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Status of the Northern Prawn Fishery Tiger Prawn Fishery at the end of 2021 with estimated TAEs for 2022 and 2023

Final Report

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Contents

Version	Updates	Approver
Version 1	Draft Final Report	AFMA
Version 2	Final Report	AFMA

List of Figures

List of Tables

Acronyms

- **NPF:** Northern Prawn Fishery
- **NPRAG:** Northern Prawn Fishery Resource Assessment Group
- **Steepness** is a parameter obtained from the stock-recruitment relationship and is the proportion of recruitment from an unfished population obtained when the spawning stock biomass is at 20% of its unfished level.
- **TAE** is the Total Allowable Effort
- $\mathbf{C_{2021}}$ is the observed catch in 2021
- **MAV** is the Moving Average
- **MSY** is the Maximum Sustainable Yield
- **MEY** is the Maximum Economic Yield
- $\mathbf{S_{MEY}/S_{MSY}}$ **(%)** is the spawning stock size at Maximum Economic Yield relative to the spawning stock size at Maximum Sustainable Yield as a percentage.
- $\mathbf{S_{2021}/S_{MSY}}$ **(%)** is the spawning stock size in 2021 relative to the spawning stock size at Maximum Sustainable Yield as a percentage.
- $\mathbf{S_{2021}/S_{MEY}}$ **(%)** is the spawning stock size in 2021 relative to the spawning stock size at Maximum Economic Yield as a percentage.
- **5-year mav(**$\mathbf{S_{2017\text{-}2021}/S_{MSY}}$**) (%)** is the 5-year moving average of the spawning stock size between 2017 and 2021 inclusive relative to the spawning stock size at Maximum Sustainable Yield.
- $\mathbf{S_{2028}/S_{MEY}}$ **(%)** is the projected spawning stock size in 2028 relative to the spawning stock size relative to Maximum Economic Yield as a percentage.
- $\mathbf{E_{2021}}$ is the observed effort in 2021.
- $\mathbf{E_{2022}}$ is the model estimated effort for 2022.
- $\mathbf{E_{2023}}$ is the model estimated effort for 2023.
- $\mathbf{E_{MSY}}$ is the effort at the Maximum Sustainable Yield.
- $\mathbf{E_{MEY}}$ is the effort at the Maximum Economic Yield.
- $\mathbf{E_{MEY}/E_{MSY}}$ is the effort at the Maximum Economic Yield relative to the effort at the Maximum Sustainable Yield.

- **E_{2021}/E_{MSY} (%)** is the observed effort in 2021 relative to the effort at the Maximum Sustainable Yield as a percentage.
- **E_{2021}/E_{MEY} (%)** is the observed effort in 2021 relative to the effort at the Maximum Economic Yield as a percentage.
- **Standardised E_{2021}/E_{MSY} (%)** is the standardised effort in 2021 relative to the effort at the Maximum Sustainable Yield as a percentage.
- **Standardised E_{2021}/E_{MEY} (%)** is the standardised effort in 2021 relative to the effort at the Maximum Economic Yield as a percentage.
- **Quad rig** is a net configuration of towing two nets per trawl boom separated by trawl boards and a sled between the two nets. A total of four nets are trawled per vessel.
- **NA** indicates the value is not applicable or not available.

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For model combinations e.g., **SSB**, **DDD**: **D** – refers to the delay difference model, **S** – for the size structured model and **B** – to biomass production model (Bayesian).

Note: for many of these the 2022 equivalent is provided.

Executive Summary

The objective of the Commonwealth Fisheries Harvest Strategy Policy is the sustainable and profitable utilisation of Australia's Commonwealth fisheries in perpetuity, through the implementation of harvest strategies that maintain key commercial stocks at ecologically sustainable levels and within this context, maximise the economic returns to the Australian community (Dichmont et al. 2012b).

As applied to the Northern Prawn Fishery (NPF) Tiger Prawn Fishery, the operational objective of this policy is to attain long term Maximum Economic Yield (MEY). This is implemented by maximising the net present value of the flow of economic profits in the fishery over a 40-year period, in this case up to 2051. The dynamic optimisation of a seven-year path to the long-term MEY is calculated as the effort level and associated catch in each year, over a seven-year projection period that leads to a long run sustainable yield that maximises economic profits over time.

In this assessment, a multispecies, weekly sex- and size-structured population model for Tiger Prawns is combined with a Bayesian hierarchical biomass production model for Blue Endeavour Prawns, and an economic model that calculates profit (the "Base case" model). This system requires predictions about future effort levels, and changes over time in costs and prices (Punt et al. 2011). Several alternative scenarios are presented to provide sensitivity analyses for these assessments.

Two groups of stock assessment models were applied: a) the Base Case, comprised of size-structured models (for two Tiger Prawn species), as well as a Bayesian hierarchical biomass dynamic model (for Blue Endeavour Prawns); and b) Deriso models for each of the three species (Dichmont et al. 2003). The latter do not use the length frequency information. Punt et al. (2011) provides a summary of the specifications of the combined model used as the Base Case. Various model improvements were included in the previous assessments including exploring sensitivity of results to including red endeavour prawn in the assessment and the bio-economic projection model (Deng et al. 2021; Hutton et al. 2018) and updated configuration of the bio-economic mode (Buckworth et al. 2015) based on a retrospective study of model performance (Deng et al.

2015). This assessment continues to include previous updates used in the past assessment. The latest models include the following developments over the last 10 years:

- An alternative statistical method to analyse fishery-independent survey length- frequency information (Burridge et al. 2014);
- The length frequency information from the most recent recruitment survey are not included in the analysis, to avoid data conflicts (but recruitment abundance is included in the model fitting process);
- A Gamma function is assumed for the selectivity of the recruitment survey instead of a logistic function;
- Sensitivity tests, which include changing the amount of effort change permitted between years, changing the lower effort threshold, and alternative fishing power levels, model structures, and predicted fishing patterns; and,
- A fishing pattern for the projections based on the average of the last two years' actual fishing patterns, as recommended by Deng et al. (2015). The model encountered optimisation difficulties with this pattern in the assessment conducted in 2014. This was addressed by first adopting the previous two years' mean fishing pattern then applying the algorithm described in Buckworth et al. (2015), to distribute available fishing effort.
- The ability to conduct a sensitivity test of the modified Base Case model to assess four target species simultaneously to provide the stock status of the prawn species.
- The sensitivity test to consider setting a lower threshold effort level for future projections. The Base Case used 2,777 days for each tiger prawn fleet, which was set more than a decade ago based on the 2007 fishing effort.

A "species-split" model, to allocate logbook catches and effort by species of Tiger and Endeavour Prawns (Venables et al. 2006), was applied to the updated fishery catch and effort data. Two updated (April 2022) fishing power models were applied as separate scenarios – the "low" model (used in the Base Case) and the "mid-high" model (Nov 2009 and May 2010 Northern Prawn Fishery Resource Assessment Group (NPRAG), see Bishop et al. 2010 for description of method).

Fishery independent monitoring surveys, undertaken for the Northern Prawn Fishery (NPF) since 2002, including the new addition of the 2020 spawning survey, the 2021 and the 2022 recruitment surveys, provide abundance indices and length-frequency data that are incorporated into the Base case assessment.

For the Base Case assessment, we used the NPRAG 2014-specified season (average of the last two years) as the fishing effort pattern (as agreed by NPRAG in March 2014 and November 2015) for the forward projections.

The assessments have two components: (1) the stock assessment of the two Tiger Prawns plus Blue Endeavour Prawns (Base case) or both Endeavour Prawns (four species sensitivity test), and (2) the bio-economic projection model (Dichmont et al. 2008, Punt et al. 2011, Deng et al. 2015). Assessments of Blue and Red Endeavour Prawns were undertaken using the Bayesian hierarchical biomass production model (Zhou et al. 2009). Previously, a delay difference model (Dichmont et al. 2003) was applied in two endeavour prawns, but this required input parameters that were poorly known, particularly for Red Endeavour prawns. In the bio-economic model, Blue Endeavour Prawns (or in the four species sensitivity analysis, both Blue and Red Endeavour Prawns) are treated as an economic byproduct, i.e., effort is not directed at the species, but catches provide revenue and only attract costs associated with the amount caught (such as freight, packaging and crew share of revenue).

Scenario tests have mainly focused on assessing the sensitivity of the outputs of the bio-economic model to assumptions related to: fishing effort pattern, fishing power, model type, the 2013 RAG-specified fishing pattern, constraining (year-on-year) changes in effort during the seven-year projection period and the minimum effort threshold. The four species sensitivity test explores the capability of the model to provide a preliminary indication of the stock status of Red Endeavour Prawns.

Differences in the results from previous assessments can mostly be attributed to: a) the updated fishing power series; b) the inclusion of the 2020 spawning survey, the 2021 and 2022 recruitment survey information; c) updated fishery catch and effort logbook data up to 2021; d) an updated fishing effort pattern; e) updated economic information; g) testing the four species model to acquire stock status information for Red Endeavour Prawns. These changes together have influenced the stock status estimates for the various species and the stock-recruitment relationship, as well as the Maximum Sustainable Yield (MSY) - and Maximum Economic Yield (MEY)-related outputs. The MEY estimate drives the Total Allowable Effort recommendation calculated by applying the harvest strategy.

This assessment produces a Total Allowable Effort (TAE) recommendation for the input management system. The RAG will make the decision to use the model-recommended TAEs or an TAE based on an alternative ad-hoc method.

Grooved Tiger Prawns (Figure 1)

The spawning stock size of Grooved Tiger Prawns was estimated to be less than SMSY, ranging from 66% to 82% among variants of the assessment, at the end of 2021. Furthermore, effort in 2021 was estimated to be well below (41-66%) EMSY. The most recent five-year average spawning stock size was estimated to be in the range of 82% to 103% of SMSY, and thus the stock was estimated to be above the limit reference point of 50% SMSY. Grooved Tiger Prawns are therefore considered not overfished, and overfishing is not occurring.

Brown Tiger Prawns (Figure 2)

The spawning stock size of Brown Tiger Prawns in 2021 was estimated to 66%-90% of S_{MSY} among variants of the assessment. The most recent five-year average spawning stock size was estimated to range from 81% to 111% of S_{MSY}, and thus is estimated to above the limit reference point, of 50% S_{MSY}. Therefore, the resource is considered not overfished. Effort in 2021 was below $E_{MSY,}$ ranging from 32% to 64%. Overfishing is therefore not occurring.

Blue Endeavour Prawns (Figure 3)

Blue Endeavour Prawns are considered a by-product and are not estimated to be over-fished relative to the target reference point of 50% S_{MSY} (based on most-recent 5-year average). In all the sensitivity scenarios tested, the spawning stock size was estimated to be less than S_{MSY} at the end of 2021 (61% to 82 %). The most recent five-year average spawning stock size estimate ranged from 62% to 83% of S_{MSY}.

Red Endeavour Prawns (Figure 4)

Red Endeavour Prawns are assumed to be a by-product species. In the four species sensitivity test, the spawning stock size was estimated to be less than S_{MSY} at the end of 2021 (87%), but the stock was estimated not to be over-fished relative to the limit reference point of 50% S_{MSY} (based on most recent 5-year average). The last five-year average spawning stock size is estimated to be 92% of S_{MSY}.

Economic assessment (Table 1, Figure 5 and Figure 6)

The bio-economic projection model calculated the ratio S_{MEY}/S_{MSY} to be respectively 1.25 and 1.35 for Grooved and Brown Tiger Prawns for the Base Case model, while for Blue and Red Endeavour Prawns, this rate is respectively 1.14 and 0.82 (four-species sensitivity test). Blue and Red Endeavour Prawns, caught as a byproduct, have costs associated with catch (e.g., packaging and freight) but not effort (e.g., fuel).

At 61% of S_{MEY}, the spawning stock size of Grooved Tiger Prawns was estimated to be less than that corresponding to MEY in the Base Case (estimated as between 52-61% in all the scenarios considered). Similarly, the spawning stock size for Brown Tiger Prawns was estimated to be less than that corresponding to MEY, with S_{2021}/ S_{MEY} = 0.66 in the Base Case (62%-72% across all scenarios). S_{2021}/ S_{MEY} was 0.57 for Blue Endeavour Prawns for the Base Case (52%-76% across scenarios) and S_{2021}/ S_{MEY} was 1.06 for Red Endeavour Prawns for the four species sensitivity test.

The Grooved Tiger Prawns are predicted to achieve their present target reference point, S_{MEY} within seven years but the Brown Tiger Prawns may need longer to achieve their S_{MEY} (Figure 5), given current harvest strategy and economic assumptions. Given the information on recruit abundance from the recruitment survey in 2022 and the fishing pattern, the model predicts a small increase in recruitment in 2022 for both Tiger Prawns, and higher catches of both Tiger Prawns than in 2021. Recruitment for subsequent years of the projection is predicted via the stock-recruitment relationships alone and hence do not account for the perhaps considerable variation in recruitment about the stock-recruitment relationship. Target effort in 2021 for Grooved Tiger Prawns is estimated to be 76% of E_{MEY} while 2021 effort for Brown Tiger Prawns was also below E_{MEY} (49%). As Blue and Red Endeavour Prawns are treated as a byproduct (i.e., these species are captured when effort is targeted at Tiger Prawns), effort targeted towards these species is reported.

The Tiger Prawn fishery is projected to be earning negative economic profits given the harvest strategy, the assumptions regarding effort, and the values for the economic parameters until 2024 (Figure 5d).[1] The major drivers are the estimated flat future abundance of the target stocks and the economic assumptions, such significant increases in the fuel cost, freight, material, packaging costs and the repair and maintenance costs.

Total allowable effort (Table 2) **– that is the model estimated TAEs**

The assessment (Base Case) predicted 2022 optimal effort levels of 2,777 boat days for Grooved Tiger Prawns and 2,777 boat days for Brown Tiger Prawns (a total of 5,554 boat days), equal to the minimum effort level specified by the RAG. The optimal total effort estimated in the various sensitivity tests (including a lower minimum effort scenario) ranged from 2,188 to 5,599 boat days.

[1] This excludes the economic profits that may be earned in the banana prawn component(s) of the fishery (common and redleg), which are not captured in the current bioeconomic model.

Figure 1. Status of the stock and effort relative to reference points for Grooved Tiger Prawns, for the Base Case.

a) Spawning stock size (S_Y) relative to the spawning stock size at Maximum Sustainable Yield (S_{MSY}) , b) spawning stock size relative to the spawning stock size at Maximum Economic Yield (S_{MEY}) , c) standardised effort (E_Y) relative to the effort at Maximum Sustainable Yield (E_{MSY}) , and d) standardised effort relative to the effort at Maximum Economic Yield (E_{MEY}) .

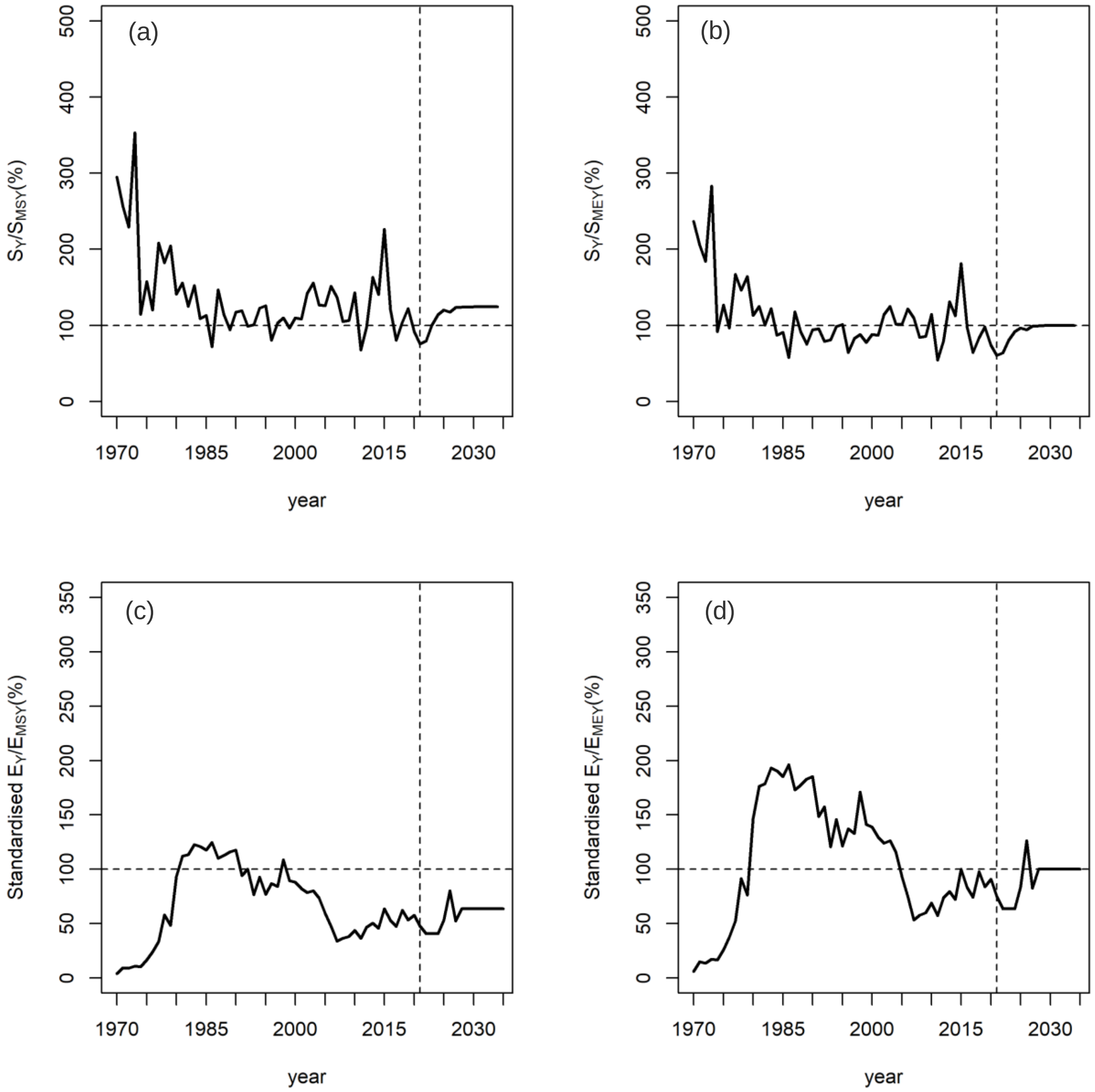

Figure 2. Status of the stock and effort relative to reference points for Brown Tiger Prawns for the Base Case.

a) Spawning stock size (S_Y) relative to the spawning stock size at Maximum Sustainable Yield (S_{MSY}) , b) spawning stock size relative to the spawning stock size at Maximum Economic Yield (S_{MEY}) , c) standardised effort (E_Y) relative to the effort at Maximum Sustainable Yield (E_{MSY}) , and d) standardised effort relative to the effort at Maximum Economic Yield (E_{MEY}) .

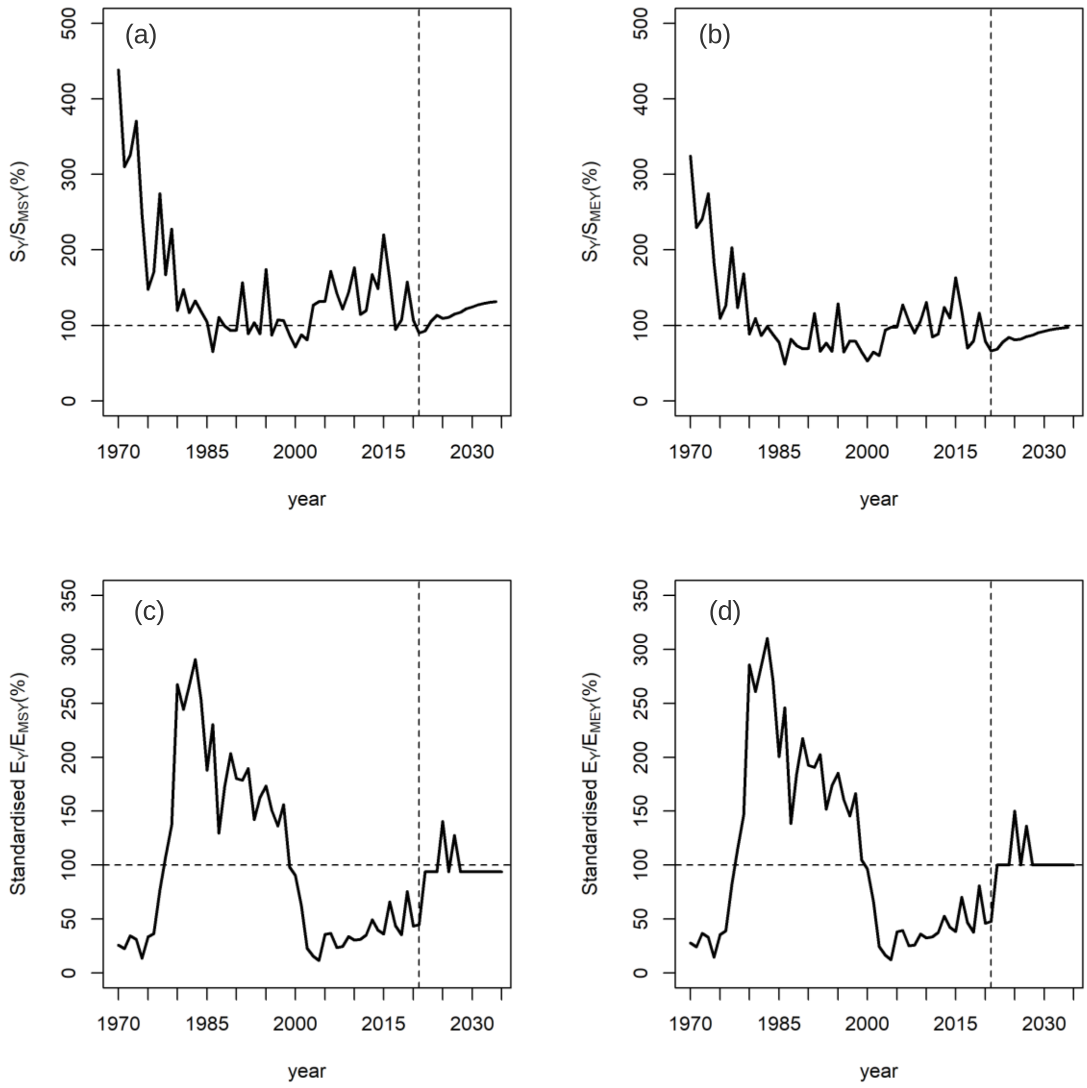

Figure 3. Status of the stock relative to reference points for Blue Endeavour Prawns for the Base Case.

a) Spawning stock size (S_Y) relative to spawning stock size at Maximum Sustainable Yield (S_{MSY}) , and b) spawning stock size relative to the spawning stock size at Maximum Economic Yield (S_{MEY}).

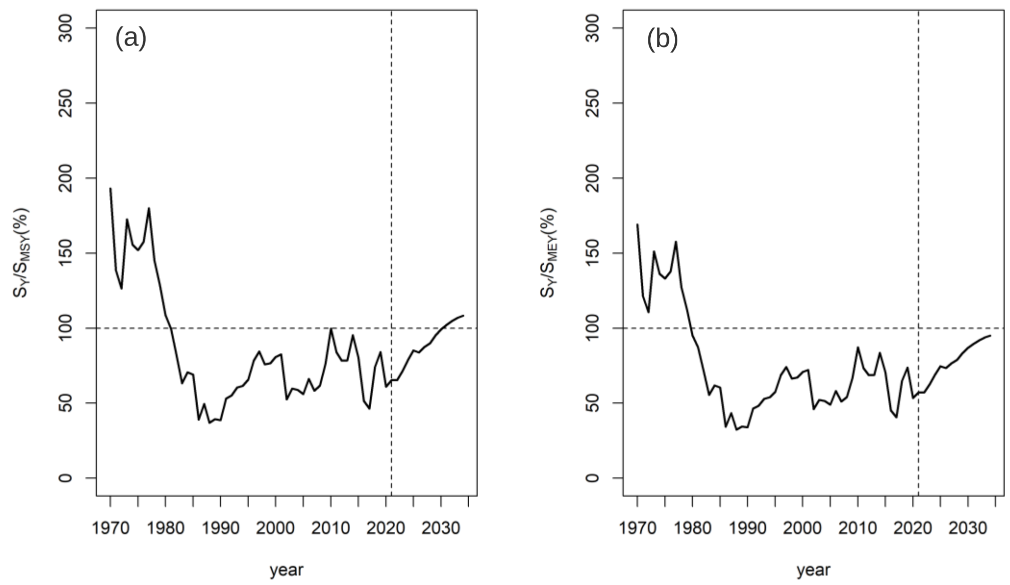

Figure 4. Status of the stock relative to reference points for Red Endeavour Prawns for the 4 species sensitivity test.

a) Spawning stock size (SY) relative to spawning stock size at Maximum Sustainable Yield (SMSY) , and b) spawning stock size relative to the spawning stock size at Maximum Economic Yield (SMEY).

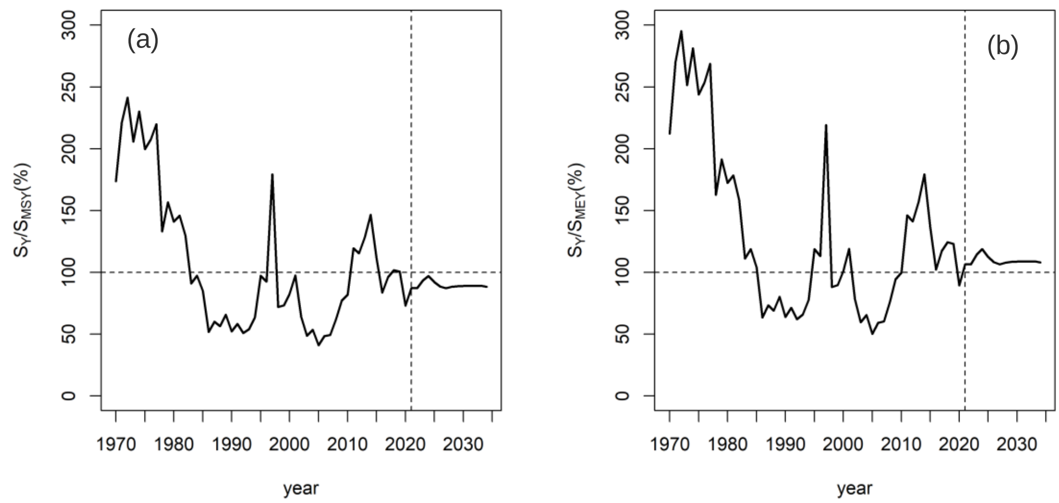

Figure 5. The key bio-economic model results (indicators) for the Base Case

(a) Tiger Prawn effort (standardised boat days), (b) prawn catch (tonnes), (c) S_Y / S_{MSY} and (d) total projected profit (millions of Australian dollars) for the Base Case assessment and projection settings.

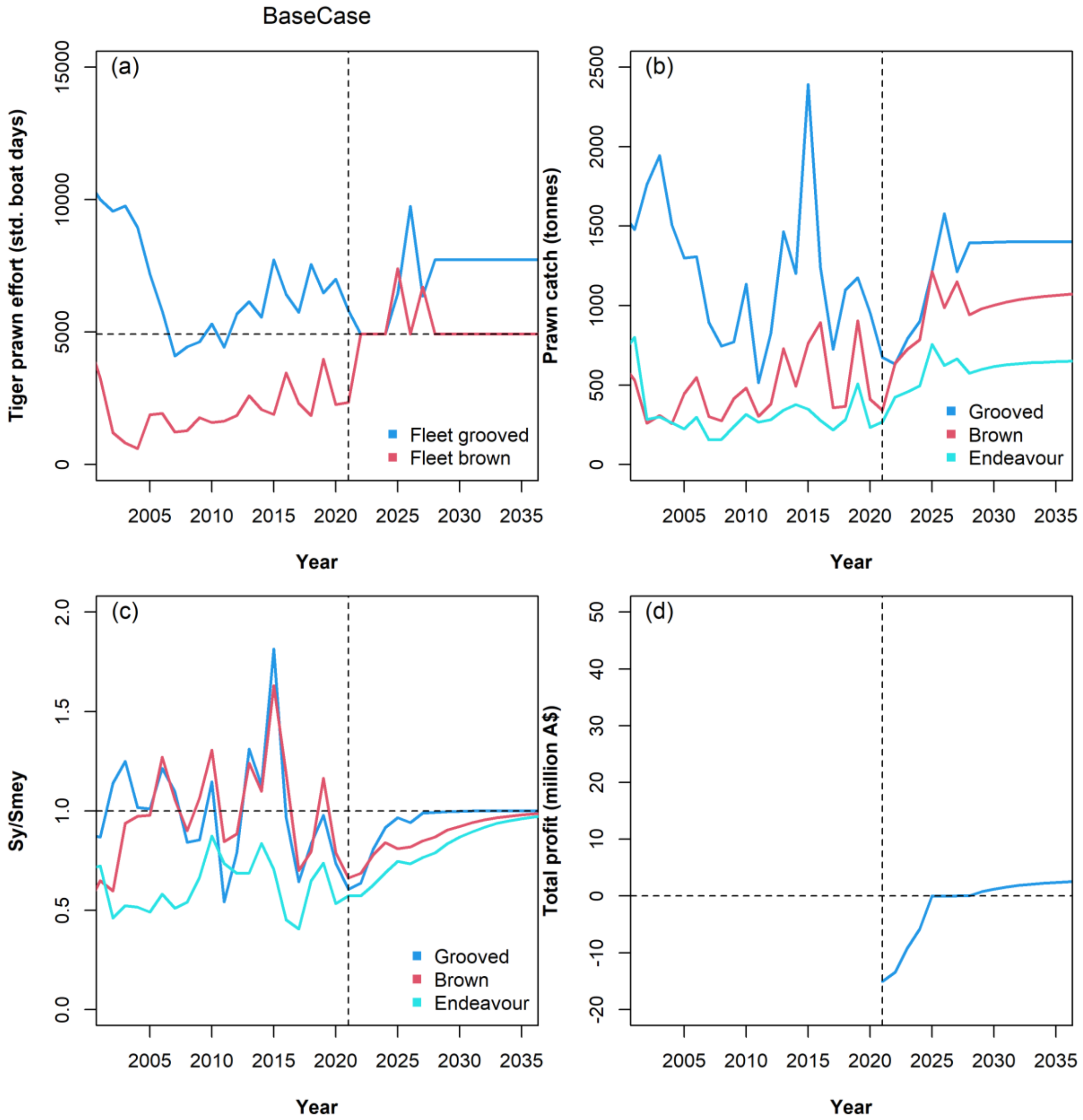

Figure 6. The key bio-economic model results (indicators) from the four species sensitivity test.

(a) Tiger Prawn effort (standardised boat days), (b) prawn catch (tonnes), (c) S_Y / S_{MEY} and (d) total projected profit (millions of Australian dollars).

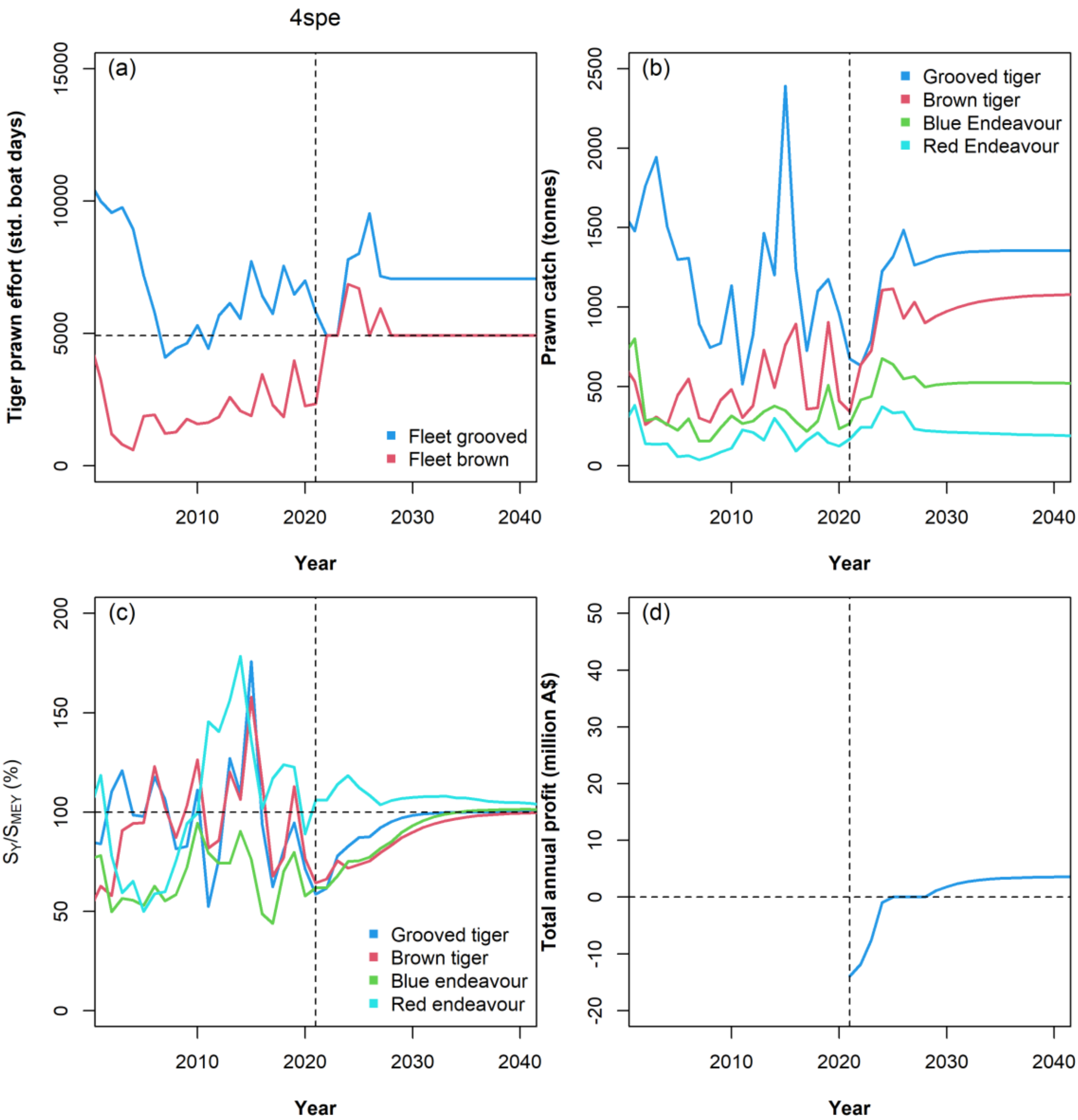

Table 1. Results of relevant management measures and parameter estimates for all three species for the "Base Case" assessment.

E_{MSY} is the effort level (expressed in terms of 2021 boat days) at which MSY is achieved and S_{MSY} is the spawner stock size at which the (deterministic) MSY is achieved. **mav = moving average**

Name	Grooved tiger prawns	Brown tiger prawns	Blue endeavour prawns
Steepness	0.386	0.337	NA
$Catch_{2022}$ (t)	632	638	424
Observed C_{2021} (t)	673	341	266
MSY (t)	1,582	1,053	787
MEY (t)	1,402	1,087	659
S_{MEY}/S_{MSY} (%)	125	135	114
S_{2021}/S_0 (%)	40	39	37
S_{2021}/S_{MSY} (%)	75	90	65
S_{2021}/S_{MEY} (%)	61	66	57
5-year mav ($S_{2017\text{-}2021}/S_{MSY}$) (%)	95	111	66
S_{2028}/S_{MEY} (%)	99	87	79
Observed nominal E_{2021} (d)	3,320	1,347	NA
Estimated nominal E_{2022} (d)	2,777	2,777	NA
Estimated nominal E_{2023} (d)	2,777	2,777	NA
E_{MSY} (d)	6,862	2,966	NA
E_{MEY} (d)	4,356	2,777	NA
E_{MEY}/E_{MSY}(%)	64	94	NA
E_{2021}/E_{MSY} (%)	48	45	NA
E_{2021}/E_{MEY} (%)	76	49	NA
Standardised E_{2021}/E_{MSY} (%)	48	45	NA
Standardised E_{2021}/E_{MEY} (%)	75	48	NA
Profit (estimated) 2021 ($m) Estimate from these 3 target species based on data provided and assumptions of fixed costs proportion to Tiger Prawn fishery versus Banana Prawn fishery. Revenue from other species (e.g. red endeavour prawns, bugs, squid) not included.	-15		

Table 2. Total nominal effort for Brown and Grooved Tiger Prawn fleets, the total effort, effort change and gear change as per the NPF Harvest Strategy under input controls.

Note, the estimated equivalent gear changes required to get the equivalent 19% effort changes from 2021, were computed using the method of Venables and Browne (2007). The TAEs (in days) were allocated across species based on the Base Case model-predicted TAE.

Year	2021 observed nominal effort (boat day)	2022 model projected effort (boat day) and changes from 2021	2023 model projected effort (boat day) and changes from 2021
Grooved Tiger Prawn nominal effort	3,320	2,777	2,777
Brown Tiger Prawn nominal effort	1,347	2,777	2,777
Total nominal effort	4,667	5,554	5,554
Effort change from 2021	NA	887 (or 19%)	887 (or 19%)
Gear change	NA	90%	90%

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1 Background

The NPF has a long history of basing management decisions on the results from quantitative stock assessments (e.g., Somers, 1990; Wang and Die, 1996; Dichmont et al., 2003). Recent and future changes in management of the fishery invariably impose challenges for the provision of scientific management advice. Specifically, data-derived assessment outcomes need to be provided for the fishing strategies necessary to target the two species of Tiger Prawn. Total Allowable Effort (TAE) is the management tool of the fishery, i.e., effort is limited by a licence to fish, season length and head rope length. Catches and effort for 2022 were estimated for both two Tiger Prawn species given the specified harvest strategy, and then summed over the two species to produce single 2022 Tiger Prawn and subsequent 2023 TAE recommendations and yearly catch estimate.

Although the provision of scientific advice in multispecies fisheries is often difficult, doing so in the NPF is especially challenging because management advice needs to be based on the objective of achieving MEY rather than MSY. The advice thus requires consideration of economic as well as biological factors. In contrast, management advice in the years up to 2008 addressed an MSY objective and was based on the results of a weekly delay-difference model (Dichmont et al., 2003), fitted to catch and effort data. We interpret the MEY objective as selecting management actions to maximise the net present value (NPV), which is calculated as the difference between total revenue and costs. Important biological constraints are: (i) prawns cannot be aged, which means that methods using age-disaggregated data cannot be applied; and (ii) the short-lived nature of prawns (a maximum age of approximately 18 months) implies the need for advice on catch and effort estimates based on forecasts of stock size that strongly reflect new and strongly variable annual recruitment (as most of the stock does not survive between years).

In this assessment, a multispecies, weekly, sex- and size-structured population model for Tiger Prawns and a Bayesian hierarchical biomass production model for Endeavour Prawns are combined with an economic model that calculates profit. This system requires predictions about future fishing effort levels, the weekly allocation pattern of fishing effort and changes over time in costs and prices (Punt et al. 2011).

2 Needs

Based on a group of short-lived, highly variable prawn species, management of the NPF requires detailed assessments to ensure maximal benefit. Specifically, under the Commonwealth Fisheries Harvest Strategy Policy, there is an agreed requirement to set TAE for tiger prawns and redleg banana prawns. Assessment is a core element of the Harvest Strategy for the fishery. Without regular, critical updates the Harvest Strategy will need considerable change and might be ineffectual.

This project was part of the on-going assessment program for the NPF, an integral part of the management of the fishery since the 1980s. The Harvest Strategy (HS) provided harvest control rules for two main species of tiger prawns, and endeavour prawns, as well as and for redleg banana prawns. There were separate assessments for these prawns. An assessment and prediction based upon a stock-recruitment relationship was unavailable for white/common banana prawns. Thus, the fishery relied on a catch rate trigger estimation procedure – which is dependent on real-time economic parameter inputs provided by Industry just prior to the beginning of the season each year; which are confidential in nature thus these are not published, but the minutes of the NPRAG meetings record the trigger limit agreed on. The calculations were undertaken in unison. Thus, over the life of this project, the common banana prawn fishery was managed via a catch-rate trigger and season length, based upon an in-season MEY target.

The multi-species assessment of the tiger prawn fishery (tiger and endeavour prawns) and the redleg banana prawn fishery, required:

1. Standardisation of effort, including an annual update to the fishing power analysis; and
2. Splitting of logbook species group catch data into species.

Additionally, application of the tiger prawn fishery bio-economic calculations requires:

- Updated economic input values;
- Estimation of the maximum economic effort levels, via the bio-economic model; and,
- Target species abundance indices from seasonal fishery-independent surveys.

The tiger prawn and redleg banana prawn fishery models provided TAEs and predicted corresponding catches, and thus made available all the information required for management. Furthermore, two ‘new” aspects were considered for continued MSC certification and sustainable management of the fishery. These being: 1) the potential inclusion of red endeavour prawns into the bio-economic model and 2) the continuous update to the harvest control rules for redleg banana prawns given the recent evidence pointing to climate drivers which will need to be considered on an annual basis (Plaganyi et al. 2020), and the outcomes of a Management Strategy Evaluation (MSE) conduced on this species. The considerations must also be undertaken to meet the requirements of the governments’ revised Harvest Strategy Guidelines.

3 Objectives

The objectives as specified in the original proposal were:

1. Provide a full assessment of the tiger prawn fishery for 2022 (based on 2021 fishery data). Due to the nature of stock assessment, the 2022 stock assessment will include all data up to 2021, including 2020 data (thus data collation at the end of 2020 was included as a cost);

2. Update the fishing power series incorporating data from gear surveys, annually (i.e., in 2020, 2021, and 2022 for the preceding fishing years) for both the tiger prawn fishery and the redleg banana prawn fishery;

3. Estimate MEY-based TAEs for the tiger prawn fishery for each of 2021 (based on 2020 assessment) and 2022, and 2023 fishing years;

4. Assess stock status of the redleg banana prawn fishery* (and relevant key environmental factors) and provide a TAE for redleg banana prawns in each of 2021, 2022, and 2023; and,

5. Support annual estimation of MEY-catch rate triggers for the white/common banana prawn fishery. This will be undertaken each year, i.e., 2021, 2022 and 2023.

*Published as a separate report.

4 Methods

This assessment is based on a weekly, size-structured model (Punt *et al.,* 2010), a Bayesian hierarchical biomass production model (Zhou *et al.,* 2009) and a bio-economic model (Dichmont *et al*., 2008, Punt *et al.,* 2011, Deng *et al.,* 2014). A full set of specifications for these models has been presented in a series of publications: a) Punt *et al.* (2010) for the size-structured model [both Tiger Prawn species]; b) Punt *et al.* (2011) for the economic formulations, (the profit function); c) Deng *et al*. (2014) for a set of revised specifications for improving the model performance; and, d) Zhou *et al.* (2009) for the Bayesian hierarchical biomass dynamic model applied to Blue Endeavour Prawns.

The bio-economic assessment that comprises this series of models firstly estimate the population dynamics, and then calculate the economic dynamics. The calculation of the quantities of interest to stakeholders therefore involves a four-step process:

1. Estimation of indices of spawning stock size and recruitment using a size-structured model (Punt *et al*. 2010) for each of the two Tiger Prawn species.
2. Estimation of the parameters of corresponding Ricker stock-recruitment relationships based on the output from these models (Dichmont *et al*. 2003).
3. Estimation of stock size in a Bayesian hierarchical biomass dynamics model (Zhou *et al.* 2009) for Blue and Red Endeavour Prawns.
4. Estimation of *MSY*, E_{MSY}, and S_{MSY} for the Tiger Prawn fleets (Dichmont *et al*. 2003), and estimation of the optimal effort pathway for each Tiger Prawn fleet in the fishery over a set period to achieve Maximum Economic Yield – outputs also include the resultant dynamic *MEY*, E_{MEY}, and S_{MEY} (Punt *et al*. 2010, 2011).

The Base Case assessment involved updates to both the assessment model and the input data. For the model, updates include improvements developed over recent years including the optimal configuration of the settings of the assessment and economic model (Deng *et al.* 2014) and an algorithm for weekly allocation of future fishing effort to ensure the allocation does not violate the fleet actual capacity which is 364 days determined by 52 vessels and 7 days per week. All the input data, such as logbook data, fishery-independent survey data and economic data are continuously collected, updated, and are reformatted for inclusion in the models. Sensitivity tests focus on the changes to the assumptions in the Base Case. These include changes in the assumed weekly fishing pattern, different fishing power series, model differences and the effort fluctuation constraints; and the four-species bio-economic model in which Red Endeavour Prawns are also assessed by using Bayesian hierarchical biomass dynamics model (Table 3).

The key points addressed for this year's assessment are:

1. The weekly effort pattern for the Base Case was set by NPRAG in March 2014 and November 2015, with the predicted fishing pattern suggested to be the average of the last two years' actual fishing pattern (Figure 9a) (see footnote to Table 3 for details). The problem of total effort being too tightly constrained by patterns derived from low tiger prawn effort years was addressed by applying the algorithm described in Buckworth *et al*. (2015), to distribute available fishing effort;
2. The model was set-up to estimate the fishing patterns (Figure 9b);
3. New February recruitment (2021, 2022) and July spawning (2020) survey abundance indices were incorporated into the assessment and hence the projections (Kenyon *et al.* 2021, Kenyon *et al.* 2022). There were no spawning abundance surveys in 2010, 2015, 2017, 2019 and 2021;
4. The fishing power series was re-estimated from 1970 to 2021 using the same method as previously (Upston *et al*. 2022 Appendix B) and with the newly updated fishery capabilities data. Two series were produced for the Tiger Prawn fishery (based on the so-called 'economic catch' , i.e. catch weight of Tiger Prawns plus half of that for the Endeavour Prawns): a Low series and a Mid-High series. The Base Case assumes the fishing power is the 'Low' estimated cumulative series;
5. In a sensitivity test, effort changes were constrained during the seven-year projected period in the bio-economic model (see footnote to Table 3 for details);

6. The length frequency data from the most recent recruitment survey were excluded from the assessment (as noted by Deng et al. 2014, as this may conflict with other information in the model);
7. Gamma functions were assumed to represent the selectivity of the recruitment survey;
8. Length frequency data are assumed to be multinomial with an effective sample size given by the product of the observed number of animals by size-class multiplied by an overdispersion parameter. The overdispersion parameters have been set to 0.55 based on an application of the McAllister-Ianelli method (McAllister & Ianelli, 1997);
9. Different model forms, such as delay difference models (Table 3), were exampled;
10. The Dirichlet multinomial method (Burridge *et al*. 2014) was applied to characterise and estimate the effective sample size for the fishery-independent survey length frequency data; and,
11. A sensitivity test of using a lower effort threshold in the bio-economic model (Table 3) was undertaken.
12. A sensitivity test of the modified Base Case model to assess four species simultaneously to provide the stock status of the prawn species (Table 3) was undertaken.

The settings of the Base Case and sensitivity tests are provided in Table 3. In the Base Case, the economic input parameters were set using predicted values provided by Tom Kompas (see section 3.4 “Economics”).

The Base Case uses the newly estimated 2022 version of the “low” fishing power series and a catchability value (*q*) from Wang (1999). The weekly effort patterns were those agreed by the NPRAG in March 2014 and November 2015, being an average of the previous two years’ patterns, adjusted as necessary using the algorithm described by Buckworth *et al.* (2015). Dichmont *et al*. (2003) showed that MSY-related results are sensitive to weekly effort patterns.

The scenarios (Base Case and sensitivity tests) estimate the changes to the MSY and MEY-related outputs by using:

(1) model estimated fishing patterns;

(2) an alternative fishing power series, the “Mid-high” series (see Figure 7);

(3) different assessment models (SSB versus DDD);

(4) constraining inter-year effort changes to a maximum 15% during the seven-year projection period in bio-economic model;

(5) alternative fishing patterns;

(6) a minimum effort threshold for the bio-economic model;

(7) four target species simultaneously to provide the stock status of the four prawn species;

See Table 3 for a description of the Base Case and various sensitivity tests.

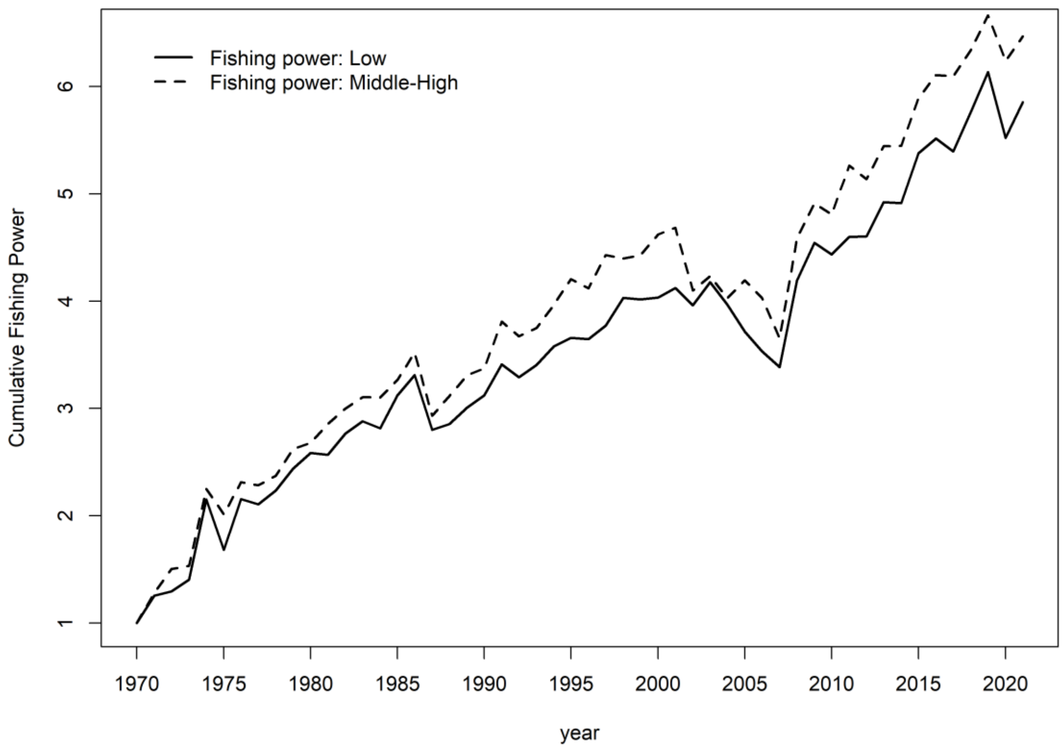
Table 3. Description of settings for the Base Case and sensitivity tests.

SSB indicates use of size- structured models for Grooved and Brown Tiger Prawns, and a Bayesian hierarchical model for Blue Endeavour Prawns. DDD indicates use of the Deriso model (Dichmont et al. 2003) for each species. SSBB indicates use of size-structured models for Grooved and Brown Tiger Prawns, and Bayesian hierarchical model for two Endeavour Prawns. An additional preliminary model run exploring assumptions regarding changes in catchability was undertaken for Blue endeavour prawns (see Appendix A).

Scenario name	Models	Fishing power	Weekly pattern	Max. effort change[2]	Low effort threshold	Effort allocation algorithm[3]	No. of species
Base Case	SSB	Low	Last 2 year average	NA	2,777	Yes	3
DDD	DDD	Low	Last 2 year average	NA	2,777	Yes	3
Mid-High Fishing Power	SSB	Mid-High	Last 2 year average	NA	2,777	Yes	3
Fixed effort pattern	SSB	Low	NPRAG 2013 specified season	NA	2,777	No	3
Estimate season	SSB	Low	Estimated	NA	2,777	No	3
Constraining effort change (year-on-year)[4]	SSB	Low	Last 2 year average	15%	2,777	Yes	3
Low minimum effort threshold	SSB	Low	Last 2 year average	NA	1,000	Yes	3
4 species (including red endeavour prawn)[5]	SSBB	Low	Last 2 year average	NA	2,777	Yes	4
No minimum effort threshold	SSB	Low	Last 2 year average	NA	1	Yes	3

[2] Strictly, effort was directly constrained and total catch was indirectly constrained. A constraint on predicted output (that is, a bound on percentage variation of the effort year-to-year of +/- 15%) was included to reduce excessive fluctuations otherwise observed in the output. Effectively, this meant that the mathematical optimisation process was forced to accommodate the practical management need to control the magnitude of inter-annual changes in effort.
[3] Modification on the model to address issues raised from 2014 assessment (Buckworth et al. 2015), in which weekly effort, based on predicted potential catch, might otherwise have exceeded the whole NPF fleet capacity. A new algorithm resolved the issue and made sure the weekly effort remained within the NPF fleet capacity.
[4] A sensitivity test informed by sensitivity runs in the MSE project (Dichmont, et al. 2012).
[5] A sensitivity test to investigate feasibility of implementing a 4 species model which includes red endeavour prawns in the model. This involves using Bayesian hierarchical model for red endeavour prawns.

Figure 7. Two estimated cumulative fishing power series: the low fishing power and the mid-high fishing power (Appendix B).



Given the substantial data input into the assessment, a series of outputs is provided for each species (Appendix A). Although there are results for three species for the Base Case and for four species for one sensitivity test, effort-related results are only provided for the Tiger Prawns. This is because Blue and Red Endeavour Prawns (the latter only in sensitivity test 7) are treated as an economic byproduct in the economic projection model. Modelled effort for the Tiger Prawn fishery is determined by total revenue (which includes Blue Endeavour Prawns (and Red Endeavour in the four-species sensitivity test)) and fishing costs, with effort-related costs driven largely by Tiger Prawn catches, and any additional costs associated with producing all catch (including the Endeavour species) such as crew shares, packaging and freight costs.

The results can be broadly divided into two groups: stock status-related results (e.g., stock status relative to MSY-based reference points, steepness), which include the results related to the Limit Reference Point, and the economic-related results (e.g., MEY series, including application of the

Harvest Strategy required to calculate the effort for 2022 and 2023) and the status relative to the Target Reference Point.

The Target Reference Point is the spawning stock size that would be achieved at the Maximum Economic Yield (MEY) and the Limit Reference Point is at the most recent five-year moving average of the spawning stock size relative to half of S_{MSY} (NPF Harvest Strategy under input controls (Dichmont *et al*. 2012b)).

5 Results

5.1 Catch and effort data

Catch and effort data from 1970 to 2021 were extracted from AFMA's logbook database for each Tiger Prawn species and for Blue Endeavour Prawns (and Red Endeavour in the four-species sensitivity test). A couple of the logbook records were excluded from both stock assessment and fishing power analyses where only squid catch was reported. Compared with the data of 2020, the Tiger Prawn species-combined catch decreased 26% (from 1,366t to 1,014t) while the corresponding effort decreased by 14% from 5,389 to 4,665 boat days (Table 4). The nominal effort targeting Grooved Tiger Prawns decreased by about 19% to 3,320 days, while that targeting Brown Tiger Prawns increased 2.8% to 1,345 days from 2020 to 2021.

Table 4. Catch (tonnes) and nominal effort (boat-days) for the two species of Tiger Prawns and Blue Endeavour Prawns in the NPF since 1993.

	Catch (tonnes)				Nominal effort (boat days)		Total	
Year	**Grooved Tiger**	**Brown Tiger**	**Blue Endeavour**	**Red Endeavour**	**Effort Grooved**	**Effort Brown**	**Tiger Prawn Catch**	**Total effort**
1993	1,325	1,208	637	115	9,097	7,320	2,533	16,417
1994	1,841	1,318	692	200	10,492	8,101	3,159	18,593
1995	1,674	2,465	801	377	8,468	8,295	4,139	16,763
1996	1,193	1,155	918	375	9,555	7,138	2,348	16,693
1997	1,451	1,253	901	1,040	8,991	6,353	2,704	15,344
1998	1,835	1,450	1,057	290	10,962	6,920	3,285	17,882
1999	1,417	753	653	233	8,948	4,223	2,170	13,171
2000	1,585	634	699	265	8,756	3,873	2,219	12,629

2001	1,478	530	801	382	8,042	2,626	2,009	10,668
2002	1,757	260	284	141	7,889	975	2,017	8,864
2003	1,950	310	301	136	7,786	653	2,260	8,439
2004	1,506	259	262	140	7,369	500	1,765	7,869
2005	1,302	445	226	59	6,287	1,623	1,748	7,910
2006	1,306	550	298	65	5,350	1,775	1,857	7,125
2007	895	303	156	39	3,957	1,185	1,197	5,142
2008	745	276	157	58	3,667	1,085	1,021	4,752
2009	769	414	241	86	3,428	1,324	1,183	4,752
2010	1,149	485	316	112	3,928	1,175	1,635	5,103
2011	510	304	268	226	3,201	1,192	814	4,393
2012	826	379	283	212	4,072	1,324	1,205	5,396
2013	1,470	731	343	164	4,176	1,789	2,201	5,965
2014	1,196	492	377	300	3,733	1,395	1,688	5,128
2015	2,405	763	348	206	4,840	1,201	3,168	6,041
2016	1,241	898	279	94	3,868	2,092	2,139	5,960
2017	724	356	219	161	3,494	1,397	1,080	4,891
2018	1,097	366	283	209	4,399	1,089	1,463	5,488
2019	1,178	908	509	147	3,535	2,181	2,086	5,716
2020	957	409	233	125	4,080	1,309	1,366	5,389
2021	673	341	266	170	3,320	1,345	1,014	4,665

By applying the low fishing power series (Figure 7) **used in** the Base Case, the 2021 standardised effort for Grooved Tiger Prawns decreased about 13.7% from 2020. For Brown Tiger Prawns, **standardized** effort increased about **8.9**% from 2020 to 2021 (see Error! Not a valid bookmark self-reference. for the low fishing power and Table 6 for the mid-high fishing power **series**).

Of more importance, given the structural changes in the fishery which make the interpretation of long-term trends in catch and effort data alone difficult to interpret, standardized catch rates for Grooved and Brown Tiger Prawns both decreased in 2021: the low fishing power series i2plies a 19% decrease for Grooved Tiger Prawns and a 24% decrease for Brown Tiger Prawns, from 2020 to 2021. These changes are consistent with the 2021 recruitment indices from the fishery-independent survey, in which there was a 12% decrease for Grooved Tiger Prawns, and a 36% decrease for Brown Tiger Prawns (Table 7

). Table 8 shows the time series of the spawning survey index (the spawning survey was not undertaken during 2010, 2015, 2017 and 2019, 2021).

Figure 8 shows the mean Catch per Unit of Effort (CPUE) indices derived from CPUEs estimated from two standardised fishing efforts based on the new fishing power series and the nominal effort. It also shows the survey-based recruitment and spawning indices.

Table 5. Standardised effort (standardised boat-days) and standardised catch-per-unit of effort (CPUE in kg per standardised boat-day) for each species of Tiger Prawn in the NPF since 1993.

Fishing power is calculated using the Low series of the updated fishing power analyses (Upston et al. 2022; Appendix B).

Low series fishing power	**Standardised effort (standardised boat-days)**		**Standardised CPUE (kg per standardised boat days)**		**Totals**	
Year	**Grooved**	**Brown**	**Grooved**	**Brown**	**Standardised effort**	**Standardised CPUE**
1993	9,097	7,320	146	165	16,417	154
1994	11,026	8,514	167	155	19,540	162
1995	9,097	8,911	184	277	18,008	230

1996	10,234	7,645	117	151	17,880	131
1997	9,962	7,039	146	178	17,001	159
1998	12,981	8,194	141	177	21,175	155
1999	10,554	4,981	134	151	15,534	140
2000	10,376	4,590	153	138	14,966	148
2001	9,739	3,180	152	167	12,919	156
2002	9,182	1,135	191	229	10,317	196
2003	9,554	801	204	387	10,355	218
2004	8,586	583	175	445	9,169	192
2005	6,860	1,771	190	251	8,631	203
2006	5,549	1,841	235	299	7,390	251
2007	3,935	1,178	227	257	5,113	234
2008	4,514	1,336	165	207	5,850	175
2009	4,575	1,767	168	234	6,342	187
2010	5,118	1,531	225	317	6,649	246
2011	4,323	1,610	118	189	5,933	137
2012	5,507	1,791	150	212	7,298	165
2013	6,040	2,587	243	283	8,627	255
2014	5,390	2,014	222	244	7,404	228

2015	7,645	1,897	315	402	9,542	332
2016	6,268	3,390	198	265	9,658	221
2017	5,539	2,215	131	161	7,753	139
2018	7,445	1,843	147	199	9,287	158
2019	6,371	3,931	185	231	10,302	203
2020	6,617	2,123	145	193	8,741	156
2021	5,710	2,313	118	147	8,023	126

Table 6. Standardised effort (standardised boat-days) and standardised catch-per-unit of effort (CPUE in kg per standardised boat-day) for each species of Tiger Prawns in the NPF since 1993.

Fishing power is calculated using the Mid-High series of the updated fishing power analyses (Upston et al. 2022; Appendix B).

Mid-High series fishing power	Standardised effort (standardised boat-days)		Standardised CPUE (kg per standardised boat days)		Totals	
Year	**Grooved**	**Brown**	**Grooved**	**Brown**	**Standardised effort**	**Standardised CPUE**
1993	9,097	7,320	146	165	16,417	154
1994	11,086	8,560	166	154	19,646	161
1995	9,492	9,298	176	265	18,790	220
1996	10,497	7,841	114	147	18,338	128
1997	10,615	7,501	137	167	18,116	149
1998	12,852	8,113	143	179	20,965	157
1999	10,568	4,987	134	151	15,555	140
2000	10,785	4,771	147	133	15,556	143
2001	10,042	3,279	147	162	13,321	151
2002	8,620	1,065	204	244	9,685	208
2003	8,791	737	222	420	9,529	237
2004	7,910	537	190	483	8,447	209

2005	7,028	1,814	185	245	8,843	198
2006	5,744	1,906	227	289	7,650	243
2007	3,856	1,155	232	262	5,010	239
2008	4,483	1,326	166	208	5,809	176
2009	4,491	1,735	171	239	6,226	190
2010	5,035	1,506	228	322	6,541	250
2011	4,493	1,673	114	182	6,166	132
2012	5,578	1,814	148	209	7,392	163
2013	6,061	2,597	243	282	8,657	254
2014	5,421	2,026	221	243	7,447	227
2015	7,602	1,886	316	404	9,488	334
2016	6,297	3,406	197	264	9,703	220
2017	5,678	2,270	128	157	7,948	136
2018	7,435	1,841	148	199	9,276	158
2019	6,280	3,875	188	234	10,154	206
2020	6,787	2,178	141	188	8,965	152
2021	5,726	2,320	118	147	8,046	126

Figure 8. Mean Catch-per-unit effort index from standardised effort series based on the low and mid-high fishing power series.

Grooved Tiger Prawns (a), Brown Tiger Prawns (b), Blue Endeavour Prawns (c), and Red Endeavour Prawns (d). The CPUE index from 1993 to 2021 is calculated using the standardised effort. The recruitment and spawning indices (no/hectare) from the fishery-independent survey are also provided for each stock (with an extension to include the 2021-2022 recruitment survey indices and additional 2020 spawning survey indices).

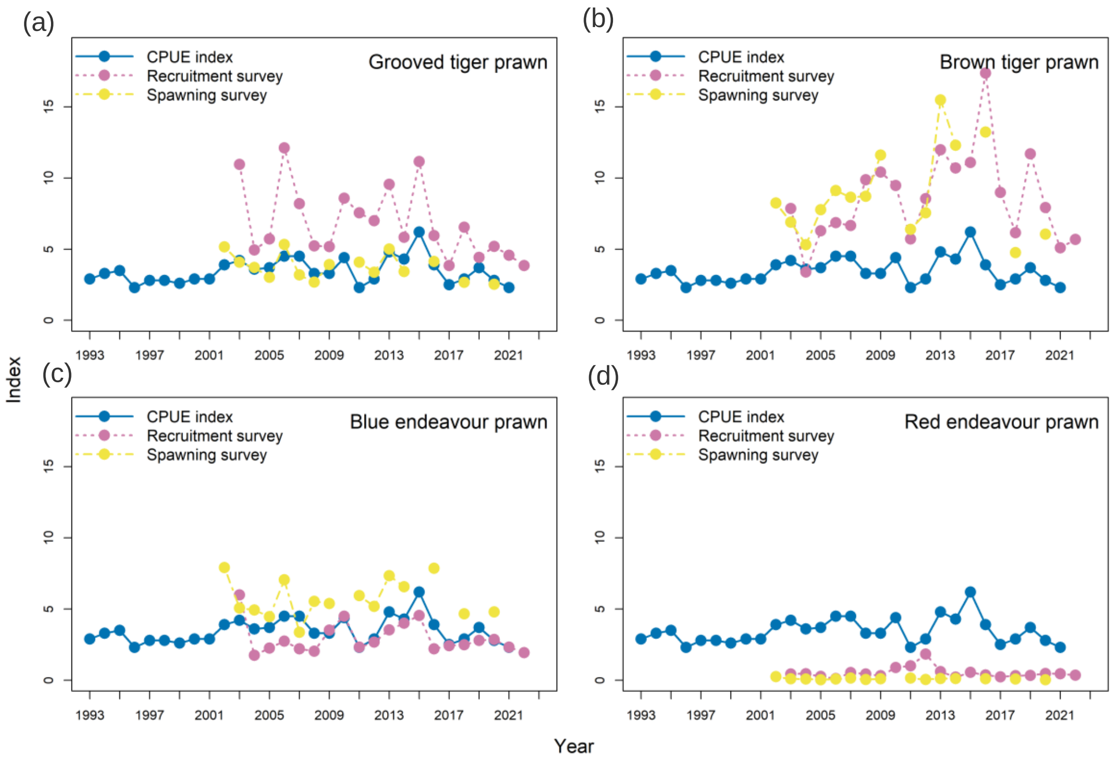


Table 7. Survey recruitment index series

	Grooved Tiger Prawns		Brown Tiger Prawns	
Year	**Recruitment index**	**CV**	**Recruitment index**	**CV**
2003	10.96	0.096	7.85	0.107
2004	4.94	0.076	3.40	0.074
2005	5.71	0.054	6.29	0.096
2006	12.11	0.218	6.87	0.071
2007	8.19	0.071	6.66	0.087
2008	5.23	0.072	9.87	0.091
2009	5.18	0.071	10.41	0.087
2010	8.58	0.069	9.47	0.063
2011	7.56	0.143	5.71	0.090
2012	7.00	0.073	8.54	0.087
2013	9.56	0.092	11.98	0.097
2014	5.84	0.061	10.71	0.103
2015	11.16	0.078	11.09	0.086
2016	5.95	0.077	17.37	0.096
2017	4.85	0.061	8.9	0.088
2018	6.54	0.066	6.15	0.091
2019	4.42	0.067	11.7	0.085
2020	5.19	0.072	7.93	0.077
2021	4.58	0.067	5.10	0.074
2022	3.84	0.077	5.69	0.081

Table 8. Survey spawning index series

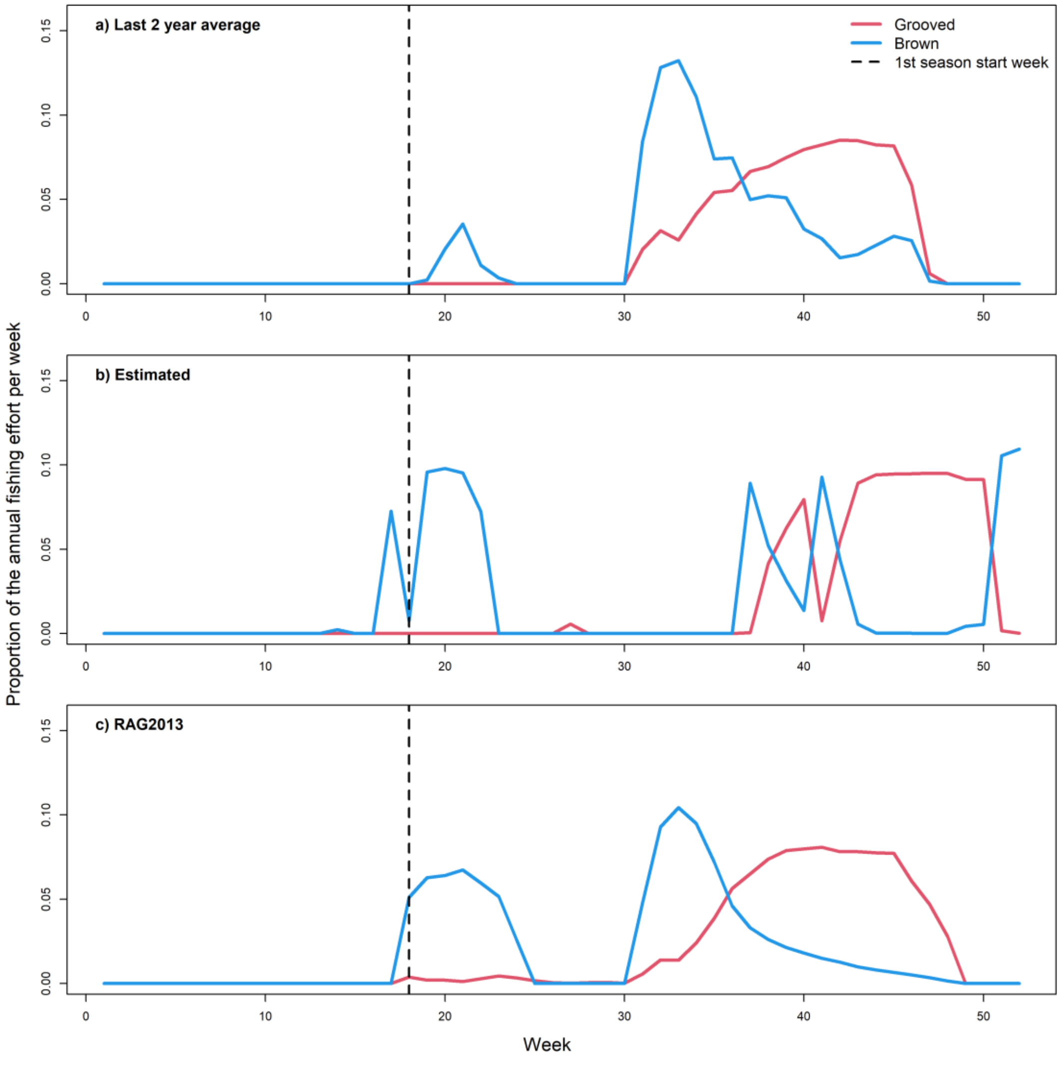
	Grooved Tiger Prawns		Brown Tiger Prawns	
Year	**Spawning index**	**CV**	**Spawning index**	**CV**
2002	5.16	0.104	8.24	0.090
2003	4.09	0.094	6.90	0.072
2004	3.72	0.087	5.47	0.104
2005	3.02	0.098	7.77	0.078
2006	5.33	0.103	9.12	0.117
2007	3.19	0.086	8.65	0.098
2008	2.68	0.135	8.72	0.072
2009	3.92	0.107	11.61	0.082
2010	NA	NA	NA	NA
2011	4.08	0.099	6.39	0.092
2012	3.38	0.116	7.56	0.108
2013	5.01	0.080	15.48	0.106
2014	3.43	0.107	12.3	0.106
2015	NA	NA	NA	NA
2016	4.13	0.082	13.22	0.092
2017	NA	NA	NA	NA
2018	2.67	0.102	4.76	0.098
2019	NA	NA	NA	NA
2020	2.53	0.111	6.06	0.142

5.2 Fishing Patterns

Figure 9 shows the three fishing patterns used in the projections of the economic model:

1. Base Case fishing pattern. This is the average of last two years' effort pattern, a protocol set by NPRAG in March 2014;
2. Estimated fishing pattern (sensitivity test). This involves allowing the bio-economic model to estimate the fishing pattern to maximise the profit function in the bio-economic model (see Punt et al. 2011); and
3. An alternative fixed pattern set by NPRAG in February 2013.

Figure 9 The relative fishing patterns. (a) the Base Case, i.e., the average of last two years' effort pattern set by NPRAG (March 2014); (b) the pattern estimated from the bio-economic model; (c) the pattern set by NPRAG in February 2013 (i.e., base case for the assessment conducted in 2013). (b) and (c) were used to compare with Base Case as sensitivity test.



5.3 Stock status

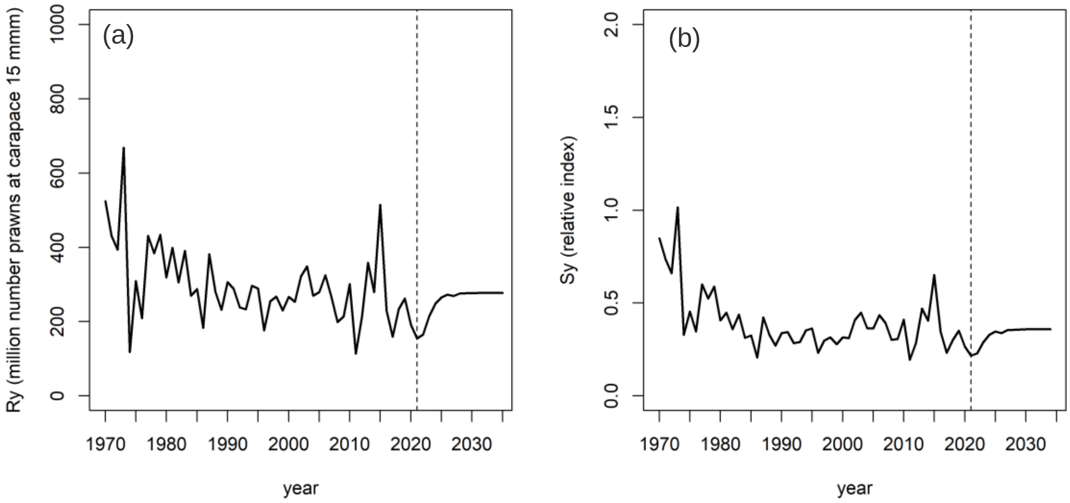
The following sections and figures describe and present the stock assessment results for Grooved and Brown Tiger Prawns, and Blue Endeavour Prawns separately.

5.3.1 GROOVED TIGER PRAWNS

The assessment model estimates of Grooved Tiger Prawn annual recruitment (R_y; millions of prawns at a carapace of 15mm) are shown in Figure 10 (left panel). A moderate decrease in recruitment was estimated from 2019 to 2021. The model projected a small increase of recruitment in 2022.

Figure 10. Estimates of recruitment (a) and spawning stock size (b) for Grooved Tiger Prawns from the Base Case model.

The vertical dotted line is 2021; any values thereafter are the results of the projections from the bio-economic model based on a stock-recruitment relationship.



The estimated spawning stock size (S_y) represents a relative measure of the abundance of female prawns in spawning condition during the year based on the model. The 2021 spawning stock size of Grooved Tiger Prawns also moderately lower than that in 2020 and is projected to be flat or to increase marginally in 2022 under deterministic projections and the assumption that recruitment is given by the stock-recruitment relationship (Figure 10) (right panel).

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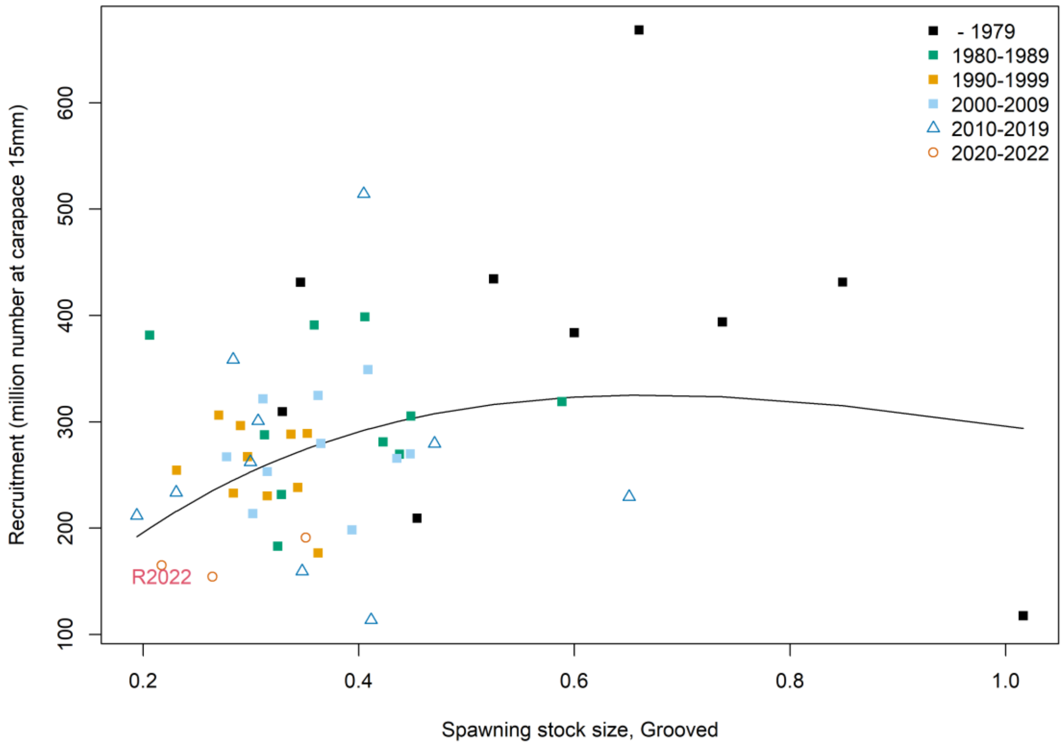
Figure 11. Estimated annual stock biomass size that produced recruits (dots), fitted as a stock-recruitment relationship (line) for Grooved Tiger Prawns for the Base Case.

The red circle with label "R2022" indicates the estimated 2021 spawning stock size and the resultant 2022 recruitment value.

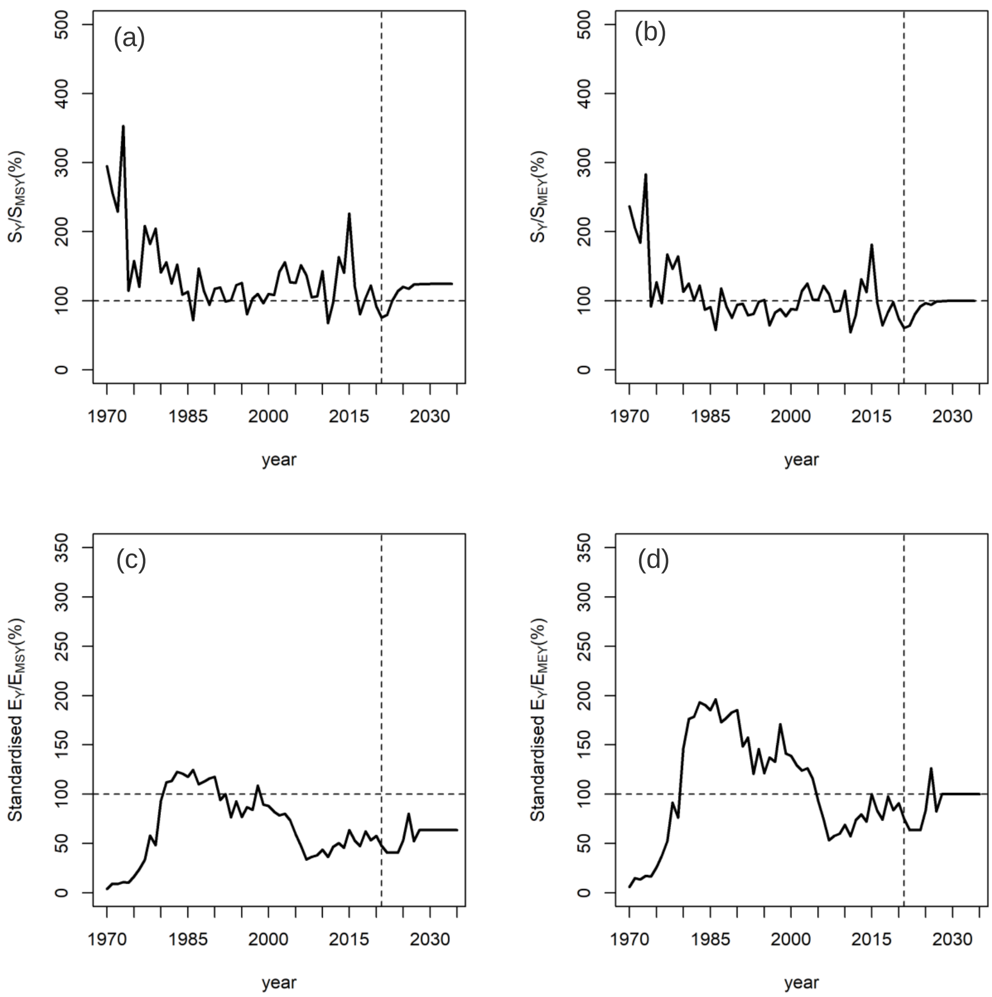


The Grooved Tiger Prawn management parameters and other quantities reported below are based on the stock-recruitment function, which relates the recruits that would be produced in the biological year to the spawners of the previous calendar year (Figure 11). Steepness, calculated by fitting a stock-recruitment relationship, is an indicator of resource productivity. The estimated value of steepness suggests that Grooved Tiger Prawn productivity is low to medium (Table Appendix A 1). The large scatter of points in Figure 11 indicates that the relationship is subject to considerable variability, which is probably temporally and environmentally driven. The colour scheme used in the figure differentiates the decadal characteristics of the relationship. In general, the early data (prior to 1980; black squares) are more variable and most of the more recent data points are evenly distributed around the estimated stock-recruitment relationship. However, it should be emphasised that the last three estimates of recruitment (since 2020) are all lower than expected. This may be a trigger point for the consideration of any fundamental changes of the species' stock. Figure 12 shows that the estimated spawning stock size for Grooved Tiger Prawns in 2021 is less (75%) than the spawning stock size corresponding to MSY (S_{MSY}). Standardised Grooved Tiger Prawn effort in 2021 was estimated to be 48% of the effort at MSY (E_{MSY}).

Table Appendix A 1 shows that the five-year moving average of $S_{2017\text{-}2021}/S_{MSY}$ is 0.95. This is above the Limit Reference Point value of 0.5. The Punt *et al.* (2010) model calculates the reference points taking into consideration the size at which the animals are caught. Effort in the Base Case is assumed to be distributed through the year according to the average of last two years' effort patterns.

Figure 12. Status of the stock and effort relative to reference points for Grooved Tiger Prawns for the Base Case.

a) Spawning stock size (S_Y) relative to the spawning stock size corresponding to Maximum Sustainable Yield (S_{MSY}), b) spawning stock size relative to the spawning stock size corresponding to Maximum Economic Yield ($\underline{S}_{MEY}$), c) standardised effort (E_Y) relative to that corresponding to



Maximum Sustainable Yield (E_{MSY}) and d) standardised effort relative to that corresponding to Maximum Economic Yield (E_{MEY}).

5.3.2 BROWN TIGER PRAWNS

The estimates of the annual recruitment of Brown Tiger Prawns is shown in Figure 13 (left panel). Recruitment decreased slightly in 2021 from 2020. Estimates of Spawning stock size represent the relative number of female prawns in spawning condition during the calendar year. The estimated time-series of spawning stock size for Brown Tiger Prawns is given in Figure 13 (right panel). The estimated spawning stock size of Brown Tiger Prawns is also estimated to have decreased slightly from 2020.

Figure 13. Estimates of recruitment (a) and spawning stock size (b) for Brown Tiger Prawns from the Base Case model.

The vertical dotted line is 2021; any values thereafter are the results of the projections from the bio-economic model based on a stock-recruitment relationship.

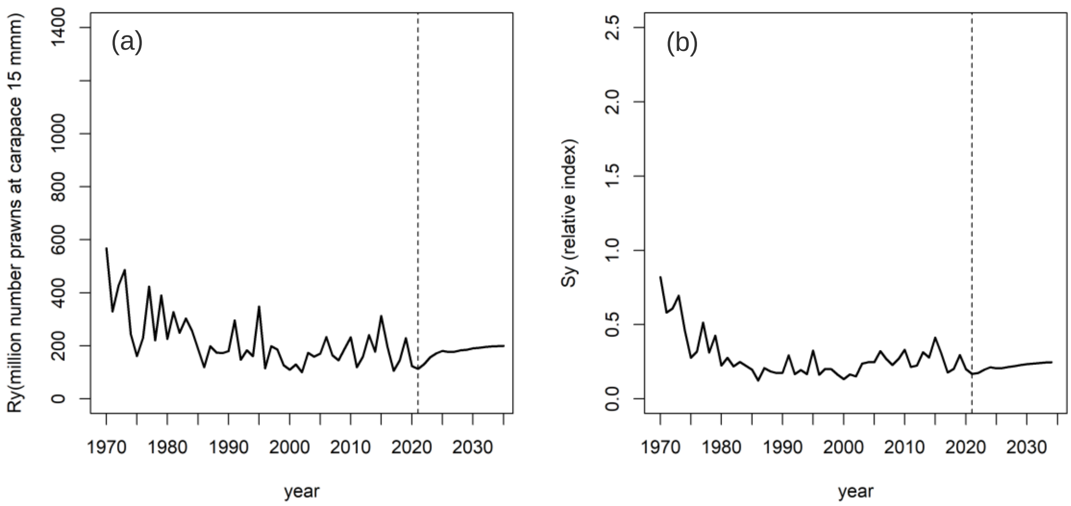
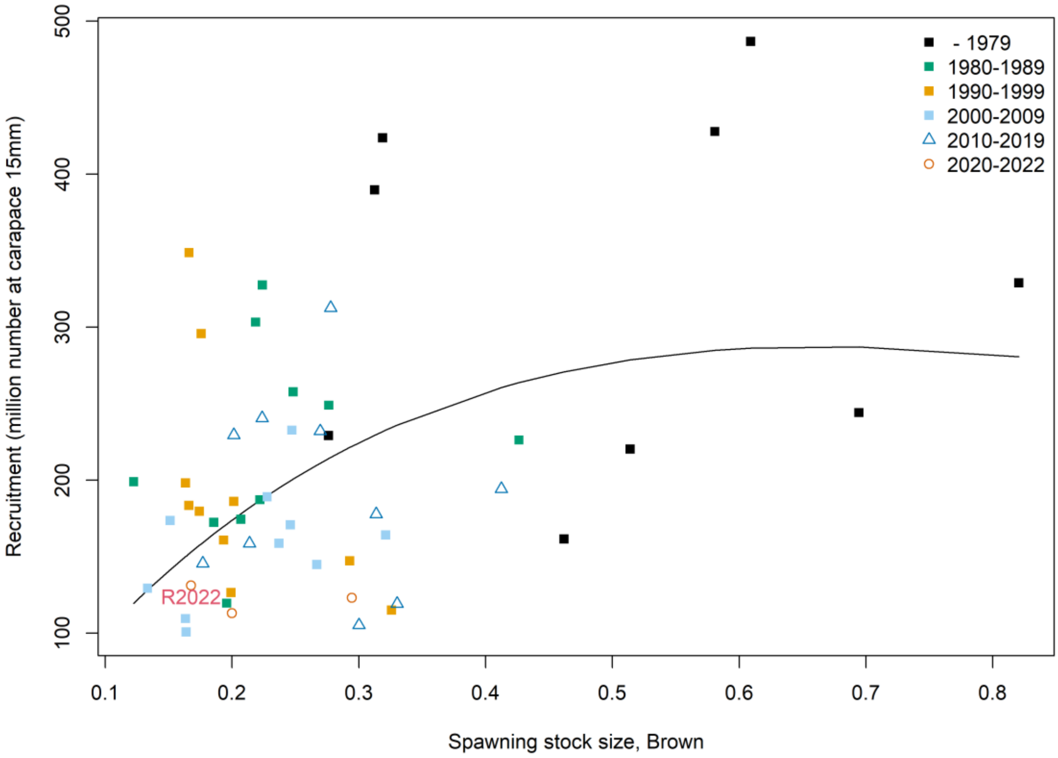


Figure 14. Estimated annual stock biomass size that produced recruits (dots), fitted as a stock-recruitment relationship (line) for Grooved Tiger Prawns for the Base Case.

The red circle with label "R2022" indicates the estimated 2021 spawning stock size and the resultant 2022 recruitment value.



The Brown Tiger Prawns Prawn management parameters and other quantities reported below are based on the stock-recruitment function, which relates the recruits that would be produced in the biological year to the spawners of the previous calendar r (Figure 14). Estimated recruitment for 2022 is low and the estimated steepness value also suggests that Brown Tiger Prawn productivity is low (Table Appendix A 1). The 2021 stock index that resulted in the 2022 recruitment is highlighted on the graph. Similar to Grooved Tiger Prawns, the last three data points are lower than expected, which suggest value in investigating whether there has been fundamental changes to the stock dynamics.

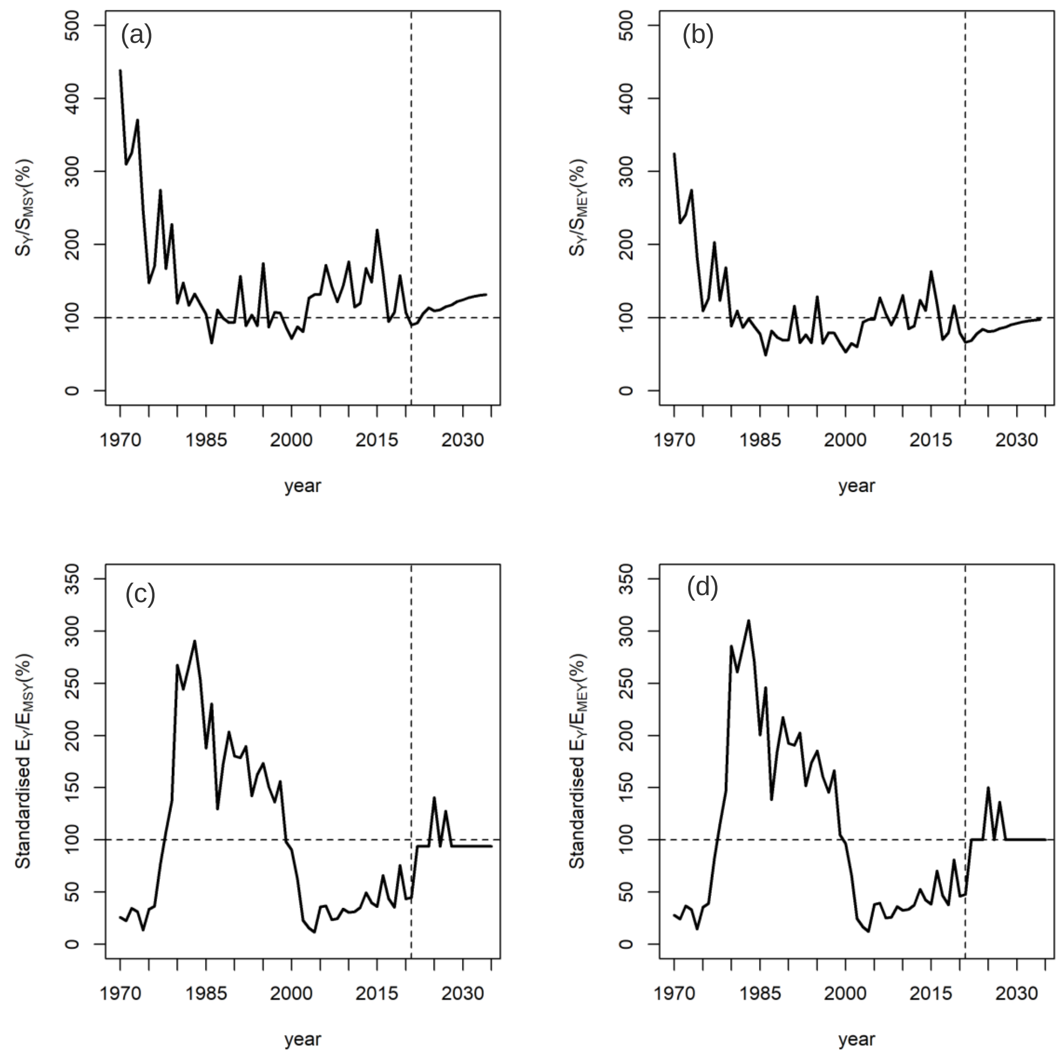
The spawning stock size Brown Tiger Prawns stock status in 2021 was estimated to be less (90%) of that corresponding to MSY (S_{MSY}) (Table Appendix A 1). Figure 15 indicates that the standardised effort in 2021 was less (45%) than the effort corresponding MSY (E_{MSY}). Similarly, Table Appendix

A 1 shows that the five-year moving average of $S_{2017\text{-}2021}/S_{MSY}$ was well above (1.11) the Limit Reference Point value of 0.5.

We note again that the Punt *et al.* (2010, 2011) model calculates the indicators whilst taking into consideration the size at which the animals are caught. Effort in the Base Case is assumed to be distributed through the year using the average of last two years' effort patterns.

Figure 15. Status of the stock and effort relative to reference points for Brown Tiger Prawns for the Base Case.

a) Spawning stock size (S_Y) relative to the spawning stock size corresponding to Maximum Sustainable Yield (S_{MSY}), b) spawning stock size relative to the spawning stock size corresponding to Maximum Economic Yield ($\underline{S}_{MEY}$), c) standardised effort (E_Y) relative to that corresponding to Maximum Sustainable Yield (E_{MSY}) and d) standardised effort relative to that corresponding to Maximum Economic Yield (E_{MEY}).

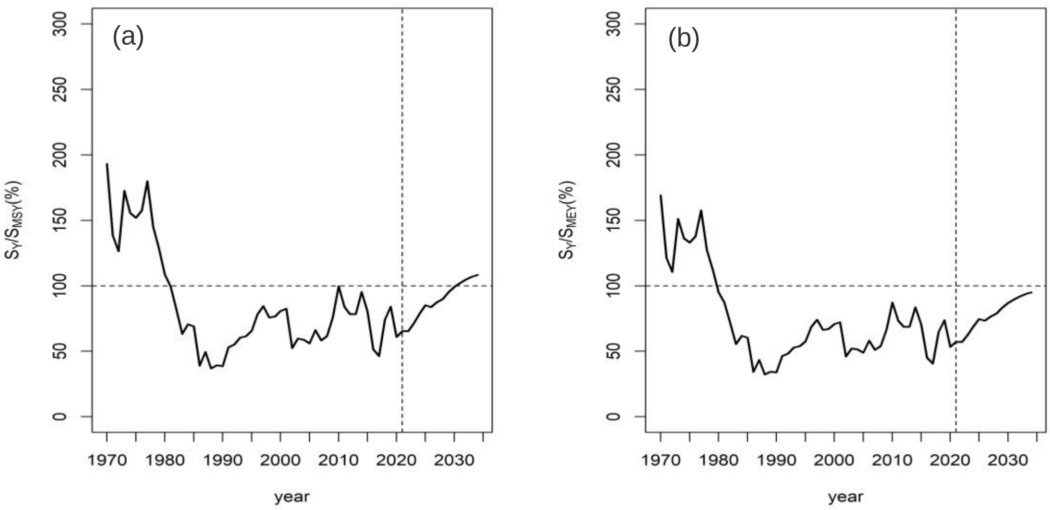


5.3.3 BLUE ENDEAVOUR PRAWNS

An assessment of Blue Endeavour Prawns is conducted using the Bayesian biomass production model (see Figure 16 and key indicators in Table Appendix A 1) but Blue Endeavour Prawns are treated as an economic byproduct in the economic projection model. The value of S_{2021}/S_{MSY}[6] is at 0.65, with $S_{2017-2021}/S_{MSY}$ estimated to be 0.66. The latter is higher than the Limit Reference Point value of 0 .5. The estimated spawning stock size trajectory from the last (Figure 17) is presented to compare with the current assessment trend. In 2020 assessment, the ratio S_{2021}/S_{MSY} was higher than in the 2022 assessment and the trend to the target of 100% less steep.

Figure 16. Estimates of spawning stock size relative to reference points for Blue Endeavour Prawns for the Base Case.

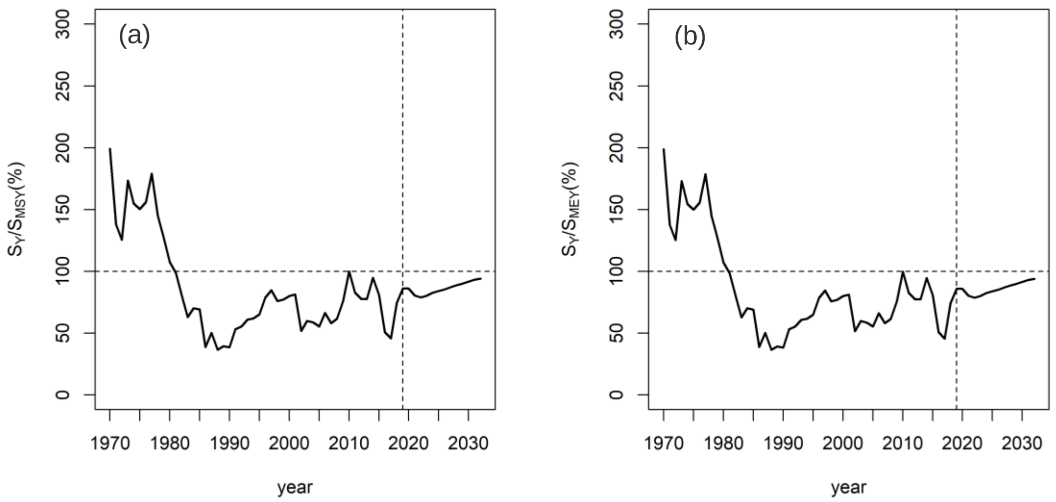
a) Spawning stock size (S_Y) relative to spawning stock size corresponding to Maximum Sustainable Yield (S_{MSY}), b) spawning stock size relative to the spawning stock size corresponding to Maximum Economic Yield (S_{MEY}).



[6] The Bayesian hierarchical biomass dynamics model estimate values for biomass thus this is strictly value of B_Y/B_{MSY}. However, the model is based on catch data and the estimated biomass is “vulnerable biomass”. It is not necessary the spawning biomass.

Figure 17 Estimates of spawning stock size relative to reference points for Blue Endeavour Prawns for the Base Case in 2020 assessment.

a) Spawning stock size (S_Y) relative to spawning stock size corresponding to Maximum Sustainable Yield (S_{MSY}), b) spawning stock size relative to the spawning stock size corresponding to Maximum Economic Yield (S_{MEY}).

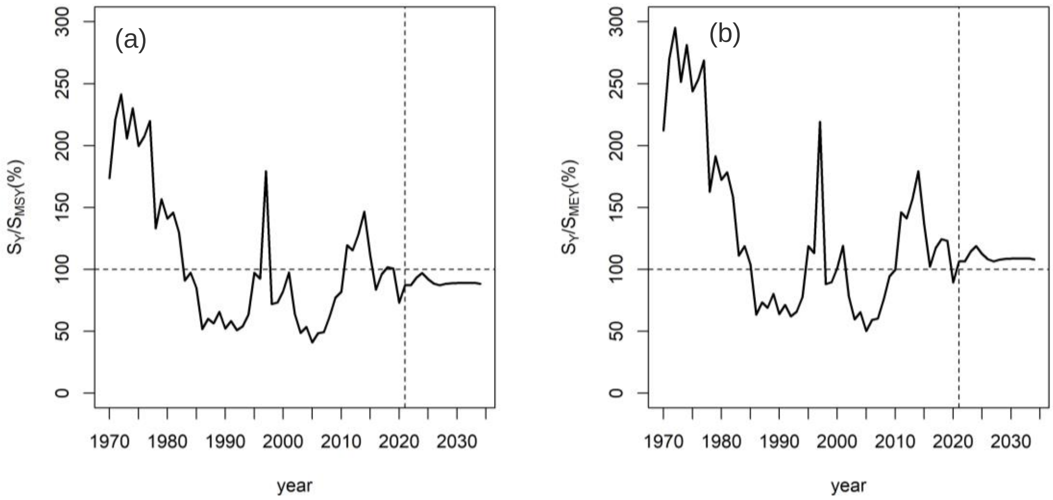


5.3.4 RED ENDEAVOUR PRAWNS

An assessment of Red Endeavour Prawns was conducted as a sensitivity test using the Bayesian biomass production model (see Figure 18 and key indicators in Table Appendix A 5). Red Endeavour Prawns are treated as an economic byproduct in the economic projection model (Figure 33). The sensitivity test indicates that the value of S_{2021}/S_{MSY} is estimated to be 0.87 and $S_{2017\text{-}2021}/S_{MSY}$ to be 0.92. The five-year moving average is above the Limit Reference Point value of 0.5 (Table Appendix A 5). These estimates remain preliminary due to the lack of red endeavour prawn-specific life history parameter information.

Figure 18. Estimates of spawning stock size relative to reference points for Red Endeavour Prawns for the 4 species sensitivity test.

a) Spawning stock size (S_Y) relative to spawning stock size corresponding to Maximum Sustainable Yield (S_{MSY}), b) spawning stock size relative to the spawning stock size corresponding to Maximum Economic Yield (S_{MEY}).



5.3.5 SENSITIVITY TESTS FOR BOTH TIGER PRAWN SPECIES

Model settings and key stock and economics-related assessment outputs are provided in Table Appendix A 2 – 5 for the four prawn species (Appendices, Appendix A).

The following scenarios explore the sensitivity of the results to assumptions of the stock assessment and economic models:

- Base Case;
- Middle-high fishing power series;
- alternative assessment model;
- fixed fishing effort pattern;
- estimated of fishing patterns;
- effort changes constrained;
- lower minimum effort threshold; and
- four-species model

They show that the highest steepness (productivity) values arise from the Base Case. The DDD model produced the lowest value for steepness. The “DDD” sensitivity tests estimates a more pessimistic stock status compared to the Base Case but the relative profit is, however, at 108% of Base Case for 2019. Not being a size-structured model, the Deriso models are unable to capture the price differentials between small and large prawns. The estimates of S2017-

2021/SMSY are greater than the Limit Reference Point for the Base Case and all sensitivity test (Table Appendix A 2 – 5) so there is no evidence from these analyses that any of the four stocks are overfished. In contrast, there are substantial differences in the values of the indicators for projected fishing effort and relative profit (82% and 84% of the Base Case values) for the “lower effort threshold” and “no effort threshold” sensitivity tests. The model responds for these two sensitivity tests to the adverse economic conditions by estimating much lower fishing effort projections to maximize NPV (Table Appendix A 2).

Fishing pattern mainly affects the estimates of profitability of the fishery: the relative profits with the “estimated pattern” are, at 104% of those for Base Case (average of the previous two years fishing) and the estimated catch values are higher. The fixed (2013 RAG) fishing pattern led to slightly (97%) lower relative profits than the Base Case. The results are not very sensitive to the alternative fishing power series (Mid-high vs Base Case in Table Appendix A 2 - 4). There was a small positive effect of constraining inter-annual effort changes to 15% or less: comparing the Base Case with the “constrained effort change” scenario, the relative profit of the “constrained effort change” scenario is about 103% of the Base Case It appears there are moderate profit differences among the alternative cases due to the adverse economic environment, such as higher fuel price and higher packing/freight costs.

5.3.6 MODEL FIT

The distribution of the catch residuals (square root-transformed differences between observed and estimated catches[7]) by Tiger Prawn species are shown for the Base Case in Figure 19. The residuals by week and year are shown in Figures 20-21. The weekly residual patterns are exhibit “runs” indicating that the assumptions regarding catchability and availability (estimated by month) are insufficient to capture changes in availability. In contrast, the residuals by year exhibit no obvious trends. The model is specified so that the total annual catch is removed almost exactly.

The fits to the recruitment and spawning survey index data are shown in Figure

[7] This transformation has been shown to be the best way to transform the data to achieve a residual distribution closest to a normal distribution (Dichmont *et al*. 2001).

22, which suggests that the model reproduces these data adequately. The confidence intervals in Figure 22 indicate both sampling error (Tables 7 and 8) and additional variation. The fits to size-composition data are shown in Figures 23-30. Some of the fits to the fishery size-composition data are poor (e.g., Figures 24 and 30). This is a long-term feature of the assessment and is attributed in part to the very limited fishery size-composition data. Figure 31 shows the estimates of biological and fishery parameters for the Base Case size-structured population model, including the recruitment seasonal availability pattern, the selectivity to the spawning and recruitment survey, and the selectivity to the fishery.

Figure 19. Distribution of the residuals (square root-transformed differences between observed and model-predicted catches) by week and year.

a) Grooved Tiger Prawns, b) Brown Tiger Prawns for the Base Case assessment.

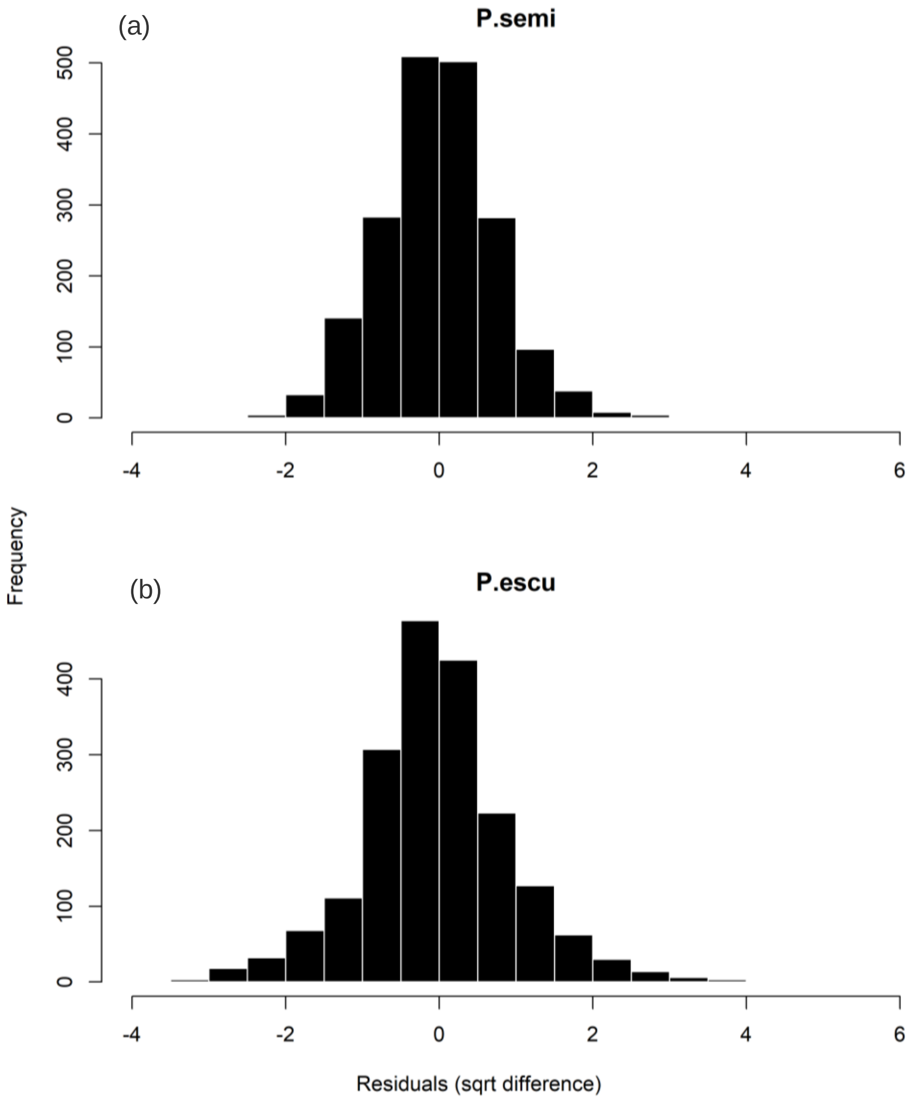


Figure 20. Total (a), within-year (b), and annual (c) residual patterns about the fit to the catch-in weight data for Grooved Tiger Prawns for the Base Case.

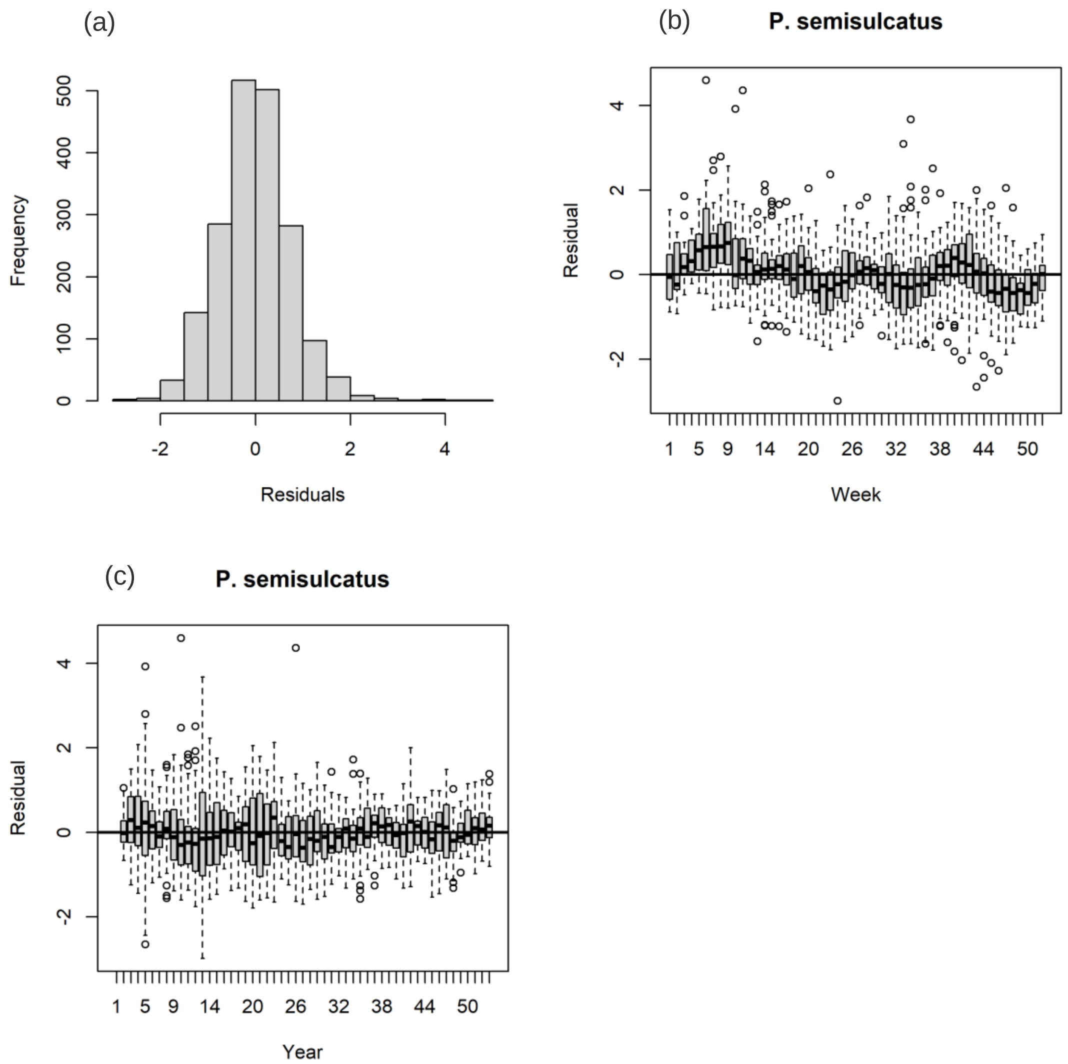


Figure 21. Total (a), within-year (b), and annual (c) residual patterns about the fit to the catch-in weight data for Brown Tiger Prawns for the Base Case.

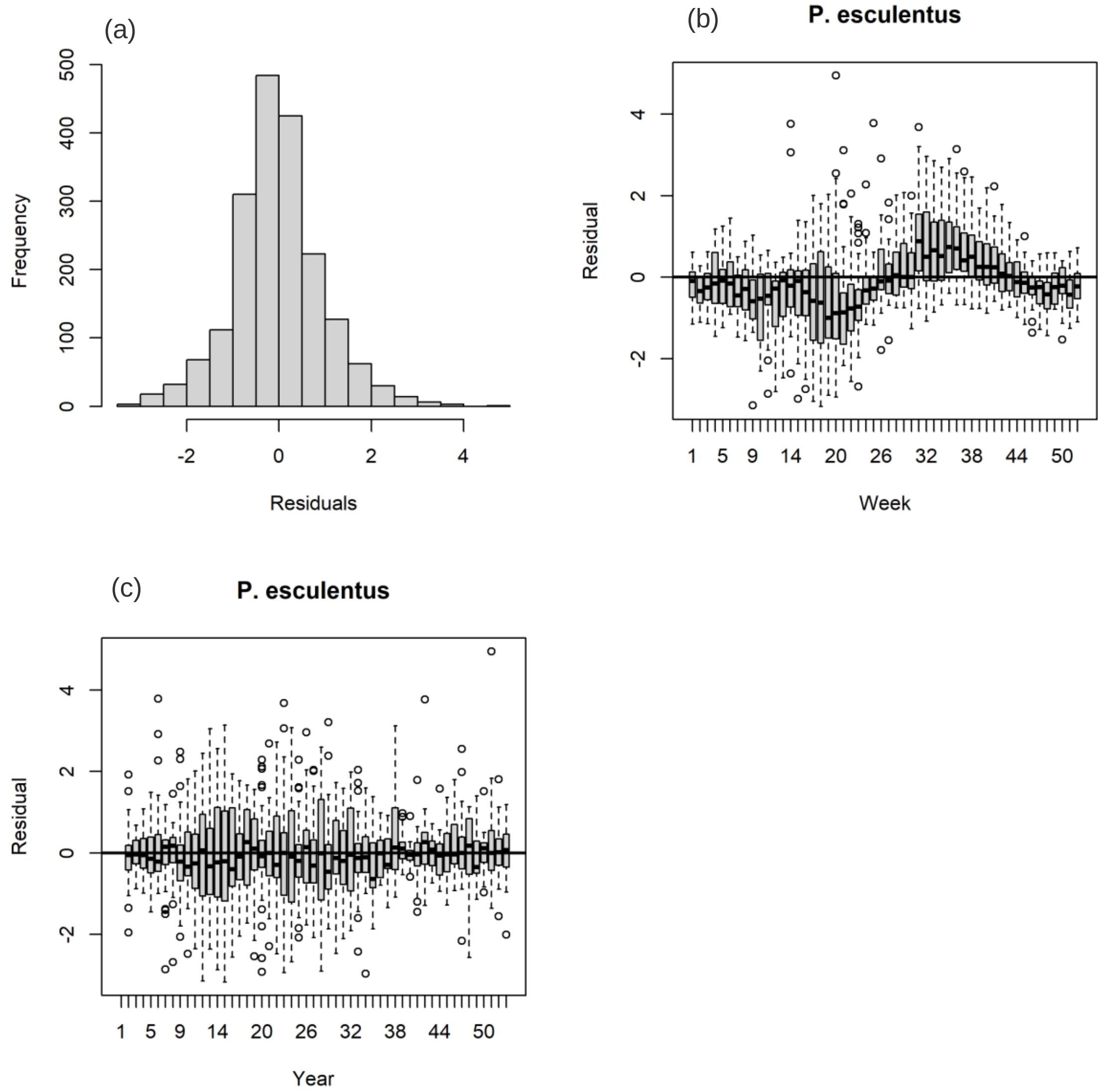


Figure 22. Observed (points as means and 1 standard error) and model-predicted index data for the Grooved and Brown Tiger Prawns' recruitment (a and b, respectively) and spawning (c and d, respectively).

The confidence intervals include both sampling error and additional variance.

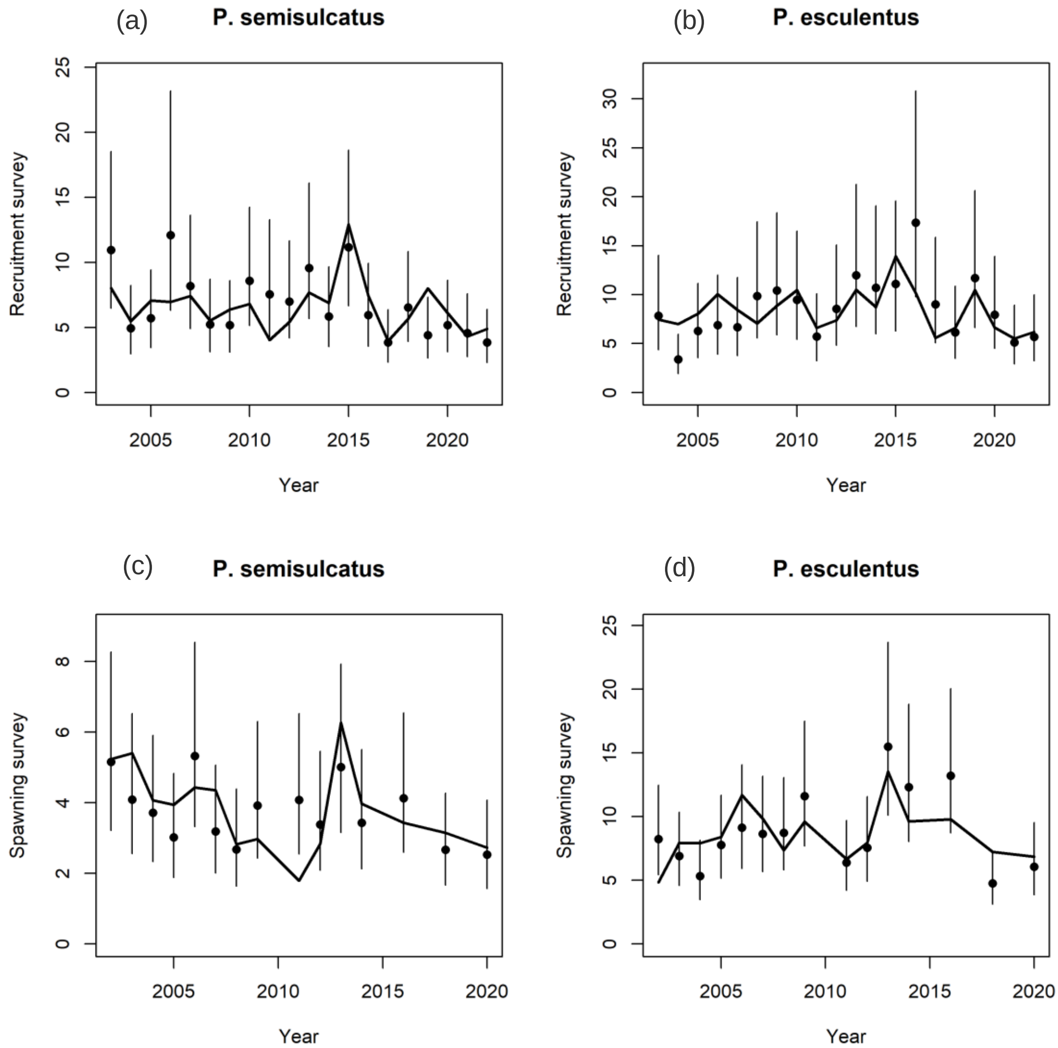
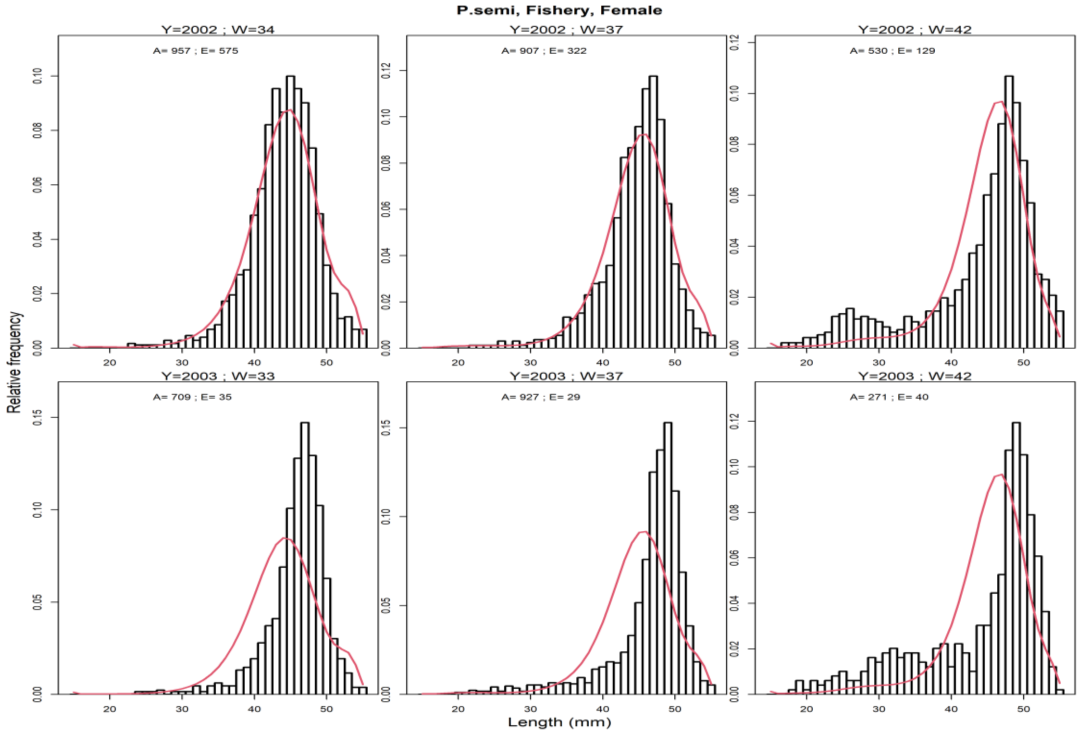


Figure 23. Observed (histograms) and model-predicted (red lines) size-compositions for the fishery for Grooved Tiger Prawns. a) female; b) male; Y = year, W = week, A = actual sample size, E = effective sample size (for all the LF plots).

a)



b)

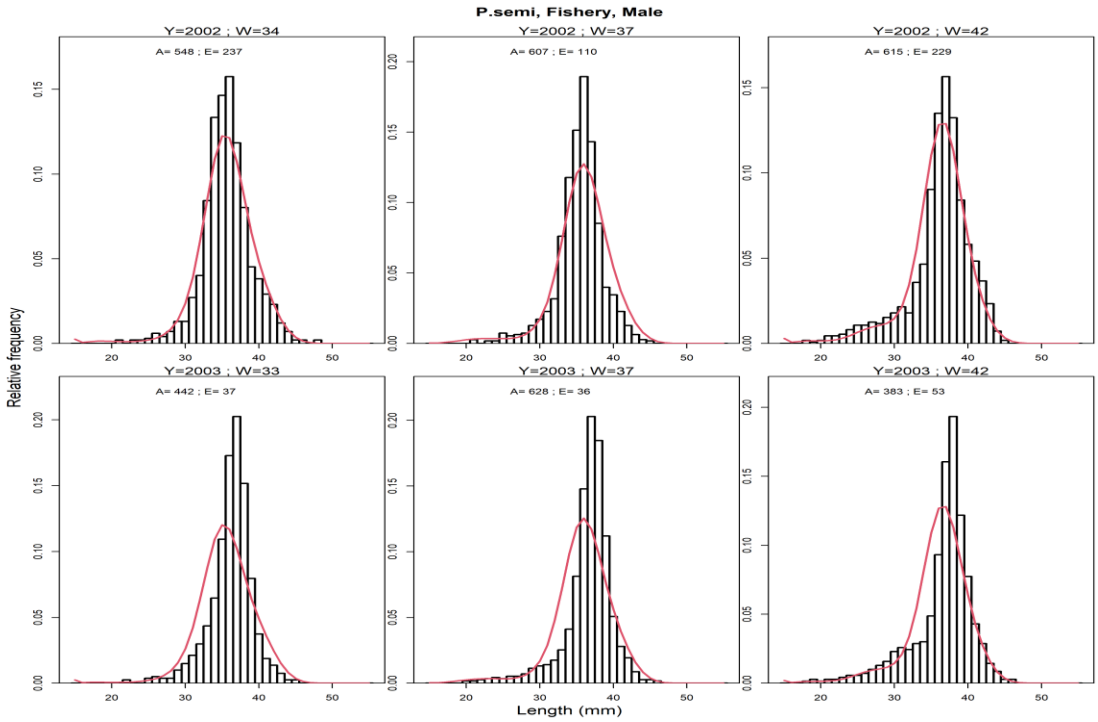
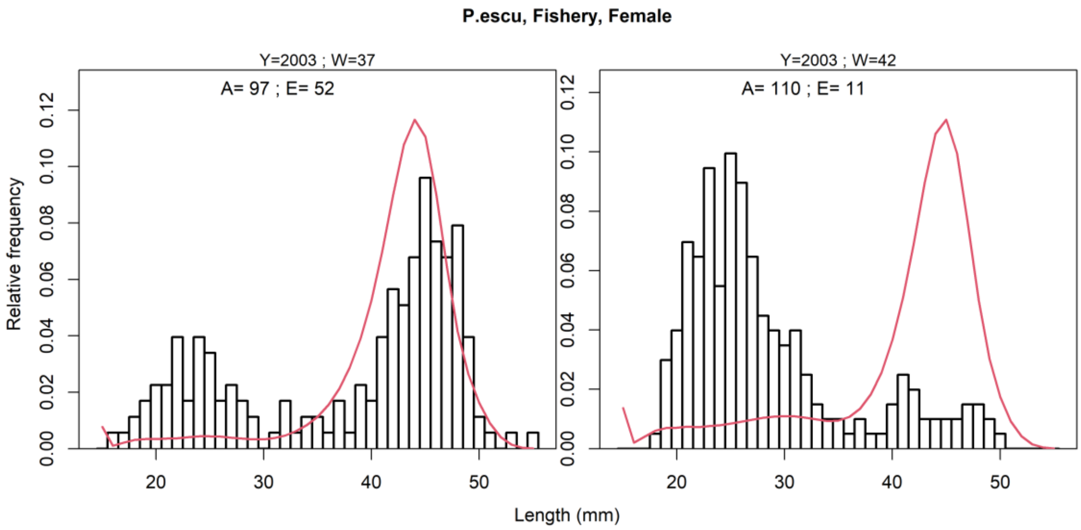


Figure 24. Observed (histograms) and model-predicted (red lines) size-compositions for the fishery for Brown Tiger Prawns**.** a) female; b) male.

a)



b)

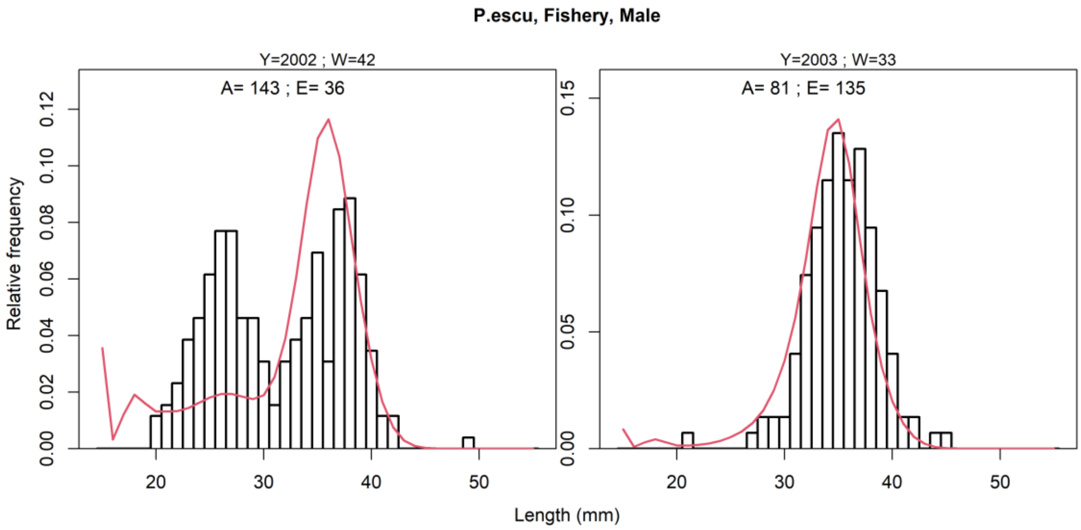
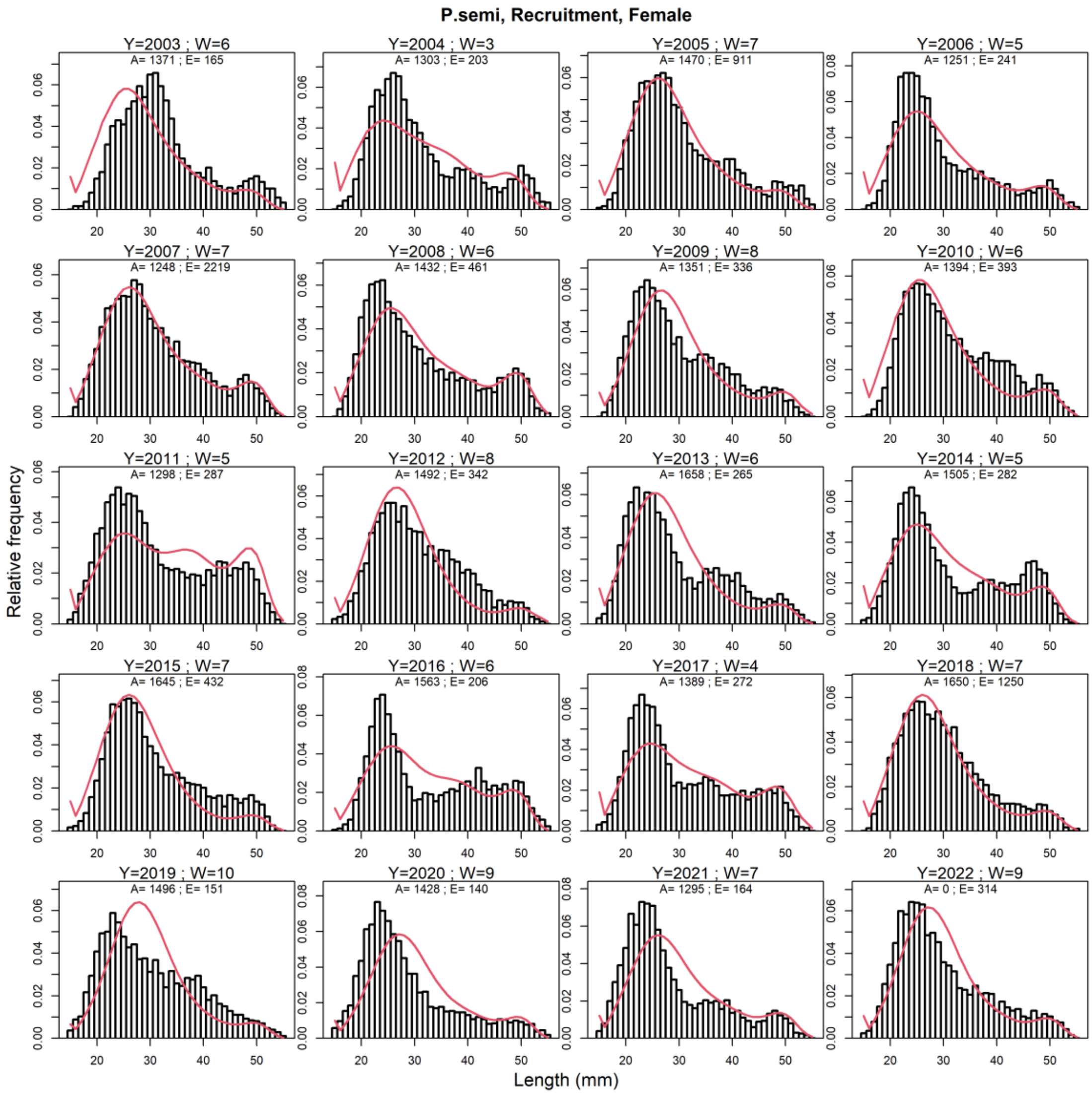


Figure 25. Observed (histograms) and model-predicted (red lines) size-compositions for the recruitment survey for Grooved Tiger Prawns**.** a) female; b) male

a)



b)

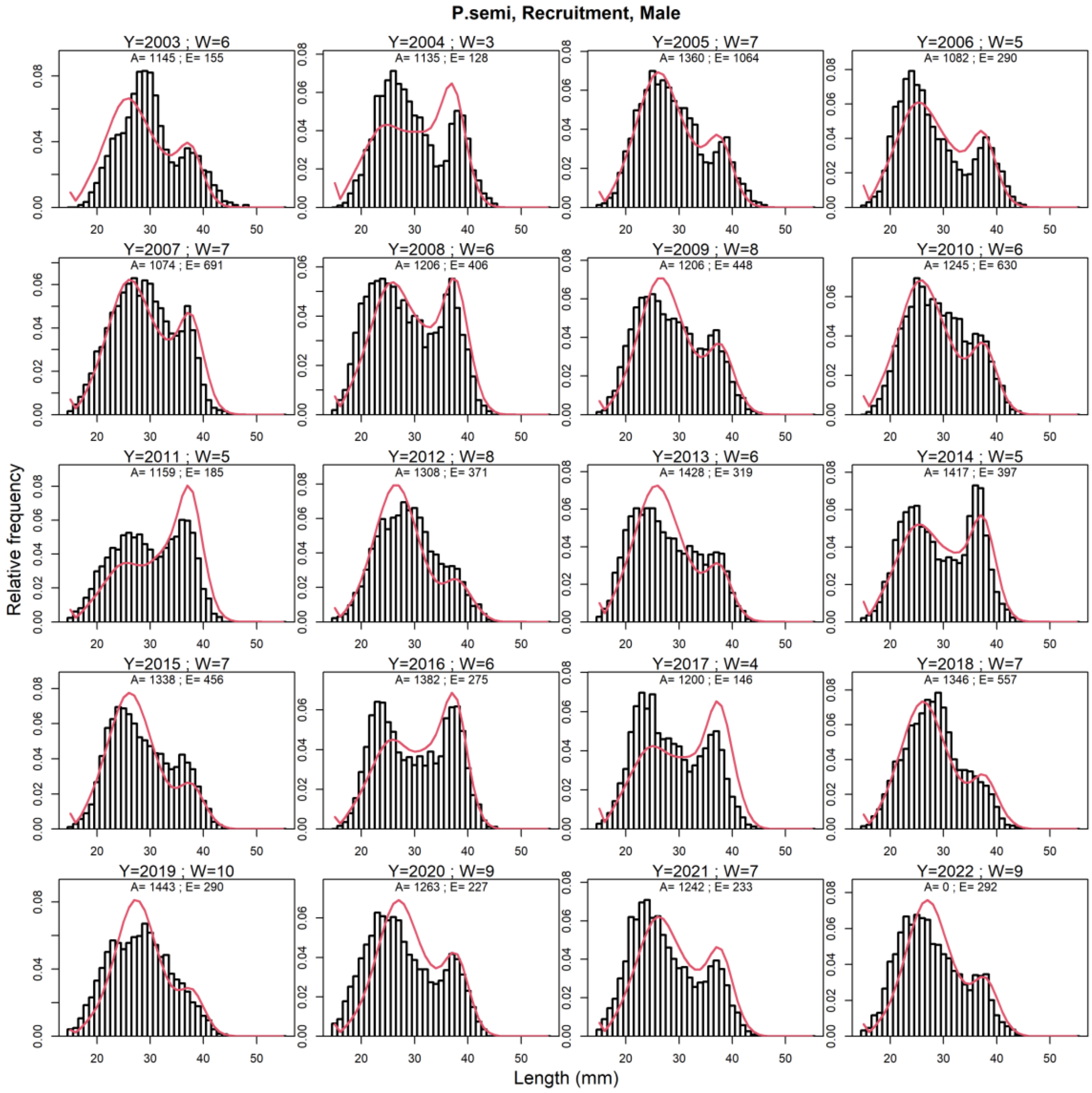
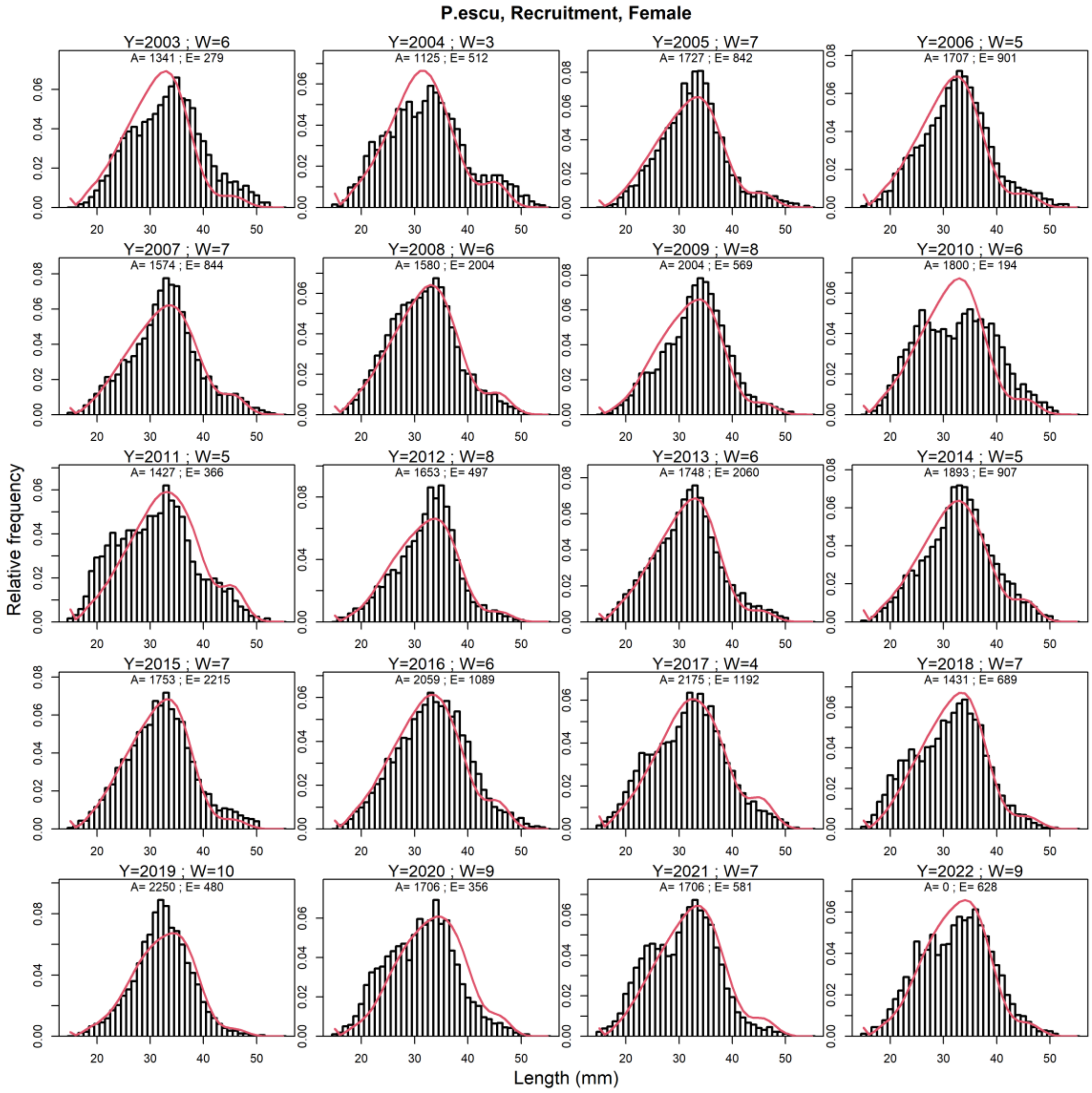

P.semi, Recruitment, Male
Y=2003 ; W=6
A= 1145 ; E= 155
Y=2004 ; W=3
A= 1135 ; E= 128
Y=2005 ; W=7
A= 1360 ; E= 1064
Y=2006 ; W=5
A= 1082 ; E= 290
Y=2007 ; W=7
A= 1074 ; E= 691
Y=2008 ; W=6
A= 1206 ; E= 406
Y=2009 ; W=8
A= 1206 ; E= 448
Y=2010 ; W=6
A= 1245 ; E= 630
Y=2011 ; W=5
A= 1159 ; E= 185
Y=2012 ; W=8
A= 1308 ; E= 371
Y=2013 ; W=6
A= 1428 ; E= 319
Y=2014 ; W=5
A= 1417 ; E= 397
Y=2015 ; W=7
A= 1338 ; E= 456
Y=2016 ; W=6
A= 1382 ; E= 275
Y=2017 ; W=4
A= 1200 ; E= 146
Y=2018 ; W=7
A= 1346 ; E= 557
Y=2019 ; W=10
A= 1443 ; E= 290
Y=2020 ; W=9
A= 1263 ; E= 227
Y=2021 ; W=7
A= 1242 ; E= 233
Y=2022 ; W=9
A= 0 ; E= 292
Relative frequency
Length (mm)

Figure 26. Observed (histograms) and model-predicted (red lines) size-compositions for the recruitment survey for Brown Tiger Prawns. a) female; b) male

a)



b)

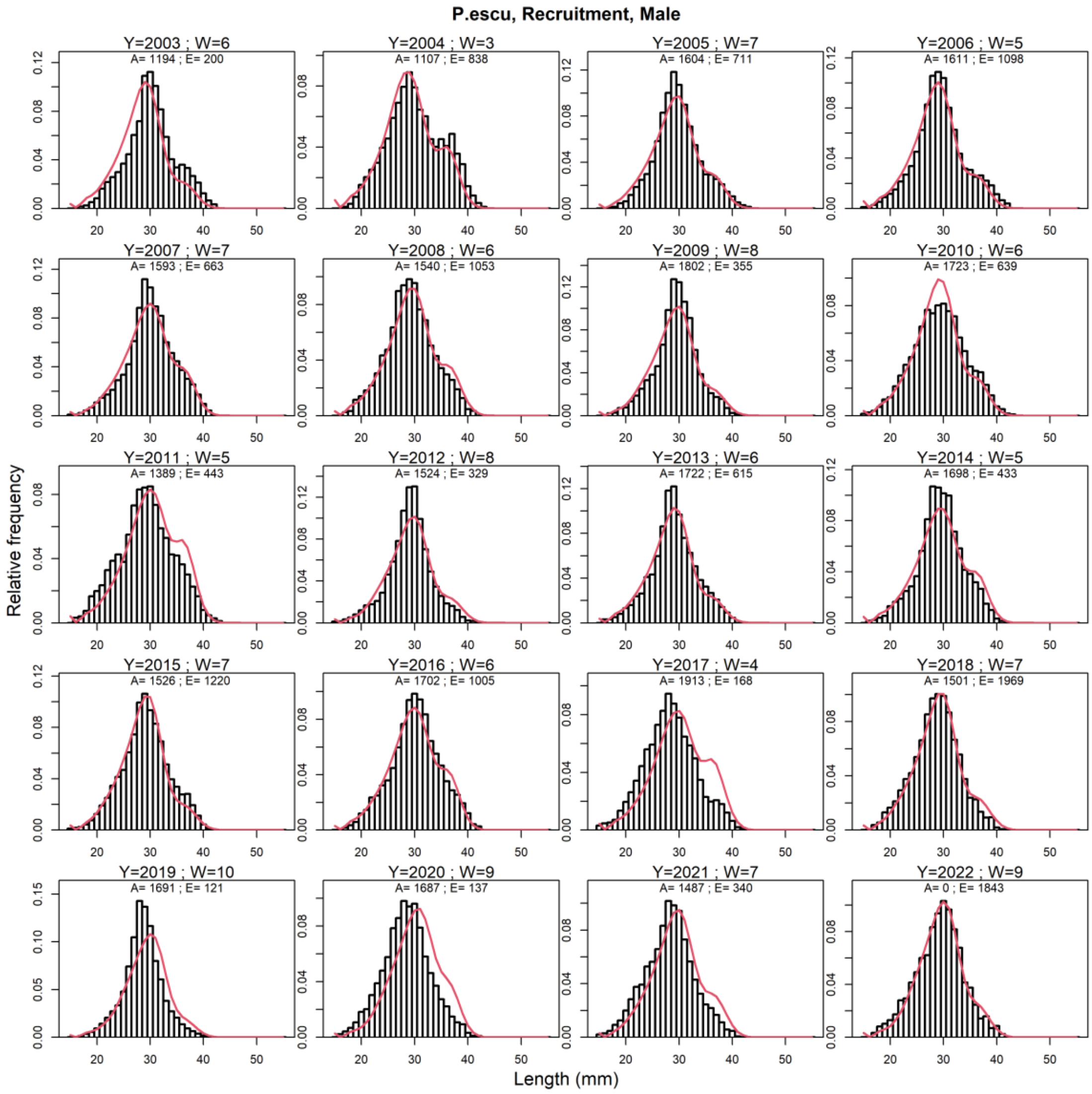
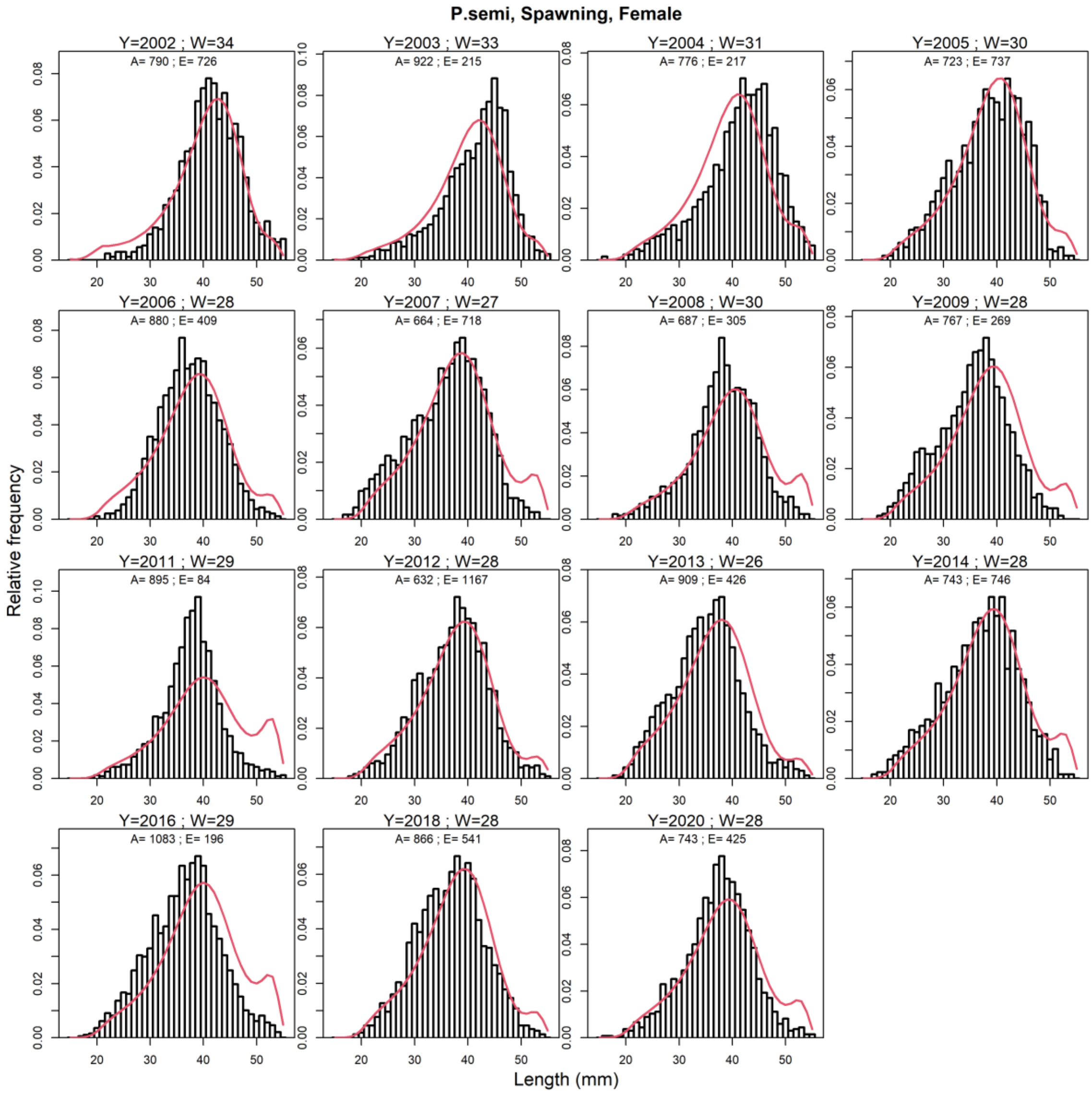

P.escu, Recruitment, Male
Y=2003 ; W=6
A= 1194 ; E= 200
Y=2004 ; W=3
A= 1107 ; E= 838
Y=2005 ; W=7
A= 1604 ; E= 711
Y=2006 ; W=5
A= 1611 ; E= 1098
Y=2007 ; W=7
A= 1593 ; E= 663
Y=2008 ; W=6
A= 1540 ; E= 1053
Y=2009 ; W=8
A= 1802 ; E= 355
Y=2010 ; W=6
A= 1723 ; E= 639
Y=2011 ; W=5
A= 1389 ; E= 443
Y=2012 ; W=8
A= 1524 ; E= 329
Y=2013 ; W=6
A= 1722 ; E= 615
Y=2014 ; W=5
A= 1698 ; E= 433
Y=2015 ; W=7
A= 1526 ; E= 1220
Y=2016 ; W=6
A= 1702 ; E= 1005
Y=2017 ; W=4
A= 1913 ; E= 168
Y=2018 ; W=7
A= 1501 ; E= 1969
Y=2019 ; W=10
A= 1691 ; E= 121
Y=2020 ; W=9
A= 1687 ; E= 137
Y=2021 ; W=7
A= 1487 ; E= 340
Y=2022 ; W=9
A= 0 ; E= 1843
Relative frequency
Length (mm)

Figure 27. Observed (histograms) and model-predicted (red lines) size-compositions for the spawning survey for Grooved Tiger Prawns. a) female; b) male

a)



b)

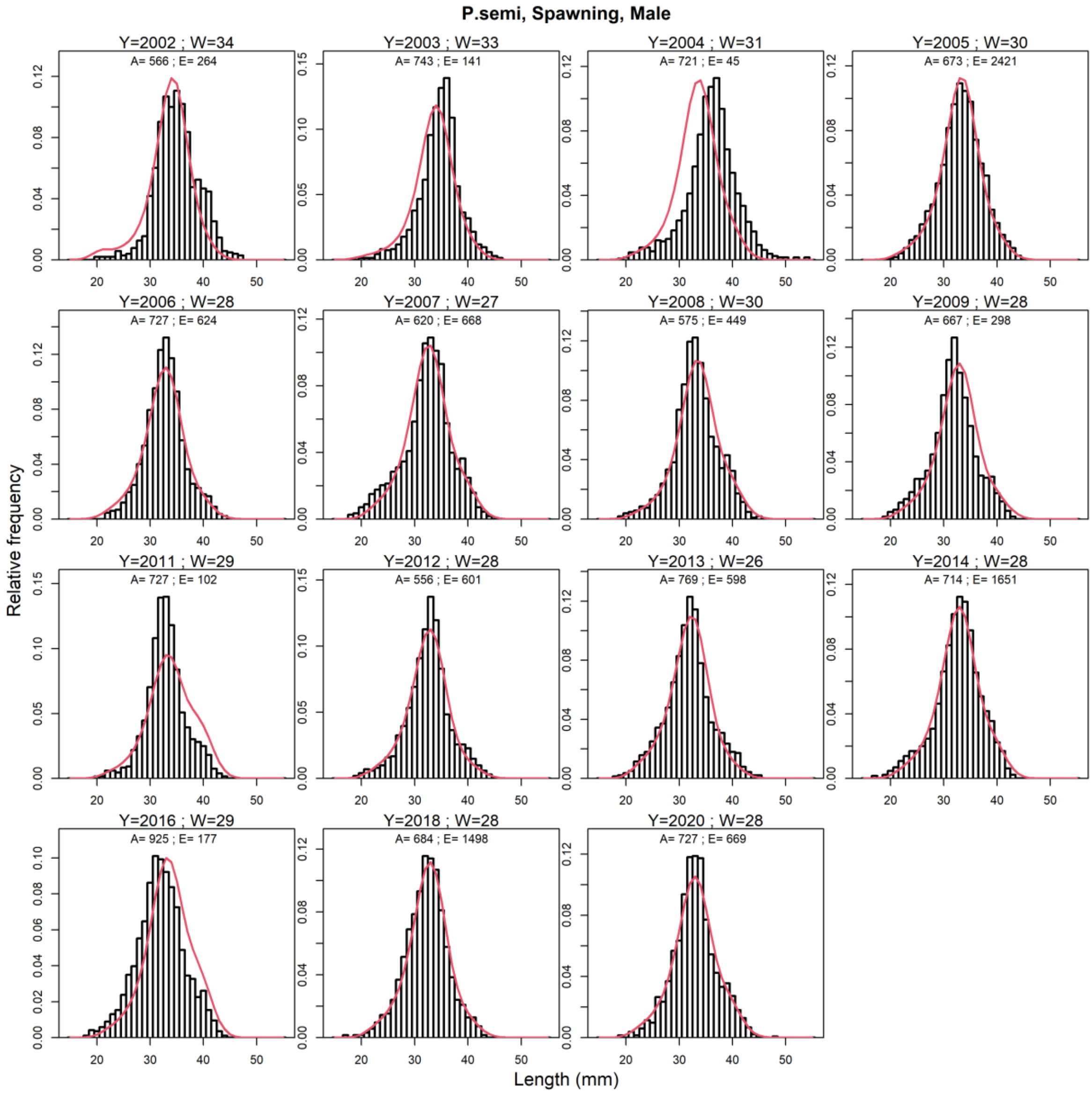
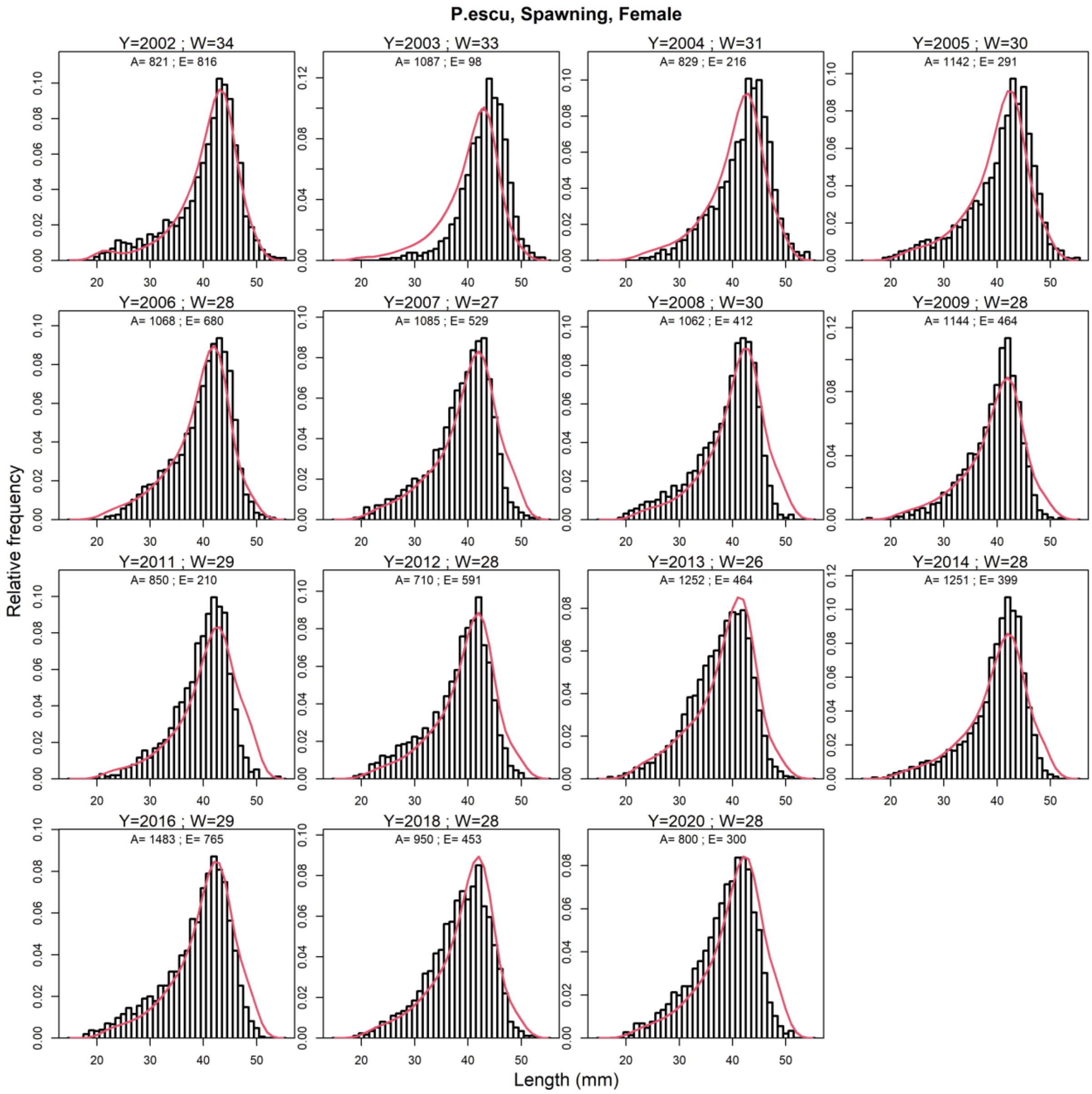

P.semi, Spawning, Male
Y=2002 ; W=34
A= 566 ; E= 264
Y=2003 ; W=33
A= 743 ; E= 141
Y=2004 ; W=31
A= 721 ; E= 45
Y=2005 ; W=30
A= 673 ; E= 2421
Y=2006 ; W=28
A= 727 ; E= 624
Y=2007 ; W=27
A= 620 ; E= 668
Y=2008 ; W=30
A= 575 ; E= 449
Y=2009 ; W=28
A= 667 ; E= 298
Y=2011 ; W=29
A= 727 ; E= 102
Y=2012 ; W=28
A= 556 ; E= 601
Y=2013 ; W=26
A= 769 ; E= 598
Y=2014 ; W=28
A= 714 ; E= 1651
Y=2016 ; W=29
A= 925 ; E= 177
Y=2018 ; W=28
A= 684 ; E= 1498
Y=2020 ; W=28
A= 727 ; E= 669
Relative frequency
Length (mm)

Figure 28. Observed (histograms) and model-predicted (red lines) size-compositions for the spawning survey for Brown Tiger Prawns. a) female; b) male

a)



b)

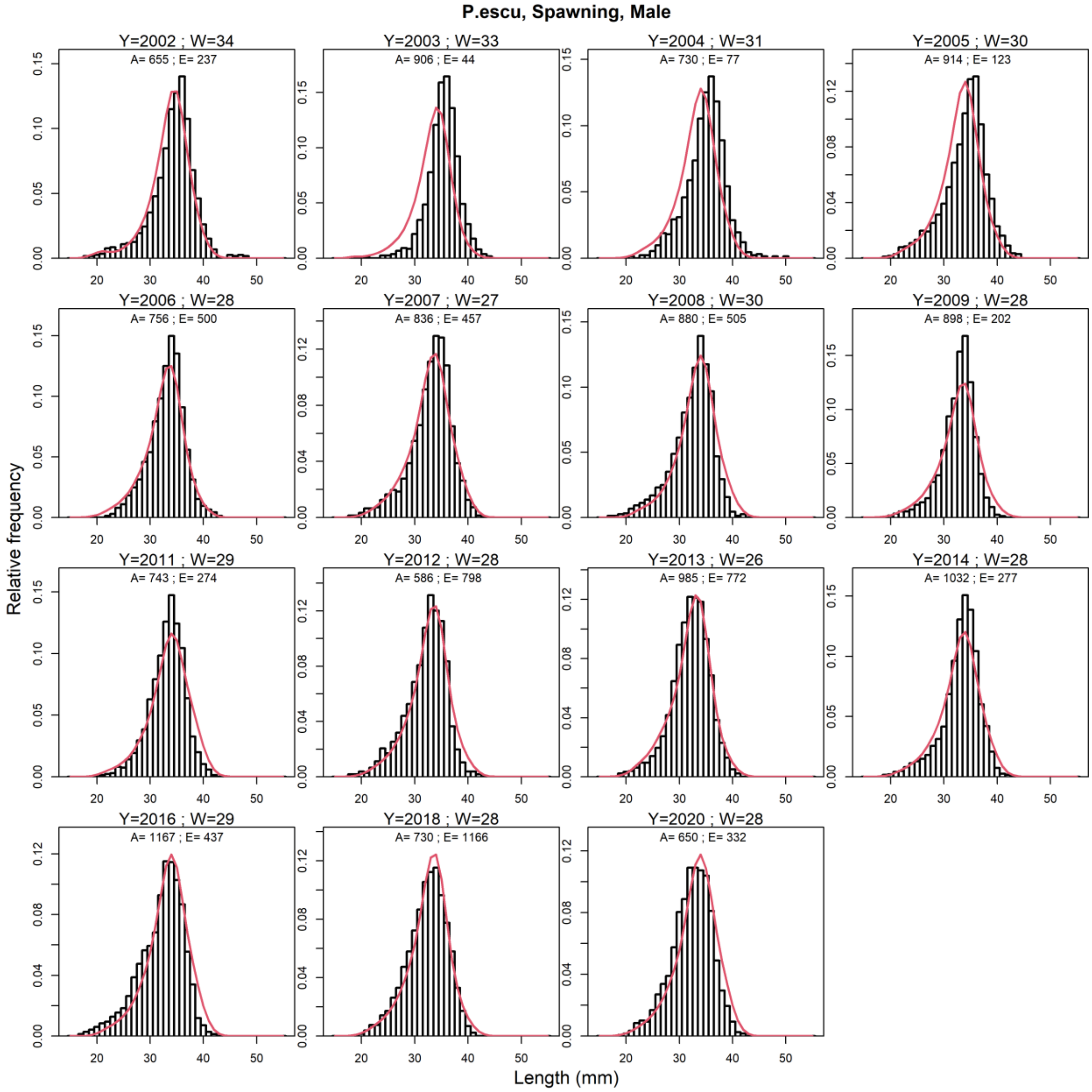

P.escu, Spawning, Male
Y=2002 ; W=34
A= 655 ; E= 237
Y=2003 ; W=33
A= 906 ; E= 44
Y=2004 ; W=31
A= 730 ; E= 77
Y=2005 ; W=30
A= 914 ; E= 123
Y=2006 ; W=28
A= 756 ; E= 500
Y=2007 ; W=27
A= 836 ; E= 457
Y=2008 ; W=30
A= 880 ; E= 505
Y=2009 ; W=28
A= 898 ; E= 202
Y=2011 ; W=29
A= 743 ; E= 274
Y=2012 ; W=28
A= 586 ; E= 798
Y=2013 ; W=26
A= 985 ; E= 772
Y=2014 ; W=28
A= 1032 ; E= 277
Y=2016 ; W=29
A= 1167 ; E= 437
Y=2018 ; W=28
A= 730 ; E= 1166
Y=2020 ; W=28
A= 650 ; E= 332
Relative frequency
Length (mm)

Figure 29. Observed (histograms) and model-predicted (red lines) size-compositions combined over time for Grooved Tiger Prawns in general, regarding spawning, and regarding recruitment for females (a, c, and e, respectively) and males (b, d, and f, respectively).

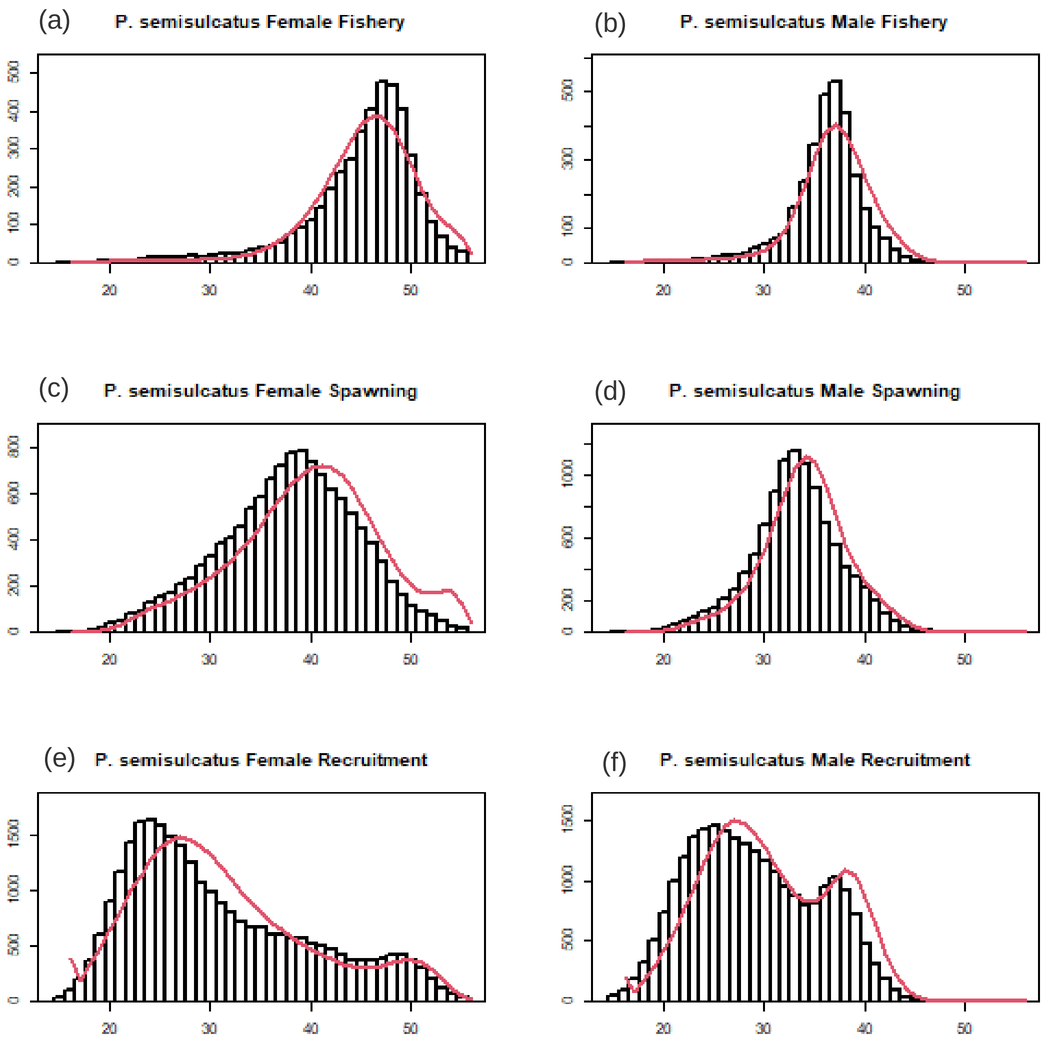


Figure 30. Observed (histograms) and model-predicted (red lines) size-compositions combined over time for Brown Tiger Prawns in general, regarding spawning, and regarding recruitment for females (a, c, and e, respectively) and males (b, d, and f, respectively).

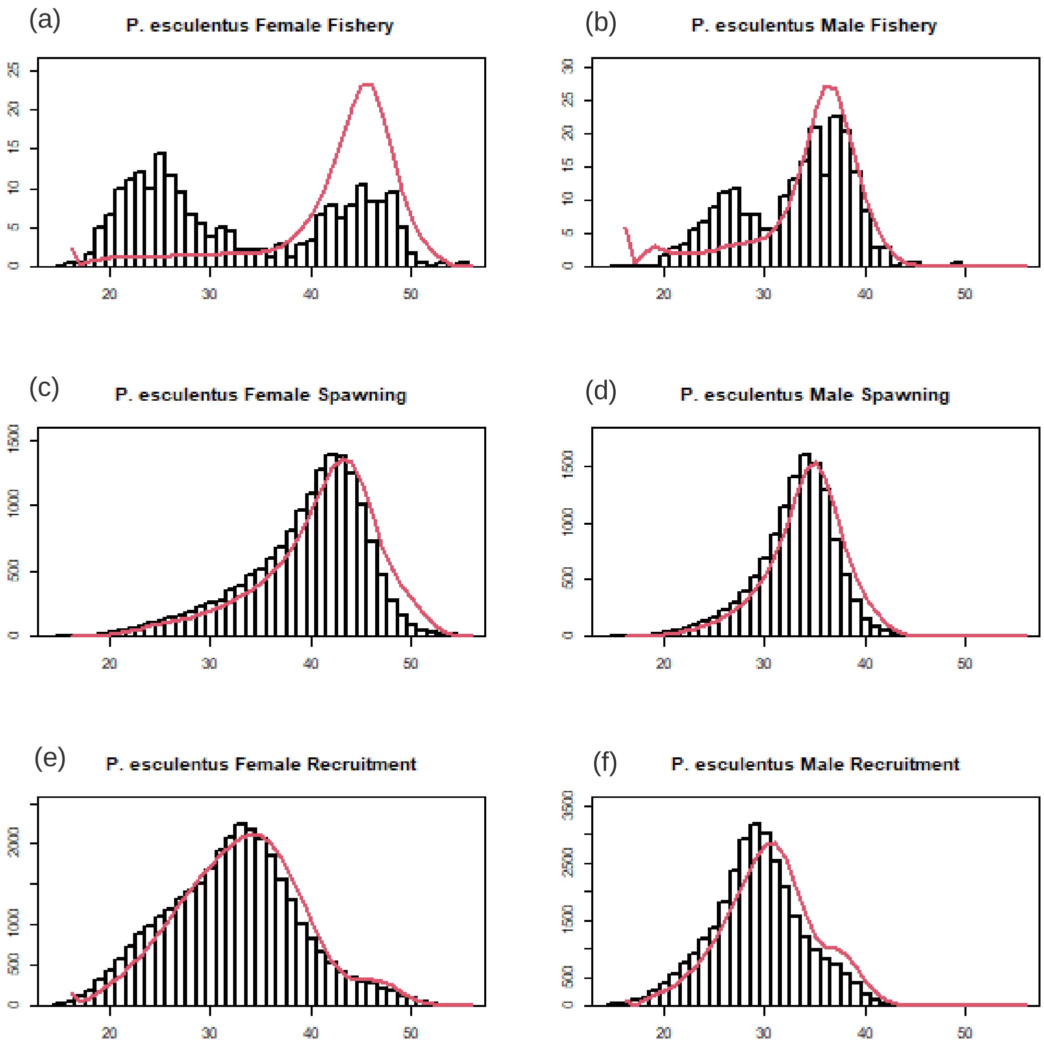
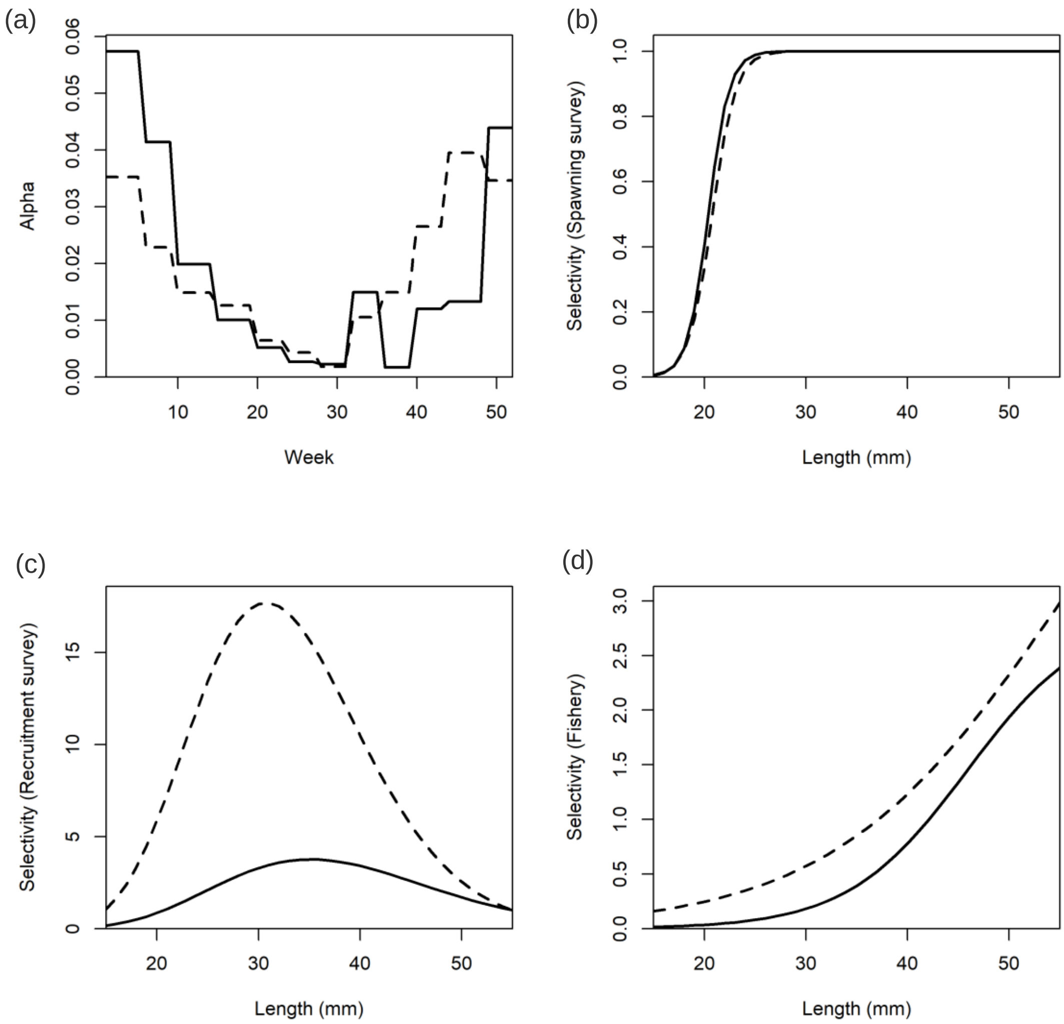


Figure 31. Estimates of biological and fishery parameters for the Base Case size-structured population model (Solid lines - Grooved Tiger Prawns; dashed lines for Brown Tiger Prawns.

(a) monthly recruitment pattern, (b) selectivity to the spawning survey, (c) selectivity to the recruitment survey, and (d) selectivity to the fishery.



5.4 Economics

Current and future (predicted) prawn prices and fuel prices (Table 9) were provided by Prof. Tom Kompas (University of Melbourne). Average prawn prices (Table 9a) relate to 2021-2022. The price ratio split across the different size grades is based on information provided by David Carter (Austral Fisheries Pty Ltd.) in February 2014.

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In this section we refer to the cost data provided in Table 9b. The cost of the labour parameter is the crew share of revenue, which is a proportion of total revenue. The “other variable costs” represent packaging, freight and other marketing related costs (including levies). Repairs and maintenance costs (which include gear costs) are estimated on a cost per day basis. Fuel and grease costs are also estimated on a cost per day basis. Annual vessel costs include administration, licence costs, insurance and other annual costs, but exclude interest and rent payments.

The capital costs estimate is provided in Table 9b. As with the annual fixed costs, a share of total capital costs (for the whole NPF) was allocated to the Tiger Prawn fishery, based on its share of total revenue (i.e. considering also the revenue earned from the banana prawn fishery).

The opportunity cost of capital (which is the “normal” expected rate of return on investment in the fishery, and is also equivalent to the discount rate used in the analysis) and the economic depreciation rate (which measures how much capital depreciates each year when fishing, after allowing for repairs and maintenance) are unchanged from the previous assessments. Table 9c provides the price and fuel cost indices used in the projections.

For most of the scenarios (Base Case plus sensitivity tests) for the two Tiger Prawn species, the stock size was close to the estimated S_{MEY} by 2028 (Table Appendix A 2 and Table Appendix A 3). Stock size of Blue Endeavour Prawns is close to S_{MSY} but would need further time to reach the estimated S_{MEY} (Figure 16 and Table Appendix A 4).

Table 9. The Base Case prices (a) and the cost variables (b) used in the current assessment (this report) as well as (c) the future (up to 2026) predicted price and fuel cost change indices.

(a) Prices (A$/kg)[8]

Species Group	All sizes	< 40 mm	40-45 mm	45-50 mm	50-55 mm	> 55 mm
Tiger prawns	20.3	16.0	20.9	23.00	27.2	32.1
Endeavour prawns	11.1					

(b) Cost variables[9]

Parameter	Values	Values used in the last assessment
Cost of labour multiplier, c_L	0.24	0.27
Unit cost of other costs, c_M	1.70 (A$/kg)	1.01 (A$/kg)
Unit cost of repairs and maintenance, c_K	504 (A$/day)	323 (A$/day)
Base unit cost of fuel and grease, c_F	2,330 (A$/day)	1,295 (A$/day)
Annual vessel costs, W_y	310,330 (A$/vessel)	305,822 (A$/vessel)
Opportunity cost of capital, o	0.05	0.05
Economic depreciation rate, d	0.02	0.02
Average value of capital, K_y	518,941 (A$ / vessel)	562,057 (A$/vessel)

(c) Prawn prices and fuel costs index[10]

Year	Prawn prices index	Fuel costs index
2022	100	100
2023	104.1	103.4
2024	106.8	104.8
2025	107.2	104.9
2026	107.8	105.2
2027	108.1	105.3
2028	108.2	105.4

[8] average prices provided by Tom Kompas and category prices are updated using information by David Carter;

[9] provided by Sean Pascoe and Tom Kompas;

[10] provided by Tom Kompas;

It should be noted when looking at the estimated effort projections (Figure 32), that annual effort will move up or down around in the first few years and then to stabilize as stock sizes approach the target levels, (S_{2021}/S_{MEY} is 61% and 66% for Grooved and Brown Tiger Prawns respectively), and reach equilibrium effort during the last few years of the projection (Figure 32). Figure 32 shows the predicted future catches, S_Y/S_{MEY}, and profit for the Base Case, along with the effort trends (as discussed).

Figure 32. The key bio-economic model results (indicators) for the Base Case

(a) Tiger Prawn effort (standardised boat days), (b) prawn catch (tonnes), (c) S_Y/S_{MSY}, and (d) total projected profit (millions of Australian dollars) for the Base Case assessment and projection settings.

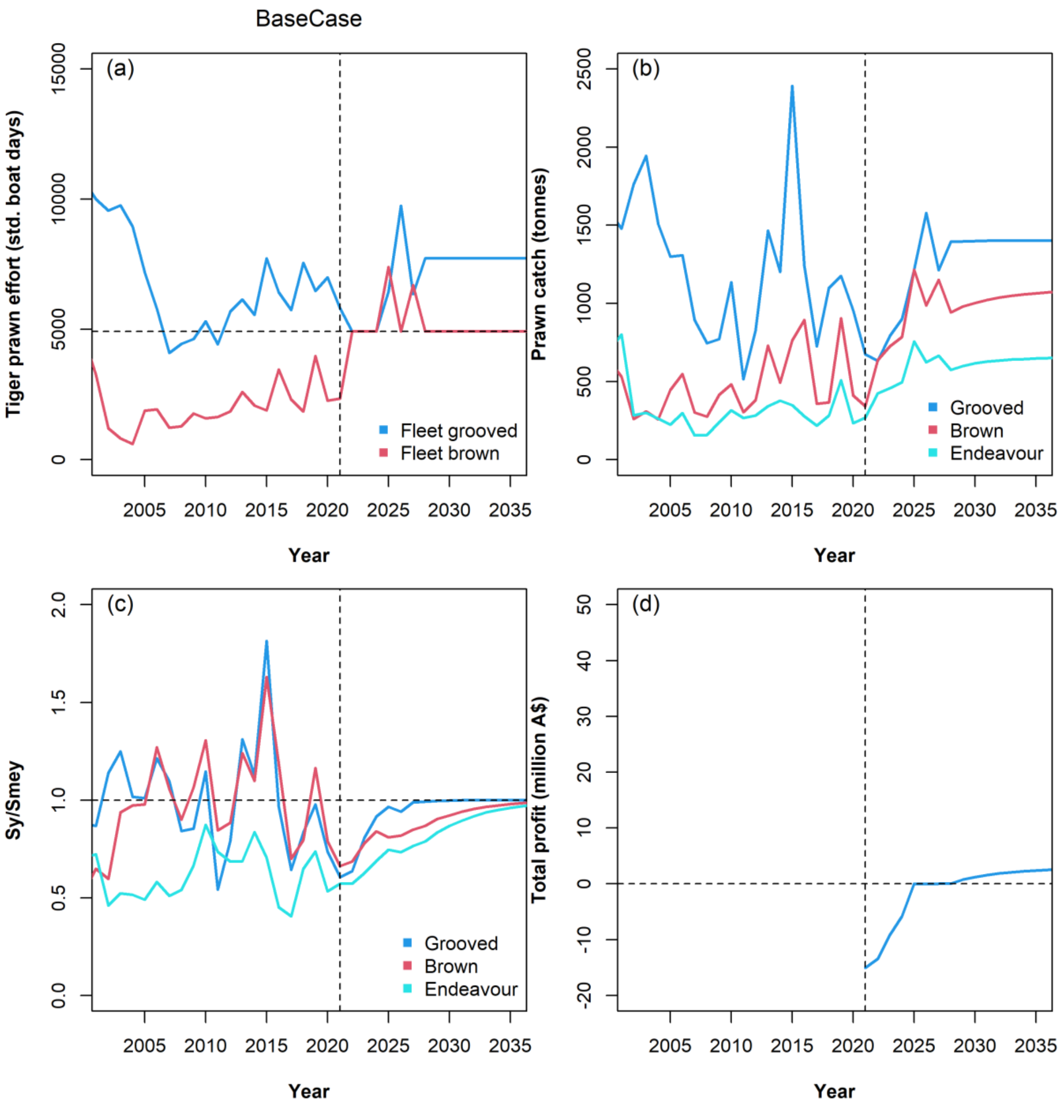
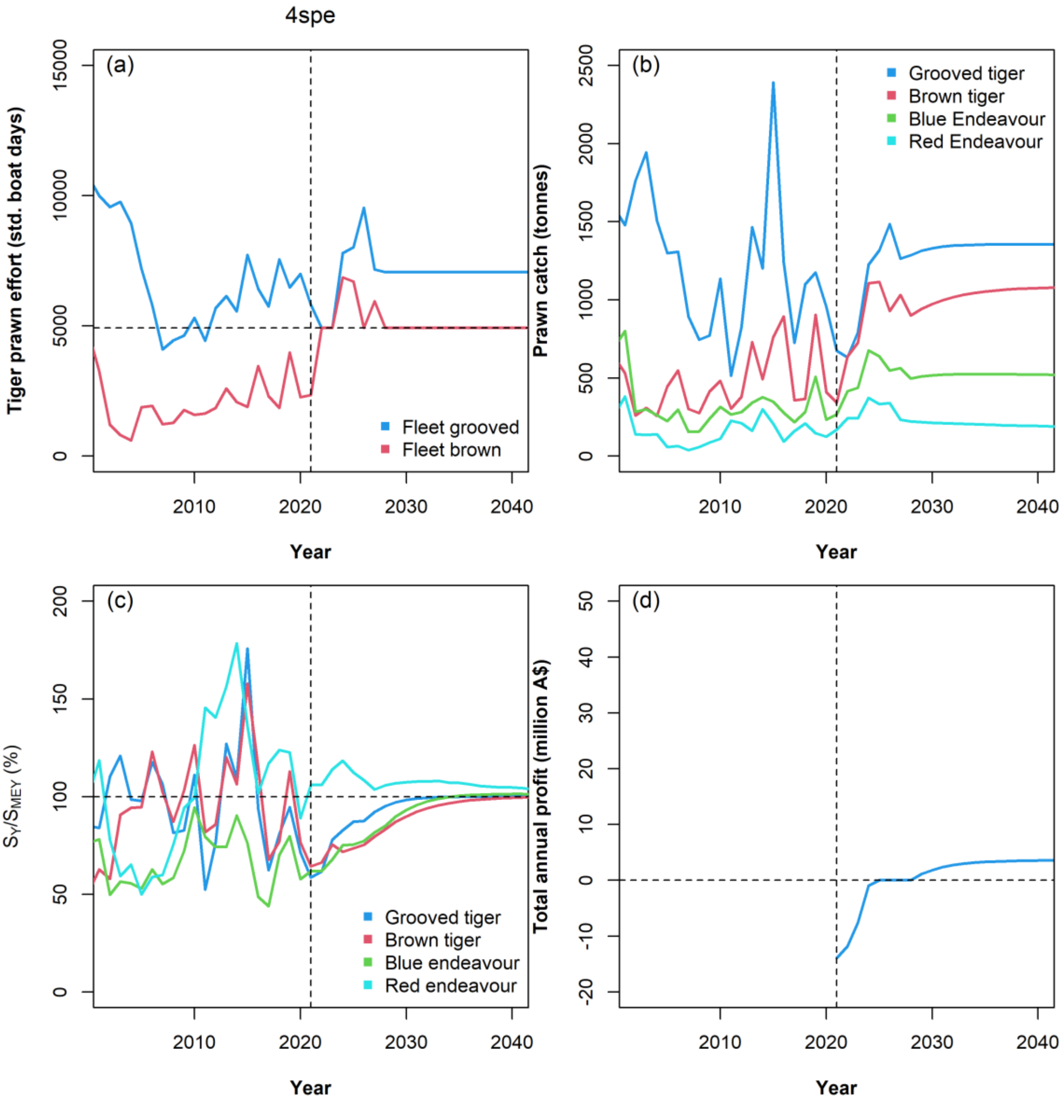


Figure 33 The key bio-economic model results (indicators) for the four-species models

(a) Tiger Prawn effort (standardised boat days), (b) prawn catch (tonnes), (c) SY/SMSY, and (d) total projected profit (millions of Australian dollars) for the Base Case assessment and projection settings.



5.6 Harvest Strategy

The estimated effort values from the Base Case as required by the NPF Harvest Strategy under input controls are provided in Table 2. Optimal modelled 2022 effort levels are 2,777 boat days for Grooved Tiger Prawns and 2,777 boat days for Brown Tiger Prawns (a total of 5,554 boat days), given the RAG-approved distribution of relative effort in 2022. This is a 19% increase on total actual effort in 2021, and is equivalent to a 90% gear size increase. The model is constrained by both of the tiger prawn fleet effort minimum thresholds in 2022 and 2023 when attempting to optimise the NPV to achieve MEY by varying the seven years projection effort pathways. The lower-limit thresholds for the Base Case are 2,777 boat days for each of two tiger prawn fleets. The model estimated 2023 effort levels as the same as that of 2022 due to the threshold restriction.

The major reason the model is setting effort at the minimum threshold levels is the due to higher fishing cost and the flattened future projection of the stock. Historically, the level of model-predicted effort was consistently above the fishery lower effort limit of 2,777 days for Grooved Tiger Prawn species and mostly above for Brown Tiger Prawn species in the Base Case. The lower-limit thresholds were introduced to ensure that the pathway to an MEY trajectory did not include very low effort levels that were not feasible or practical for the fishery.[11]

Normally, once the Base Case for the model is agreed, the NPRAG would use the MEY stock assessment model to determine TAE in the tiger prawn fishery. However, given that:

1. the fishery independent surveys have indicated a potential and possibly significant fall in stock size in the tiger prawn fishery over the past three years;
2. the substantial recent increase in fuel prices, which is likely to be persistent; and
3. the recommended effort level was (artificially) higher than previous year's actual effort due to the minimum effort constraints in the model;

the NPRAG decided in the interim to not use the results of the MEY analysis to set TAE, and instead took a temporary and precautionary once-off approach to setting effort in the tiger prawn fishery, recommending a moderate cut in effort (as nominal days) relative to the recent five-year average in the fishery.

[11] This restriction is currently being re-examined, and may be changed in future assessments pending RAG agreement.

7 Benefits and Adoption

The assessment provided estimates of stock status for grooved and brown tiger, blue endeavour and redleg banana prawns. The outcome provided was a demonstration of the sustainability of the NPF target species, and estimated levels of sustainable fishing effort for each tiger prawn species. Additionally, the economic analyses evaluated the degree to which the fisheries for these species were operating near economic optimum. Under current fishery economic condition and target species stock status, the assessment projected negative economic profit from 2022 to 2025, running roughly breakeven from 2026, and a small positive profit level from 2028 onwards. In accordance with the NPF Harvest Strategy the predictive component of the models supported recommendations for:

1. The TAE for the tiger prawn fishery (including endeavour prawns; 2021 and 2022, and 2023) (full assessment in 2022 only).
2. However, with the considerations of (1) the fishery independent surveys have indicated a potential and possibly significant fall in stock size in the tiger prawn fishery over the past three years, (2) the substantial recent increase in fuel prices, which is likely to be persistent, and (3) model-recommended effort levels higher than in the previous year due to the minimum effort constraint in the model, the NPRAG decided in the interim to use the results of the MEY analysis to set TAE, and took a temporary and precautionary once-off approach to setting effort in the tiger prawn fishery, and recommended a moderate cut in effort (as nominal days) relative to the recent five-year average in the fishery.
3. The TAE for redleg banana prawns (2021, 2022 and 2023) (published as a separate report).
4. The estimation of trigger catch rate limits for the white/common banana prawn fishery for 2021, 2022 and 2023 (see NPRAG minutes for the set trigger limit levels). The benefit was that the fishery operated near economic optimum for these components.

As the primary clients of this work were the management group of the Northern Prawn fishery (AFMA, NORMAC, NPRAG and NPFI), principal methods and results were communicated via the provision of progress reports to meetings of these groups. In addition, the various forums provided feedback on the assessment project outputs which were incorporated to improve model outcomes. Presentations of all the work in this project were provided at all the NPRAG meetings (and many of the NORMAC meetings) during the time frame of this project. Meeting minutes provide a public record of project outcomes and the recommendations for the TAE for each year that were endorsed by the NPRAG and NORMAC. The endorsed recommendations were sent to the AFMA Commission.

8 Further Development & Planned Outcomes

This project is in its first major phase of the three-year NPF Assessment project commenced in July 2021 (2021-2024). This project has been achieving the same set of objectives as outlined and delivered previously, although under new and different circumstances and challenges. Given the critical importance of the NPF to the nation as a key Commonwealth fishery, its ongoing assessment (biological sustainability) must be maintained along with the maintenance of the key objective of maximising economic yield. The project co-PIs will maintain a close association with the NPF and continue to attend NPRAG and NORMAC meeting and provides ongoing project updates.

9 Conclusion and Recommendations

Developed and much improved over the last 30 years, the assessment provided a quantitative measure of the stock status of four short-lived, highly-fecund prawn species that, without rigorous data inputs and analyses, would be difficult to manage sustainably. Each of the prawn species have highly variable populations, subject to annual tropical-extreme, monsoon-pulsed environmental drivers and on-going harvest pressure. The assessment is critical to the NPF Harvest Strategy for several reasons. The Harvest Strategy mandated that an assessment will be conducted biennially. In addition, the assessment provided key metrics for input into management decision making. The Harvest Strategy accounts for the large interannual variability of recruitment by deploying a pivotal decision rule that uses a 5-year moving average of S_Y/S_{MSY} to ensure that the value does not fall below 50% or management action is taken. The ratio S_Y/S_{MSY} was an output of the assessment, as were other metrics. The 5-year moving average targeted recruitment variation that, for each of the four tiger and endeavour prawn species, has been identified in Australian tropical fisheries.

The assessment (Base Case) projected 2022 optimal effort levels of 2777 boat days for both the Grooved Tiger Prawns and The Brown Tiger Prawns (a total of 5554 boat days). The optimal total effort estimated in the various sensitivity tests ranged from 5554 to 5599 boat days (excluding the lower effort or no effort threshold scenarios). The model estimated effort levels for the 2023 tiger prawn fishing season were the same boat days as for 2023, also for the two tiger prawn species.

However, with the considerations of (1) the fishery independent surveys have indicated a potential and possibly significant fall in stock size in the tiger prawn fishery over the past three years, and (2) the substantial recent increase in fuel prices, which is likely to be persistent, and (3) model-recommended effort levels higher than in the previous year due to the minimum effort constraint in the model, the NPRAG decided in the interim to use the results of the MEY analysis to set TAE, and took a temporary and precautionary once-off approach to setting effort in the tiger prawn fishery, and recommended a moderate cut in effort (as nominal days) relative to the recent five-year average in the fishery.

The two lower or no minimum (i.e., zero) effort threshold scenarios suggested the future fishing effort should be much lower than the current minimum effort threshold imposed in the model. The model is constrained by both of the tiger prawn fleet current minimum effort thresholds in 2022 and 2023 when optimising the NPV to achieve MEY by varying the seven years projection effort pathways.

The major reason the model setting effort at threshold levels is the higher fishing cost and the flattened future projection of the stock. Historically, the level of model-predicted effort was consistently above the fishery lower effort limit of 2,777 days for Grooved Tiger Prawn species and mostly above for Brown Tiger Prawn species in the Base Case. The lower-limit thresholds were introduced to ensure that the pathway to an MEY trajectory did not include very low effort levels that were not economically feasible nor practical for the fishery.

The assessment provided projected efforts from various scenarios to help the NPRAG to make the decision to set up the current fishing seasons TAE. By this measure, the assessment supported sustainable management of the NPF via the Harvest Strategy.

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Appendices

Appendix A. Summary tables for base case and sensitivity tests

Table Appendix A 1. Values of relevant management measures and parameter estimates for the three species for the Base Case (SSB - “low” fishing power, the average of last two years’ effort patterns).

E_{MSY} is the effort level (expressed in terms of 2021 days) at which MSY is achieved and S_{MSY} is the spawner stock index at which the (deterministic) MSY is achieved.

Name	Grooved tiger prawns	Brown tiger prawns	Blue Endeavour prawns
Steepness	0.386	0.337	NA
$Catch_{2022}$ (t)	632	638	424
Observed C_{2021} (t)	673	341	266
MSY (t)	1582	1053	787
MEY (t)	1402	1087	659
S_{MEY}/S_{MSY} (%)	125	135	114
S_{2021}/S_0 (%)	40	39	37
S_{2021}/S_{MSY} (%)	75	90	65
S_{2021}/S_{MEY} (%)	61	66	57
5-year mav ($S_{2017\text{-}2021}/S_{MSY}$) (%)	95	111	66
S_{2028}/S_{MEY} (%)	99	87	79
Observed nominal E_{2021} (d)	3320	1347	NA
Estimated nominal E_{2022} (d)	2777	2777	NA
Estimated nominal E_{2023} (d)	2777	2777	NA
E_{MSY} (d)	6862	2966	NA
E_{MEY} (d)	4356	2777	NA
E_{MEY}/E_{MSY}(%)	64	94	NA

E_{2021}/E_{MSY} (%)	48	45	NA
E_{2021}/E_{MEY} (%)	76	49	NA
Standardised E_{2021}/E_{MSY} (%)	48	45	NA
Standardised E_{2021}/E_{MEY} (%)	75	48	NA
Profit (estimated) 2021 ($m) Estimate from these 3 target species based on data provided and assumptions of fixed costs proportion to Tiger Prawn fishery versus Banana Prawn fishery. Revenue from other species (e.g. the Red Endeavor Prawns, bugs, squid) not included	-15		

Table Appendix A 2. Sensitivity test outputs for Grooved Tiger Prawns. Sensitivity test outputs for Grooved Tiger Prawns.

E_{MSY} is the effort level (expressed in terms of 2021 boat days) at which MSY is achieved and S_{MSY} is the spawner stock index at which the (deterministic) MSY is achieved. A dash indicates that the value is the same as that for the Base Case.

	Base Case	**Mid-High**	**DDD**	**Fixed effort pattern**	**Estimate Pattern**	**Constrained effort change**	**No effort threshold**	**Lower effort threshold**	**4 species (including red endeavour prawn)**
Steepness	0.386	0.382	0.355	-	-	-	-	-	-
$Catch_{2022}$ (t)	632	634	650	639	646	639	121	292	632
Observed C_{2021} (t)	673	-	-	-	-	-	-	-	-
MSY (t)	1582	1567	1471	1610	1645	-	-	-	1588
MEY (t)	1402	1355	1361	1395	1395	1285	1385	1387	1355
S_{MSY}	0.288	0.257	0.521	0.286	0.266	-	-	-	0.283
S_{MEY}	0.359	0.361	0.602	0.372	0.421	0.386	0.363	0.362	0.37
S_{MEY}/S_{MSY} (%)	125	140	116	130	158	134	126	126	131
S_{2021}/S_0 (%)	40	38	37	-	-	-	-	-	40
S_{2021}/S_{MSY} (%)	75	81	66	76	82	75	75	75	77
S_{2021}/S_{MEY} (%)	61	58	57	58	52	56	60	60	59
5-year mav($S_{2017-2021}/S_{MSY}$) (%)	95	102	82	95	103	95	95	95	96
S_{2028}/S_{MEY} (%)	99	95	100	98	98	96	99	99	96
Observed nominal E_{2021} (d)	3320	-	-	-	-	-	-	-	-
Estimated nominal E_{2022} (d)	2777	-	-	-	-	2822	345	1000	-

Estimated nominal E_{2023} (d)	2777	-	_	_	_	-	2850	2407	-
E_{MSY} (d)	6862	7723	5040	7246	8140	6862	6862	6862	7104
E_{MEY} (d)	4356	3891	3804	4137	3822	3498	4175	4195	3984
E_{MEY}/E_{MSY}(%)	64	50	76	57	47	51	61	61	56
E_{2021}/E_{MSY} (%)	48	43	66	46	41	-	-	-	47
E_{2021}/E_{MEY} (%)	76	85	87	80	87	95	80	79	83
Standardised E_{2021}/E_{MSY} (%)	48	43	65	45	40	-	-	-	46
Standardised E_{2021}/E_{MEY} (%)	75	85	86	79	86	94	79	78	82
Standardised E_{2021} (d)	5810	5794	-	-	-	-	-	-	-
Standardised E_{2022} (d)	4926	4887	4926	4926	4926	5006	612	1774	4926
Total loss to that of Base Case(%)[1]	100	104	108	97	80	103	82	84	71

[1] This doesn't apply to the Grooved Tiger Prawns only. It is the sum for all Tiger Prawn fishery fleets and species included in the assessment, and based on estimated allocation of fixed costs to the Tiger Prawn fishery (versus the Banana prawn fishery) dependent on the revenue share of each fishery to total.

Table Appendix A 3. Sensitivity test outputs for Brown Tiger Prawns.

E_{MSY} is the effort level (expressed in terms of 2021 days) at which MSY is achieved and S_{MSY} is the spawner Stock index at which the (deterministic) MSY is achieved**.** A dash indicates that the value is the same as that for the Base Case.

	Base Case	**Mid-High**	**DDD**	**Fixed effort pattern**	**Estimate Pattern**	**Constrained effort change**	**No effort threshold**	**Lower effort threshold**	**4 species (including red endeavour prawn)**
Steepness	0.337	0.335	0.284	-	-	-	-	-	-
$Catch_{2020}$ (t)	638	635	693	637	728	640	267	425	638
Observed C_{2021} (t)	341	-	-	-	-	-	-	-	-
MSY (t)	1053	1033	1041	1054	1218	-	-	-	1060
MEY (t)	1087	1120	1089	1080	1079	1071	1124	1123	1082
S_{MSY}	0.187	0.232	0.505	0.209	0.222	0.187	0.187	0.187	0.201
S_{MEY}	0.253	0.234	0.519	0.257	0.243	0.271	0.232	0.233	0.261
S_{MEY}/S_{MSY} (%)	135	101	103	123	110	145	124	125	130
S_{2021}/S_0 (%)	39	37	36	-	-	-	-	-	39
S_{2021}/S_{MSY} (%)	90	70	66	80	76	90	90	90	83
S_{2021}/S_{MEY} (%)	66	69	64	65	69	62	72	72	64
5-year mav ($S_{2017-2021}/S_{MSY}$) (%)	111	87	81	99	94	111	111	111	103
S_{2028}/S_{MEY} (%)	87	93	90	86	86	89	90	90	83
Observed nominal E_{2021} (d)	1347	-	-	-	-	-	-	-	-
Estimated nominal E_{2022} (d)	2777	-	-	-	-	-	1109	1843	-
Estimated nominal E_{2023} (d)	2777	_	_	_	_	-	2528	1955	-
E_{MSY} (d)	2966	2105	3052	2582	4227	2966	2966	2966	2724
E_{MEY} (d)	2777	3191	3194	2777	2777	2777	3217	3199	2777

E_{MEY}/E_{MSY}(%)	94	152	105	108	66	94	109	108	102
E_{2021}/E_{MSY} (%)	45	64	44	52	32	-	-	-	49
E_{2021}/E_{MEY} (%)	49	42	42	49	49	49	42	42	48
Standardised E_{2021}/E_{MSY} (%)	45	63	43	51	31	-	-	-	48
Standardised E_{2021}/E_{MEY} (%)	48	42	41	48	48	48	41	41	48
Standardised E_{2021} (d)	2345	2343	-	-	-	-	-	-	-
Standardised E_{2022} (d)	4926	4887	4926	4926	4926	4926	1967	3270	4926

Table Appendix A 4. Sensitivity test outputs for Blue Endeavour Prawns**.**

E_{MSY} is the effort level (expressed in terms of 2021 boat days) at which MSY is achieved and S_{MSY} is the spawner stock index at which the (deterministic) MSY is achieved. A dash indicates that the value is the same as that for the Base Case.

	Base Case	**Mid-High**	**DDD**	**Fixed effort pattern**	**Estimate Pattern**	**Constrained effort change**	**No effort threshold**	**Lower effort threshold**	**4 species (including red endeavour prawn)**
$Catch_{2022}$ (t)	424	424	377	429	439	452	144	255	416
Observed C_{2021} (t)	266	-	-	-	-	-	-	-	-
MSY (t)	787	760	531	779	791	-	-	-	731
MEY (t)	659	656	539	644	615	576	654	657	509
S_{MEY}/S_{MSY} (%)	114	106	103	114	151	125	115	114	117
S_{2021}/S_0 (%)	37	36	29	-	-	-	-	-	-
S_{2021}/S_{MSY} (%)	65	61	79	64	82	-	-	-	72
S_{2021}/S_{MEY} (%)	57	58	76	56	54	52	57	57	62
5-year mav($S_{2017-2021}/S_{MSY}$) (%)	66	62	80	65	83	-	-	-	74
S_{2028}/S_{MEY} (%)	79	81	92	78	78	78	78	78	85

Table Appendix A 5. Sensitivity test outputs for Red Endeavour Prawns**.**

E_{MSY} is the effort level (expressed in terms of 2021 boat days) at which MSY is achieved and S_{MSY} is the spawner stock index at which the (deterministic) MSY is achieved.

Indicator	Base Case	4 species (including red endeavour prawn)
$Catch_{2022}$ (t)	NA	241
Observed C_{2021} (t)	NA	170
MSY (t)	NA	324
MEY (t)	NA	177
S_{MEY}/S_{MSY} (%)	NA	82
S_{2021}/S_0 (%)	NA	41
S_{2021}/S_{MSY} (%)	NA	87
S_{2021}/S_{MEY} (%)	NA	106
5-year mav ($S_{2017\text{-}2021}/S_{MSY}$) (%)	NA	92
S_{2028}/S_{MEY} (%)	NA	106

Appendix B. Fishing Power Analysis

Northern Prawn Fishery: Update of the tiger prawn fishing power time series for 2021.

J. Upston, M. Miller, R.A. Deng, and C. Moeseneder.

CSIRO Oceans and Atmosphere

The fishing power analysis method was developed by Janet Bishop, Bill Venables, Cathy Dichmont, and other contributors (Dichmont *et al.* 2003; Bishop *et al.* 2008; Dichmont *et al*. 2010).

The relative fishing power time series for the Tiger Prawn fishery was extended to include information for 2020 (there was no formal stock assessment for the 2020 fishing season) and 2021. We report on the 2021 model estimates in this document. The fishing power estimates account for changes in vessels and gear, and changes in the spatial pattern of fishing. In 2010, some minor updates and corrections were made to the historical fishing power data (first compiled in 2003), which slightly affected some years in the early 1970s. No further changes to the historical series have been made in the current year.

Fifty-two vessels fished for Tiger Prawns during 2021. For each vessel, the swept area performance of the trawls was predicted by Sterling's Prawn Trawl Performance Model (PTPM; Sterling, 2005), using the so-called gape/wing version (described in Bishop and Sterling, 2007). This version used real wingend and frameline taper data collected during the 2021 gear survey of each vessel (an annual survey was implemented in 2010).

Relative fishing power was assessed by means of two linear regression models: the Low and Mid-High models (reported to the NPRAG and described by Bishop *et al*. 2010). The integrated Low model is used for input to the Base Case stock assessment and represents the lower bound of trends in relative fishing power in the NPF; the Mid-high model represents a "middle series", by fixing trygear and plotter coefficients at higher levels by offsets, and uses the spatial-year definition of fishing power instead of spatial-season 2 (Bishop *et al*. 2010). In both regression models, the coefficients were estimated from the 1970 - 2019 dataset. Changes in relative fishing power were obtained by making projections for a second dataset that consisted of the known and imputed fleet characteristics 1970 to 2021.

Since 2006, quad rig has been allowed again in the NPF, and increasing numbers of operators have converted over to quad from twin rig. In 2021 approximately 96% of the fleet towed quad rig when targeting Tiger Prawns, up from 90% in 2013, 77% in 2012, and from 40% in 2009. Fleet-wide, the average swept area performance in 2021 was estimated to be 28.3 hectares per hour (like 2019 and 2020). Greater average swept area performance in the last eight years may be explained, in part, by more boats towing quad rig (most using bison boards), as well as the uptake by some fishers of a greater headline length allowance (approximately 8%) for the second season of 2011.

Overall, the relative fishing power increased by 4-6% in 2021 relative to 2020 (Figure Appendix B 1;Table Appendix B 1). There was an increase (~ 3%) in engine power between 2020 and 2021. Other gear inputs to the fishing power model were comparable, on average, between 2020 and 2021. However, there were marked changes in the spatial pattern of fishing, with less effort in North Groote (approximately one third the effort in 2020) and more in Vanderlins. Similarly, there were notable changes in the fishing pattern between 2019 and 2020, with less effort in Karumba and Vanderlins (approximately half the effort in 2019) and more effort in Coburg-Melville.

We note the decrease in relative fishing power by 6-10% in 2020 relative to 2019, and coinciding with a poor Tiger Prawn season (also COVID-19 disruptions, to the extent season 2 was impacted). The gear inputs to the fishing power model were comparable between 2019 and 2020. However, the spatial pattern of fishing was notably different. In addition, average local Tiger Prawn effort, a variable which reflects the number of vessels fishing (targeting Tiger Prawns) in a local area at the same time (~ 10-mile radius each week), was notably reduced (average of 20 vessel-days in 2021 and 2020 c.f. 29 vessel-days in 2019). The local Tiger Prawn effort variable is intended to account for any relationship between reductions in fleet size (and search potential), and catch rates (Bishop *et al*. 2010).

Figure Appendix B 1. Estimates of relative fishing power trends in the NPF Tiger Prawn fishery. Relative fishing power units are daily catch rates relative to the fleet of 1970.

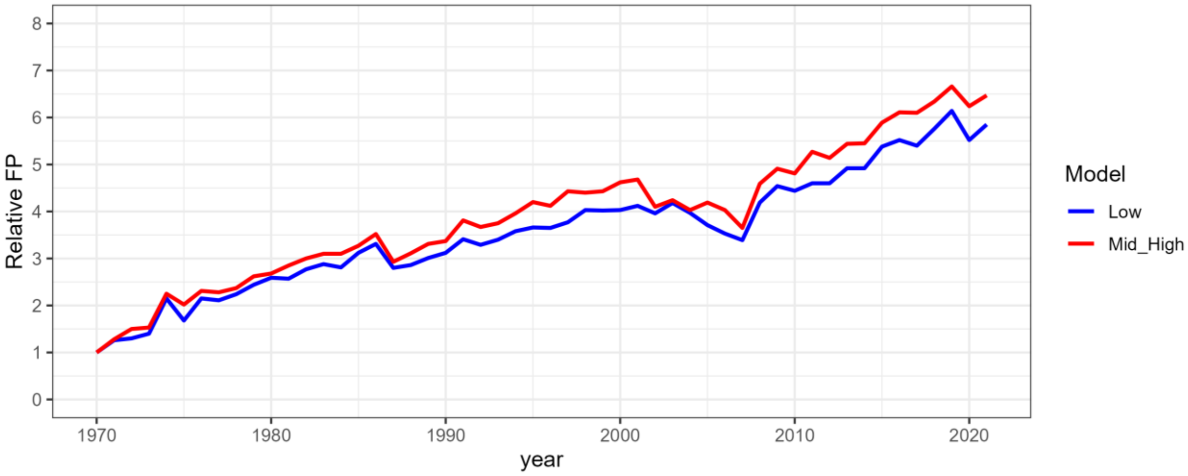

Table Appendix B 1. Estimates of relative fishing power in the NPF tiger prawn fishery. Relative fishing power units are daily catch rates relative to the fleet of 1970, and q_{inc} are annual increments relative to the previous year.

	Low		Mid-High	
	Relative fishing power	q_{inc}	Relative fishing power	q_{inc}
1970	1.00		1.00	
1971	1.26	1.26	1.28	1.28
1972	1.30	1.03	1.50	1.18
1973	1.40	1.08	1.53	1.02
1974	2.15	1.53	2.25	1.47
1975	1.68	0.78	2.02	0.90
1976	2.15	1.28	2.31	1.15
1977	2.11	0.98	2.28	0.99
1978	2.24	1.06	2.37	1.04
1979	2.44	1.09	2.62	1.11
1980	2.59	1.06	2.68	1.02
1981	2.57	0.99	2.85	1.06
1982	2.77	1.08	3.00	1.05
1983	2.88	1.04	3.10	1.04
1984	2.81	0.98	3.10	1.00
1985	3.12	1.11	3.27	1.05
1986	3.31	1.06	3.52	1.08
1987	2.80	0.85	2.93	0.83
1988	2.86	1.02	3.11	1.06
1989	3.01	1.05	3.31	1.06
1990	3.12	1.04	3.37	1.02
1991	3.41	1.09	3.81	1.13
1992	3.29	0.97	3.67	0.96
1993	3.40	1.03	3.75	1.02
1994	3.58	1.05	3.96	1.06

1995	3.66	1.02	4.20	1.06
1996	3.65	1.00	4.12	0.98
1997	3.77	1.03	4.43	1.07
1998	4.03	1.07	4.40	0.99
1999	4.02	1.00	4.43	1.01
2000	4.03	1.00	4.62	1.04
2001	4.12	1.02	4.68	1.01
2002	3.96	0.96	4.10	0.87
2003	4.18	1.05	4.24	1.03
2004	3.97	0.95	4.03	0.95
2005	3.71	0.94	4.19	1.04
2006	3.53	0.95	4.03	0.96
2007	3.39	0.96	3.65	0.91
2008	4.19	1.24	4.59	1.25
2009	4.54	1.08	4.91	1.07
2010	4.44	0.98	4.81	0.98
2011	4.60	1.04	5.27	1.10
2012	4.60	1.00	5.14	0.98
2013	4.92	1.07	5.44	1.06
2014	4.92	1.00	5.45	1.00
2015	5.38	1.09	5.89	1.08
2016	5.52	1.03	6.11	1.04
2017	5.40	0.98	6.10	1.00
2018	5.76	1.07	6.34	1.04
2019	6.14	1.06	6.66	1.05
2020	5.52	0.90	6.24	0.94
2021	5.85	1.06	6.47	1.04

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