estimates, ranging from up to a 75% decrease in total mortality for Redfish (*Centroberyx affinis*) through to a 132% increase for small shelf predators (Table 5).

The re-estimations undertaken for changed productivities required significant shifts in group biomasses for many targeted predators and their prey - particularly Redfish – unless diets involving the relevant species (as predator or prey) have substantially changed. This is because the suggested shifts in productivity were quite large – 75% decrease for Redfish, close to 50% decrease for Tiger Flathead, 30% decrease for Jackass Morwong (*Nemadactylus macropterus*) and the School Whiting group (*Sillago* spp.) and 20% decrease for Blue Grenadier (*Macruronus novaezelandiae*; Table 5).

The projected catches under the different parameterisations were lower than under the original EwE model. If natural mortalities were modified, then projected total catches decreased by 10%. Across all the variants where diets were shifted, a decrease in catches of 11-23% occurred. The smallest decrease in catch occurred when only biomasses were altered, while the largest occurred when only total mortalities were altered. There was a difference between the total catches in the original models and those estimated across the model variants (new diets, incorporating M used in stock assessments) of 15%.

Atlantis

When the relative range of biomass was compared with the baseline time series values seen in the variants, some species saw little change (Figure 2) due to compensatory dynamics (for example, a reduction in numbers can release cohorts or species from competition for prey). Other species were quite heavily impacted as slowed growth (for example) results in longer periods of exposure to the highest levels of predation. Food web responses result in some species, especially bycatch species and other non-exploited parts of the food web, increasing substantially, even as many main target species decline. Even under the most responsive form of current management practices, the changed life history parameters typically suggest lower sustainable catch levels (Figure 3). It is only under some diet variants that significant increases in catch may be possible, due to shifts in biomass resulting from increased prey availability or decreased predation pressure (and thus natural mortality). A 20% decrease in growth resulted in individuals being exposed for mortality for longer periods of time and a decrease in reproductive potential further contributed to lower productivity. This was because it took individuals a longer time to move into larger size groups that both reduced predation from other species and increased their ability to contribute to the population (i.e., produce substantially more offspring). By the end of the projection period of each run, results run with gradually changing parameters sat within the confidence bounds of those run with flat changes. This suggests that the magnitude of change, rather than trajectory of change in the altered parameter appears to ultimately be more important (noting that shorter term differences will exist between the two cases while the parameters in the gradual change case are still transitioning).

Table 5. Percent change in biomass (B) through the ecosystem required when mortality (M) is changed to balance the Ecopath with Ecosim model. Trophic groups where no change in biomass was required are not shown.

Species/Species group name	**% change in B**	**% change in total M**	**Group name**	**% change in B**	**%change in total M**
Pelagic Large Predator	> 5000	0	Polychaeta	2.9 to 36.8	0
Benthic Producer	up to > 500	0	Slope ocean perch	7.8 to 24.4	5.7 to 7.3
Oreodories	7.6 to >500	up to 7.1	Slope small invertebrate feeder	-1.5 to 24.3	0
Ocean Jacket	-42.3 to >300	up to -42.5	Slope medium invertebrate feeder	6.9 to 23.1	+0.7
Redfish	up to 178.8	-75.8 to -9.6	Large zooplankton	1.5 to 21.6	0
Shelf Small Predator	28.8 to 156.3	20 to 132	Shelf ocean perch	10.1 to 19.5	10.8 to 15.4
Dories	up to -78.9	up to -4	Commercial prawn	2.8 to 18	0
Pelagic Medium Invertebrate Feeder	up to 81.6	0.9 to 13.7	Squid	-1.8 to 15.6	0
School Whitings	10.7 to 69.7	-33.3 to -20	Pelagic small invertebrate feeder	1.9 to 12.5	0
Slope Large Invertebrate Feeder	-64.4 to + 56.3	0	Small zooplankton	0.3 to 10.4	0
Lings	5.1 to 60.5	-18.2 to 4.5	Shelf large invertebrate feeder	3.9 to 9.2	1.9 to 3.8
Flatheads	<-0.1 to 57	-32.7 to -48	Shelf medium predator	-8.3 to 8.6	up to -10
Gemfish	up to 56.8	up to -30.9	Redbait	-5.5 to 2.2	0
Gelatinous Nekton	-52.1 to 5.2	0	Pelagic medium predator	-2.3 to 3.2	0
Cardinalfishes	3.4 to 48.5	0	Pelagic shark	3	0
Jackass Morwong	up to 47.7	-31.8 to 50	Euphausiid	0.1 to 6.5	0
Macrobenthos	1.4 to 40.3	0	Tuna/billfish	0.1	0
Shelf Small Invertebrate Feeder	8.6 to 39	0	Mesopelagic fish	0	up to 113.1
Shelf Medium Invertebrate Feeder	15.9 to 37.7	up to 19.8	Blue grenadier	0	up to -22.6
Blacktip Cucumberfish	6.6 to 35.46	up to 17.3	Jack mackerel	0	up to -29.8
Slope Medium Predator	-33.4 to 5.8	0	Blue and Silver warehou	0	1.1
Megabenthos	5.2 to 40.3	0			

While EwE and Atlantis changed parameters in different ways, the outputs of the two models and their implications can be compared for specific species (Table 6). The results per species do not match in magnitude across the two models, but there is overlap in the results between the models - noting though that increases in biomass were typically smaller in Atlantis and decreases in biomass more common. The differences in model outputs are due in large part to the varying ways the parameters are altered in the two models, but also reflects differences in the structure of the models and the processes they represent (e.g., Atlantis incorporates age structure, gape limitation of feeding and ontogenetic shifts in diet that EwE does not). Both models however highlight that observed changes in life history parameters have quite substantial implications for biomass estimates for key target species. This means that parameter mis-specification, such as due to relying on older parameter estimates that encode predator-prey and other ecosystem processes from a system state that has since changed, could be a real issue for assessments in this region.

By not incorporating processes that recognise changes in growth, reproductive potential and mortality, stock assessment outputs may over-estimate productivity.

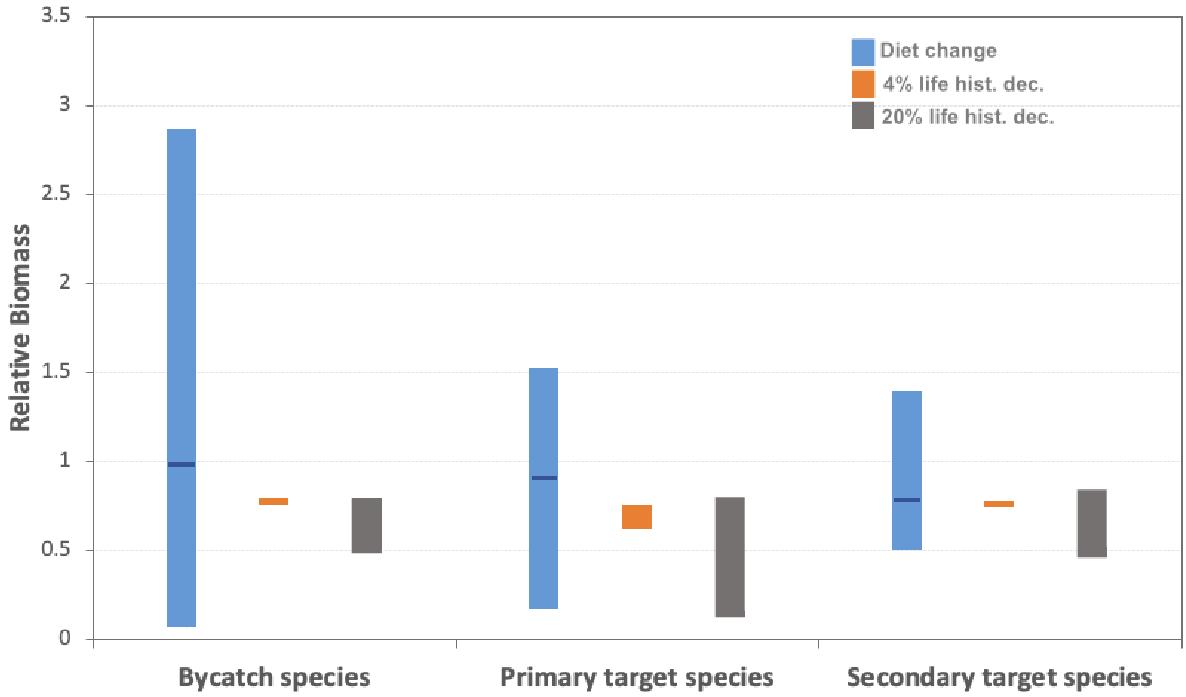

Figure 2: Relative biomass (vs baseline values) for variant parameters of the Atlantis-CCR model for the SESSF.

Table 6: Comparison of estimated per cent change in biomass for various species estimated by the EwE and Atlantis models.

Species/Species group	EwE	Atlantis
Oreodories and Dories	-80 to 500	up to 11
Redfish	up to 178	-54 to 330
Whitings	10.7 to 69.7	-50 to 123
Pink Ling	5.1 to 60.5	-26 to 123
Tiger Flathead	up to 57	-25 to 5
Gemfish	up to 56.8	-35 to 170
Cardinalfishes	3.4 to 48.5	up to 187
Jackass Morwong	up to 47.7	-41 to 280
Redbait	-5.5 to 2.2	-4 to 11
Royal Red Prawn	2.8 to 18	-20 to 62
Squids	-1.8 to 15.6	up to -44

When the outputs from Atlantis are compared with the outputs of stock assessment sensitivity analysis (Table 7), approximately one third of outputs demonstrate similar magnitudes of change. The inclusion of trophic interactions in the ecosystem models results in changes (and resulting realised mortality shifts) being buffered when compared with the assessment models. In just under a half of the comparisons, the range of changes in parameters in the assessment model sensitivity analysis is larger than those estimated by the ecosystem model (in some cases because the parameter change in the assessment model is larger than in the ecosystem model). The change in biomass for two of the 12 species considered is estimated to be much larger in the ecosystem model than in the assessment model even though the change to parameter values in both models are of the same size.

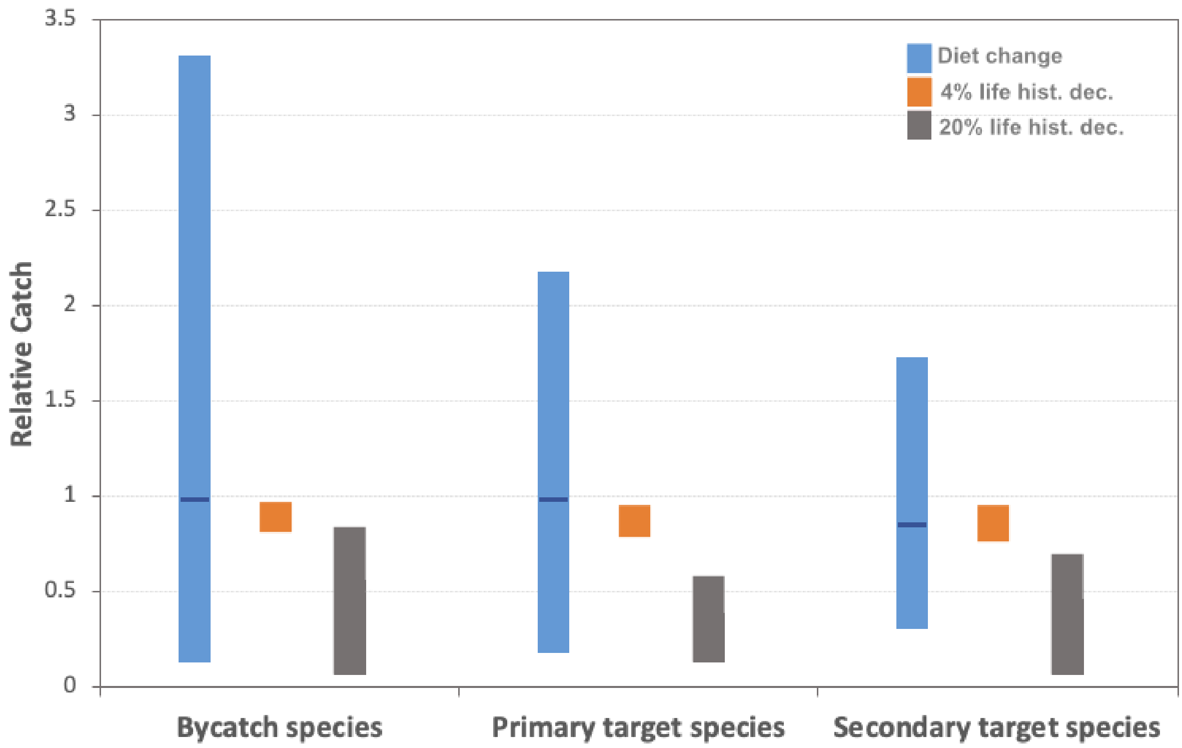

Figure 3: Relative biomass (vs baseline values) for variant parameters of the Atlantis-CCR model for the SESSF.

This suggests that sensitivity analyses for stock assessments for some species are already addressing uncertainty to levels that would cover the levels of divergence suggested by the additional processes captured in the ecosystem models, so long as the full range of uncertainty in biomass values given by the sensitivity analyses is considered in decision-making and the base case is not used as a "one point of truth". Nevertheless, given that change in this region is ongoing (so values currently considered on the margin of the sensitivity analysis may actually be closer to the core value) and the way in which trophic amplification of change and uncertainty occurs for some species (such as Redfish and Gummy Shark; *Mustelus antarcticus*), **updating parameters in stock assessments, modifying base cases, or more heavily drawing on results from sensitivity analysis in discussion of stock assessment results would be strongly advisable, especially in regions where large environmental shifts are known to be occurring.** If parameter values are indeed 4-20% different to those currently assumed in the base case run of assessments, and consequently, the base case biomass estimate is consistently 10-40%

too high, then this has the potential to undermine decision making (via unconscious, persistent and potentially unrecognised bias in the information being used as the basis of quota setting).

Table 7: Change in biomass projected by Atlantis and standard stock assessment models when alternative parameter settings are used (assessment model results are derived from the most recently published stock assessment for that species).
*Both increases and decreases in parameter values were considered in the assessments, however only changes analogous to those estimated by Atlantis are considered here (e.g., decrease in growth).
^change in biomass under analogous parameter changes implemented in Atlantis.

Species common name	**Change to parameter(s) in assessment model***	**Median percent change in biomass (assessment model)**	**Median change in biomass (Atlantis)^**
Silver Warehou	~5 % change to life history (e.g., M)	- 19.3	-8.9
Pink Ling	Varying M and CPUE (up to 35 % decrease in B estimate)	-23.1	-7.5
Blue Grenadier	2-10 % change to life history (changes M by 20 %).	-31.5	-25.3
Jackass Morwong	5-10 % change to life history (changes M by ~50 %)	-22.4	-7.1
Blue Mackerel	5 % increase to life history	-39.8	-5.7
Jack Mackerel	30 % change to life history	-35.6	-5.9
Gummy Shark	2-5 % change to life history (changes M by ~5 %)	-4.2	-10.1
Orange Roughy	2-5 % change to life history (changes M by ~30 %)	-10.9	-8.5
Redfish	5-10 % change to life history (changes M by ~25 %)	-18.1	-23.3
Tiger Flathead	2 % change to life history (changes M by ~30 %)	-19.5	-5.6
Bight Redfish	2-15 % change to life history (changes M by ~25 %)	-55.9	-20.7
Deepwater Flathead	10-15 % change to life history (changes M by ~8 %)	-10.5	-28.1

Stage 3. Expert review and development of prioritisation guidelines.

Review of investigation into parameter provenance and identification of risk

Parameter provenance

The workshop participants reiterated that the project had captured those parameters that influenced stock assessments the most and highlighted that lack of knowledge on stock/population structure and population connectivity were major issues for many assessments.

The value of developing a table that provided details on parameters and their estimation was considered as an important tool as this provided an opportunity for rapid exchange of information across species and fisheries and potential cross-learning opportunities for assessment groups particularly in method development and sensitivity analysis approaches.

It was also noted that resources such as the international FishBase[3] were not always accurate, so ongoing support for regular and consistent updating of the parameter provenance table would provide a useful mechanism for feeding updated information to these resources to ensure accuracy of information. If ongoing support for the parameter provenance table (Appendix 1) was to occur, it was noted that some effort would be needed to translate the current excel spreadsheet into an easily accessible and searchable database to ensure widespread use and encourage submission of updated information.

In reviewing those parameters where provenance was not able to be established, it was noted that there was likely to be grey literature (that is currently difficult to find) that could potentially fill in some of the current gaps associated with provenance. While some further grey literature was identified as a result of these discussions, this only served to fill a very small number of gaps.

Any further development of the provenance table could potentially benefit from further targeted discussions with those involved in historical stock assessments, particularly where relevant information may be contained in assessment-related meeting reports, theses or internal reports. In association, the hard copy nature of much of this information was recognised as a barrier to its accessibility and as a result, consideration of digitising historical material was highlighted as important for ensuring traceability. As libraries are dissolved and replaced by centralised or digital resources, the few remaining hard copies of the older grey literature are lost. While some have been retained in the private collections of the original authors, these are not readily accessible (or even known to exist) and consequently digitising them before they are permanently lost is critical.

Identification of risk/Implications of changing parameters

While the two ecosystem models identified that a shift in trophic interactions influenced biomass, it was noted that teasing apart the drivers on productivity and recruitment were not straight forward even in models where the underlying processes are explicit. It was also not clear how to implement consideration of trophic interactions in current stock assessment models, particularly when information on trophic dynamics and interactions is currently universally poorly understood. Within the context of climate change driven changes in parameters, it was noted that climate change has likely been placing some influence on marine environments for much of the time period of most datasets and that trophic interactions alone may not be informative of change, particularly within the context of other drivers of biological change such as density-dependence.

If parameters have changed and are influencing stock assessment outputs, there is typically insufficient information available currently to be able to determine this influence. As a result, a need for further exploratory work (beyond the current project) across multiple aspects of stock assessment models was highlighted, if the implications of changing parameters on current stock assessment are to be fully understood. This included investigating:

- how important/influential each parameter was on assessments, particularly those for which sensitivity analyses were not conducted;
- the relationship between parameters (i.e., how do parameters interact) and how change in one or more influences assessment outputs;
- the flow on effects of changes in growth, for example on density dependence at very old/young age classes etc or on surplus production;

[3] https://www.fishbase.se/search.php

- the degree to which stock assessment sensitivities might be changing, given that changes are likely to be occurring at different rates across species;
- temporal and spatial gridding approaches that might capture changes in parameters in space and time;
- how consistent (smoothly varying) change can be implemented across an array of parameters in stock assessment models and in particular, what augmentation/adaptation of model frameworks might be needed to accommodate these;
- in association with the above, whether time-varying parameters can be incorporated into models in a rigorous enough manner or whether it is better to keep models simpler and explore other avenues (e.g., utilising ensemble approaches).

More broadly, it was identified that there was a need to investigate the drivers of declines of some species (e.g., shelf species in the SESSF). For example, are declines due to changes in life histories with the result that assessments are currently not capturing those changes? Or are the declines due to mis-specification of parameters (including other parameters not considered by this project) in stock assessment models? Are current harvest strategies appropriately capturing uncertainties and therefore providing the guidance needed to ensure recovery?

It was also noted that many of the species currently considered to be undergoing change in the SESSF are those that the approaches used in Ecosystem Risk Assessment (ERA) process identify should be the most robust. Further exploratory work is therefore needed to investigate why the approaches utilised in the ERA process are not currently capturing those risks. Additionally, work is needed in further developing the process so that it does capture risks associated with biological shifts more comprehensively.

The ecosystem modelling undertaken in Stage 2 of this project (particularly the use of EwE) identified that parameters currently sourced from tables utilised in the ERA process were not always consistent with those used in stock assessments. While it is noted that a stock assessment supersedes an ERA assessment for assessed species (so both processes are not undertaken for a species), it is still important to ensure consistency across methods. This is particularly relevant to other species considered in the ERA assessment (e.g., sister species or where an inconsistency highlights an issue for a particular life history type). Consequently, a component of any work in this area needs to include an updating of the parameters used in ERAs, so that they are consistent with those used in stock assessments.

Several projects either currently underway or planned were highlighted as being able to provide some opportunities for exploring related concepts, including:

- Multi-species harvest strategies: this work has the potential to explore incorporation of multiple parameter values that change through time;
- Dynamic B_0: this work is exploring whether harvest strategies can cope and provide sustainable outcomes regardless of change;
- RV Investigator voyages revisiting the south-east ecosystem (voyages planned for 2023/24): these voyages will provide fisheries independent information on the ecosystem and changes that have occurred since the area was last sampled 25 years ago. It will also provide the opportunity for PhDs and postdoctoral fellows to progress some work in exploring changes occurring in species.

Recommendations for prioritising future work

While the project considered Commonwealth fisheries around Australia, given the higher incidence of issues with provenance, the frequency of ageing parameters and the growing evidence of changes occurring in the SESSF, it was suggested that the SESSF might be a good starting focal area. In addition, given the faster rate of change occurring in the southeast Australian region, it was suggested that focusing on the SESSF might provide an opportunity for identifying key priorities, considerations and areas of focus that could then be applied to other Commonwealth fisheries, and provide important guidance for those fisheries in identifying and implementing best practices. The upcoming focus of RV Investigator voyages in the southeast region of Australia in 2023 and 2024 led by the CSIRO (https://mnf.csiro.au/en/Voyages/Schedules) also provides the opportunity to collect fishery independent data across a number of species in this fishery, and build understanding of processes not currently captured in stock assessments and their influence on productivity (e.g., trophic interactions). Again, this could potentially provide useful guidance to other Commonwealth fisheries on the research effort required for attaining updated biological samples for evaluating parameters, understanding change occurring in ecosystems and assessing risks to stock assessment of changes in the biology of species.

It was noted that identifying priority species that work could be focused on was beyond the scope of this project, and was further likely to vary depending on the fishery considered and the key questions being asked in association with each fishery (and by whom). As general guidance, the prioritisation processes being utilised in climate change focused projects, when combined with information on provenance provided by the table developed by the project, was suggested as a mechanism for identifying which parameters and which species to focus on. This could then be implemented within a staged approach to addressing current gaps and uncertainties. This prioritisation process uses a combination of information sources including:

1. the oldest age of the parameters, or if parameter values exist (information now available in the parameter provenance table);
2. the ecological vulnerability of the species derived from the ERA process and the recently published climate adaptation handbook (Fulton et al. 2020, see also https://www.frdc.com.au/project/2016-059);
3. the status of the species (derived from stock assessments), including if there was evidence of recovery or non-recovery (Knuckey et al. 2018);
4. the climate sensitivity scores of Fogarty et al. (2019);
5. the availability of new research (information now available in the parameter provenance table), and
6. whether cross-jurisdiction coordination needed to be considered.

Given that much of the information required for informing this process is now readily available (via the parameter provenance table in Appendix 1), this would be relatively straightforward to implement. It was also noted that once an understanding of the implications of parameter mis-specification was achieved, this could be incorporated into the above framework to prioritise targeted efforts in the future.

Several additional considerations were identified that should be incorporated into any prioritisation process. These included:

- the steps (initial exploratory work, sub-projects etc.) needed to achieve a framework for ensuring that stock assessments appropriately captured changes occurring in species (i.e., incorporating time-varying parameters into assessments) and the most effective ways of achieving those steps (including the costs and benefits);
- the steps needed to identify what data might be needed to quantify changes, where the greatest sensitivities occur within assessments, and what are the implications of parameter uncertainty within the context of harvest strategy frameworks.

Stage 4. Development of guidance on work plans for addressing current uncertainties

In addition to the potential processes and considerations that could guide prioritisation of work identified in Stage 3, some general thematic areas were identified from stages 1, 2 and 3. These provide an initial starting point in developing specific work plans that could be implemented to address current uncertainties associated with knowledge gaps on parameters, potential changes in parameters and their influence on stock assessment outputs and advice provided to fishery managers and the industry.

Improving information workflows and information accessibility

Building on the work undertaken to compile the parameter provenance table (Appendix 1), it was identified that in order to better understand the parameters included in assessments and their associated uncertainties, it was important to ensure that all parameters are documented fully in reports each time an assessment is done. This contrasts with the current approach where the preference is simply to refer to previous reports. This was particularly relevant for understanding the robustness of those parameters that are estimated outside of models, given that they might not be updated on a regular basis It is also relevant as investigation of the sensitivity of models to these parameters may not be undertaken as part of regular assessments processes.

One way of facilitating this is to implement a standard template that could be used for all assessments outlining the minimum information needed for ensuring that provenance is maintained, information is clearly and accurately provided, and that information is standardised over time both within fisheries and across fisheries. In some Commonwealth fisheries this has evolved to some degree, with some assessments following the same format as previous assessments. However, this process has also resulted in information gaps with important detail not included (because reference is made to previous assessment report where no detail is actually provided) and change processes not necessarily detailed. Development of reports where templates or consistent formats could be built on to ensure that they included key information for maintaining provenance would be relatively straightforward for some species/fisheries, whilst in other fisheries some work would be needed to ensure reports include the required minimum information. Processes would also need to be implemented, potentially by Resource Assessment Groups (e.g., through guidelines, templates,) to ensure that reports continue to include the required minimum information are appropriately completed.

Discussions during the workshops held by this project identified that assessments conducted on New Zealand fisheries required that a log or register documenting changes made to the model structure and parameters used was included with assessment reports. This serves to maintain a time series of changes that can be tracked, thereby maintaining provenance. The Working Group on Biological Parameters of the International Council for Exploration of the Sea (ICES) has developed a series of Terms of Reference that (i) details calibration exercises on biological parameters, (ii) standardises and updates best practice guidelines for determining biological parameters (e.g. age reading, maturity staging) (iii) identifies quality indicators associated with each biological parameter used in stock assessment and (iv) identifies priorities for critical parameters needed for stock assessments (ICES WGBIOP 2018). Implementation of similar processes into Commonwealth fishery stock assessments would facilitate clear communication of priorities, best practice methods, uncertainties and where (when and how) changes have been undertaken.

A centralised and accessible database of parameters across Commonwealth fisheries would make any future comparative analyses easier, and would also aid ensuring consistency across different assessment approach and model types (e.g., single and multi- species assessment models, ecosystem models, ERA and climate focused vulnerability assessments etc). Creating a standardised reporting format would not only advance consistency in individual assessment reporting, (e.g., see Dorn and Zador 2020), but would also improve the robustness of system assessments, which are likely to become more common as climate influences are more routinely considered in fisheries. Standardising reporting format across Commonwealth fisheries would facilitate automation, making compliance more straight forward, increase transparency of the assessment process (aiding social licence and trust building) and support the straightforward updating of global information systems such as Fishbase.

Although a tedious process, digitising old stock assessment or parameter estimation documents and reports should be prioritised to support provenance processes. This would also allow for easy access to information that could facilitate the development of targeted comparative work based on a recognised time series of parameters. It would also support the investigation of drivers of change and changes in the relationships between parameters through time.

Better understanding stock assessment uncertainties

At present most evaluation of assessments focuses on catch rates, changes in catch-per-unit effort (CPUE) and the sensitivities of assessment to small variations in a limited number of parameters (e.g. mortality, steepness). There are currently gaps in overall understanding of how uncertainties in parameters propagate through stock assessments, how parameters interact (i.e., how a change in one parameter might influence other parameters) and how these interactions might influence stock assessment outputs. These gaps are currently limiting overall ability to assess the consequences, relative to the probability, of a stock assessment mis-specifying a biological parameter. This was well recognised across workshop participants as a knowledge gap and was also identified as being recognised elsewhere. An evaluation of declining indicators in the SESSF identified that better understanding how changing assessment inputs influenced assessment outputs and greater understanding of the mechanisms influencing the productivity of species was needed (Knuckey et al. 2018). While stage 2 of the current project was a first step in addressing this issue, highlighting the immediate potential level of impact these uncertainty issues may be having on the outputs of assessments, dedicated exploration of the full implications of the mis-specification and interaction of assessment parameters was well beyond the resources of this project and requires dedicated and specialist attention.

As such, dedicated analyses will take time to occur and may not be an option available to all fisheries. In the first instance, in order to facilitate broader investigations into the sensitives of assessment to parameters, recommendations could be made to Resource Assessment Groups to: (i) undertake broader sensitivity exploration than is currently conducted, (ii) dedicate time to working through those uncertainties with members of Resource Assessment Groups and (iii) in assisting with (i) and (ii), consider greater use of ensemble modelling approaches and dynamic approaches to determining reference points. Recent research investigating the use of stationary and non-stationary biological parameters have identified quite major changes in stock assessment outputs with varying implications for harvest control rules (Bessell-Browne et al. 2022). This highlights the need for dedicated efforts in understanding how changes in parameters might influence assessment outputs. Work undertaken elsewhere might also provide useful guidance to Resource Assessment Groups on where to focus and prioritise efforts. For example, a number of organisations are undertaking research efforts focused on understanding how changes to parameters might influence fisheries yields, (e.g., the joint ICES/PICES Working Group on Impacts of Climate Warming on Growth Rates and Fisheries Yeilds, WGGRAFY; see https://www.ices.dk/community/groups/Pages/WGGRAFY.aspx) as well as developing stock assessment approaches that incorporate environmental variables for exploring the consequences of differing environmental impacts on population demographics and productivity (see ICES 2019; Punt et al. 2021).

While it is recognised that implementing such processes might extend current assessment timelines, they will ensure that there is good understanding of uncertainties in assessments across all stakeholders, allow for the identification of key activities in workplans that might be enacted to reduce those uncertainties, and ensure overall advice based on the outputs of stock assessments captures uncertainties.

It would have been ideal to have had examples of best practice guidelines – or good and poor examples - of how to deal with parameter updating and uncertainty. However, the reality is that in those places grappling with climate change influenced parameters, the process is still underway and there is currently no clearly laid out process and outcome to refer to. Lessons are still being shared. While parameter updating processes do exist for North American and European nations, these are couched within an ongoing workflow that is based on extensive data collection. No developed country, with fisheries managed in the same way as Australia, finds itself in a position where so little fisheries independent data is collected that it creates conditions where parameters may not be updated for decades at a time. This means simple translation of extant processes is unrealistic/unhelpful given available data streams, while more analogous efforts to deal with climate influences on parameters are incomplete. This has led to the project team to make the recommendations provided here and to suggest that this project effectively be considered the scoping stage of a longer-term process involving individual Commonwealth fisheries as most appropriate given their individual contexts.

Streamlining parameter determination and improving cost-effectiveness

A key factor identified in filling knowledge gaps and implementing processes that ensure that the provenance of parameters is maintained into the future and that stock assessments incorporate changing parameters, was cost-effectiveness. Implementing the recommendations identified in Stage 3 of the project, particularly in addressing knowledge gaps and the increasing age of biological parameters used in assessments, won't come without cost. Ongoing collection and analyses of new samples will be required to ensure that changes occurring to species, whether they be the result of commercial fishing itself, or environmental change are captured.

In addition, technological and methodological developments in sample collection and analyses could be implemented to streamline processes and reduce costs over the longer-term. Rapid advances in automating or semi-automating some forms of data gathering could be explored and implemented into both sample collection (e.g., real time capture of fish lengths via artificial intelligence processing of images – see Tseng and Kuo 2020, Qiao et al. 2021,) and analyses (e.g., machine learning processes for reading annuli in otoliths to determine age – see Moen et al. 2018, Politikos et al. 2021). Implementing the relevant technologies and methodologies will require dedicated investment to establish, however over the longer-term they are likely to reduce overall costs, analysis times and associated work force costs, thereby allowing for regular re-assessment of parameters and incorporation of change into stock assessment processes.

In addition, consideration of where there could be greater involvement of supervised students, not only in assessing parameters, but in the development of methods and pathways for streamlining processes to increase cost-effectiveness should occur. This would have the benefit of not only progressing some areas of work, but also increasing capability in the next generation of fisheries scientists. It would also have the benefit of building capability that connects the biological components of fisheries science with stock assessment components to ensure that outputs are appropriate and meet the needs for updating stock assessments. This need to build capacity has recently been recognised by the AFMA Research Council and in association, projects that incorporate both progressing research needs and developing capacity incorporated into recent calls for projects funded through the Fisheries Research and Development Corporation.

Improving processes for implementing change

Management of change processes that might be associated with introducing updated parameters, expanding exploration of sensitivities and uncertainties in models and introducing new approaches to incorporate change in stock assessments was highlighted as an area that needed to be considered when progressing any work. This was particularly important for ensuring that all stakeholders involved understood the reasons for change and the benefits of implementing change. Many changes have been introduced into stock assessment processes in the past, and there is likely to be lessons learned from those instances, particularly in association with how changes were managed, who was involved and what steps were followed. There are no doubt lessons that can be learned from other organisations in implementing changes to assessment inputs and processes that could also be drawn upon.

Key to the process of implementing change, is that putative changes implemented into the stock assessment process need to be clearly explained, they must demonstrate improvements to the assessment, they must recognise what change might mean for historical outputs, and they need to ensure confidence in the scientific activities being conducted. Discussions during the workshops held by this project identified that there are draft guidelines that have been developed for moving assessments from one structure to another in the SESSF. These might serve as a starting point for co-development of guidelines by those involved in assessments, the Resource Assessment Groups and Management Advisory Committees that could be implemented more broadly across Commonwealth fisheries. Other examples from Commonwealth fisheries include the implementation of a management procedure for southern bluefin tuna, a process that involved substantial changes to the assessment and management setting process (see Hillary et al. 2016) and implementation of close-kin approaches to stock assessments (e.g. Thomson et al. 2020).

Conclusion

Australian waters are warming faster than the global average, with associated changes occurring in marine ecosystems in response including changes to species life histories, phenologies and distributions. As species life histories shift and specific traits change, there is an associated need for assessment models used to evaluate the status of populations to account for these changes. Without an ability to account for change, inputs into models are likely to quickly become outdated, thereby increasing uncertainties in the outputs from models and any advice derived from them.

Evaluation of the provenance of current biological parameters incorporated into Commonwealth stock assessments and some of the risks associated with not accounting for biological shifts identified several issues likely to impact assessments that could be resolved through:

- more consistent and standardised approaches to reporting;
- commencement of research projects focused on understanding uncertainties associated with parameters and their interactions more broadly within assessment models and;
- targeted projects focused on filling current knowledge gaps and updating parameters including through the utilisation of improved and contemporary methods (and new relevant biological sampling) combined with the development of methods that streamline data gathering and analysis processes.
- Improving processes for managing change, particularly as stock assessments will likely need more frequent evaluation, updating and be accommodating of non-stationary parameters.

Implementing actions across these four areas and engaging all stakeholders in the process will provide a foundation that can be built on for ensuring future adaptability of stock assessments. In association, current uncertainties in assessments will be better understood and reduced, with the result that advice provided to management for supporting future sustainability of species and fisheries will be improved.

Implications

The outputs from this project outline current issues with the stock assessment process for Commonwealth fisheries and provide a realistic and feasible pathway for identifying a range of activities that will futureproof the assessment process.

Implementing the guidance provided by this project will reduce uncertainty around the veracity of information used to manage the fisheries and broader ecosystem, thereby building confidence in the sustainability of management guidance. It will also serve to increase basic understanding of shifts occurring in the life histories of commercial species, and in association support clearer understanding of developments needed to progress assessments in accounting for changes occurring in marine systems. This will assist with increasing understanding across stakeholders and avoiding maladaptation as fishers and other ocean users look to adapt practices in response to the changed ecosystem and fish stock status.

Implementing the recommendations from this project won't come without cost. However, it does now provide a guide for AFMA, the Resource Assessment Groups and those involved in stock assessments in identifying activities that might be incorporated into workplans over the near term and consider those activities in processes for ensuring fisheries management is robust under a changing climate.

Recommendations

See Results and Discussion: Stage 4.

Extension and Adoption

The project has largely been based on a set of continuing conversations with stock assessment developers, those carrying out stock assessments within Commonwealth fisheries and those involved in historical assessments. A number of presentations were made to Resource Assessment Groups to provide background to the project (both verbal and formal presentations – see Appendix 2) and the workshops conducted as part of Stage 3 of the project included consultations with fishery biology scientists, assessment scientists, fishery managers, and industry experts.

The outputs of Stage 4 informed a submission to the Commonwealth Research Advisory Council for a project on "Biological parameters for stock assessments in South Eastern Australia – an information and capacity uplift" which was then incorporated into the FRDC May 2022 funding call.

A final presentation to AFMA staff, and the project steering committee was provided on 20 September 2022 (see Appendix 4).

There is widespread support across those that the project has engaged with for making the table of biological parameters (Appendix 1) fully accessible and able to be updated (i.e. as a living document). Doing so, with a requirement that all future stock assessments need to update their parameters in the table, would not only serve to ensure that the details of parameters is maintained, and that knowledge can be readily exchanged, but also that there is a clear record of when changes were introduced into assessments (and potentially the table could be expanded to detail why changes were implemented).

Project materials developed

A full assessment of the provenance of parameters for all Commonwealth tier 1 assessments is provided in Appendix 1 (see separate Excel spreadsheet).

The background presentation provided to Resource Assessment Groups by the project is provided in Appendix 2.

A summary of the workshop held as part of Stage 3 of the project and associated presentations is provided in Appendix 3.

A presentation provided to AFMA managers and the project steering committee summarising the final results of the project is provided in Appendix 4.

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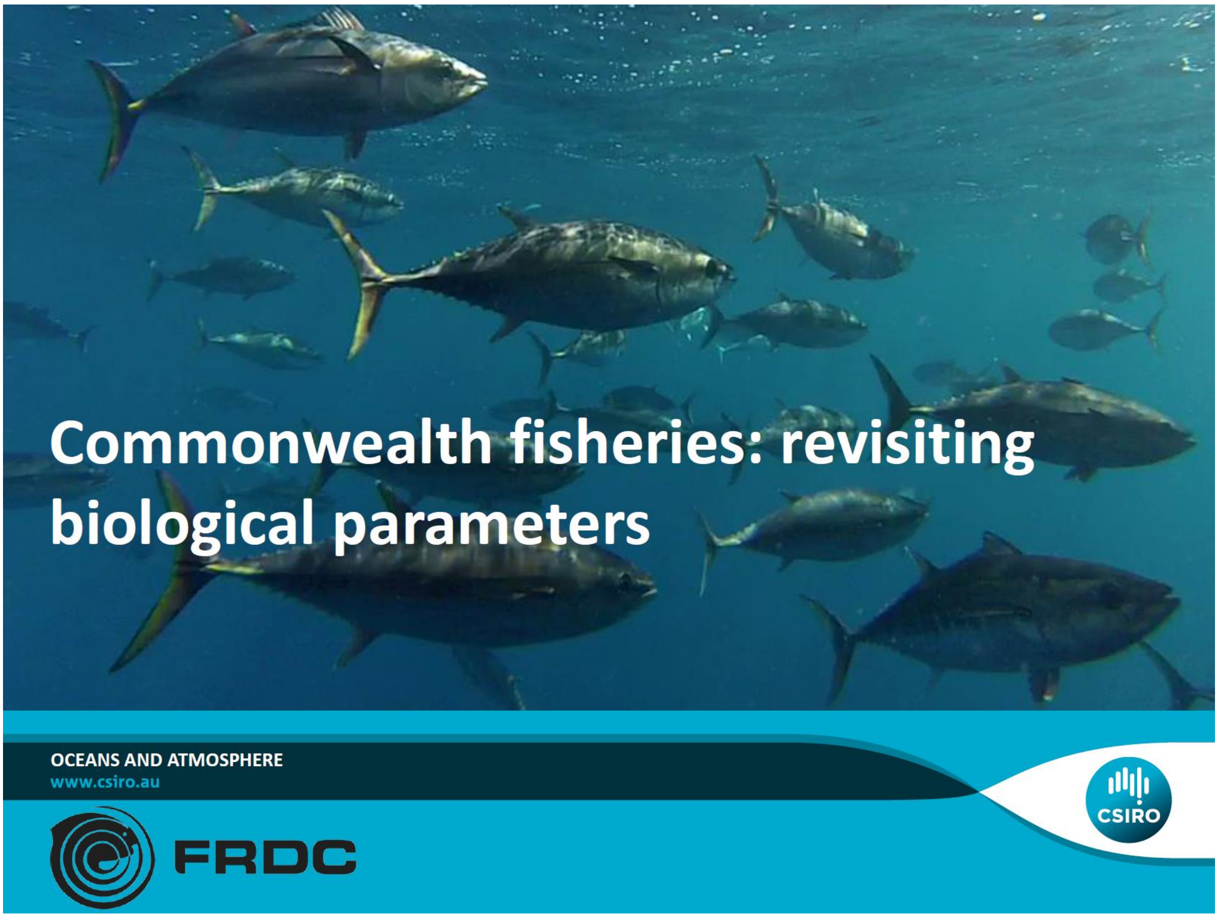
Appendices

Appendix 1: Parameter provenance table

See separate Excel spreadsheet.

Appendix 2: Project background presentation



Uncertainties

Many assessment models rely on biological parameters/inputs that:

- Are old (some 20+ years)
- Of unknown origin
- Based on datasets that no-one has access to/knows where they are

Previous projects have identified that:

- Time varying growth is present whenever it is looked at
- Length conversions factors are not always appropriate/accurate
- Productivity varies in space and time

While some assessments have updated parameters, many have not assessed information available to determine if parameters can be updated (need to be updated)

Reviewing biological parameters

FRDC-CSIRO project: "Revisiting biological parameters and information used in the assessment of Commonwealth fisheries: a reality check and work plan for future proofing" 2019-010

Objectives:

1. Identify the provenance of biological information used in current assessments (including age, appropriateness of methods used)
2. Assess the implications and risks associated with using dated and borrowed information in assessments
3. Identify methods (including novel approaches) that might be applied to update priority biological parameters.
4. Articulate a work plan including appropriate sampling regimes required for updating priority biological parameters.

Where are we?

1. Which fisheries, which parameters?
   - Pivot of originally planned workshop to a series of focused interviews with folks involved in stock assessment – both current and historic
   - Pinch points in terms of parameters used
   - Sensitivities within assessments

Tier 1 assessments

Parameters associated with:

- Age, growth and reproduction
- Mortality
- Steepness

Length/weight conversion factors

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Where are we?

2. Digging into the details – falling down the rabbit hole
   - Making sure we capture where the uncertainties lie
   - Identifying what sensitivity tests (if any) have been done and their outputs – what flags do these raise?
     - Estimation methods (alternatives)
     - Data inputs
     - Drivers of uncertainty
     - Spatial and temporal components
     - Current/planned work

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What does the data look like?

Example: yellowfin tuna (ETBF)

Assessment method: integrated model
Model used: MULTIFAN-CL
Parameter: growth
Source of parameter: Tremblay-Boyer (2017)
Estimated/fixed: estimated
Method: model fits otolith age-at-length and size data from the troll fishery
Last updated: 2017
Uncertainty: low
Driver of uncertainty: juvenile data doesn't match length-frequency modes
Sensitivity analysis: yes
Degree of sensitivity: medium
Alternative/more recent parameters: no
Spatial component: yes
Spatial component captured: no
Work on updating underway/planned: yes

Developing a flagging/significance system based on information collated in the table – traffic light grading for easy identification/interpretation

Reviewing biological parameters

Were to next?

1. Consultation with steering committee and FRDC on where we are and our thoughts on where to next

2. Some testing of significant parameters beyond sensitivity analyses already done – ERA process, ecosystem models

3. Workshop with AFMA managers, FRDC, others (hopefully in person – first half of 2021)

4. Develop a framework for a workplan – provide guidance on priority areas for updating/revising parameters

Project team

Karen Evans
Sharon Appleyard
Cathy Bulman
Jemery Day
Jessica Farley
Beth Fulton
Ashley Williams
Shijie Zhou

Steering committee:

Daniel Corrie (AFMA), David Smith (AFMA Commissioner), Michael Steer (SARDI/PIRSA), James Woodhams (DAWE)

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Appendix 3: Stage 3 workshop summary and presentations

Background and guidance for workshops

Background to project

Much effort has been placed over the last couple of decades on the development of harvest strategies, stock assessments, risk assessments and the strategic use of ecosystem models to facilitate meeting the needs of the Commonwealth's Harvest Strategy Policy. A focus on modelling to improve fisheries management has required effort towards method development. However, little effort has been made towards revisiting and updating the biological parameters that fundamentally underpin such modelling (e.g., growth rates, age and size at maturity, natural mortality rates, mixing rates and stock structure) and the tools or methods used to derive them. As a result, most models now rely on parameters and community dietary data derived from information collected during the 1970s-1990s, or information that is borrowed from other regions or species. Whether such old or borrowed values are now representative for commercial Australian fish species is unknown but many factors point to major changes occurring in our marine environment. Australian waters in the southeast and southwest are climate hotspots and, overall, Australian waters have warmed faster than the global average.

Key components of the productivity of marine fish (growth, maturity, and recruitment) are expected to be undergoing directional changes under a changing climate and it is entirely possible that there have been changes in fundamental productivity parameters for some Australian stocks. The reliance of current assessments on what is likely to be out-of-date information leads to increased uncertainty, which propagates into management decisions. Without an understanding of any changes in biological parameters and how any change might impact assessment frameworks, determining whether current management measures are ensuring sustainability becomes highly uncertain.

The last time that any assessment of the provenance of parameters used in assessments was undertaken was in 2002 (published in Bruce et al. 2002). With the significant development of assessments over the last 20 years and the changes occurring in the marine environment, it is timely to consider the appropriateness of parameters used in assessments and where efforts should be placed reducing uncertainties in assessments.

This project aims to achieve the following objectives:

1. Identify the origin and provenance of biological information used in the most recent assessments of species in Commonwealth fisheries;
2. Assess the implications and risks associated with using dated and borrowed information in assessments;
3. Identify the methods that might be applied to update priority biological parameters and;
4. Articulate a work plan including appropriate sampling regimes required for updating priority biological parameters used in assessments.

Project progress

To ensure that achieving the four objectives was achievable within the timeframe and budget of the project we have chosen to focus on Tier 1 assessments. These assessments are those with the greatest information available, are often those that the greatest amount of effort is put into and are often those of the highest priority from an overall perspective due to their importance to industry.

The project has completed work against the first three objectives. Part of this process has been to:

- Identify the key parameters that assessment are most sensitive to;
- Identify the provenance of those parameters.

This part of the project has involved a series of one-on-one and small group discussions with those involved in assessments to determine a defined list of parameters to focus on (as the project does not have the resources to cover all parameters) and to highlight key historical literature that have informed the choice of assessments.

The expertise of the project team has been utilised to then:

- Identify if there are newer/alternative parameters that could be utilised;
- Identify if there are newer/alternative approaches available for estimating those parameters;
- Identify if there is work currently underway in updating parameters

Using ecosystem modelling approaches we have also undertaken a series of simulations on a small number of target species to investigate how changes in parameter values might influence assessment outcomes. This follows on from some of the earlier work done by Audzijonyte et al. (2013) and aimed both to investigate whether outputs were consistent with earlier projections or had changed, and if so how and to assist with the prioritisation process for developing a set of recommendations that could shape a workplan.

The next steps in the project are to seek input from those currently and historically involved in assessments, fisheries managers and others on the work done so far. This will help shape the final deliverables for the project and ensure that the recommendations developed by the project are both appropriate and achievable and will assist in reducing current uncertainties in assessments.

Workshop format

The workshop will be split into two sessions held on February 9 and 17th.

The first session will predominantly be focused on presenting the work of the project progressed to date and gathering feedback on parameters, their provenance, and the scenarios. It will begin a process of prioritising activities that can address some of the uncertainties around parameters.

The second session will utilise the outputs from the first session and further progress identifying priorities for activities that can be put forward as recommendations by the project that can be used for shaping a workplan These recommendations will need to consider what might be most feasible looking forward in updating parameters and supporting assessments.

Feedback activities and focus

The project would like to seek broader feedback from those engaged in assessments on the outputs from the project produced to date. We have provided, with this guidance, two key documents we would like you to look over to help us in this task:

- A table of parameters grouped by (i) fishery and then within each fishery tab by (ii) species for which Tier 1 assessments have recently been carried out;
- A summary of the outputs from the simulation analyses.

Specifically, we are seeking feedback in relation to:

- ***The choice of parameters***. Do these encompass the parameters that assessments are most sensitive to? Should we be considering others that assessments are highly sensitive to?

- ***Parameter values and estimation***. Are these correct? Have we misinterpreted information in assessment reports?
- ***The provenance of parameters***. We recognise that we still have a lot of unknowns in our table of parameters, so have we overlooked information? Has there been a decision making process that has not been documented that we should be aware of and ensure is captured? Did we misinterpret things along the provenance pathway?
- ***Work underway/planned***. Is there work planned that we have not been made aware of and therefore not captured?
- ***The simulations***. Do the outputs make biological sense? Are there alternative scenarios that should be considered (within the context of the timeline and budget of the project)?

We will gather feedback on the parameters and simulations during the workshop through a series of guided conversations and gather input into priorities through small group activities. Detailed agendas for each session will be provided.

What happens if I can't attend one or both of the workshop sessions?

We note that some people can only make one session of the workshop or can only attend part of each session. The table of parameters and the summary of simulations will be made available to everyone via a Google Drive folder. We would like to provide all with the opportunity for input into the project so please and encourage those that are unable to attend one or both of the sessions to provide feedback to the project team out of session, so that those suggestions can be included in finalising the project.

Acknowledgements

We would like to acknowledge the time and effort that many have put into assisting the project team in progressing the project to date, including providing access to historical information, useful insights into decision making and providing encouragement along the way.

References

Audzijonyte A, Kuparinen A, Gorton R, Fulton EA. 2013 Ecological consequences of body size decline in harvested fish species: positive feedback loops in trophic interactions amplify human impact. Biol Lett 9: 20121103. http://dx.doi.org/10.1098/rsbl.2012.1103.

Bruce, BD, Bradford R, Daley M, Green M, Phillips K. 2002. Targeted review of biological and ecological information from fisheries research in the south east marine region. CSIRO Marine Research. 175pp.

Project team (alphabetical order)

Sharon Appleyard, Cathy Bulman, Jemery Day, Karen Evans, Jessica Farley, Beth Fulton, Ashley Williams, Shijie Zhou

Workshop agenda

Session 1: Wednesday 9 February 2022 (all times AEDT)

Time	Topic	Who
10:00-10:10	Welcome and introductions, housekeeping	Karen
10:10-10:20	Background to project, purpose of workshop	Karen
10:20-10:35	Introduction to biological parameters used in assessments and their provenance	Karen
10:35-10:45	Short Q&A on process associated with biological parameters	All
10:45-11:20	Provision of feedback on biological parameters: break-out room discussions	All
11:20-11:30	Break-out room reports	Breakout room leads
11:30-11:40	Break and stretch	
11:40-11:55	Introduction to scenarios and insights into changing parameter effects on assessment outcomes	Beth
11:55-12:05	Short Q&A on process associated with scenarios	All
12:05: 12:35	Provision of feedback on scenarios: break-out room discussions	All
12:35-12:45	Break-out room reports	Breakout room leads
12:45-13:00	Next steps in the development of priorities for future work and Q&A	Karen and all
13:00	Close	

Session 2: Thursday 17 February 2022 (all times AEDT)

Time	Topic	Who
10:00-10:10	Welcome and introductions, housekeeping	Karen
10:10-10:15	Recap on workshop objectives and plan for session	Karen
10:15-10:30	Summary of session 1 discussions	Karen
10:30-10:45	Short Q&A on session 1 discussions and any further insights to add	All

10:45-11:30	Prioritisation of species and parameters – break out room discussions and Miro boards	All
11:30-11:35	Quick break and stretch	
11:35-11:45	Break-out room reports	Breakout room leads
11:45-12:00	Next steps in the project and Q&A	Karen and all
12:00	Close	

List of invitations to the workshops

AFMA

Lara Ainley

Daniel Corrie

Fiona Hill

Brodie Macdonald

Darci Wallis

Sally Weekes

CSIRO

Pia Bessell-Browne

Rich Hillary

Alistair Hobday

Trevor Hutton

Rich Little

Eva Plaganyi Lloyd

Robin Thomson

Geoff Tuck

FRDC

Patrick Hone

Chris Izzo

Carolyn Stewardson

Others

Rik Buckworth

Malcolm Haddon

Neil Klaer

Andre Punt

Tony Smith

Sally Wayte

Project steering committee

Daniel Corrie

David Smith

Michael Steer

James Woodhams

Summary of discussions from workshop on revisiting biological parameters

Session1: 9th February 2022

Investigation of the provenance of biological parameters and uncertainties

- The greater value in putting together the table of parameters is that the work done across fisheries and species provides opportunities for cross learnings between assessment groups (method and information sharing, sensitivity analyses etc)
- General agreement that the project has captured the obvious parameters with stock structure and population connectivity a big issue for sensitivities in assessments
- Issue that knowing if parameter values have changed can influence assessment outcomes, but typically insufficient data outside dedicated project to be able to tell
- Request to look through the table and where information might be available that hasn't been captured to provide that to the project team, including information on work that might be planned or underway

Scenario work investigating effects of changing parameters on productivity

- Change in diet has the influence on biomass, however least information known on diet and changes – how to consider in current assessments – difficult to tease apart drivers on recruitment and how you implement those not clear
- 20% change in life history parameters means that species are exposed for mortality for longer periods of time and reproductive potential changes with flow on influences productivity (longer time spent small more predation, single large mothers contribute more than multiple smaller mothers)

- Can't forget density dependent changes – might be more realistic to look at rate of change
- Climate change has been happening since the beginning of many datasets and trophic interactions can be very unintuitive in terms of implications
- May need assessments to consider multiple values as the parameters are continually changing – can be implemented but how varies across assessment approaches, multi-species harvest strategy ratpack has the capacity now. If a parameter is changing, need to also consider what augmentation needs to occur but haven't figured out how to do this. Augmentation as to why the parameter has changed is important.
    - Other approaches used elsewhere is an ensemble approach (use of alternative parameter values) – has issues of its own but moves away from the expectation that one model is "known to be correct"
- Lots of exploratory work would be needed to look into changes occurring in assessments – currently no time
    - Should consider how important/influential each parameter or relationship between variables changes and the implications (how do the parameters interact)
- Further work to cross compare individual species outputs between EwE and Atlantis
- Desire to explore increases in parameters not only decreases (although literature suggests less likely to happen) – rerun Atlantis with sliding parameters
- Desire to corroborate outputs from EwE and Atlantis with outputs of assessments – could be done once linking Atlantis to the multi-species harvest strategy ratpack is working. Could also explore the sensitivity analysis already done in assessment to see if outputs concur with ecosystem model results
- Explore change in parameters (same as in EwE and Atlantis) in Stock Synthesis
    - Explore time blocks to allow for changes in parameters through time, similarly explore spatial differences in parameters
    - Would also need to consider the flow on from changes in growth (changes in density dependence at very old/young age classes etc)
    - Look at how surplus production changes
    - Check whether sliding parameters can be done in a rigorous enough manner or better to keep model simpler as assessment getting close enough anyway
- Time variation is critical as there has been reluctance to accept that there is enough evidence to support some change in a parameter. By the time this is accepted, it may be too late!
- Whether a smoothly varying change can be implemented across an array of parameters is a lovely idea but beyond the data at present. But we certainly need to stress that changes are happening and happening now!
- Could learn lessons from the SESSF that could teach other fisheries what things need to be considered in the future
- Needs to be some expectation management - can increase growth, change production, but we don't have sufficient information for the assessment (would be speculative), so while aspirations are good, what can actually be implemented might not be to the same level (not there yet)
- Other relevant projects
    - Multi-species harvest strategies
    - Dynamic B_0
        - exploring whether or not harvest strategies can cope and provide sustainable outcomes regardless of change
    - Recently awarded RV Investigator voyages revisiting the south-east ecosystem (voyages planned for 2023/24)

        - Provide fisheries independent view on the ecosystem and changes that have occurred since last sampled 25 years ago
        - Opportunity for PhDs and postdocs to progress some work
- Potential topic for new project (informed by this project): looking into drivers of declines in shelf species – is this due to changes in life histories with the result that assessments and harvest strategies not supporting sustainability/rebuilding? Is it mis-specification of parameters in the models, what about harvest strategies, what could we have done better?
- Need to also consider why the species that are demonstrating change (in the SESSF) are the ones that the ERA process identifies should be the most robust – is it climate, is it fisheries or is there something in the ERA process

Next steps: Prioritisation process

- Need to consider criteria for prioritisation – what are the key criteria?
- Understanding the implications of param mis-specification can help to prioritise where to target updating in the future
- This project only looking at param uncertainty but that has to sit within a bigger story of other things that could be influencing harvest strategies etc
    - What are the data needed to be able to quantify changes
    - What are the implications of that level of uncertainty
- Need to avoid putting all the weight on models
- Time is required to pursue exploratory examinations of possible explanations for changes in productivity and yield.
- Recommend looking into climate and FIE induced change on parameters and how to cope with these changes in assessments
- Need to think about steps (sub-projects, initial work) needed to achieve recommendations – e.g. to achieve time varying parameters need to collect information and do some exploratory work with assessments

Session2: 9th February 2022

Aim of the session is to identify priority recommendations based on the work done so far in ascertaining the provenance of priority biological parameters and scenario exploration (see summary of session 1) to inform a work plan including appropriate sampling regimes required for updating parameters and reducing uncertainty in assessments.

See the table provided in the Google Drive that summarises the current uncertainties in parameters across Commonwealth fisheries.

Feedback on work done so far:

- Lots of grey literature that is hard to find that could potentially fill in some of the current unknowns in the parameters table (Karen to provide a list of species in the SESSF where provenance unknown to David S to follow up on)
- For some parameters a change does not change the advice provided from the assessment so may not be a good return on investment – important to investigate sensitivities, particularly the interactions with selectivity (e.g. growth rates can be influenced by selectivity) to determine if worth the effort
- Should note that entries into FishBase not accurate – so having the parameters table available online with a custodian that can update the table would be useful. Challenges

associated with translating the table into something that is widely available and regularly updated discussed

- Parameters estimated in/out of the model – how robust are those that are estimated outside of models, given that they might not be updated/models may not be sensitive to these over time.

Virtual whiteboard component

1. Approach to prioritisation process for parameters

The aim of this session was to collate some quick views on key features that could be used to assist with prioritising the focus of any future work on parameters. For example, should the focus be on individual parameters (across all species in all fisheries) or a species by species or fishery by fishery approach? Should the approach focus on parameters where the methods or data were greater than 10 years old or alternatively, those parameters where updated or new methods for estimation were available regardless of the age of parameters? See download of virtual whiteboard for comments made.

Discussion:

- A general note was made that an approach to doing this as part of climate work used a combination of factors including the oldest age of the parameters, the ecological vulnerability of the species (from the ERA process and climate adaptation handbook), whether the species was recovering/non-recovering (in regard to SESSF species), the status of the species (in regard to sharks and rays, based on shark action plan), the climate sensitivity scores of Fogarty et al. (2019), the availability of new research and whether cross-jurisdiction coordination needs to be considered.
- It was also noted that the parameters used in ERAs were not always consistent with those used in stock assessments, so one exercise that needs to be done is to update the parameters used in ERAs
- Prioritisation needs to consider the most effective pathways
- Under harvest strategies where catch rates are the driver, updated parameters may not be needed as biological information is not what is limiting decision making
- Needs exploration of cost-benefit
- Need to consider that sensitivities vary across species
- There may be interactions between parameters that need to be considered

2. Responding to uncertainties

The aim of this session was to gather feedback on possible actions that could be recommended in responding to various uncertainties in parameters such as where provenance was unknown, or the data or methods associated with a parameter were old. See download of virtual whiteboard for comments made.

Discussion:

- Some general themes included digitising old documents to fill gaps and maintain a record of provenance, keep a time series of parameter estimates, undertake some comparative work on old and new parameters and investigate relationships between parameters, undertake new sampling
- Recommendations could be made to RAGs to (i) undertake sensitivity exploration; (ii) to ensure that all parameters included in stock assessments are documented in reports each

time an assessment is done (rather than referring to previous reports) and in association their provenance and how they are derived documented ; (iii) ensure that all units are recorded as they are not always; in some cases it is unclear if gms or kgs are being used or if lengths are LCF or TOT; (iv) have some consistent standards in assessment recording/reports (across fisheries, species)

- Suggestion that potentially a standard template could be used for all assessments – noted that in some fisheries this has evolved to some degree, but things often evolve or diverge over time with different authors
- Noted that assessments in NZ have a log included as an Appendix that documents changes made to the model structure and parameters used – maintains a time series of changes and provides information on provenance and where changes have been introduced.
- Was noted that introducing change needed to be carefully handled as it often generated uncertainty in itself
- There could be lessons learned from those instances where change has been introduced and how that change was managed at the time. Noted that the changes have to be clearly explained and they have to demonstrate improvements to the assessment as well as ensure confidence in the science. Probably some strategic discussions between RAG/MAC chairs on how to manage change could be considered
- Highlighted that draft guidelines have been developed in the SESSF for moving the assessment from one structure to another model to another
- Importance of informed handovers between those involved in assessments
- New is not necessarily better, so some care and consideration of when and how to apply change is important as it may not be relevant or appropriate for historical data – how do you apply a progressive change through time? Need to also consider the effect of new information on uncertainties associated with historical data – can it still be utilised?

3. Workplan prioritisation

The aim of this session was to identify some “low hanging fruit” that could be implemented easily to address parameter uncertainties and what might need more effort. This could assist in developing a staged approach to recommendations that could be implemented as a workplan. See download of virtual whiteboard for comments made.

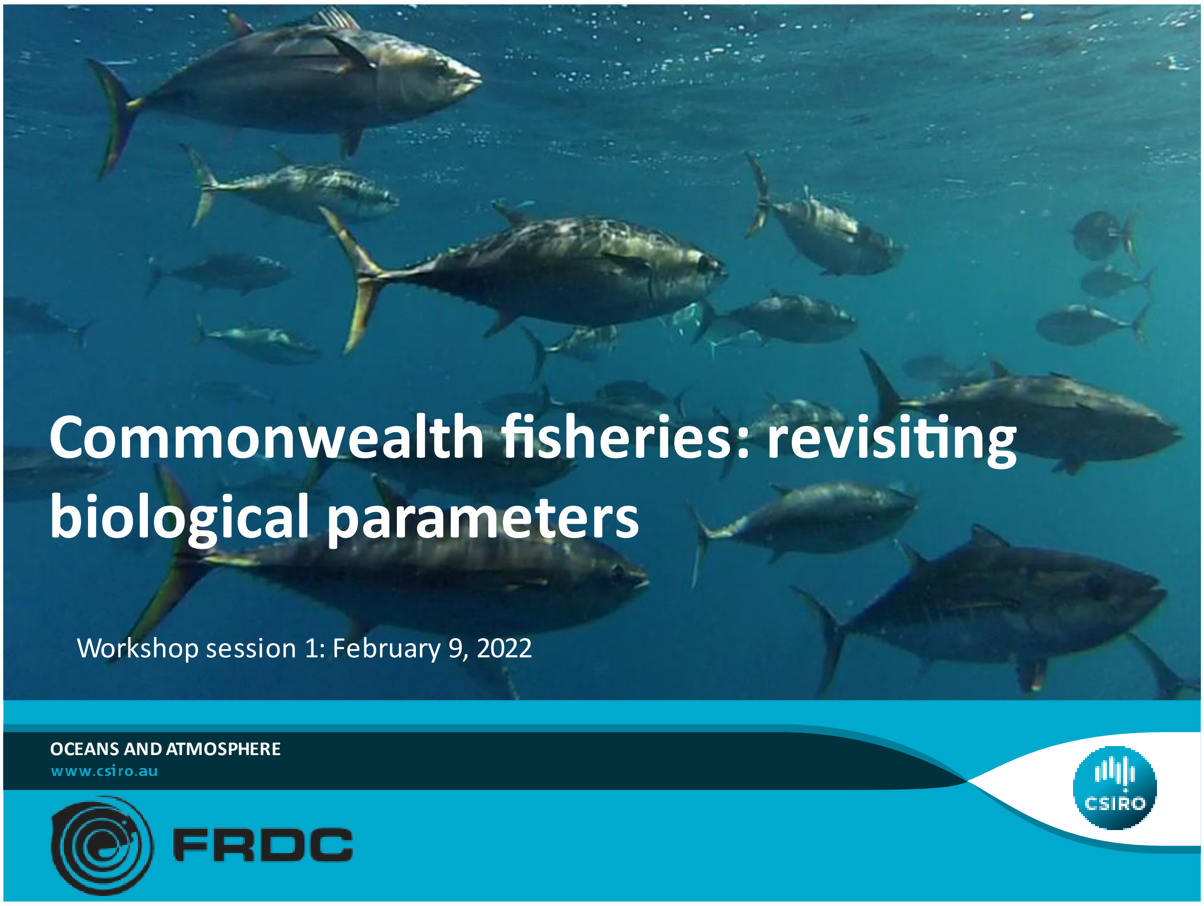
Discussion:

- Need to consider how to make things cost-effective
- Also need to consider how to implement, particularly where new data/samples might need to be collected – where electronic monitoring has been implemented and there are no observers, may need to consider port/processor sampling
- Need to think about how you make biological data collection interesting and useful
- What could be appropriate for students?

Workshop presentations

Session 1

Background and parameter provenance



Project team

Karen Evans
Sharon Appleyard
Cathy Bulman
Jemery Day
Jessica Farley
Beth Fulton
Ashley Williams
Shijie Zhou

Steering Committee: Dan Corrie, David Smith, Mike Steer, James Woodhams

Background: uncertainties

Focus on meeting the needs of the Commonwealth Harvest Strategy Policy

Development of
- Harvest strategies
- Newer approaches to assessments
- Risk assessments

Less of a focus on biological parameters underpinning assessment and advances in methods to derive them

Many assessment models rely on biological parameters/inputs that:
- Are old (some 20+ years)
- Of unknown origin
- Based on datasets that noone has access to/knows where they are

Background: uncertainties

Previous projects and the wider literature* have identified that:

- Time varying growth is present whenever it is investigated
- Length conversions factors are not always appropriate/accurate
- Productivity varies in space and time

So if parameters have changed through space and time what does this mean for assessments?

While some assessments have updated parameters, many have not

Many assessment have not had the time to assess if information is available to update parameters or if there is a need to consider newer methods (and what those methods might be)

*See Audzijonyte et al 2013, 2014, 2016; Clark et al 2021, Pauly and Cheung 2019

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Reviewing biological parameters

FRDC-CSIRO project 2019-010: "Revisiting biological parameters and information used in the assessment of Commonwealth fisheries: a reality check and work plan for future proofing"

Objectives:

1. Identify the provenance of biological information used in current assessments (including age, appropriateness of methods used)
2. Assess the implications and risks associated with using dated and borrowed information in assessments
3. Identify methods (including novel approaches) that might be applied to update priority biological parameters.
4. Articulate a work plan including appropriate sampling regimes required for updating priority biological parameters.

5 |

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Two parts to the session

Parameter provenance– progress to date

Split into breakout groups

Come back to plenary to report on discussions

Break and stretch around 11.30am

Scenarios – implications of parameter change

Breakout discussions and report back to plenary

Next steps: taking the parameters & uncertainties, scenarios and developing a set of priorities that can inform a workplan for delivery against objective 4

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Parameter provenance

Which fisheries, which parameters?

In an ideal world…

Workshop to bring everyone together to discuss

And then…

COVID

Which fisheries, which parameters?

Pivot to a series of focused interviews with those involved in stock assessment –both current and historic

- Pinch points in terms of parameters used
- Sensitivities within assessments

Tier 1 assessments

Parameters associated with:

- Age and growth
- Reproduction
- Mortality
- Steepness

Length/weight conversion factors

Parameter provenance and uncertainty: falling down the rabbit hole

Literature review of all assessments

Where did the parameter originate from?
How was/is it estimated?
What are the data inputs?
What are the drivers of uncertainty?
In estimation
Sensitivity tests
Are there alternatives?
Are there spatial and temporal considerations?
Is there any current/planned work for updating?

What does the data look like?

Yellowfin tuna (ETBF)

- Assessment method: integrated model
- Model used: MULTIFAN-CL
- Parameter: growth
- Source of method: Vincent et al. (2020), Farley et al. (2020), Eveson et al. (2020)
- Estimated/fixed: some parameters estimated, some fixed (three growth curves)
- Method: otolith age at length, integrated otolith & tag recaptures, size data
- Last updated: 2020 (method & data)
- Uncertainty: low
- Driver of uncertainty: varies across datasets (ageing error, fits to data)
- Sensitivity analysis: yes
- Degree of sensitivity: high, growth most influential axis of uncertainty
- Alternative/more recent parameters: no
- Spatial component: likely
- Spatial component captured: no
- Work on updating underway/planned: yes, age validation work underway

What does the data look like?

Blue endevour prawn (NPF)

- Assessment method: bio -economic model
- Model used: Bespoke Bayesian hierarchical biomass production
- Parameter: growth
- Source of method: Punt et al. (2010) based on “auxiliary analyses”
- Estimated/fixed: fixed
- Method: unknown
- Last updated: unknown
- Uncertainty: unknown
- Driver of uncertainty: unknown
- Sensitivity analysis: no
- Degree of sensitivity: n/a
- Alternative/more recent parameters: unknown
- Spatial component: unknown
- Spatial component captured: no
- Work on updating underway/planned: unknown

What does the data look like?

Pink ling (SESSF)

- Assessment method: integrated model
- Model used: Stock Synthesis
- Parameter: growth
- Source of method: Withel and Wankowski (1989), Thomson et al. (2001)
- Estimated/fixed: estimated
- Method: fits to length -at-age
- Last updated: estimation process: 2021, data: 2011, method: 2003
- Uncertainty: medium
- Driver of uncertainty: dataset 10+ yrs old
- Sensitivity analysis: no
- Degree of sensitivity: unknown
- Alternative/more recent parameters: no
- Spatial component: likely
- Spatial component captured: east and west assessed separately
- Work on updating underway/planned: unknown

Feedback

- ***Parameter focus*** . Do these encompass the parameters that assessments are most sensitive to? Should we be considering others?
- ***Parameter values and estimation*** . Are these correct? Have we missed/misinterpreted information in assessment reports? Are there new approaches currently not captured?
- ***Parameter provenance*** . Have we overlooked information? Is there information that can fill in "unknowns"? Have we missed/misinterpreted anything?
- ***Work underway/planned*** . Is there work planned that we have not captured?
- ***The simulations*** . Do the outputs make biological sense? Are there alternative scenarios that should be considered (within the context of the timeline and budget of the project)?

Focus of discussion session

- ***Parameter focus***. Do these encompass the parameters that assessments are most sensitive to? Should we be considering others?
- ***Parameter values and estimation***. Are these correct? Have we missed/misinterpreted information in assessment reports?
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References

Audzijonyte A et al. 2014. Ecosystem effects of contemporary life-history changes are comparable to those of fishing. Mar Ecol Prog Ser 495: 219–231.

Audzijonyte A et al. 2013. Ecological consequences of body size decline in harvested fish species: positive feedback loops in trophic interactions amplify human impact. Biol Lett 9: 20121103.

Audzijonyte A, et al. 2016. Trends and management implications of human influenced life-history changes in marine ectotherms. Fish Fish. 17, 1005-1028

Clarke et al. 2021. Aerobic growth index (AGI): An index to understand the impacts of ocean warming and deoxygenation on global marine fisheries resources Progress in Oceanography 195, 102588.

Pauly and Cheung 2019. Sound physiological knowledge and principles in modeling shrinking of fishes under climate change Global Change Biology 24, e15–e26.

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Prioritising work needed for updating parameters, filling in gaps and reducing uncertainties

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Prioritisation process

Next steps: taking the parameters & uncertainties, scenarios and developing a set of priorities that can inform a workplan

- Main focus of the second day of the workshop (17th Feb)
- Spend time in breakout groups using electronic whiteboards
  - Are there other approaches we should consider?
- Structured approach to gathering views on priorities
  - What is feasible/achievable?
  - What will have highest impact/greatest outcomes?
  - Best approaches to addressing uncertainties?

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Results from the scenario exploration

Implications of parameter uncertainty

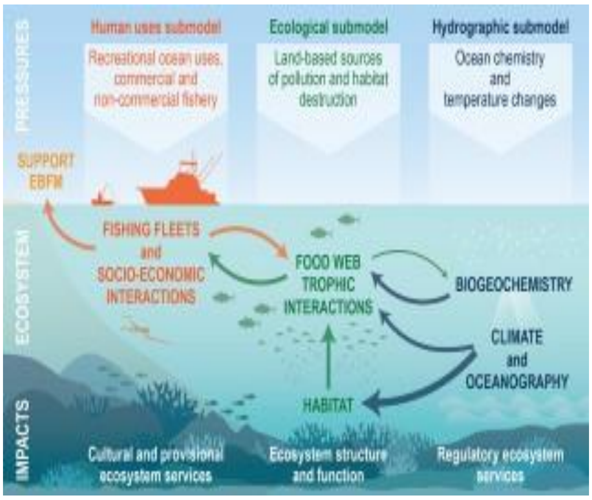
Model-based insights

Beth Fulton | 2022

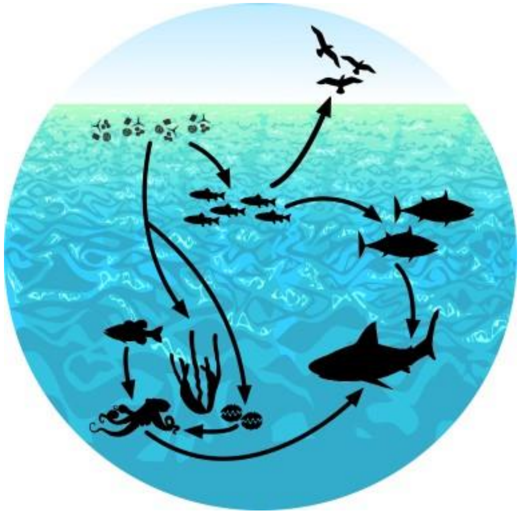
Australia's National Science Agency

Ecosystem Models

Atlantis – entire system (varying details)



EwE – trophic connections & fishing



Parameters modified

+ Run with assessment (look at divergence) in near future

Atlantis only

- Growth rates
- Size at age
- Larval supply levels

Both EwE and Atlantis

- Diets

EwE only

- Natural mortality rates
- Productivity

EwE exploration - method

- Redo the model with new parameters
  - diets updated based on Revill et al 2016
  - update Z used with M from assessments and other sources
  - re-estimate biomasses or productivity
  - project long term catches

EwE exploration - results

Species type	Biomass change* (%)	Total mortality change (%)
Target	+5.1 to + 178.8	-75.8 to +50
Secondary	-78.9 to >+300	-42.5 to +132
Other	-64.4 to > +5000	+1.9 to +113.1

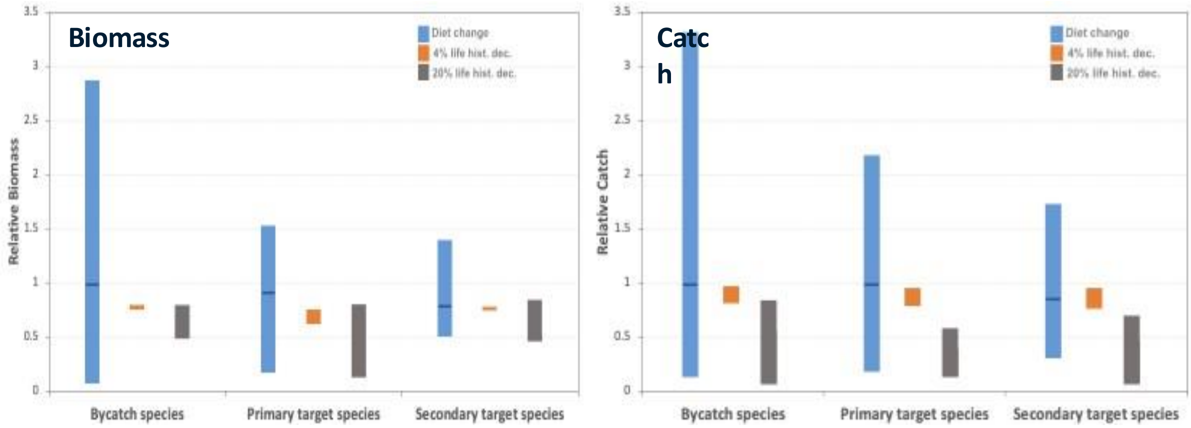
* Given diets (new or old) the additional biomass needed to meet predation pressure if alternative parameters used

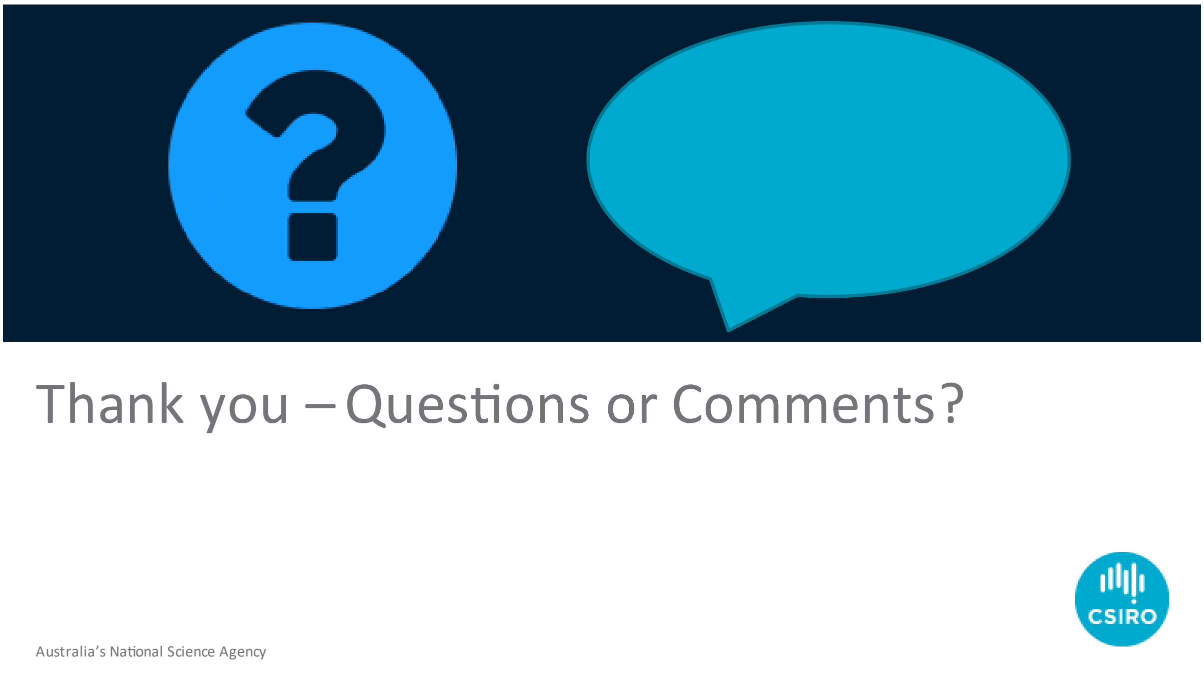
Atlantis exploration - method

- Standard parameter set used = reference
- For older parameters (for target species) try variant values
- Diet – updated based on Revill et al 2016
- Growth, size, reproduction drop by:
  - 4% (lower end of observed changes nationally and internationally)
  - 20% (based on theory and upper end of observed changes)

Atlantis exploration - results

- Range of results across species & multiple simulations (some more sensitive than others)




Thank you – Questions or Comments?
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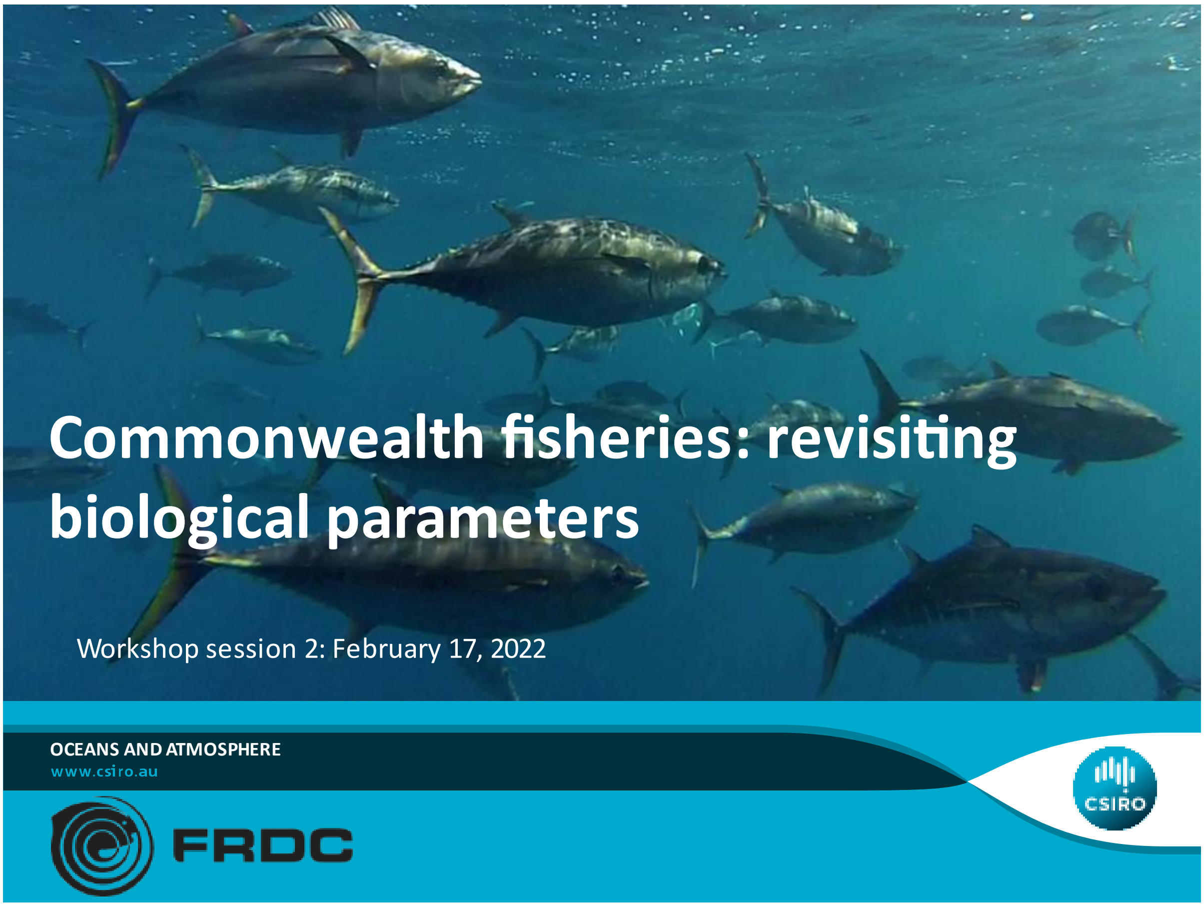
Session 2


Commonwealth fisheries: revisiting biological parameters
Workshop session 2: February 17, 2022
OCEANS AND ATMOSPHERE
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FRDC
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Project team

Karen Evans
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Session breakdown

Quick summary of session 1 and any feedback post session 1 and on the parameters table

Move to first Miro board – quick scoring exercise

Discussion on scoring

Move to second Miro Board – what approach might we take to address uncertainties

Discussion on approaches

Break and stretch somewhere around 11.00-11.30am

Move to final Miro Board – what information do we have to guide a workplan

Final discussion, Q&A, where to next

Close

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Session 1

5 |

Focus of discussion session

- ***Parameter focus*** . Do these encompass the parameters that assessments are most sensitive to? Should we be considering others?

- ***Parameter values and estimation*** . Are these correct? Have we missed/misinterpreted information in assessment reports?

- ***Parameter provenance*** . Have we overlooked information? Is there information that can fill in "unknowns"? Have we missed/misinterpreted anything?

- ***Work underway/planned***. Is there work planned that we have not captured?

- ***The simulations***. Do the outputs make biological sense? Are there alternative scenarios that should be considered (within the context of the timeline and budget of the project)?

Which fisheries, which parameters?

Tier 1 assessments
Parameters associated with:
- Age and growth
- Reproduction
- Mortality
- Steepness
- Length/weight conversion factors
- Population structure and connectivity

Population structure and connectivity identified as important but often missing

Table provides opportunity for cross learning between fisheries and assessments

Scenario work

Diet (availability of prey has highest influence on productivity

Change in life history (decrease in growth) leads to:
- greater exposure to mortality
- lower reproductive potential

Highlighted the need for more exploratory work
- temporal changes in parameters
- why parameters are changing
- how parameters interact

For project:
- cross compare individual species betweenEwE and Atlantis
- explore change in both directions
- corroborate outputs from ecosystem models with assessment models (SS)

Are limits to what can be done given the data available though!

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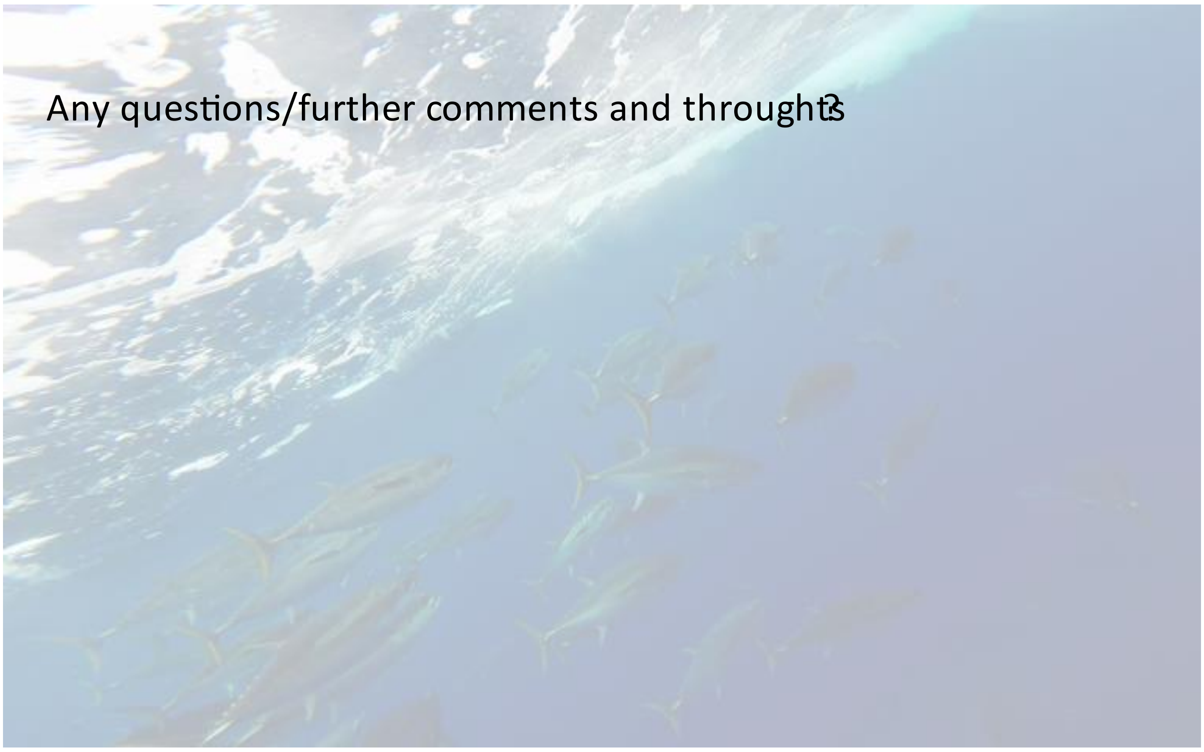

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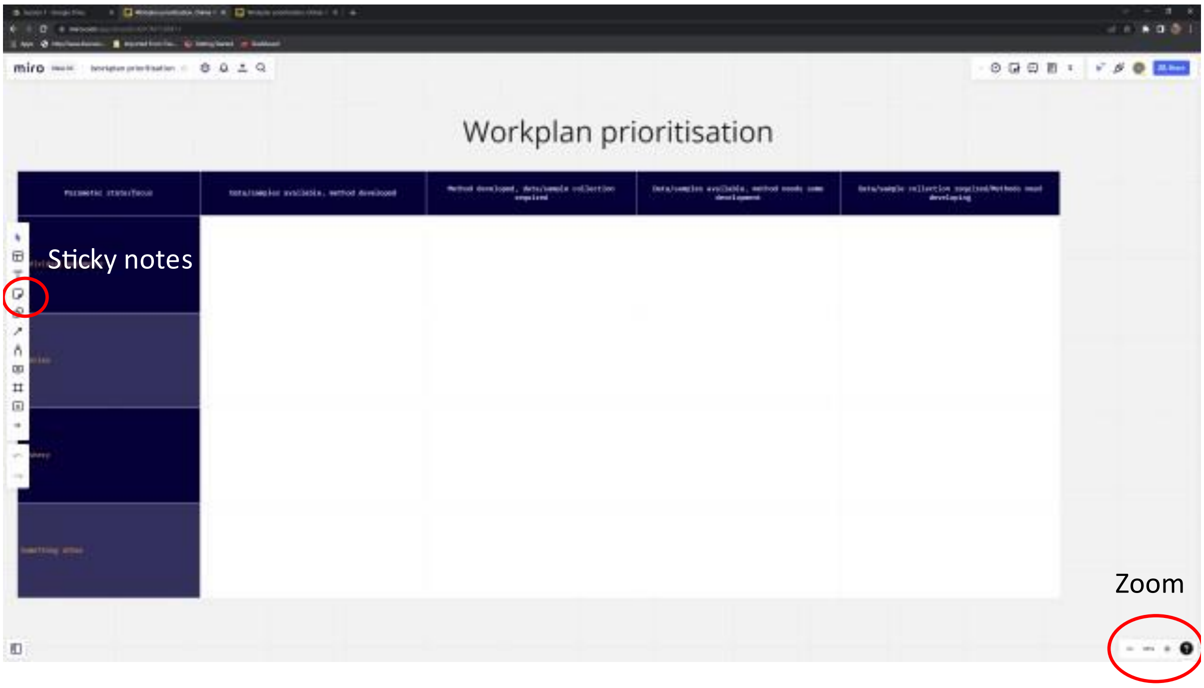
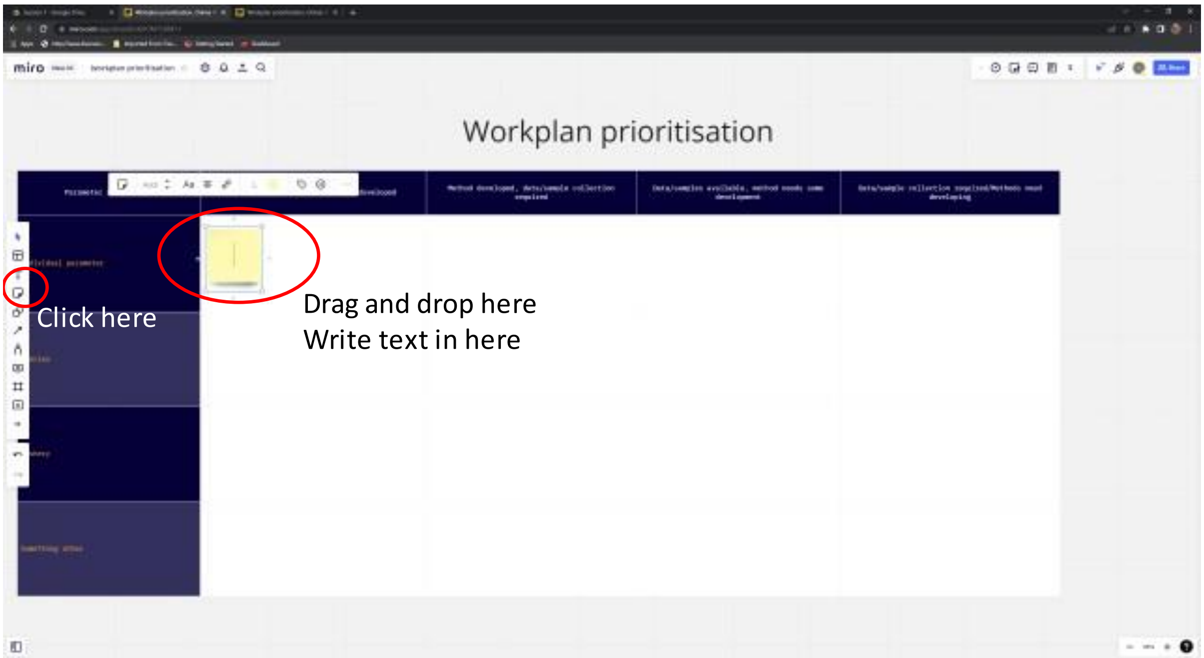
Session 2

Miro Boards



Miro Boards


Workplan prioritisation
Click here
Drag and drop here
Write text in here


Any questions?

Next steps

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Delivery of recommendations

Articulate a work plan including appropriate sampling regimes required for updating priority biological parameters.

- Distil down all of the information gathered
- Follow-up with some further scenario work
- Develop a set of recommendations that outline a stepped approach for updating parameters/reducing uncertainties
- Final presentation on project outputs to stakeholders

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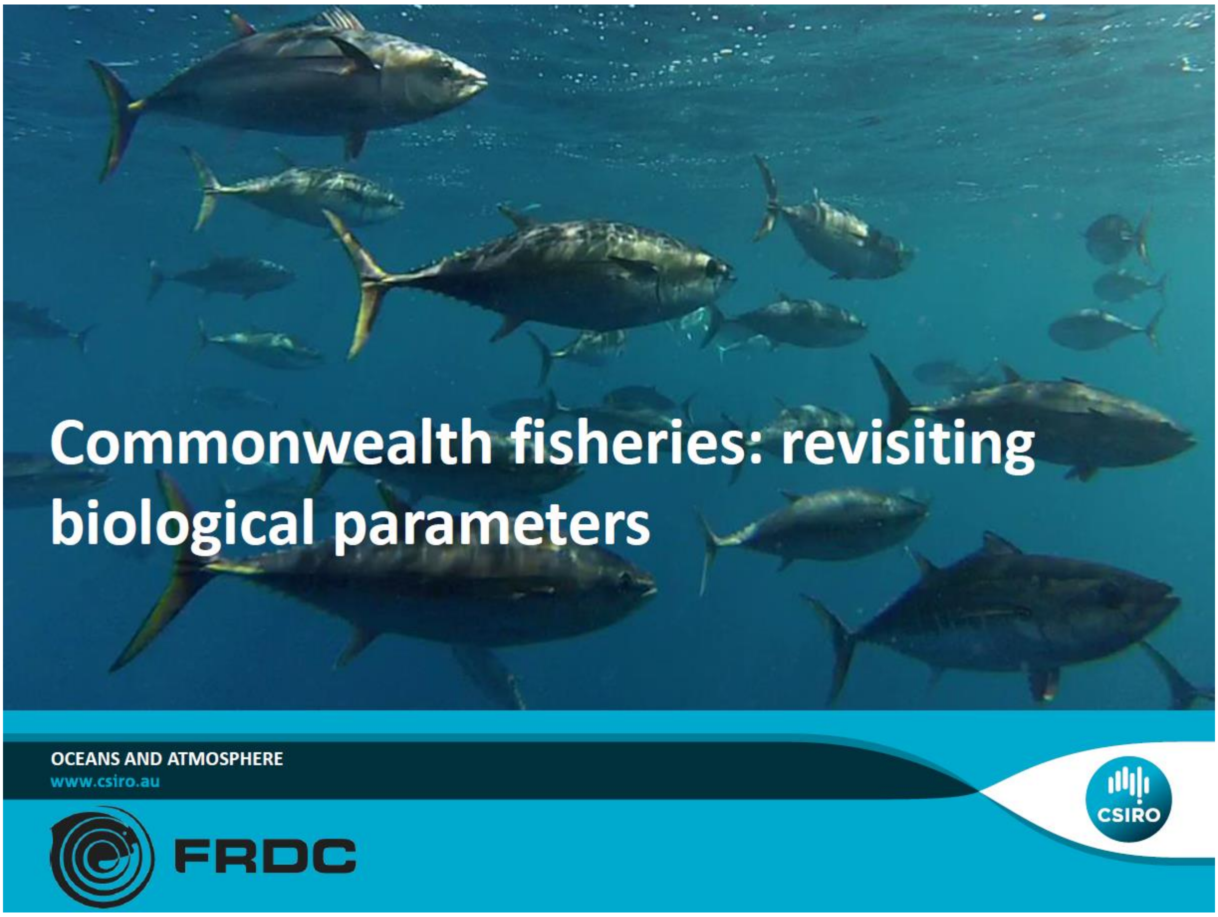
Appendix 4: Final report presentation to AFMA



Project team

Karen Evans
Sharon Appleyard
Cathy Bulman
Jemery Day
Jessica Farley
Beth Fulton
Ashley Williams
Shijie Zhou

Steering Committee: Dan Corrie, David Smith, Mike Steer, James Woodhams

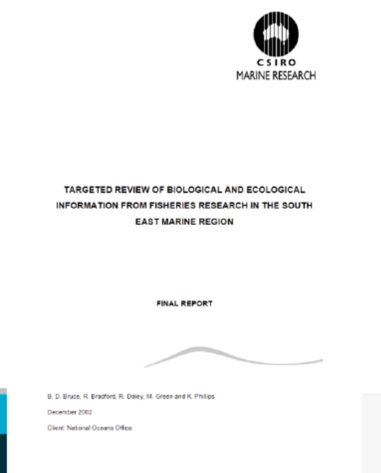
Background: uncertainties

Commonwealth Harvest Strategy Policy

- considerable focus on supporting assessments, models and tools
- less focus on the biological parameters that underpin models

Concern many assessment models rely on biological parameters/inputs that:

-Are old (some 20+ years)
-Of unknown origin
-Based on datasets that no-one has access to/knows where they are
-Are borrowed from other regions/species



CSIRO MARINE RESEARCH

TARGETED REVIEW OF BIOLOGICAL AND ECOLOGICAL INFORMATION FROM FISHERIES RESEARCH IN THE SOUTH EAST MARINE REGION

FINAL REPORT

B. D. Bruce, R. Bradford, R. Daley, M. Green and K. Phillips

December 2002

Client: National Oceans Office

Background: uncertainties

Many factors point to major changes occurring in marine environments
- How appropriate are old/borrowed values?

Previous projects and wider literature have identified that:
- -Time varying growth is present whenever it is looked at
- -Length conversions factors are not always appropriate/accurate
- -Productivity varies in space and time

Some assessments have updated parameters ✓

Many have not assessed information available to determine if parameters can be updated/need to be updated

Last overall assessment: 2002

4 |

Background: uncertainties

So if parameters have fundamentally changed through space and time and are shifting…

What does this mean for assessments?

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Reviewing biological parameters

FRDC-CSIRO project: "Revisiting biological parameters and information used in the assessment of Commonwealth fisheries: a reality check and work plan for future proofing" 2019-010

Objectives:

1. Identify the provenance of biological information used in current assessments (including age, appropriateness of methods used)
2. Assess the implications and risks associated with using dated and borrowed information in assessments
3. Identify methods (including novel approaches) that might be applied to update priority biological parameters.
4. Articulate a work plan including appropriate sampling regimes required for updating priority biological parameters.

The how

1. Which fisheries, which parameters?

Workshop to bring everyone together

And then…

COVID

The how

Pivot to a series of focused interviews with folks involved in stock assessment – both current and historic

– Pinch points in terms of parameters used
– Sensitivities within assessments

Tier 1 assessments
Parameters associated with:

Age, growth and reproduction
Mortality
Steepness
Length/weight conversion factors
Stock structure/connectivity

The how

2. Digging into the details – falling down the rabbit hole

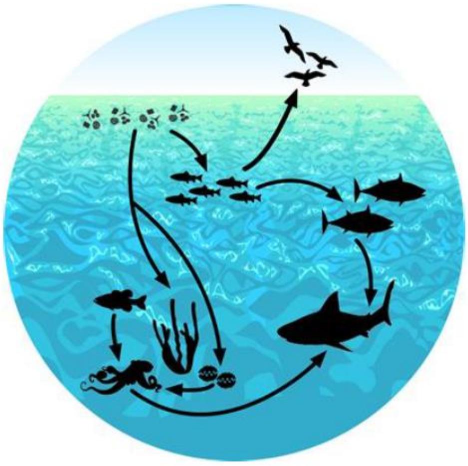
Literature review of all assessments

– Where did the parameter originate from?
– How was/is it estimated?
– What are the data inputs?
– How old are the data?
– What are the drivers of uncertainty?
– How sensitive is the model to change?
– Are there spatial and temporal considerations?
– Are there alternatives?
– Is there work underway/planned?

The how

3. Risks associated with uncertainty: scenario testing

   - Explored changes in growth, mortality on productivity
   - What does this mean for catches over the long term?
   - Utilised two ecosystem models
   - Compared outputs with assessment sensitivities



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The how

4. Are we on the right track?

Virtual workshop with stock assessment folks

Parameters:
- Have we captured those parameters assessments are most sensitive to?
- Have we captured available information well?
- Have we missed something?
- Have we interpreted the information correctly?

Simulations
- Do the simulation outputs make biological sense?
- Should we look at alternative scenarios/additional outputs?
- Should we try something different?

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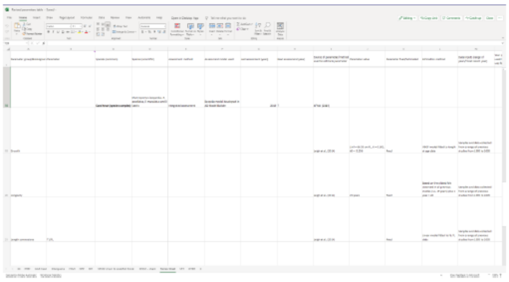
Parameter provenance

Built a table consisting of individual species grouped into each fishery – will be delivered with final report



Example: yellowfin tuna (ETBF)

Assessment method: integrated model
Model used: MULTIFAN-CL
Parameter: growth
Source of parameter: Tremblay-Boyer (2017)
Estimated/fixed: estimated
Method: model fits otolith age-at-length and size data from the troll fishery
Last updated: 2017
Uncertainty: low
Driver of uncertainty: juvenile data doesn't match length-frequency modes
Sensitivity analysis: yes
Degree of sensitivity: medium
Alternative/more recent parameters: no
Spatial component: yes
Spatial component captured: no
Work on updating underway/planned: yes

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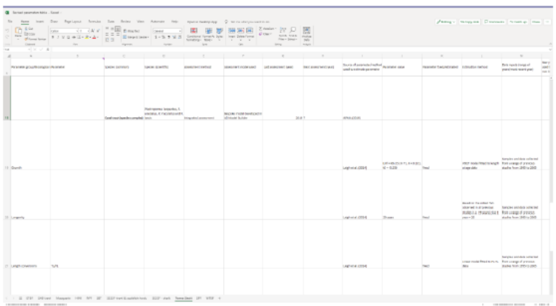
Parameter provenance

Unclear parameter provenance:
- 22.3% of all parameters – occurred across all parameters
- Largest numbers in NPF and SESSF

Old parameters
- Those associated with reproduction and conversion factors
- Largest numbers occurred in the GAB, NPF, SESSF, SPF

High uncertainty
- Steepness, mortality, stock structure
- All fisheries



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Implications of parameter uncertainty

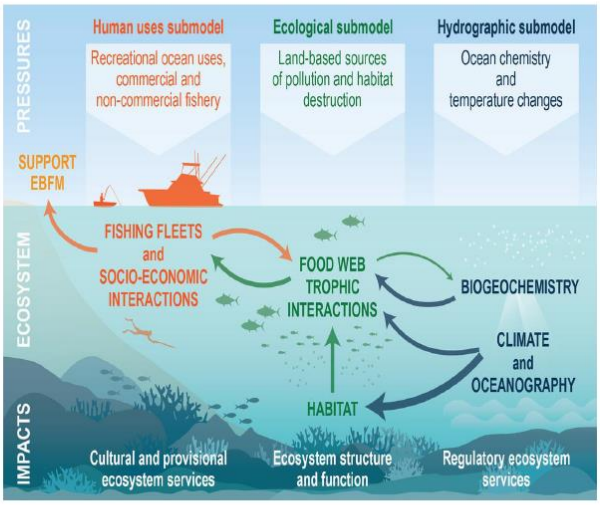
Model-based insights

Beth Fulton | 2022

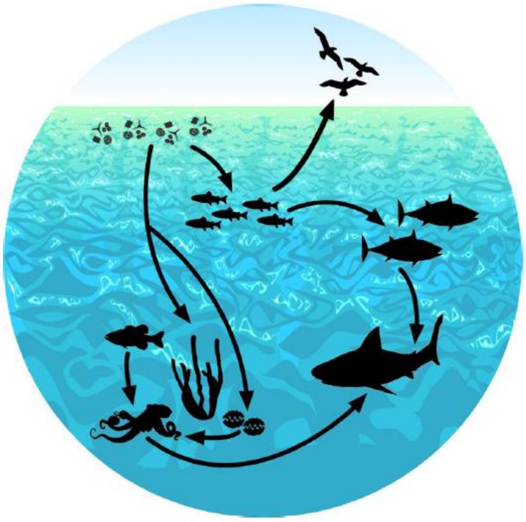
Australia's National Science Agency

Ecosystem Models

Atlantis – entire system (varying details)



EwE – trophic connections & fishing



Parameters modified

+ Run with assessment (look at divergence) in near future

Atlantis only

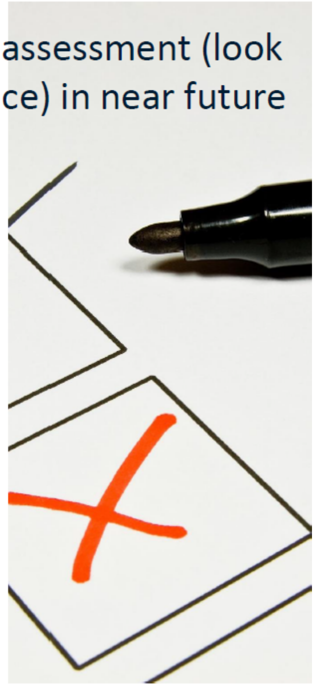
- Growth rates
- Size at age
- Larval supply levels

Both EwE and Atlantis

- Diets

EwE only

- Natural mortality rates
- Productivity



EwE exploration - method

- Redo the model with new parameters
  - diets updated based on Revill et al 2016
  - update Z used with M from assessments and other sources
  - re-estimate biomasses or productivity
  - project long term catches

EwE exploration - results

Species type	Biomass change* (%)	Total mortality change (%)
Target	+5.1 to + 178.8	-75.8 to +50
Secondary	-78.9 to >+300	-42.5 to +132
Other	-64.4 to > +5000	+1.9 to +113.1

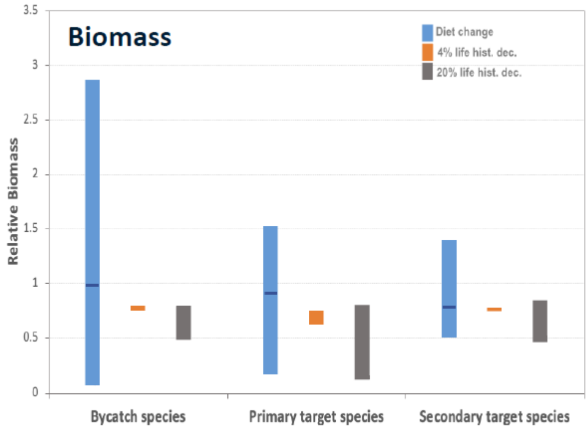
* Given diets (new or old) the additional biomass needed to meet predation pressure if alternative parameters used

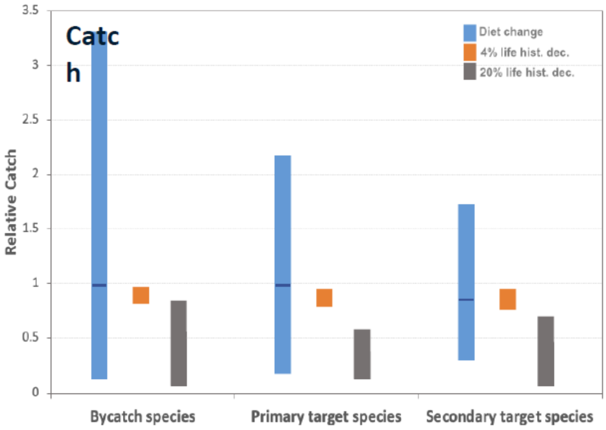
Atlantis exploration - method

- Standard parameter set used = reference
- For older parameters (for target species) try variant values
- Diet – updated based on Revill et al 2016
- Growth, size, reproduction drop by:
  - 4% (lower end of observed changes nationally and internationally)
  - 20% (based on theory and upper end of observed changes)

Atlantis exploration - results

- Range of results across species & multiple simulations (some more sensitive than others)





Feedback

Parameter provenance:

- Value of developing the table as a "living document"
- Utility for feeding information into resources such as FishBase
- Some further grey literature identified

Assessment of risk (scenario exploration)

- Identification of further exploratory work – some incorporated
- Importance of exploratory work highlighted - often insufficient data available to determine influence of biological change within current assessment processes
- Broader work focused on investigating drivers of observed declines identified

Feedback

Exploratory work – not incorporated

- Understanding the influence of individual parameters;
- Understanding the relationship between parameters (how do the parameters interact) and the implications;
- Flow on effects of change in growth, for example on density dependence or surplus production;
- Understanding the degree at which stock assessment sensitivities varying;
- Exploration of temporal and spatial changes in parameters;
- Exploration of approaches to implementing change across an array of parameters in stock assessment models;
- Exploration of whether time-varying parameters can be incorporated into models in a rigorous enough manner.

Priority areas identified

1. Improving information workflows and accessibility
   - Improved documentation
   - Templates, logs, registers?
   - Digitisation of historical information
2. Better understanding uncertainties
   - Fill gaps in understanding – uncertainties and stakeholders
   - Broader sensitivity exploration
3. Streamlining parameter determination and improving cost-effectiveness
   - Ongoing monitoring cannot be avoided
   - Utilisation of novel methods to facilitate semi-automation
   - Incorporation of students – building capacity
4. Improving processes for implementing change
   - Change management – improvement is central
   - Lessons learned from historical experience

To summarise

- Utilisation of the parameter table to ensure adequate understanding of the state of parameters – avoid doing the same process in 20 years from now
- More consistent and standardised approaches to reporting including methods that streamline parameter updating processes;
- Commencement of research projects focused on understanding uncertainties associated with parameters more broadly within assessment models and;
- Targeted projects focused on updating parameters including through new relevant biological sampling and utilisation of improved and contemporary methods