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Status of the Northern Prawn Fishery Tiger Prawn Fishery at the end of 2020 with estimated TAEs for 2020 and 2021

Final Report

AFMA Project No. 2017/0833

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Project Principal Investigators: Trevor Hutton (Trevor.Hutton@csiro.au) and Roy Deng (Roy.Deng@csiro.au)

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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
- **C_{2019}** is the observed catch in 2019
- **MAV** is the Moving Average
- **MSY** is the Maximum Sustainable Yield
- **MEY** is the Maximum Economic Yield
- **S_{MEY}/S_{MSY}** is the spawning stock size at Maximum Economic Yield relative to the spawning stock size at Maximum Sustainable Yield.
- **S_{2019}/S_{MSY} (%)** is the spawning stock size in 2019 relative to the spawning stock size at Maximum Sustainable Yield as a percentage.
- **S_{2019}/S_{MEY} (%)** is the spawning stock size in 2019 relative to the spawning stock size at Maximum Economic Yield as a percentage.
- **5-year mav($S_{2015\text{-}2019}/S_{MSY}$) (%)** is the 5-year moving average of the spawning stock size between 2015 and 2019 inclusive relative to the spawning stock size at Maximum Sustainable Yield.
- **S_{2026}/S_{MEY} (%)** is the projected spawning stock size in 2026 relative to the spawning stock size relative to Maximum Economic Yield as a percentage.
- **E_{2019}** is the observed effort in 2019.
- **E_{2020}** is the model estimated effort for 2020.
- **E_{MSY}** is the effort at the Maximum Sustainable Yield.
- **E_{MEY}** is the effort at the Maximum Economic Yield.
- **E_{MEY}/E_{MSY}** is the effort at the Maximum Economic Yield relative to the effort at the Maximum Sustainable Yield.
- **E_{2019}/E_{MSY} (%)** is the observed effort in 2019 relative to the effort at the Maximum Sustainable Yield as a percentage.

- **E_{2019}/E_{MEY} (%)** is the observed effort in 2019 relative to the effort at the Maximum Economic Yield as a percentage.

- **Standardised E_{2019}/E_{MSY} (%)** is the standardised effort in 2019 relative to the effort at the Maximum Sustainable Yield as a percentage.

- **Standardised E_{2019}/E_{MEY} (%)** is the standardised effort in 2019 relative to the effort at the Maximum Economic Yield as a percentage.

- **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 2020 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. This is achieved via 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 profits in the fishery over a long period of 40 years up to 2050. 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 profits over time.

The assessment (the "Base Case" model) incorporated three complementary models:

- a multispecies, weekly sex- and size-structured population model for two species of tiger prawns,
- a Bayesian hierarchical biomass production model for blue endeavour prawns, and
- an economic model which calculates profit.

This framework requires predictions about future effort levels, and changes over time in costs and prices (Punt et al. 2011). Several alternative scenarios were presented to provide sensitivity analyses for the assessments.

Two different groups of stock assessment models are 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 (described above); and b) Deriso models for each of the three species (Dichmont et al. 2003). The latter did not use the length frequency information. Punt et al. (2011) provided a summary of the combined model used as the Base Case. Various model improvements were included in the previous assessments including red endeavour prawn prawns added into sensitivity testing (Hutton et al. 2018) and updated configuration in Buckworth et al. (2015) based on a retrospective study of model performance (Deng et al. 2015). This assessment continued to include previous updates used in the past assessment. Recent model changes include:

- An alternative statistical method to analyse fishery-independent survey length frequency information (Burridge et al. 2014);
- Length frequency information from the most recent recruitment survey was not included in the analysis, to avoid data conflicts as this was found to be the case in previous analyses (however recruitment abundance is included) in model fitting (Deng et al. 2015);
- Gamma functions replaces logistic functions as descriptors of fishing selectivity for recruitment survey data;
- Sensitivity tests, which included using variations to the amount of effort change permitted between years, variations to the lower effort threshold, and alternative fishing power levels, model structures, and predicted fishing patterns;
- 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; and,
- The sensitivity test of the modified Base Case model to assess 4 target species simultaneously to provide the stock status of the prawn species.

A "species-split" model, to allocate logbook catches and effort by species of tiger and endeavour prawns (Venables et al. 2006), is applied to the updated fishery catch and effort data. Two updated (April 2020) fishing power models were applied as separate scenarios – the "low" fishing power model (used in the Base Case) and the "mid-high" fishing power model (Nov 2009 and May 2010 Northern Prawn Fishery Resource Assessment Group (NPRAG), see Bishop et al. (2008) for description of method). We encourage the reader if interested in the fishing power models to read up on the definitions and background to the “low” and “mid-high” settings and models as there is not enough space in this report to go through the detail in those studies, or do that work any justice by having a short explanation. Fishery independent monitoring surveys undertaken in the NPF since 2002 (with this assessment including additional survey data with additions being the 2018 spawning survey, and the 2019 and 2020 recruitment surveys), that provided abundance indices that were incorporated into the assessment Base Case.

For the Base Case assessment, we used the NPRAG 2014-specified season (that is average effort pattern of the last two years) as the fishing effort pattern (as agreed by NPRAG in March 2014 and November 2015) for the forward projection. We also provide recommended effort for two years in advance (inclusive of the year the assessment is undertaken). This two effort projection should not be confused with historical fishing season effort patterns (averaged over 2 years) used as an input setting.

The assessments had two components: (1) the stock assessment of the two tiger prawns species plus blue endeavour prawns (Base case) or both endeavour prawn species (as a 4 species sensitivity test), and (2) the bio-economic assessment (Dichmont et al. 2008, Punt et al. 2011, Deng et al. 2015). The blue endeavour prawn assessment and red endeavour prawn assessments were undertaken with the Bayesian hierarchical biomass production model (Zhou et al. 2009). Previously, a delay difference model (Dichmont et al. 2003) was applied to the two endeavour prawn species, 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 4 species test, both blue endeavour prawns and red endeavour prawns) were treated as an economic byproduct, i.e. effort was not directed at the species but catches provided revenue and attracted costs associated with the amount caught (such as freight and packaging).

Scenario tests had mainly focused on assessing the sensitivity of the outputs to assumptions regarding the factorial components of the model: fishing effort pattern, fishing power estimates, model type, the 2013 RAG-specified fishing pattern, constraining (year-on-year) effort change during a seven-year projection period and the lower effort threshold in the bio-economic model.

The 4 species test was to explore the capability of the model to provide a preliminary indication of the stock status of red endeavour prawns. Previous Management Strategy Evaluations (MSEs) have considered all four socies however, all were modelled as delay difference models. In terms of year-on-year (or strictly every second year) differences in the assessment model predictions of the status of each stock, there are many reasons for these differences. Differences in the results from previous assessments could mostly be attributed to: a) the updated fishing power series; b) the inclusion of the 2018 spawning survey indices, the 2019 and 2020 recruitment survey indices and prawn size data; c) updated fishery catch and effort logbook data up to 2019; d) updated fishing effort patterns and the application of the additional effort allocation algorithm; e) alternative assumptions regarding blue endeavour prawn catchability; f) updated economic information, and; g) testing the 4 species model to acquire stock status information for red endeavour prawns. All these changes together had influenced the stock status estimates for the different species and the stock-recruitment relationship, as well as the Maximum Sustainable Yield (MSY) - and Maximum Economic Yield (MEY) - related outputs. The MEY estimate drove the Total Allowable Effort (TAE) recommendation calculated by applying the harvest strategy. The NPRAG decided on and set all the inputs and assumptions to the models and chose, as the Base Case, the model that used all the available data (i.e., the size-structured model for both tiger prawn stocks). This assessment produced a TAE recommendation for the input management system.

Grooved Tiger Prawns (Figure 1)

In all scenarios tested, the grooved tiger prawn stock abundance was above S_{MSY}, ranging from 103% to 123%, at the end of 2019. Furthermore, effort in 2019 was well below that at E_{MSY}. The five-year average abundances were all above 100% of S_{MSY}, and thus well above the limit reference point, 0.5 S_{MSY}. Grooved tiger prawns are therefore, considered not overfished, and overfishing was not occurring.

Brown Tiger Prawns (Figure 2)

The brown tiger prawn stock in 2019 ranged from 109% to 139% of S_{MSY} in all scenarios tested. The five-year average abundances were all above 100% of

S_{MSY}, and thus well above the limit reference point, 0.5 S_{MSY}. Therefore, the resource was considered not overfished. Effort in 2019 was below that at E_{MSY}. Overfishing was therefore, not occurring.

Blue Endeavour Prawns (Figure 3)

Blue endeavour prawns were considered a byproduct species and were not considered to be over-fished relative to the limit reference point of 0.5 S_{MSY} (based on a 5-year moving average). In the majority of sensitivity tests tested, the stock abundance was under S_{MSY} at the end of 2019 (84% to 113 %). The five-year average abundance estimate ranged from 68% to 87% of S_{MSY}.

Red Endeavour Prawns (Figure 4)

Based on the sensitivity test, red endeavour prawns were considered a byproduct species, and were not considered to be over-fished relative to the limit reference point of 0.5 S_{MSY} (based on a 5-year moving average). The sensitivity also indicated that the stock abundance was above S_{MSY} at the end of 2019 (113%). The five-year average abundance was estimated to be 104% of S_{MSY}. This was a preliminary result, and there is currently a project underway to update the assessment, which is dependent on obtaining updated information on life history characteristics.

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

The bio-economic assessment this year indicated that the ratio of S_{MEY}/S_{MSY} for grooved and brown tiger prawns was 122% and 112% for the Base Case, respectively, while for blue endeavour prawns and red endeavour prawns, they were 100% and 90% (4-species sensitivity test), respectively. We noted that for blue endeavour prawns and red endeavour prawns, caught as a byproduct, and they have costs associated with catch (e.g. packaging and freight) but not effort (e.g. fuel).

At 99% of S_{MEY}, the spawning stock of grooved tiger prawns was estimated to be approaching the spawning stock size at MEY for Base Case. Similarly, the spawning stock size for brown tiger prawns was higher than that at MEY, with S_{2019}/ S_{MEY} at 125%; and the ratio for blue endeavour prawns was 86% approaching MEY. In the 4 species test, the ratio for red endeavour prawns was 126%.

Both tiger prawn stocks were predicted to achieve their respective present S_{MEY} within seven years (the target reference point), as specified by the current harvest strategy and economic assumptions. We noted that, given the recruitment abundance from the recruitment survey in 2020 and the fishing pattern, the model predicted a moderate recruitment decrease for 2020 for grooved tiger prawns and brown tiger prawns. Consequently, lower catches of grooved tiger prawns than in 2019 and a similar level catch of brown tiger prawns as that in 2019 were expected. Recruitment for subsequent years of the projection was predicted via the stock-recruitment relationships alone. Target effort in 2019 on grooved tiger prawns was at 75% of E_{MEY}. Target effort in 2019 on brown tiger prawns was also below E_{MEY} (70%). As blue endeavour prawns and red endeavour prawns were treated as a byproduct (and so these species were captured when effort is targeted at tiger prawns), this ratio was not calculated.

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

The assessment (Base Case) predicted 2020 optimal effort levels of 2816 boat days for grooved tiger prawns and 3390 boat days for brown tiger prawns (a total of 6206 boat days). The optimal total effort estimated in the various sensitivity tests ranged from 5966 to 6830 boat days (excluding the lower effort scenario). The 2021 model estimated effort levels were 3877 and 3363 boat days, respectively, for grooved tiger prawns and brown tiger prawns (a total of 7059 boat days). The estimated 2021 effort was a 27% increase on total actual effort of 2019 and equivalent to a 137% gear size increase.

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

Top left: Spawning stock size (S_Y) relative to the spawning stock size at Maximum Sustainable Yield (S_{MSY}). Top right: spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}). Bottom left: standardised effort in a year (E_Y) relative to the effort at Maximum Sustainable Yield (E_{MSY}). Bottom right: standardised effort in a year (E_Y) relative to the effort at Maximum Economic Yield (E_{MEY}).

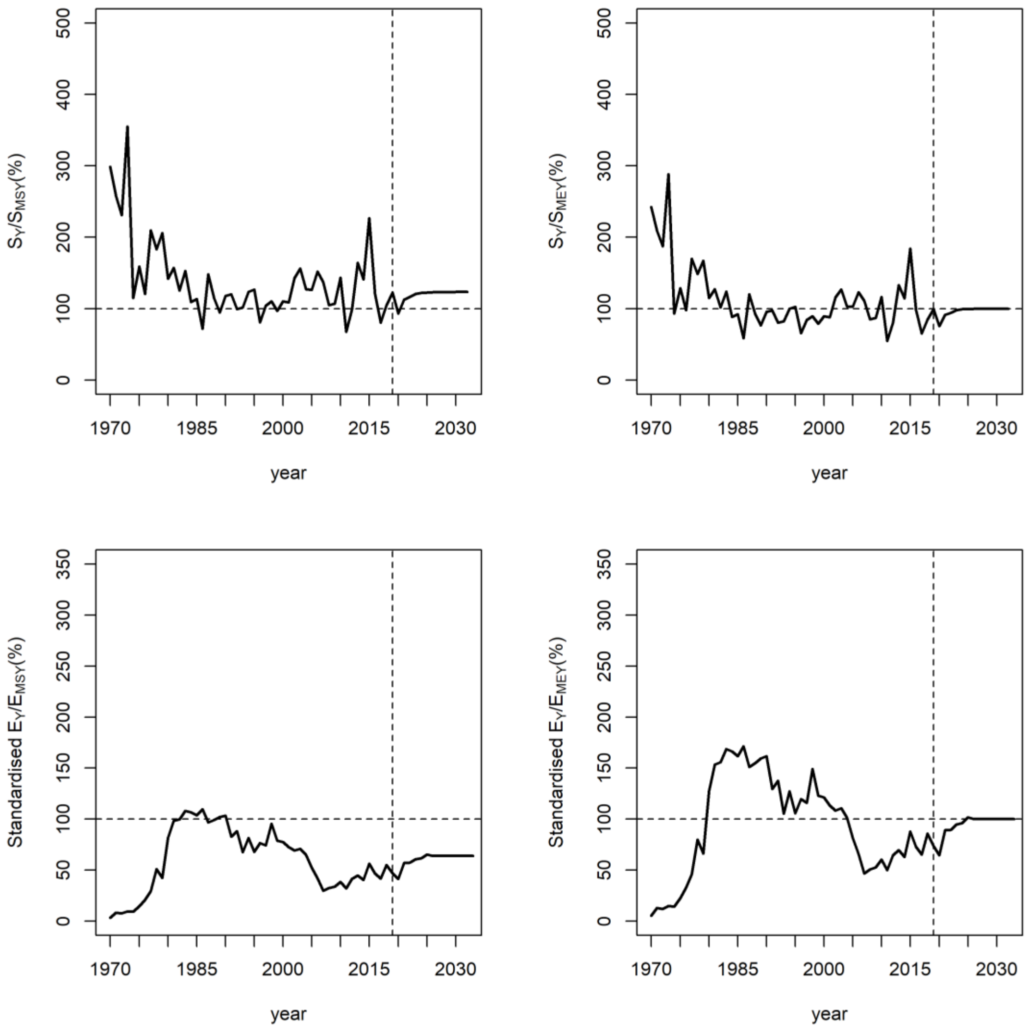


Figure 2. Status of the stock and effort relative to reference points for Brown Tiger Prawns for the Base Case.

Top Left - spawning stock size (S_Y) relative to the spawning stock size at Maximum Sustainable Yield (S_{MSY}). Top Right - spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}). Bottom left - standardised effort in a year (E_Y) relative to the effort at Maximum Sustainable Yield (E_{MSY}). Bottom right - standardised effort in a year (E_Y) relative to the effort at Maximum Economic Yield (E_{MEY}).

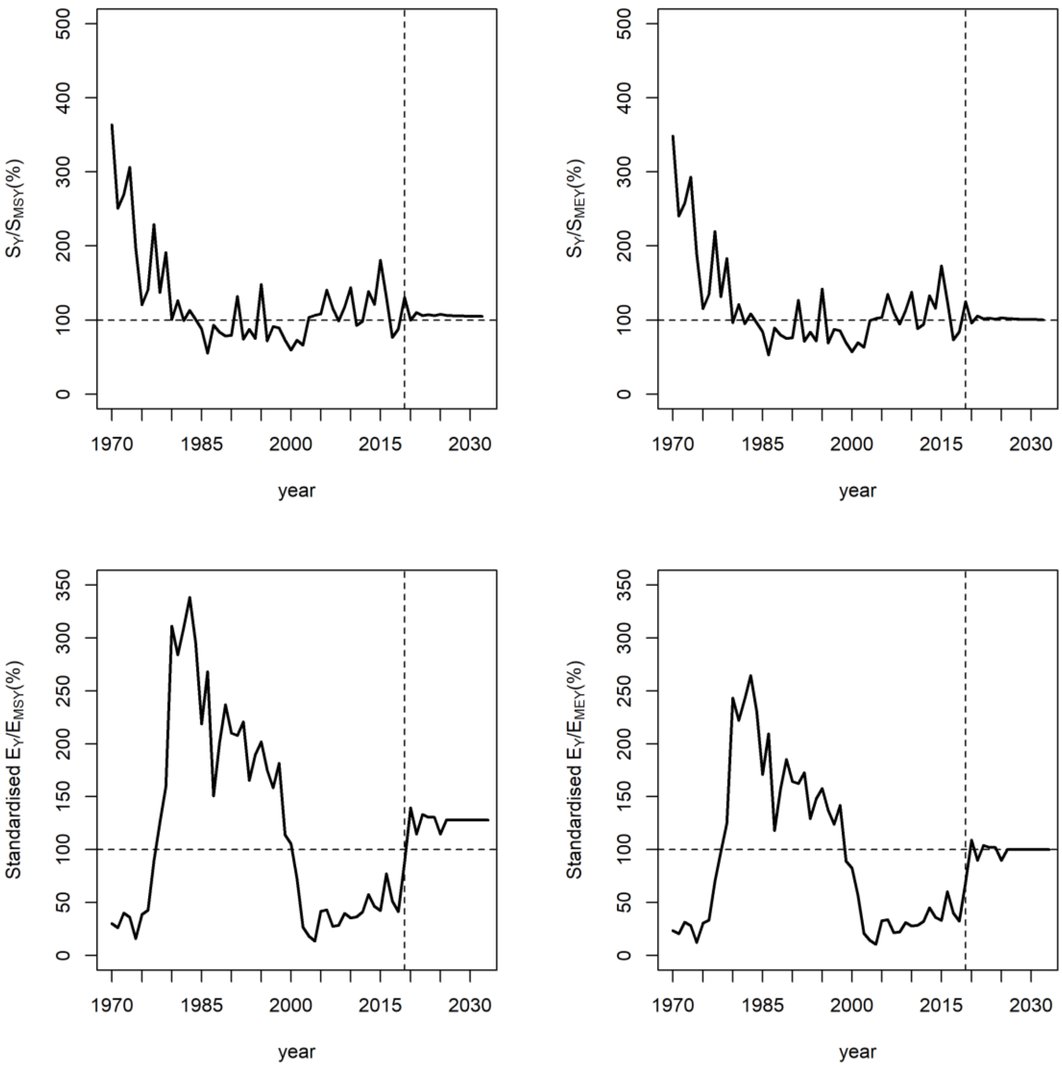


Figure 3. Status of the stock relative to reference points for Blue Endeavour Prawns for the Base Case.

Left - spawning stock size (S_Y) relative to spawning stock size at Maximum Sustainable Yield (S_{MSY}). Right - spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}).

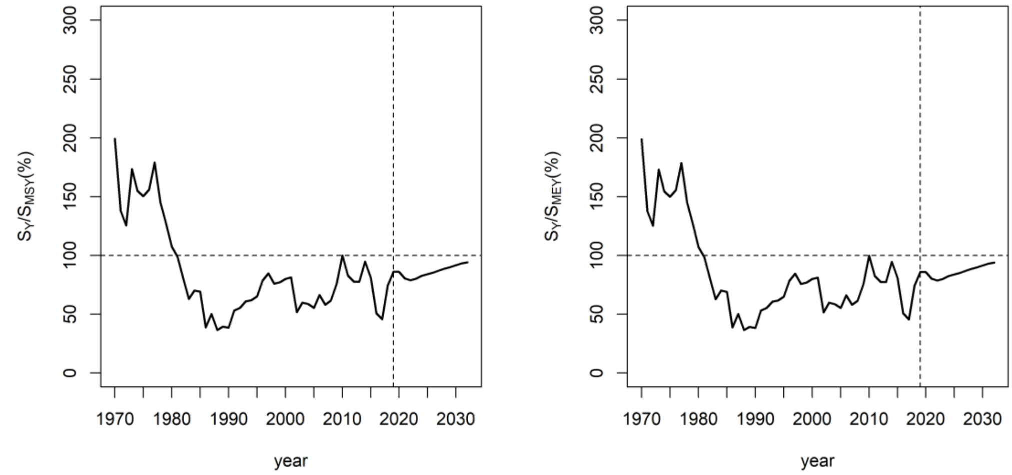


Figure 4. Status of the stock relative to reference points for Red Endeavour Prawns for the 4 species sensitivity test.

Left - spawning stock size (S_Y) relative to spawning stock size at Maximum Sustainable Yield (S_{MSY}). Right - spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}).

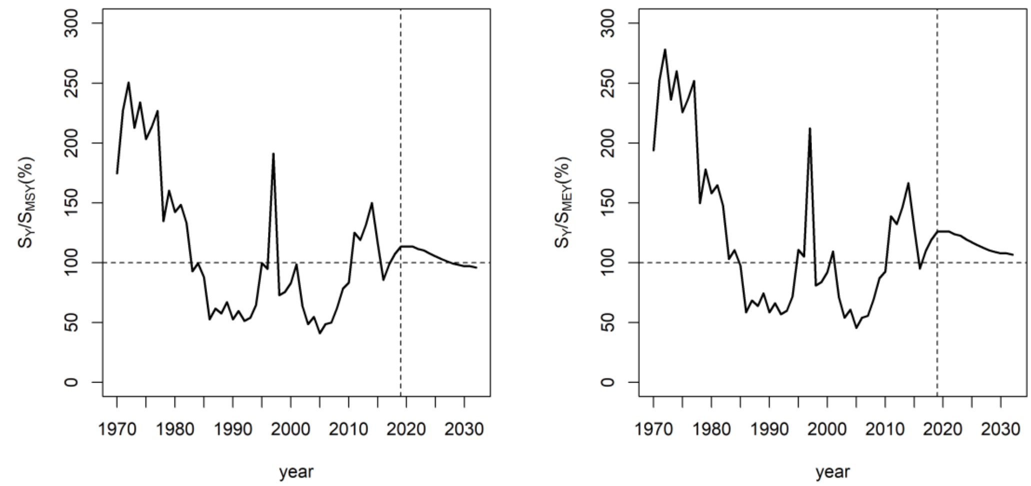


Figure 5. The key bio-economic model results (indicators) for the Base Case

(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 SSB assessment using the Base Case assessment settings.

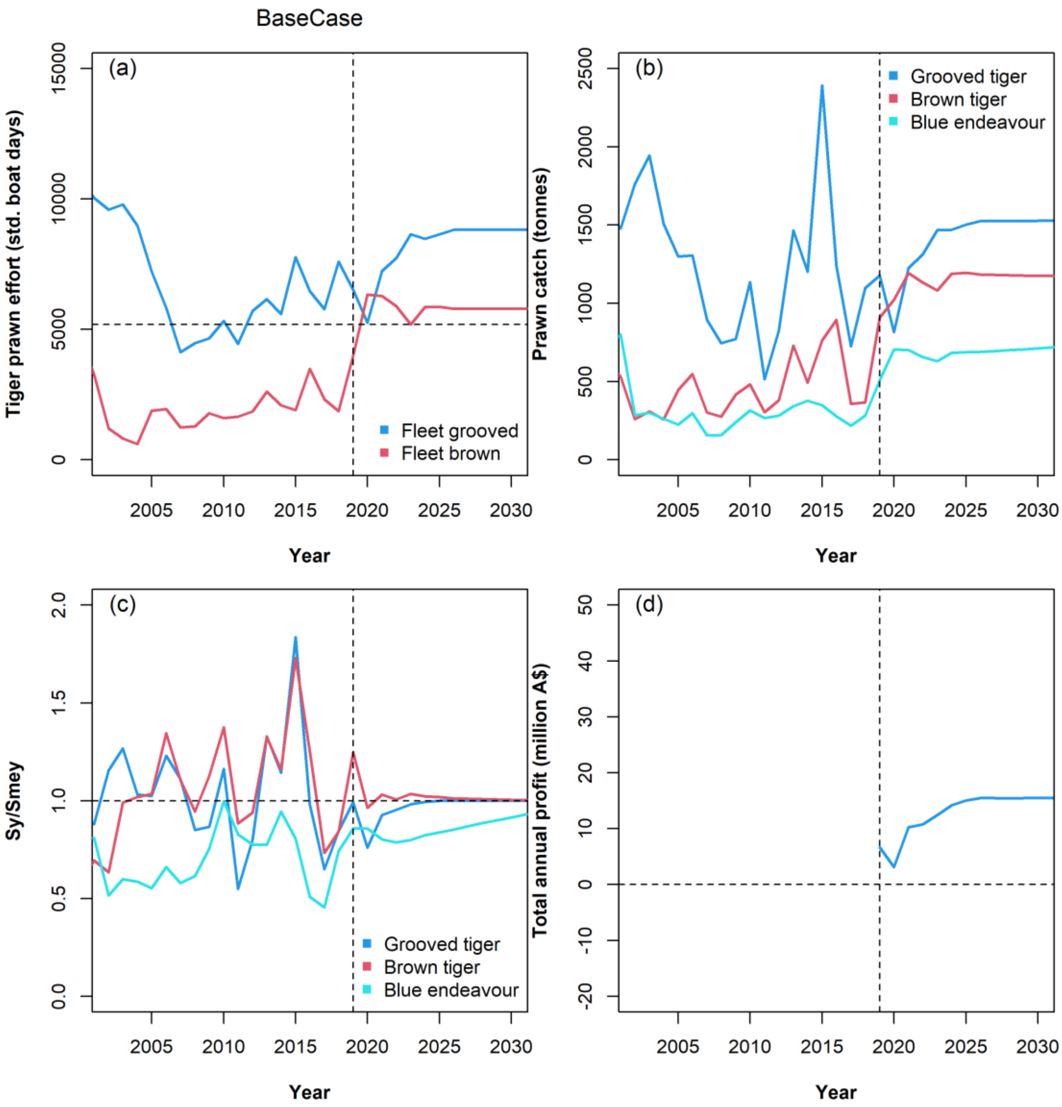


Figure 6. The key bio-economic model results (indicators) from the four species sensitivity test.

(a) Tiger Prawn effort (standardised boat days), (b) prawn catch (tonnes), (c) S_Y / S_{MSY} and (d) total projected profit (millions of Australian dollars) for the SSB assessment using the Base Case assessment setting for 2 tiger prawns and blue endeavour prawn plus red endeavour prawn.

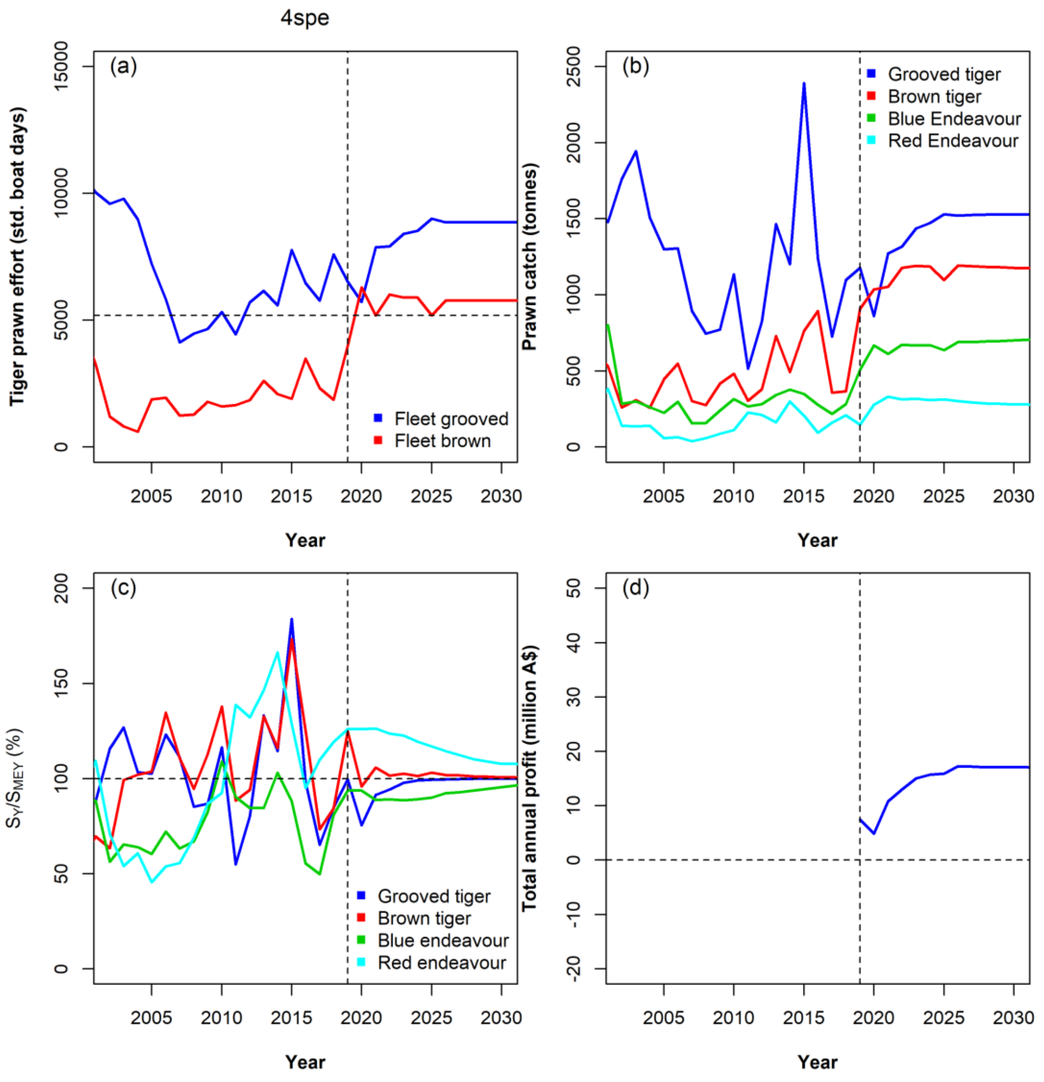


Table 1. Results of relevant management measures and parameter estimates for all three species for the "Base Case" assessment.

E_{MSY} is the effort level (expressed in terms of 2019 boat 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	0.394	0.341	NA
$Catch_{2020}$	816	1022	705
Observed C_{2019}	1178	908	509
MSY	1687	1113	808
MEY	1526	1170	747
S_{MEY}/S_{MSY}	122	112	100
S_{2019}/S_0 (%)	63	67	48
S_{2019}/S_{MSY} (%)	121	139	86
S_{2019}/S_{MEY} (%)	99	125	86
5-year mav($S_{2015-2019}/S_{MSY}$) (%)	129	130	68
S_{2026}/S_{MEY} (%)	100	101	85
Observed nominal E_{2019}	3535	2181	NA
Estimated nominal E_{2020}	2816	3390	NA
E_{MSY}	7163	2665	NA
E_{MEY}	4723	3099	NA
E_{MEY}/E_{MSY}(%)	66	116	NA
E_{2019}/E_{MSY} (%)	49	82	NA
E_{2019}/E_{MEY} (%)	75	70	NA
Standardised E_{2019}/E_{MSY} (%)	49	80	NA
Standardised E_{2019}/E_{MEY} (%)	74	69	NA
Profit (estimated) 2019 ($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.	6.7		

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 8.6% and 26.7% effort changes from 2019, 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	**2019 observed nominal effort (boat day)**	**2020 model projected effort (boat day) and changes from 2019**	**2021 model projected effort (boat day) and changes from 2019**
Grooved Tiger Prawn nominal effort	3535	2816	3877
Brown Tiger Prawn nominal effort	2181	3390	3363
Total nominal effort	5716	6206	7059
Effort change from 2019	NA	490 (or 8.6%)	1524 (or 26.7%)
Gear change	NA	35.5%	139%

An update to the 2020 catch and effort data per prawn stock and the 2020 stock abundance indices from the independent monitoring survey is provided in Appendix C.

Acknowledgements

This project benefitted from consultation with, and extensive feedback from, members of the Northern Prawn Fisheries Resource Assessment Group (NPRAG). Australian Fisheries Management Authority (AFMA) and the Northern Prawn Fishery Industry (NPFI, Ltd.) are acknowledged for providing the data required for this project. Adrianne Laird (NPFI) is thanked for checking and collating the logbook data in the required format and her significant efforts at ensuring its accuracy and completeness. Anthea Donovan from CSIRO NPF monitoring team (PI: Rob Kenyon) provided abundance survey index and survey length frequency data. Tom Kompas (UM) analysed the economic data (provided by the NPFI). The NPRAG established the Base Case and sensitivity test criteria in November 2019. The updated fishing power series was provided by the fishing power project team of Judy Upston, Margaret Miller and David Sterling. Emma Lawrence is acknowledged for providing statistical expert review of the fishing power analysis and species split analyses, and Shijie Zhou is acknowledged for providing advice on Bayesian production models. The research would not have been possible without the logbook, gear and economic data, provided by the fishing industry and collected and managed by AFMA and NPFI. The assessment was recommended by the NPRAG and was funded by the AFMA Research Fund, CSIRO and NPFI.

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). However, recent and future changes in management of the fishery invariably throw up challenges for the provision of scientific management advice. Specifically, scientific advice needs to be provided for the fishing strategies that target the two species of tiger prawns. It was decided that a TAE will be used in the future management of the fishery, i.e. effort will be limited by season length and trawl head rope length. Individual species' projected catches and effort for 2020 were estimated for each of the two tiger prawn species and then summed together to produce a single tiger prawn 2020 and 2021 TAE recommendation and 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 were combined with an economic model which calculated profit. The framework required predictions about future effort levels, weekly allocation patterns 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 2020 (based on 2019 fishery data). Due to the nature of stock assessment, the 2020 stock assessment will include all data up to 2019, including 2018 data (thus data collation at the end of 2018 was included as a cost);

2. Update the fishing power series incorporating data from gear surveys, annually (i.e. in 2019, 2020, and 2021 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 2019 (based on 2018 assessment) and 2020, and 2021 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 2019, 2020, and 2021; 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. 2019, 2020 and 2021.

*Published as a separate report.

4 Methods

This assessment used 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), in a four-step process as outlined below. A full set of specifications for these models was presented in a series of publications: a) Punt et al. (2010) for the full specification of the size model [both tiger prawn species]; b) the economic formulations, (the profit function), were presented in Punt et al. (2011); c) Deng et al. (2014) presented a set of revised specifications for improving the model performance; and, d) Zhou et al. (2009) developed the Bayesian hierarchical biomass dynamic model applied to blue endeavour prawns. The assessment uses data from two main sources. Catch and effort data from 1970 to 2019 were extracted from AFMA's logbook database for each tiger prawn species and for endeavour prawns species. Fishery independent indices of abundance and prawn size data were provided by the NPF Monitoring Project.

The bio-economic assessment that comprised this series of models firstly estimated the population dynamics, and then calculated the economic dynamics. The calculation of the quantities of interest to stakeholders therefore involved 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 dynamic model (Zhou et al. 2009) for blue endeavour prawns and red endeavour prawns.
4. Estimation of MSY, E_{MSY}, and S_{MSY} for the tiger prawn fleet (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 MEY – outputs

also include the resultant dynamic MEY, E_{MEY}, and S_{MEY} (Punt et al. 2010, 2011).

The Base Case assessment was implemented by including all updates in two aspects; the assessment model and the data. For the model aspect, it incorporates all the improvements developed in the last few years including optimal configuration of the model settings (Deng et al. 2014) and an algorithm of weekly allocation of future fishing effort to ensure the allocation did not violate the fleet actual capacity (364 days, determined by 52 vessels and 7 days per week). For the data aspect, all the input data, such as logbook data, fishery independent survey data and economic data were continuously collected to update the latest series and for inclusion in the model. Sensitivity tests focused on the changes to the Base Case; including – the weekly fishing pattern, different fishing power series, model differences and the effort fluctuation constraint; and the new 4 species bio-economic model in which red endeavour prawns were assessed by using Bayesian hierarchical biomass dynamic model (Table 3).

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

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 recruitment (2019, 2020) and spawning (2018) survey abundance indices were incorporated into the model for projecting future dynamics. We noted that there were no spawning abundance surveys in 2010, 2015, 2017 and 2019;
4. The fishing power series was re-estimated from 1970 to 2019 using the same method used in the last assessment (Upston et al. 2014) with the newly updated fishery capabilities data. Two series were produced: a Low fishing power series and a Mid-High fishing power series. The

Base Case assumed the fishing power is the ‘Low’ estimated cumulative fishing power 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. Excluded from the analysis were the length frequency data from the most recent recruitment survey (as noted by Deng et al. 2014, as this may conflict with other information in the model, as per explanation in that publication);
7. Applied gamma functions for calculation of recruitment survey fishing selectivity;
8. A test of different model forms, such as delay difference models (Table 3);
9. 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;
10. A sensitivity test used a lower effort threshold in the bio-economic model (Table 3); and,
11. The sensitivity test of the modified Base Case model to assess 4 target species simultaneously provided the stock status of the prawn species (Table 3).

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 estimate and predicted values provided by Tom Kompas (see section 5.4 “Economics”). The Base Case used the newly estimated 2020 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 were sensitive to weekly effort patterns, hence the use of recent year effort patterns.

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

(1) model estimates fishing patterns;

(2) an alternative fishing power 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 lower effort threshold for the bio-economic model;

(7) assess 4 target species simultaneously to provide the stock status of the prawn species;

See Table 3 for a description of the Base Case and different sensitivity test scenarios.

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

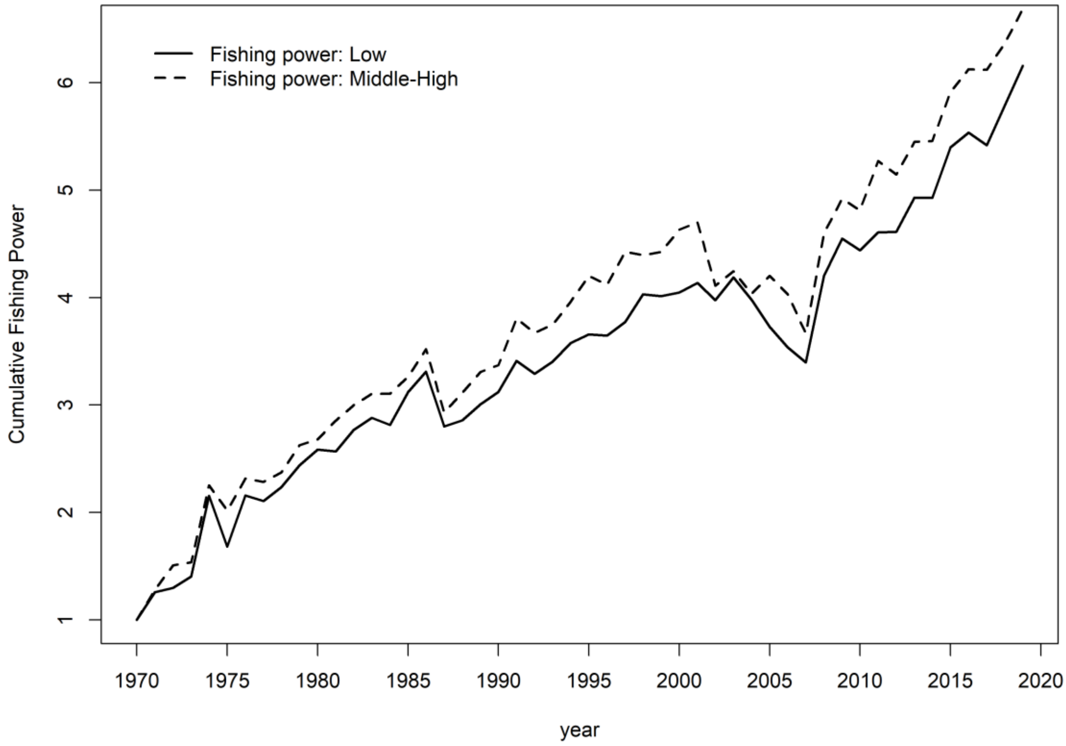
SSB indicates use of size structured models for Grooved and Brown Tiger Prawns, and the Bayesian hierarchical model for Blue Endeavour Prawns. DDD indicates Deriso models (Dichmont et al. *2003*) for each species. SSBB indicates use of size structured models for Grooved and Brown Tiger Prawns, and Bayesian hierarchical model for two Endeavour Prawns.

Scenario name	Models	Fishing power	Weekly pattern	Max. effort change[1]	Low effort threshold	Effort allocation algorithm[2]	No. of species
Base Case	SSB	Low	Last 2 year average	NA	2777	Yes	3
DDD	DDD	Low	Last 2 year average	NA	2777	Yes	3
Mid-High Fishing Power	SSB	Mid-High	Last 2 year average	NA	2777	Yes	3
Fixed effort pattern	SSB	Low	NPRAG 2013 specified season	NA	2777	No	3
Estimate season	SSB	Low	Estimated	NA	2777	No	3
Constraining effort change (year-on-year)[3]	SSB	Low	Last 2 year average	15%	2777	Yes	3
Low effort threshold	SSB	Low	Last 2 year average	NA	1000	Yes	3
4 species (including red endeavour prawn)[4]	SSBB	Low	Last 2 year average	NA	2777	Yes	4

[1] 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.
[2] 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.
[3] A sensitivity test informed by sensitivity runs in the MSE project (Dichmont, et al. 2012).

[4] 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 (see Upston et al. 2020, Appendix B).



Given the substantial data input into the assessment, an expanded series of output results are provided for each species. These are provided in Appendix A. It should be noted that although there are results for three species out of the Base Case and one species from a sensitivity test, effort-related results are only provided for tiger prawns. This is because blue endeavour prawns and red endeavour prawns (output of the sensitivity test) are treated as an economic byproduct in the assessment. This meant that modelled effort for the fishery (and costs associated with effort) was driven by tiger prawn catches (thus the model assumed blue endeavour prawns and red endeavour in the sensitivity test were not "targeted"). Economic calculations included blue endeavour prawn (and red endeavour in the sensitivity test) revenues and the additional costs associated with producing them (packaging and freight etc.).

The results were broadly divided into two groups: stock status-related results (e.g. the MSY series, steepness) which included the results related to the Limit Reference Point, and the economic-related results (e.g. MEY series, including the Harvest Strategy required effort for 2020 and 2021) and the status relative to the Target Reference Point.

The Target Reference Point was the spawning stock that would be achieved at the MEY and the Limit Reference Point was 50% of the five-year moving average of the spawning stock relative to S_{MSY} (NPF Harvest Strategy under input controls (Dichmont et al, 2012b)).

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5 Results

5.1 Catch and effort data

Catch and effort data from 1970 to 2019 were extracted from AFMA's logbook database for each tiger prawn species and for endeavour prawns. Compared with the data from 2018, the tiger prawn species-combined 2019 catch increased 40% (from 1463 t to 2086 t). Corresponding effort increased by only 4.2% from 5488 to 5716 boat days in 2019 compared to 2018 (Table 4). The nominal effort targeting grooved tiger prawns decreased by about 20%, while the effort targeting brown tiger prawns increased 100% from 2018 to 2019.

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

By applying the low fishing power series (Figure 7) which was the setting for the Base Case, the 2019 standardised effort for grooved tiger prawns decreased about 14.5% from 2018. For brown tiger prawns, effort increased about 113% from 2018 to 2019 (see Table 5 for the low fishing power and Table 6 for the mid-high fishing power estimates).

Of more importance were the structural changes in the fishery which made the interpretation of long-term trends in catch and effort data alone difficult to interpret. Despite the uncertainty, catch rates for grooved and brown tiger prawns were both predicted to increase in 2019. The 'low' fishing power assessment model provided an estimated 26% increase for grooved tiger prawns and 16% increase for brown tiger prawns, from 2018 to 2019 (Table 5). However, this was not fully consistent with the 2019 survey recruitment indices, in which there was a 32% decrease for grooved tiger prawns, but a 90% increase for brown tiger prawns (Table 7). Table 8 shows the time series of the spawning survey index (the spawning survey was not undertaken in 2010, 2015, 2017 and 2019).

Figure 8 shows the mean Catch per Unit of Effort (CPUE) indices derived from CPUEs estimated from two standardised fishing effort series based on the new fishing power series and the nominal effort. It also shows the survey recruitment and spawning indices. CPUE did not increase in 2019 relative to 2018 as predicted by the assessment model.

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. 2020).

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	8,513	167	155	19,539	162
1995	9,095	8,910	184	277	18,005	230
1996	10,232	7,644	117	151	17,876	131

1997	9,963	7,040	146	178	17,003	159
1998	12,977	8,192	141	177	21,168	155
1999	10,548	4,978	134	151	15,526	140
2000	10,409	4,604	152	138	15,013	148
2001	9,771	3,190	151	166	12,961	155
2002	9,211	1,138	191	228	10,349	195
2003	9,580	803	204	386	10,383	218
2004	8,610	584	175	443	9,194	192
2005	6,880	1,776	189	251	8,656	202
2006	5,560	1,845	235	298	7,405	251
2007	3,948	1,182	227	256	5,130	233
2008	4,528	1,340	165	206	5,868	174
2009	4,580	1,769	168	234	6,349	186
2010	5,125	1,533	224	316	6,658	246
2011	4,331	1,613	118	188	5,944	137
2012	5,517	1,794	150	211	7,310	165
2013	6,050	2,592	243	282	8,642	255
2014	5,403	2,019	221	244	7,422	227
2015	7,676	1,905	313	401	9,580	331

2016	6,290	3,402	197	264	9,692	221
2017	5,562	2,224	130	160	7,786	139
2018	7,475	1,850	147	198	9,325	157
2019	6,394	3,945	184	230	10,338	202

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. 2020, 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	11,088	8,561	166	154	19,650	161
1995	9,492	9,298	176	265	18,790	220
1996	10,498	7,842	114	147	18,340	128
1997	10,615	7,500	137	167	18,115	149
1998	12,850	8,112	143	179	20,961	157
1999	10,566	4,987	134	151	15,552	140
2000	10,820	4,786	146	132	15,606	142
2001	10,076	3,290	147	161	13,366	150
2002	8,648	1,069	203	243	9,717	208
2003	8,817	740	221	419	9,557	236
2004	7,934	538	190	481	8,472	208
2005	7,049	1,820	185	245	8,869	197

2006	5,756	1,910	227	288	7,666	242
2007	3,869	1,159	231	262	5,028	238
2008	4,498	1,331	166	207	5,829	175
2009	4,497	1,737	171	238	6,234	190
2010	5,043	1,509	228	322	6,552	250
2011	4,502	1,676	113	181	6,178	132
2012	5,588	1,817	148	209	7,405	163
2013	6,072	2,601	242	281	8,673	254
2014	5,436	2,031	220	242	7,467	226
2015	7,633	1,894	315	403	9,527	333
2016	6,320	3,418	196	263	9,738	220
2017	5,703	2,280	127	156	7,984	135
2018	7,468	1,849	147	198	9,316	157
2019	6,304	3,889	187	233	10,194	205

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

From upper to bottom panels: Grooved Tiger Prawns, Brown Tiger Prawns, Blue Endeavour Prawns and Red Endeavour Prawns. CPUE index from 1993 to 2019 was calculated using the two standardised efforts series. The mean survey recruitment and spawning indices were also provided for each stock (with an extension to include the 2017–2020 recruitment survey indices and additional 2018 spawning survey indices).

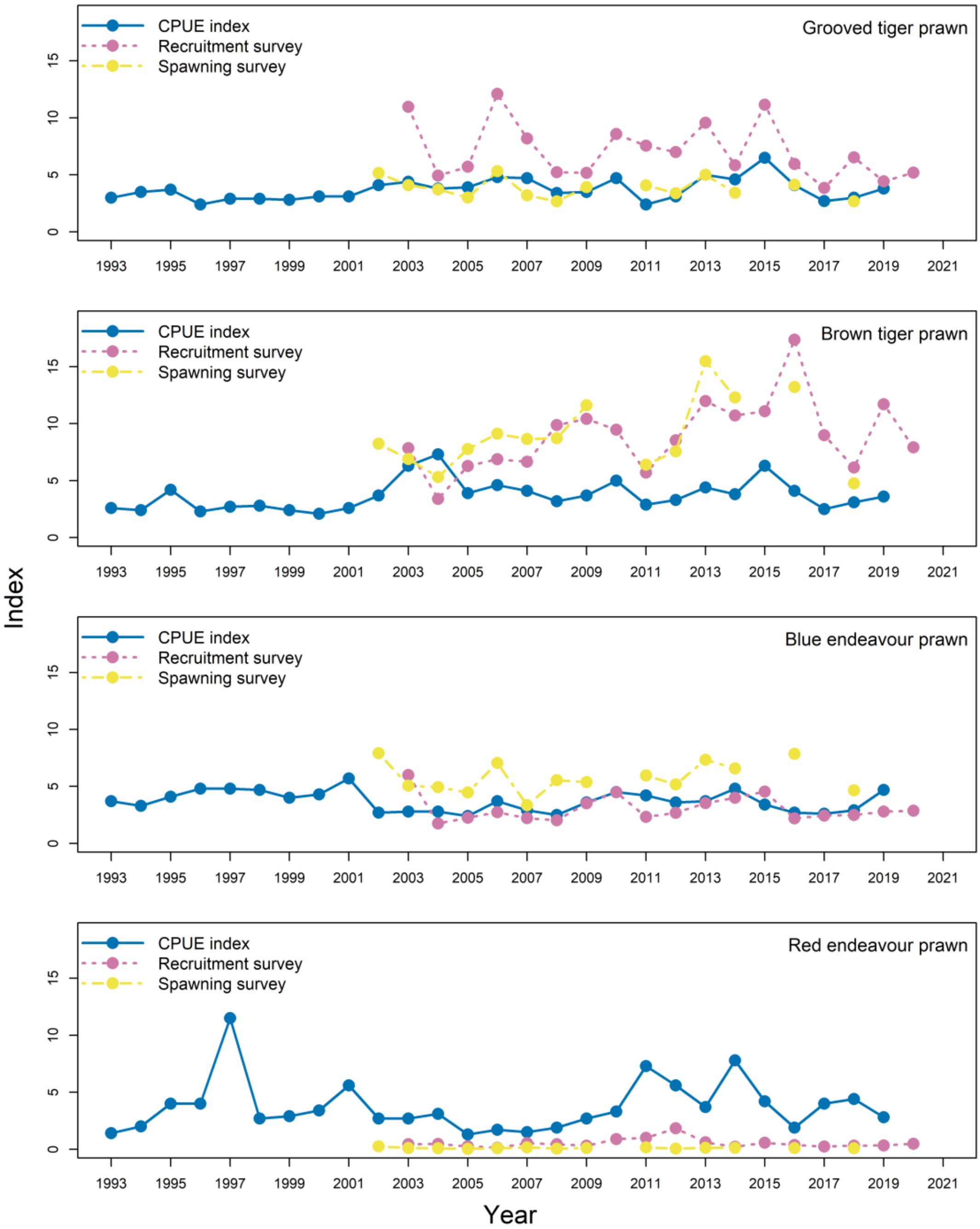


Table 7. Survey recruitment index series

	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

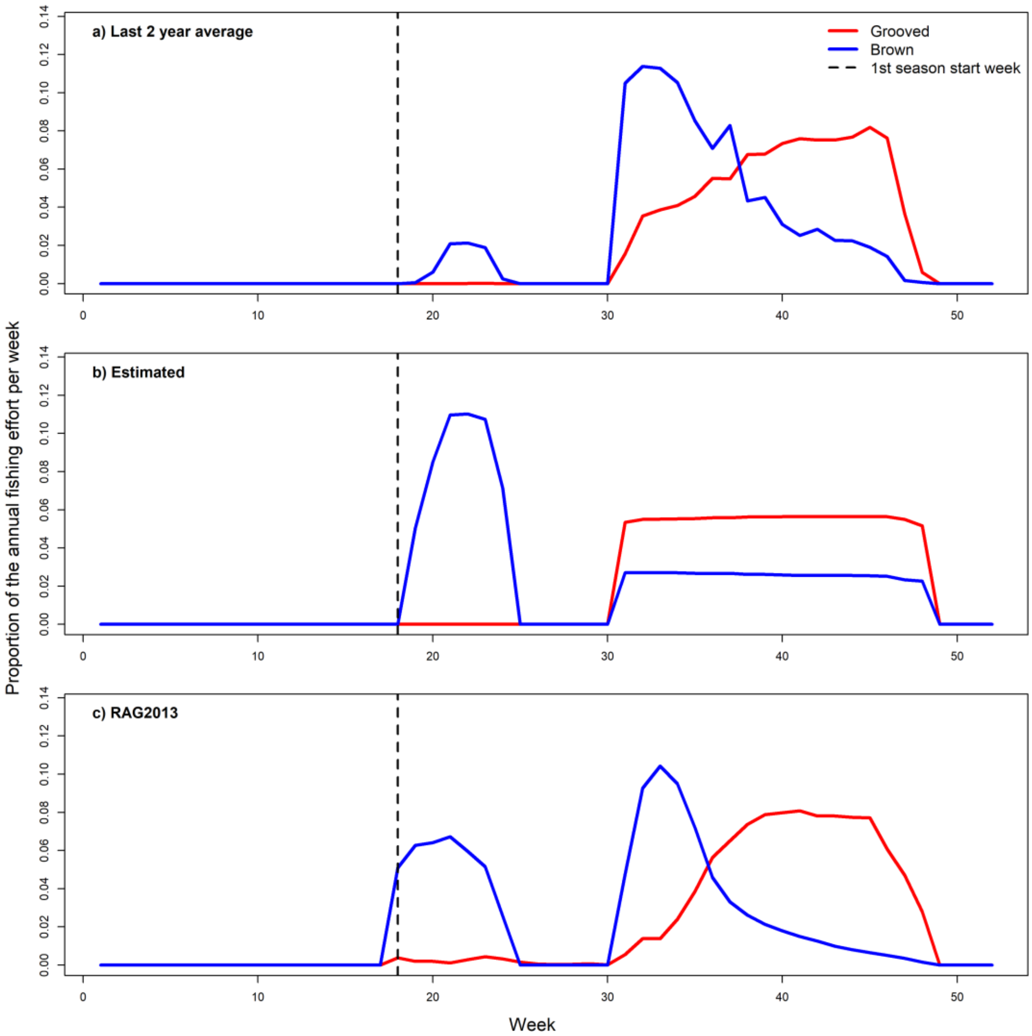
Table 8. Survey spawning index series

	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

5.2 Fishing Patterns

Figure 9. The relative fishing pattern (for three cases).

(a) the pattern for the Base Case, as average of the last two years' effort pattern set by NPRAG (March 2014); the pattern (b) 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.



5.3 Stock status

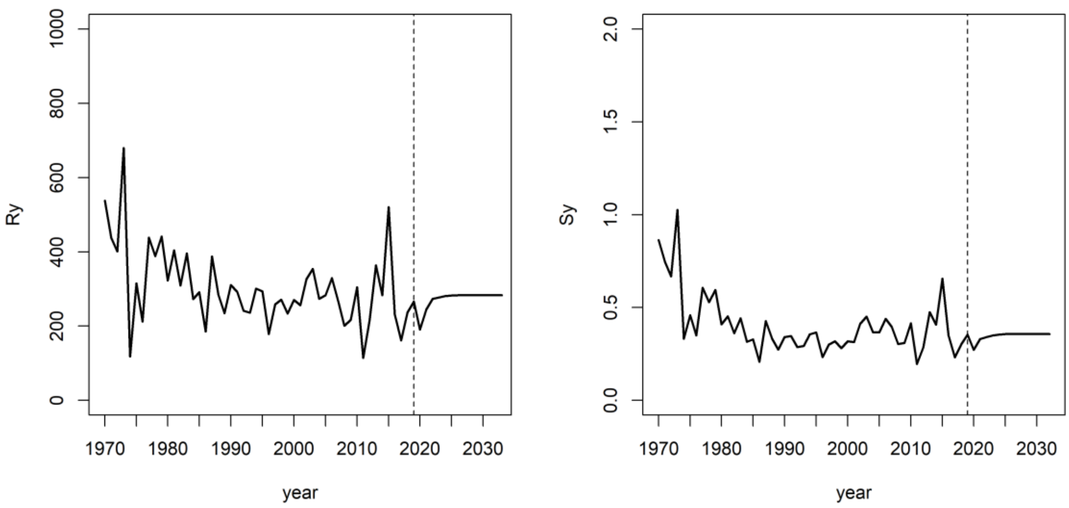
The stock assessment results for grooved and brown tiger prawns, and blue endeavour prawns for 2019 compared to 2018 are described below (5.3.1 to 5.3.4). Levels of the 2020 recruitment for the two Tiger Prawn species from the 2019 stock are also predicted. The sensitivity test results and model fit are detailed separately (5.3.5 and 5.3.6).

5.3.1 GROOVED TIGER PRAWNS

The estimates of grooved tiger prawn annual recruitment are shown in Figure 10 (left panel). A moderate decrease in recruitment was seen from 2018 to 2019.

Figure 10. Recruitment (left) and spawning (right) stock size indices for Grooved Tiger Prawns, calculated from the model, for the Base Case tests.

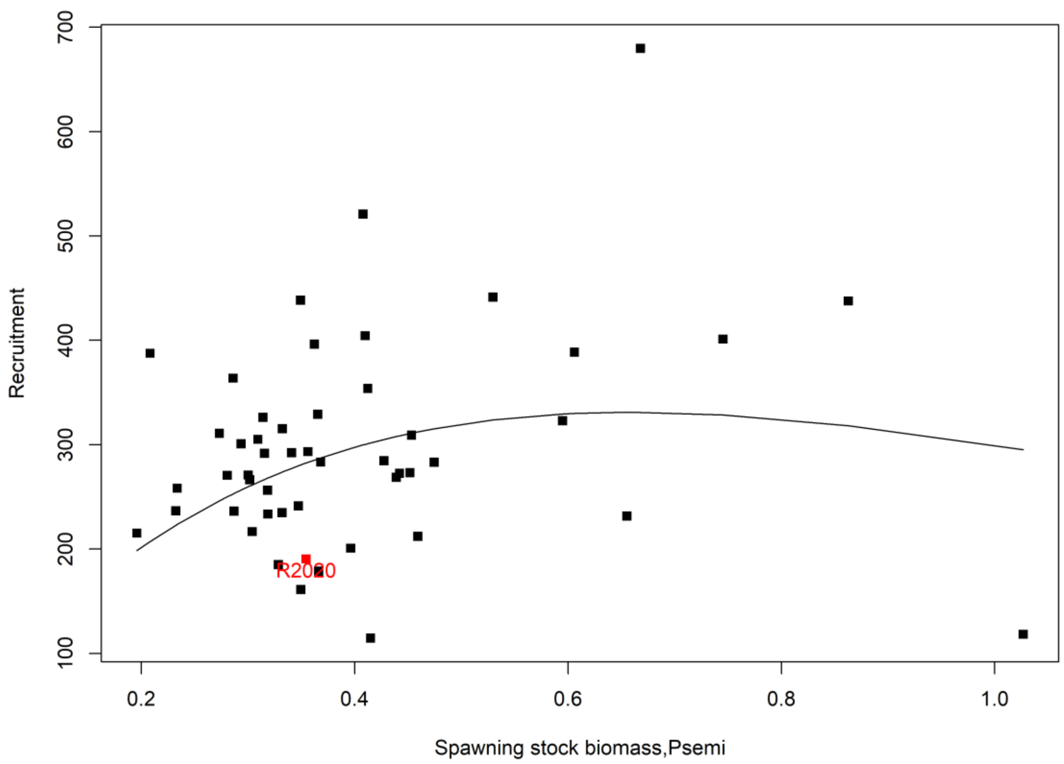
The vertical dotted line is 2019; any values thereafter are the results of the estimated projections from the bio-economic model.



The spawning stock index represented the abundance of female prawns in spawning condition during the year. The 2019 spawning stock index of grooved tiger prawns moderately increased from the previous year (Figure 10, right panel).

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

The red spot indicates the estimated 2019 spawning index and resultant 2020 recruitment value.



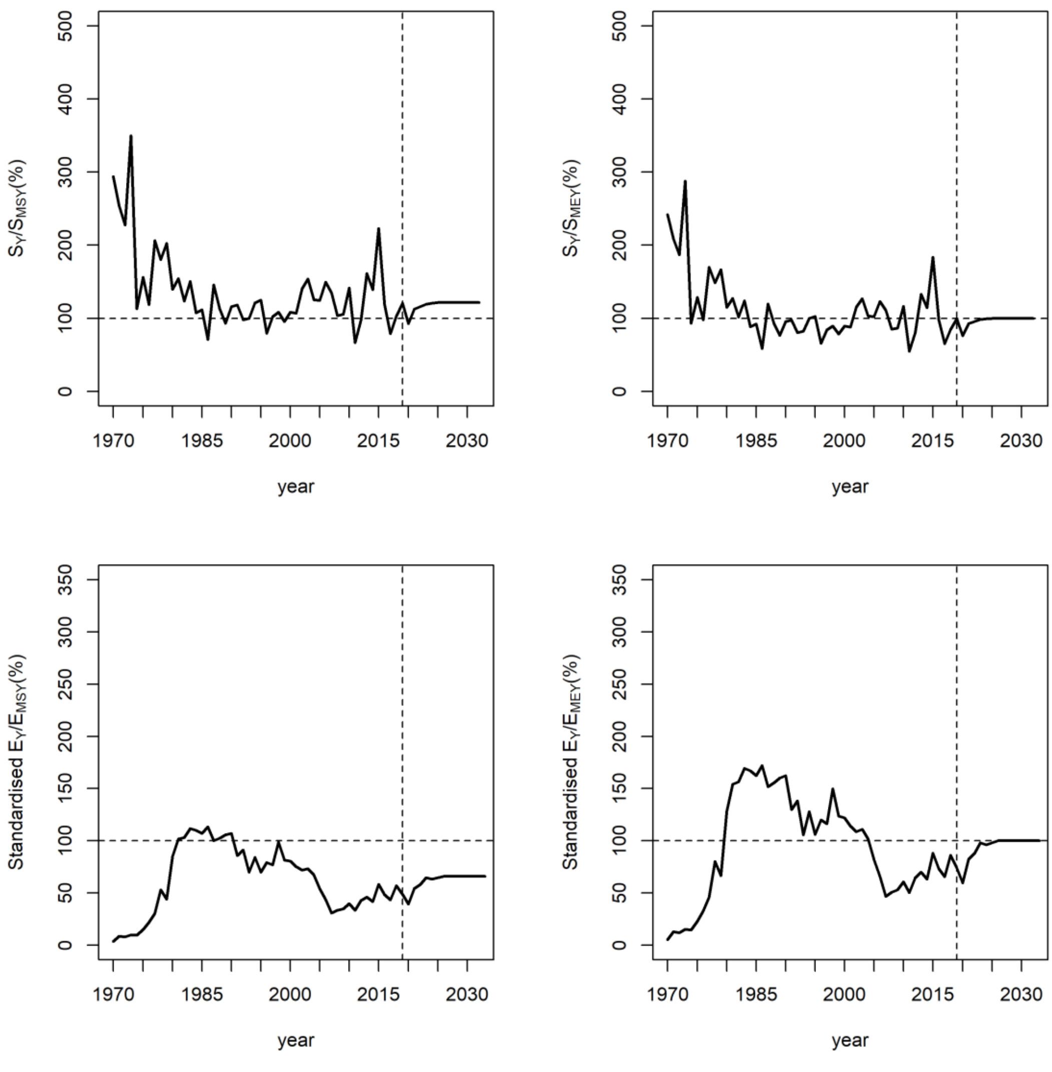
The grooved tiger prawn's management and other quantities reported below were derived from the stock-recruitment function, which related the recruits that would be produced in the biological year to the spawners of the previous calendar year (Figure 11). Steepness, calculated from the stock-recruitment relationship, was an indicator of resource productivity. The large scatter of points in Figure 11 indicated that the relationship was subject to a large amount of variability that was probably environmentally driven. The estimated value of steepness suggested that grooved tiger prawn's productivity was low to medium (Table 10). The 2019 stock index that resulted in the 2020 recruitment is highlighted in red on the graph.

Figure 12 shows that the value for the grooved tiger prawns stock status in 2019 was above (121%) the spawning stock size at MSY (S_{MSY}). Standardised grooved tiger prawn effort in 2019 was estimated to be 49% of the effort at MSY (E_{MSY}).

Table 10 shows that the five-year moving average of S2015-2019/S_{MSY} was 129%. This was well above the Limit Reference Point value of 50% as required by the NPF Harvest Strategy (Dichmont et al. 2014). Importantly, the Punt et al. (2010) model calculated the indicators taking into consideration the size at which the animals were caught. Effort in the Base Case was assumed to be distributed through the year according to the average of last two years' effort patterns (see Figure 9a).

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

1) Spawning stock size (S_Y) relative to the spawning stock size at Maximum Sustainable Yield (S_{MSY}) (top left), 2) spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}) (top right), 3) standardised effort in a year (E_Y) relative to the effort at Maximum Sustainable Yield (E_{MSY}) (bottom left) and 4) standardised effort in a year (E_Y) relative to the effort at Maximum Economic Yield (E_{MEY}) (bottom right).



5.3.2 BROWN TIGER PRAWNS

The estimated brown tiger prawns' annual recruitment trend is shown in Figure 13 (left panel). Recruitment decreased in 2019 from 2018. Spawning stock biomass indices for the year represented the relative number of female prawns in spawning condition during the calendar year. The estimated spawning stock index of brown tiger prawns has increased from 2018 onwards (Figure 13, right panel).

Figure 13. Recruitment index (left) and spawning index (right) for Brown Tiger Prawns, calculated from the model, for the Base Case test.

The vertical dotted line is 2019; any values thereafter were the results of the estimated effort projections based on the bio-economic model.

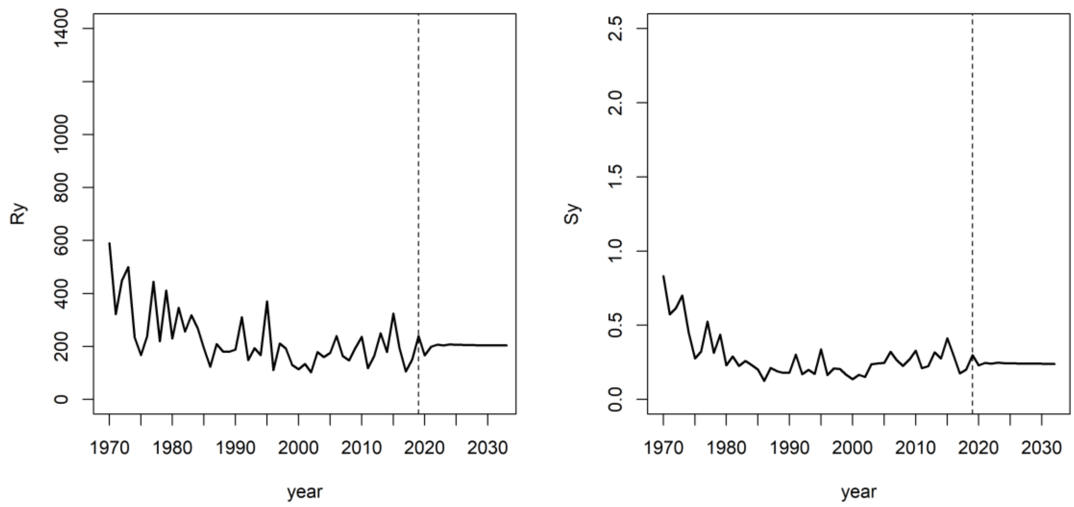
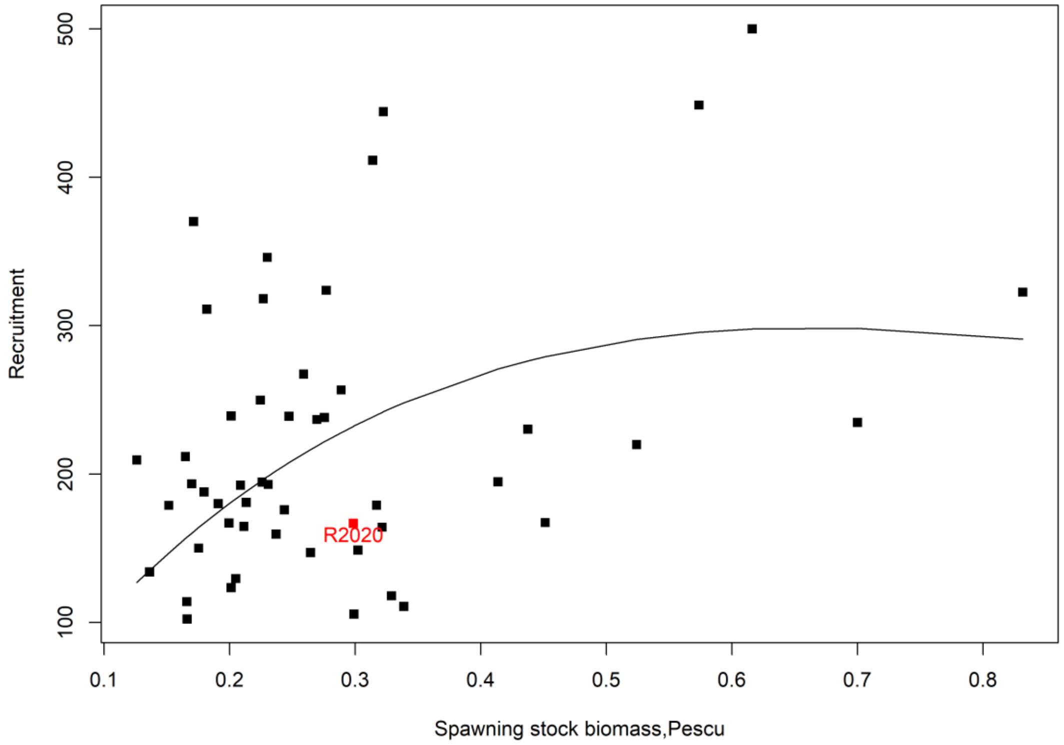


Figure 14. Estimated annual spawning stock biomass index that produced recruits (dots), fitted as a stock-recruitment relationship (line) for Brown Tiger Prawns for the Base Case.

The red spot indicates the estimated 2019 spawning index and resultant 2020 recruitment value.



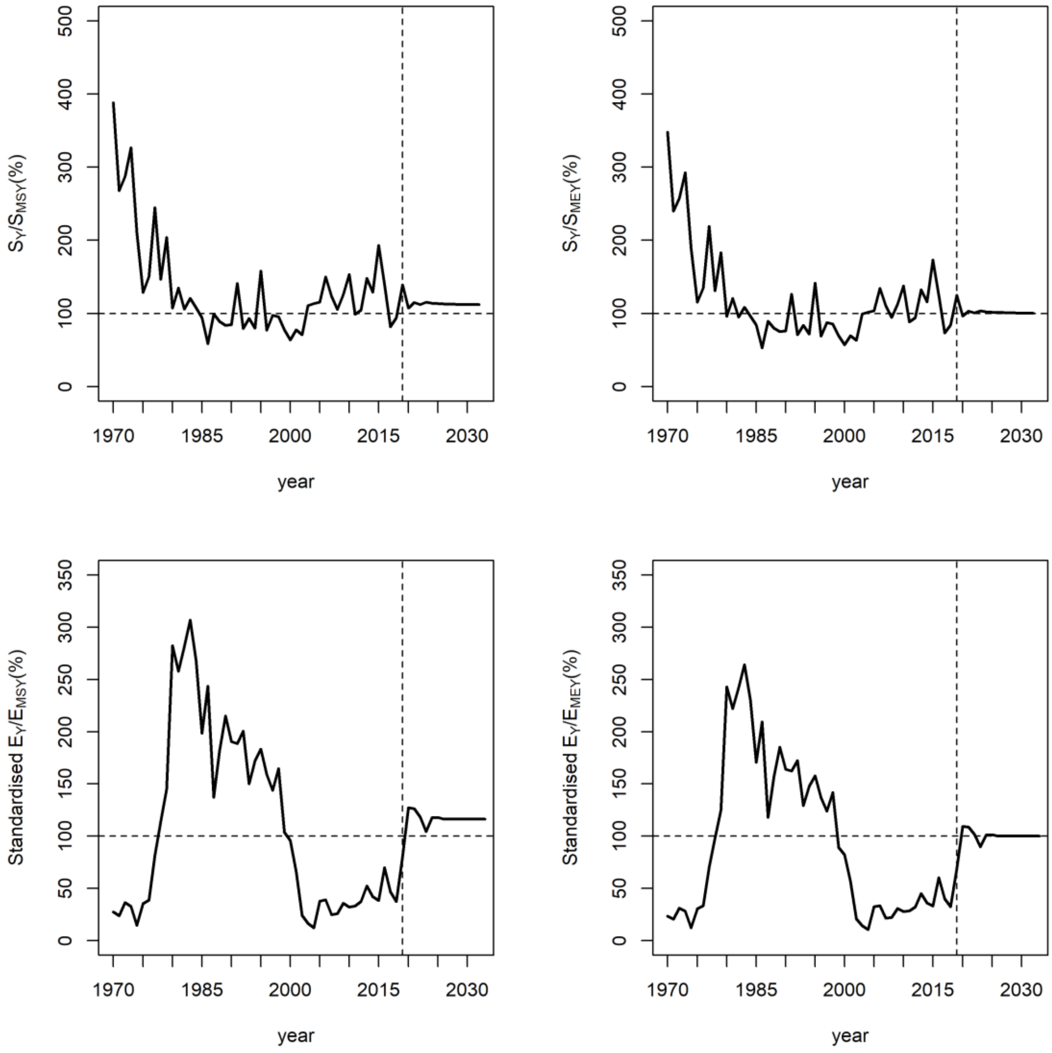
The brown tiger prawns' management and other quantities reported below were derived from the stock-recruitment function, which related the recruits that would be produced in the subsequent biological year with the spawners of the previous calendar year (Figure 14). Steepness, calculated from the stock-recruitment relationship, was an indicator of resource productivity. Predicted recruitment in 2020 was low and the estimated steepness value also suggested that brown tiger prawns' productivity was low (Table 10). The 2019 stock index that resulted in the 2020 recruitment is highlighted in red on the graph.

The value for the brown tiger prawns stock status in 2019 was above the spawning stock size at MSY (S_{MSY}) (139%, Table 10). Figure 15 indicates that the standardised effort in 2019 was below (80%) the effort at MSY (E_{MSY}). Similarly, the five-year moving average of S2015-2019/S_{MSY} was well above the Limit Reference Point value of 50% (130%, Table 10), as required by the NPF Harvest Strategy (Dichmont et al. 2014).

AS for the grooved tiger prawns, Punt et al. (2010, 2011) model calculated the indicators whilst taking into consideration the size at which the animals were caught. Effort in the Base Case was assumed to be distributed throughout the year using the average of last two years' effort patterns (see Figure 9a).

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

1) Spawning stock size (S_Y) relative to the spawning stock size at Maximum Sustainable Yield (S_{MSY}) (top left), 2) spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}) (top right), 3) standardised effort in a year (E_Y) relative to the effort at Maximum Sustainable Yield (E_{MSY}) (bottom left) and 4) standardised effort in a year (E_Y) relative to the effort at Maximum Economic Yield (E_{MEY}) (bottom right).

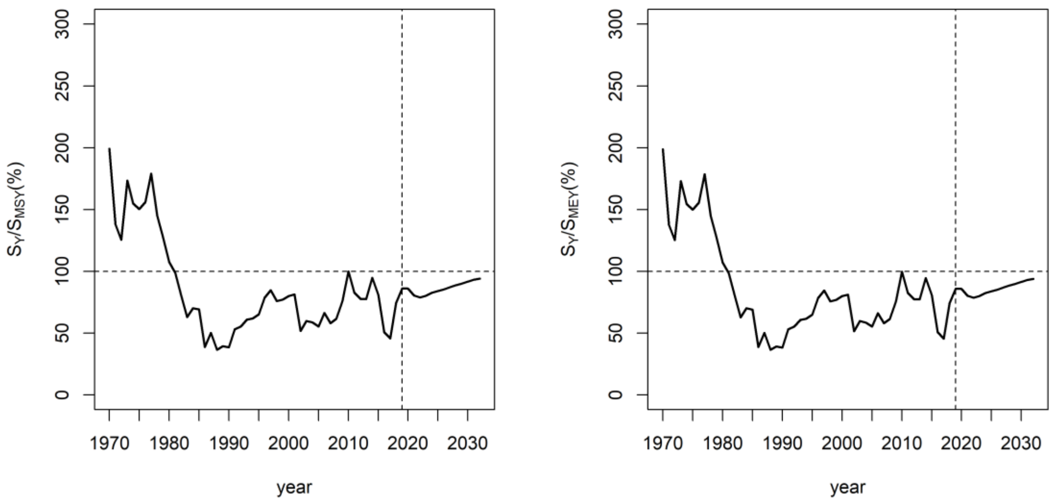


5.3.3 BLUE ENDEAVOUR PRAWNS

A blue endeavour prawns assessment was included using the Bayesian biomass production model (see Figure 16 and key indicators in Table 10) although this species are treated as an economic byproduct. The value of $S2019/S_{MSY}$[5] was at 86% (Table 10). Its five-year mav of $S_{2015\text{-}2019}/S_{MSY}$ was at 68%. This was above the Limit Reference Point value of 50%, as required by the NPF Harvest Strategy (Dichmont et al. 2014).

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

1) Spawning stock size (S_Y) relative to spawning stock size at Maximum Sustainable Yield (S_{MSY}) (left), 2) spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}) (right).



5.3.4 RED ENDEAVOUR PRAWNS

A red endeavour prawns assessment was included in a sensitivity test using the Bayesian biomass production model (see Figure 17 and key indicators in Table 10). Red endeavour prawns were treated as an economic byproduct. The sensitivity tests indicated that the value of $S2019/S_{MSY}$[6] was at 90% (Table 10). The sensitivity indicated that the five-year mav of $S_{2015\text{-}2019}/S_{MSY}$ is at 113%. This level was also above the Limit Reference Point value of 50%, as required by the NPF Harvest Strategy (Dichmont et al. 2014). The result was preliminary due to the lack of red endeavour prawn life history parameter information.

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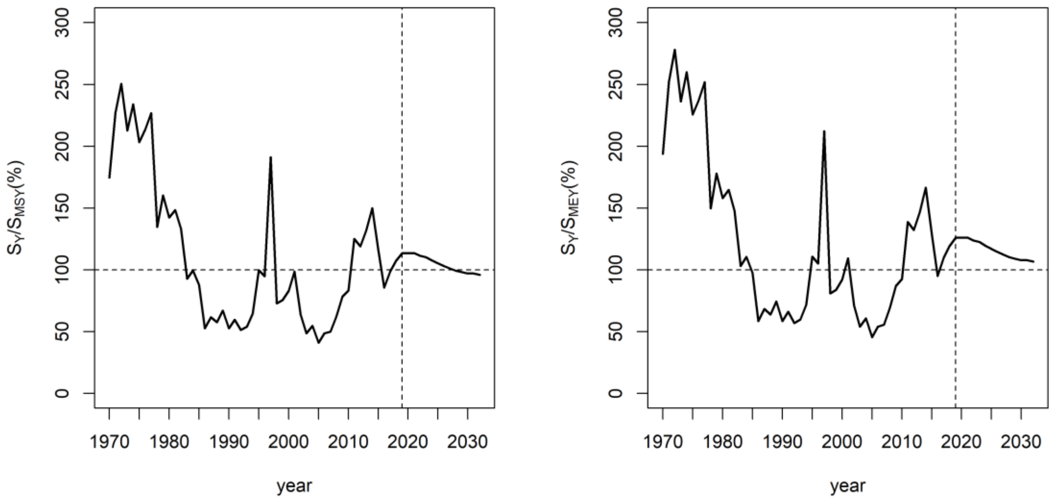
[6] The Bayesian hierarchical biomass dynamic model outputs values for biomass thus this is strictly B_Y/B_{MSY}. Since the model is not size or age structured, the ratio is essentially similar to any ratio of stock (S) status.

Figure 17. Status of the stock relative to reference points for Red Endeavour Prawns for the 4 species sensitivity test.

1) Spawning stock size (S_Y) relative to spawning stock size at Maximum Sustainable Yield (S_{MSY}) (left), 2) spawning stock size in a year relative to the spawning stock size at Maximum Economic Yield (S_{MEY}) (right).



5.3.5 SENSITIVITY TESTS FOR BOTH TIGER PRAWN SPECIES

The major outputs for stock and economic status and setting future effort for each prawn species are provided (see Table 11 for grooved tiger prawns, Table 12 for brown tiger prawns, Table 13 for blue endeavour prawns and Table 14 for red endeavour prawns; Appendix A).

The following scenarios tested the stock assessment model assumptions:

- Base Case including 'low' fishing power series;
- middle-high fishing power series;
- alternative assessment models;
- fixed fishing effort pattern;
- estimation of fishing patterns;
- constrain the size of effort changes;
- lower effort threshold; and
- four species model.

They showed that the highest steepness (productivity) values arose from the Base Case. The DDD model produced the lowest productivity value.

The fishing pattern had implications for mainly estimated profitability of the fishery: comparing the Base Case with the “estimated pattern” (Figure 9b), the relative profits with the “estimated pattern” were, at 112%, a little higher than the Base Case. In addition, the model predicted higher catch values over an “optimised” open season. The scenario of a fixed fishing pattern (Figure 9c) RAG 2013 pattern) produced the same relative profits to that of the Base Case (100%). It appeared there were only a few profit differences among the alternative cases due to the favourable economic environment (lower fuel price, lower exchange rate and higher prawn price).

The results were not sensitive to fishing power. Comparing the Base Case with “mid-high” fishing power series, there were no substantial differences in the indicators such as steepness, S_{2019}/S_{MSY} or the relative profits.

Under none of the scenarios, for any species, have the values for five-year moving average of $S_{2015\text{-}2019}/S_{MSY}$ fallen below 50%, and therefore all the prawn stocks are above the Limit Reference Point. The species were not overfished as defined by the Commonwealth-approved NPF Harvest Strategy (Dichmont et al. 2014).

There was little effect of constraining inter-annual effort changes to 15% or less: comparing the Base Case with the “constrained effort change” scenario, the relative profit was about 100% of the Base Case.

“DDD” estimated stock status conservatively relative to the Base Case but under this scenario, the five-year moving average of $S_{2015\text{-}2019}/S_{MSY}$ was still above the Limit Reference Point (50%). The relative profit was, however, at 95% of Base Case for 2019. Not being a size-structured model, the Deriso (delay-difference) models were unable to capture the price differentials between small and large prawns.

Comparing the Base Case with “lower effort threshold”, there were no substantial differences in the indicators such as steepness and S_{2019}/S_{MSY}, and the relative profit of the scenario was close to 100% of the Base Case.

5.3.6 MODEL FIT

The distribution of the catch residuals by species is shown for the Base Case (see Figure 18). The residuals (transformed difference between observed and estimated catch) were shown as a distribution of the model fits to weekly catch data from 1970 to 2019 (Figure 18, Figure 19 and Figure 20). These values were on the square root-transformed scale as used in the assessment likelihood. This transformation was shown to be the best method to transform the data to achieve values closest to a normal distribution (Dichmont et al. 2001). The fairly even and apparently normal distributions of the residuals indicated that the fit of weekly catch was unbiased.

The observed survey and estimated recruitment and spawning indices are plotted in Figure 21. The model versus observed fits for the size-specific data from commercial and survey data (per species) are shown in Figure 22-Figure 27. The model fits are all good to reasonable. Figure 28 shows the estimates of biological and fishery parameters for the base-case size-structured population model, including the recruitment pattern, the selectivity to the spawning and recruitment survey, and selectivity to the fishery.

Figure 18. Distribution of the residuals (square root-transformed difference between observed and predicted catch) by week and year values.

Top) Grooved Tiger Prawns, bottom) Brown Tiger Prawns for the Base Case assessment.

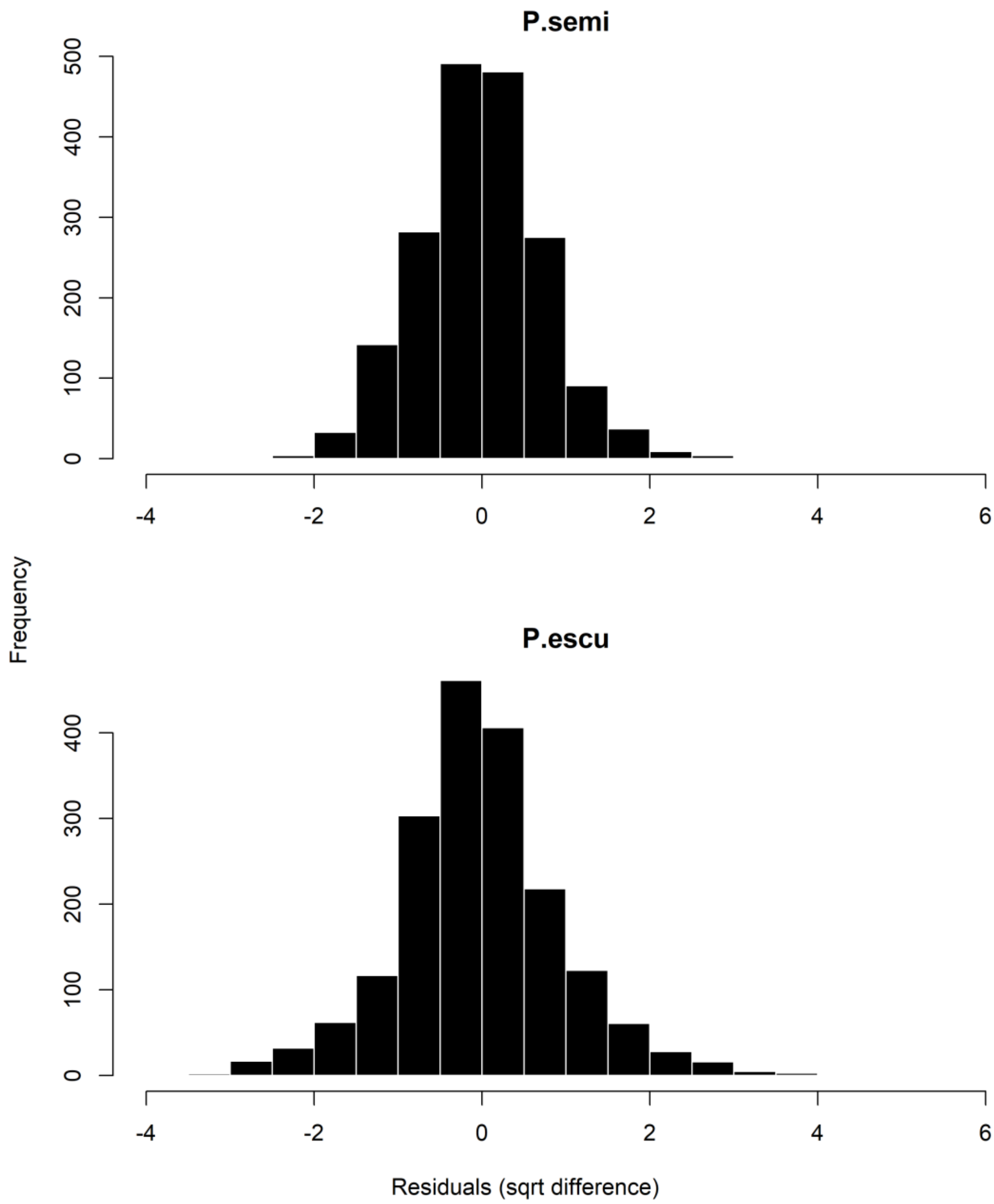


Figure 19. Annual (top left and bottom left) and within-year (top right) residual patterns about the fit to the catch-in weight data for Grooved Tiger Prawns for the Base Case.

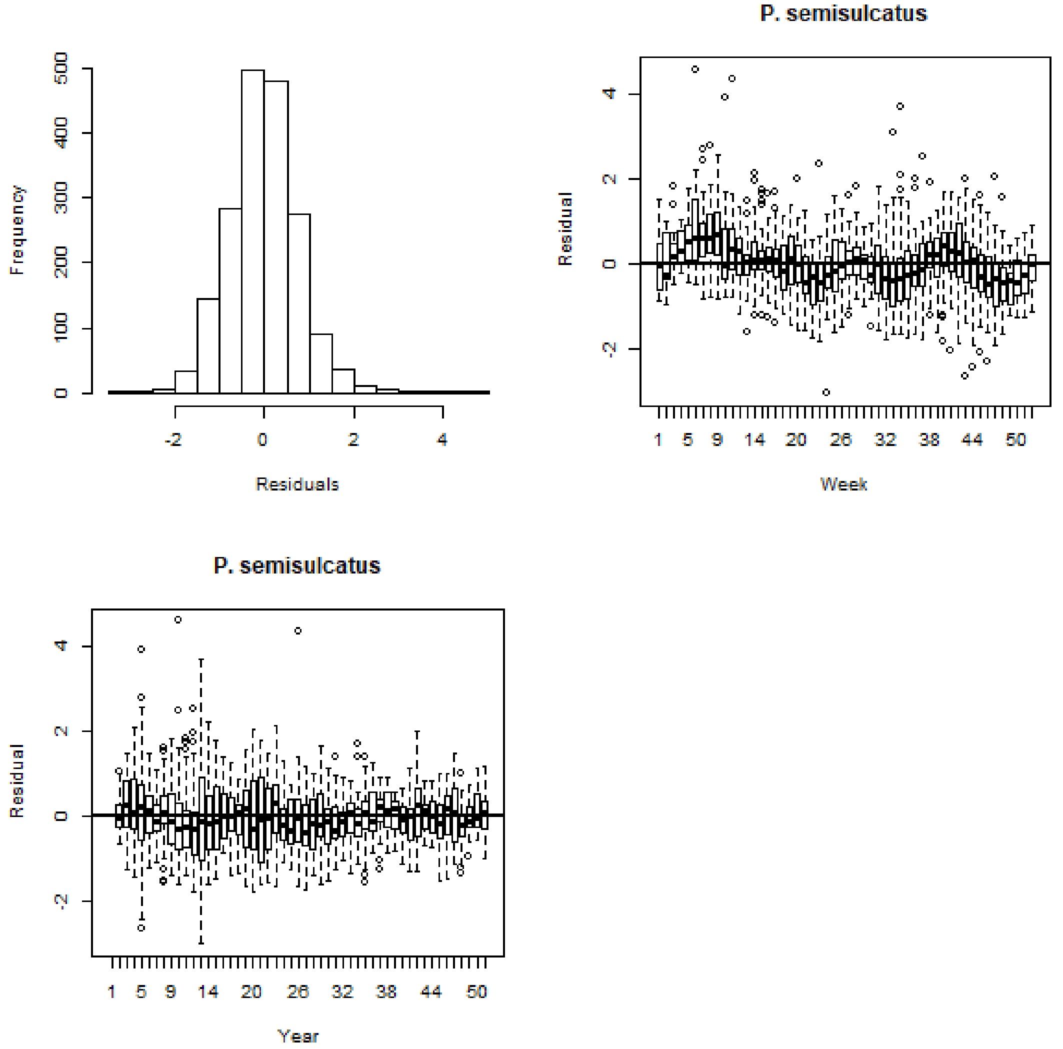


Figure 20. Annual (top left and bottom left) and within-year (top right) residual patterns about the fit to the catch-in weight data for Brown Tiger Prawns for the Base Case.

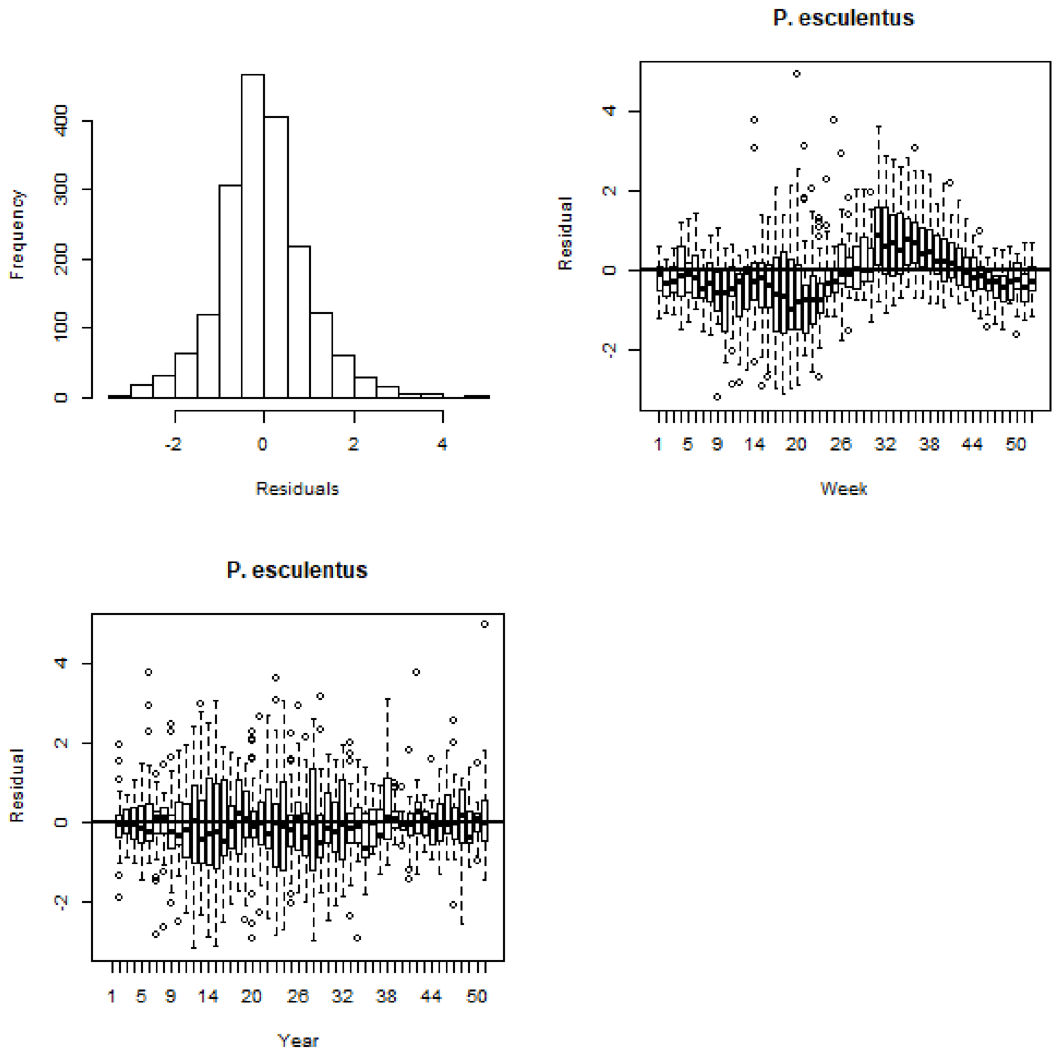


Figure 21. Model estimated survey index (solid line) and observed index (points as means and 1 standard error).

Upper panel: Recruitment index. Lower panel: Spawning index. Left panel: Grooved Tiger Prawns; right panel: Brown Tiger Prawns.

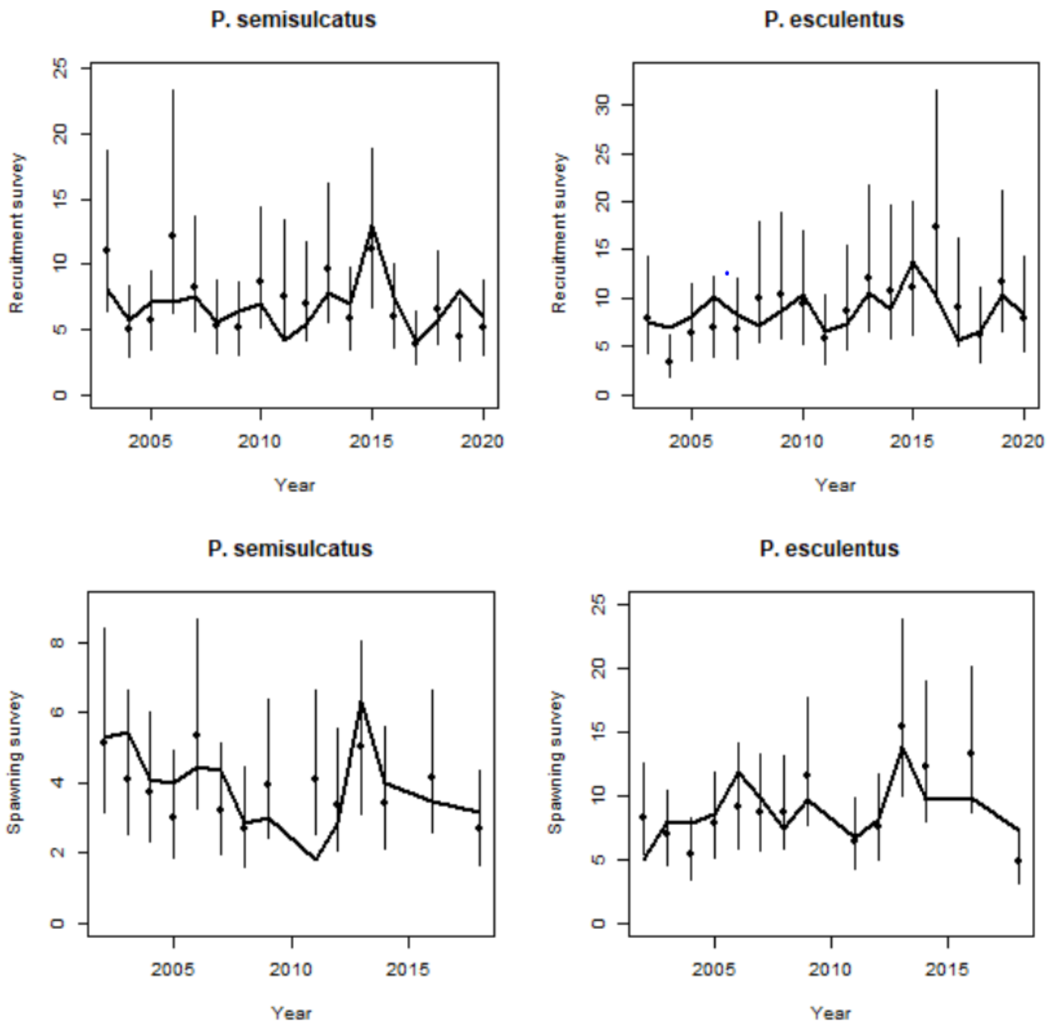
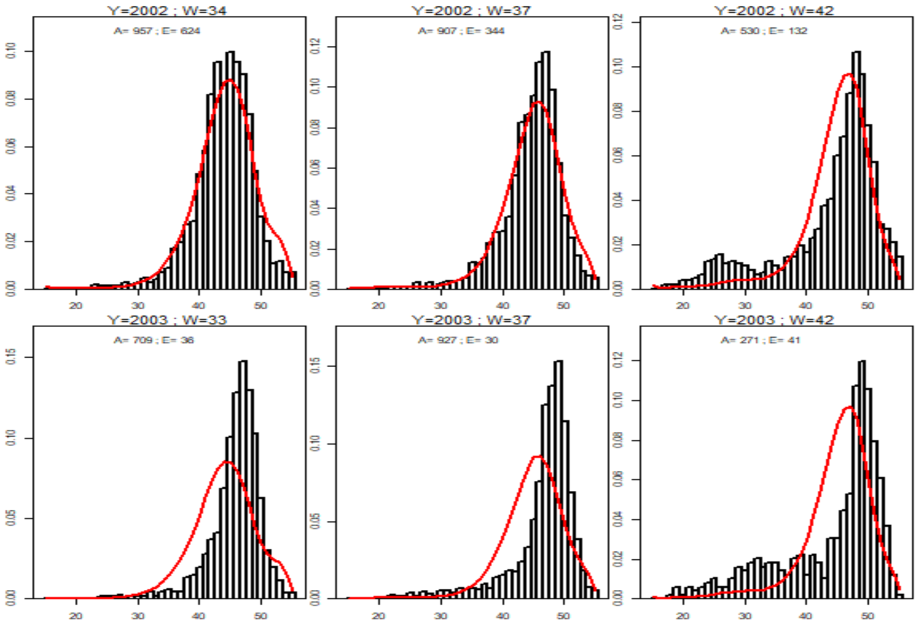


Figure 22. Estimated LF curves (red line) and observed commercial composite data for Grooved Tiger Prawns. a) female; b) male. Y = year, W = week, A = actual sample size, E = effective sample size (for all the LF plots).

a)



b)

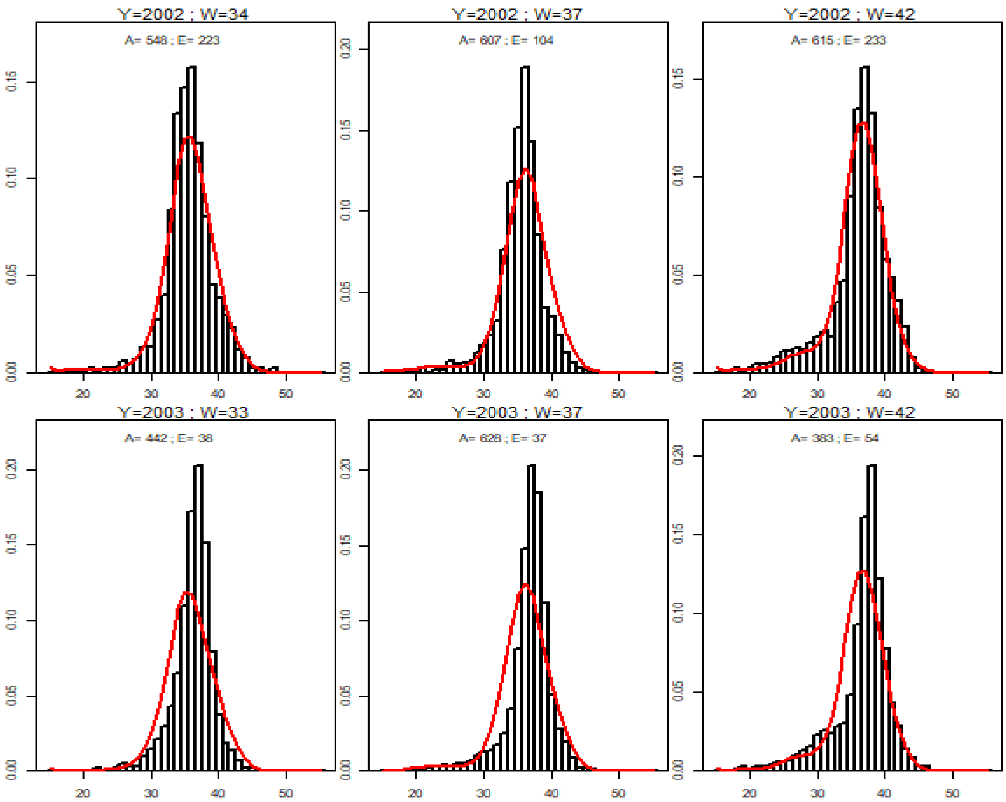
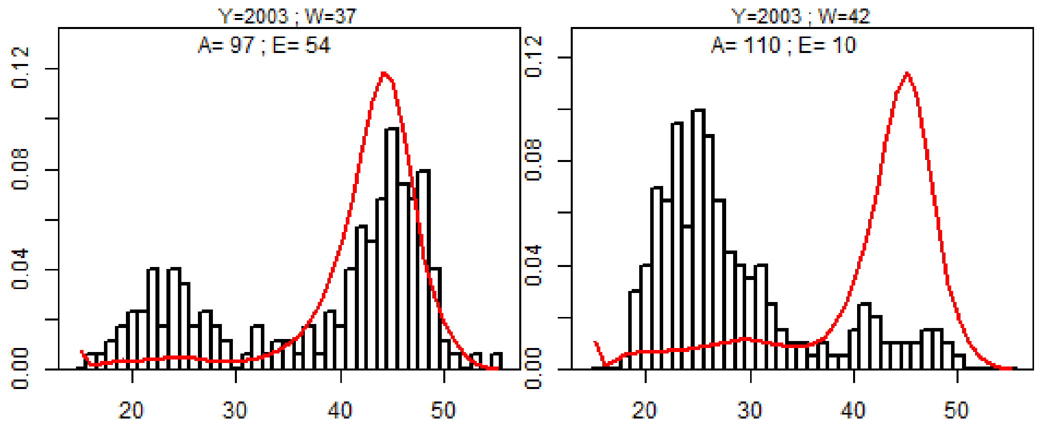


Figure 23. Estimated LF curves (red line) and observed commercial composite data for Brown Tiger Prawns**.** a) female; b) male.

a)



b)

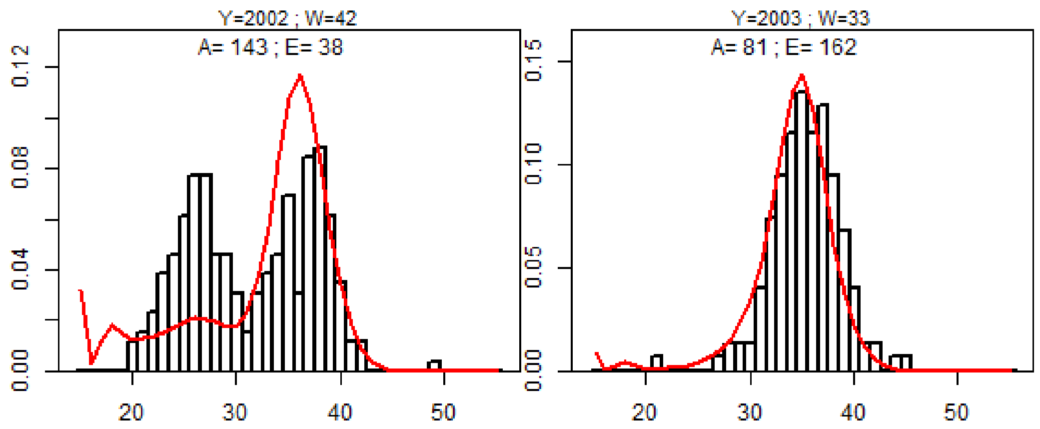
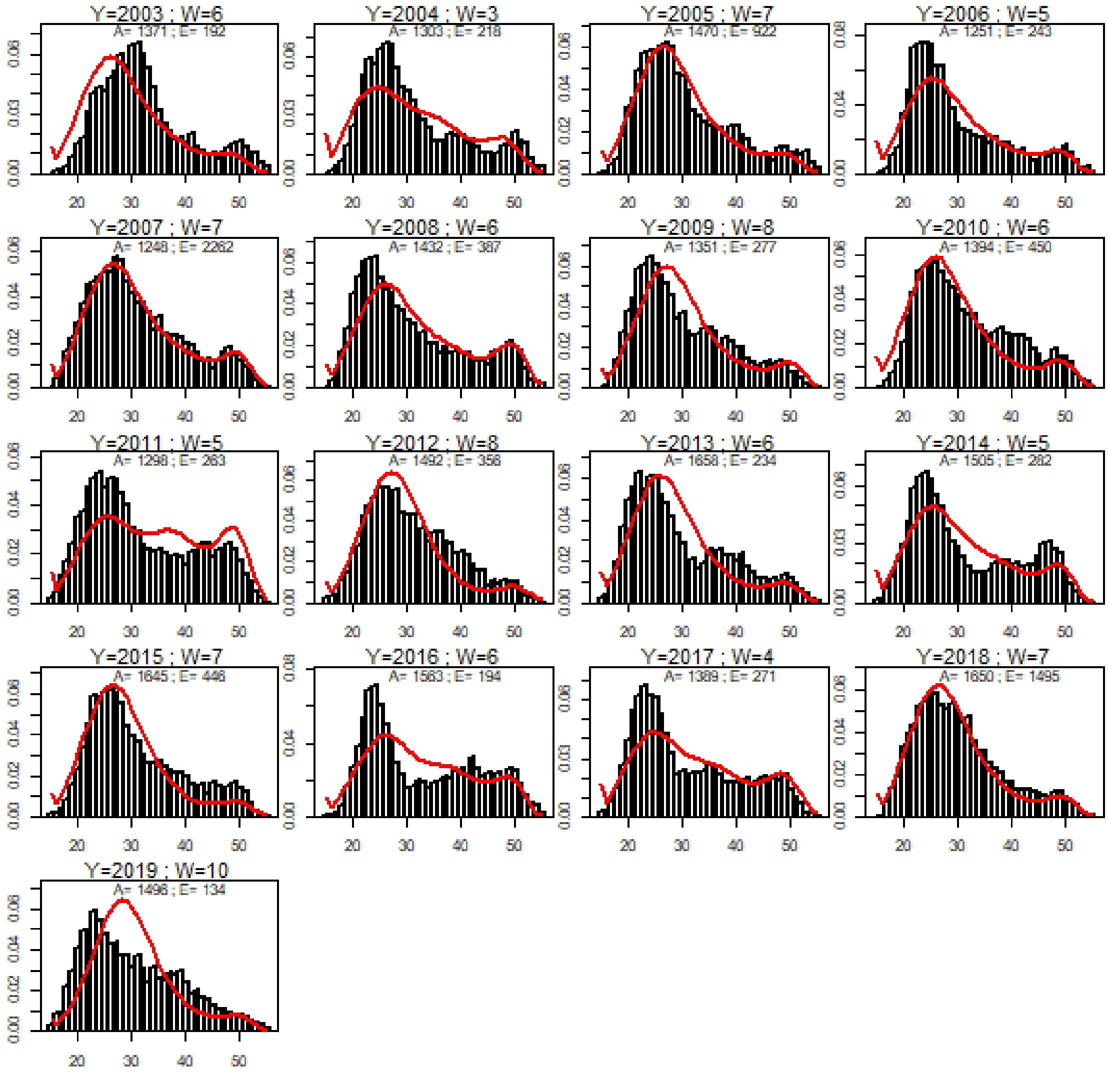


Figure 24. Estimated LF curves (red line) and observed recruitment survey composite data for Grooved Tiger Prawns**.** a) female; b) male

a)



b)

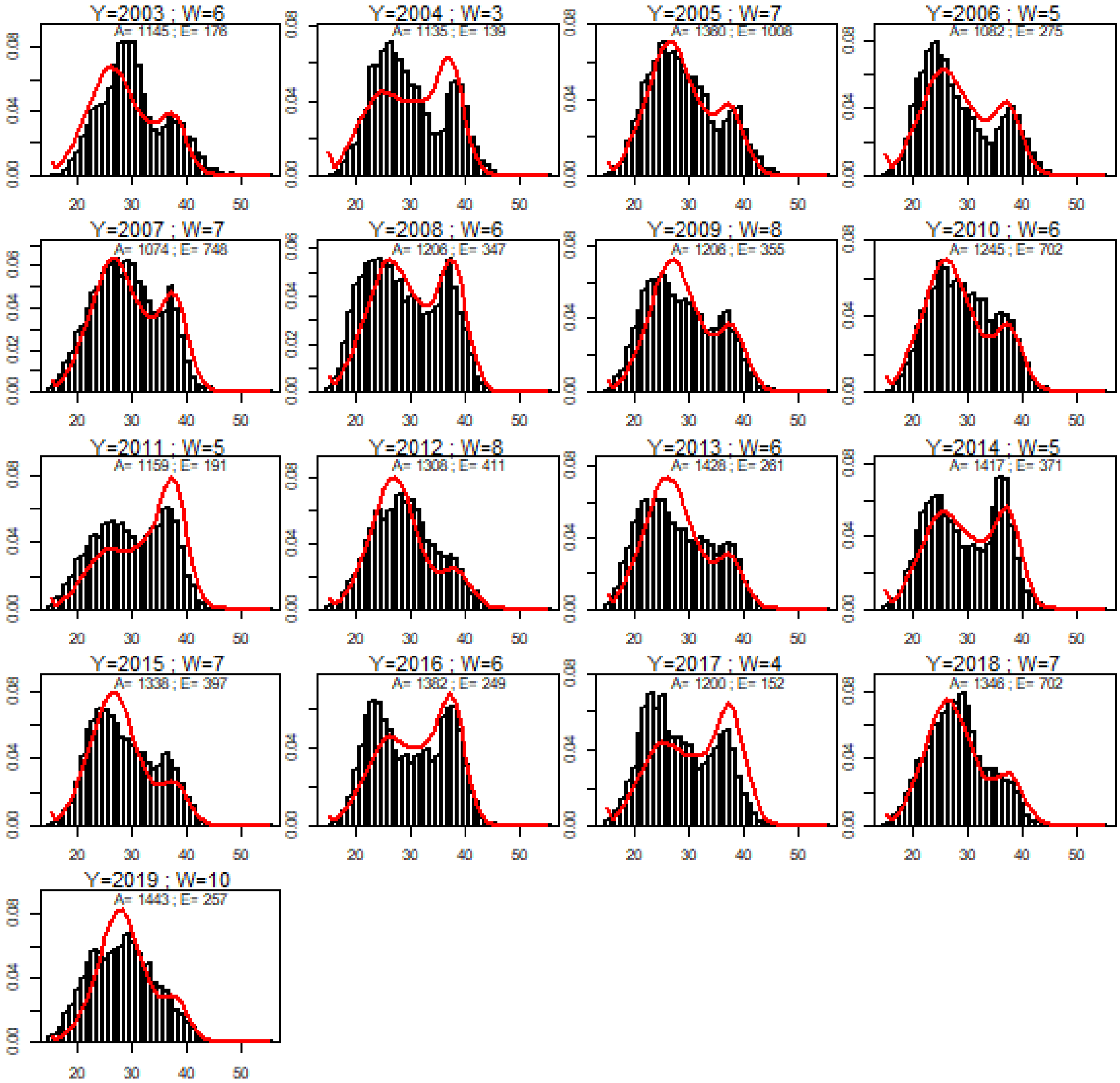
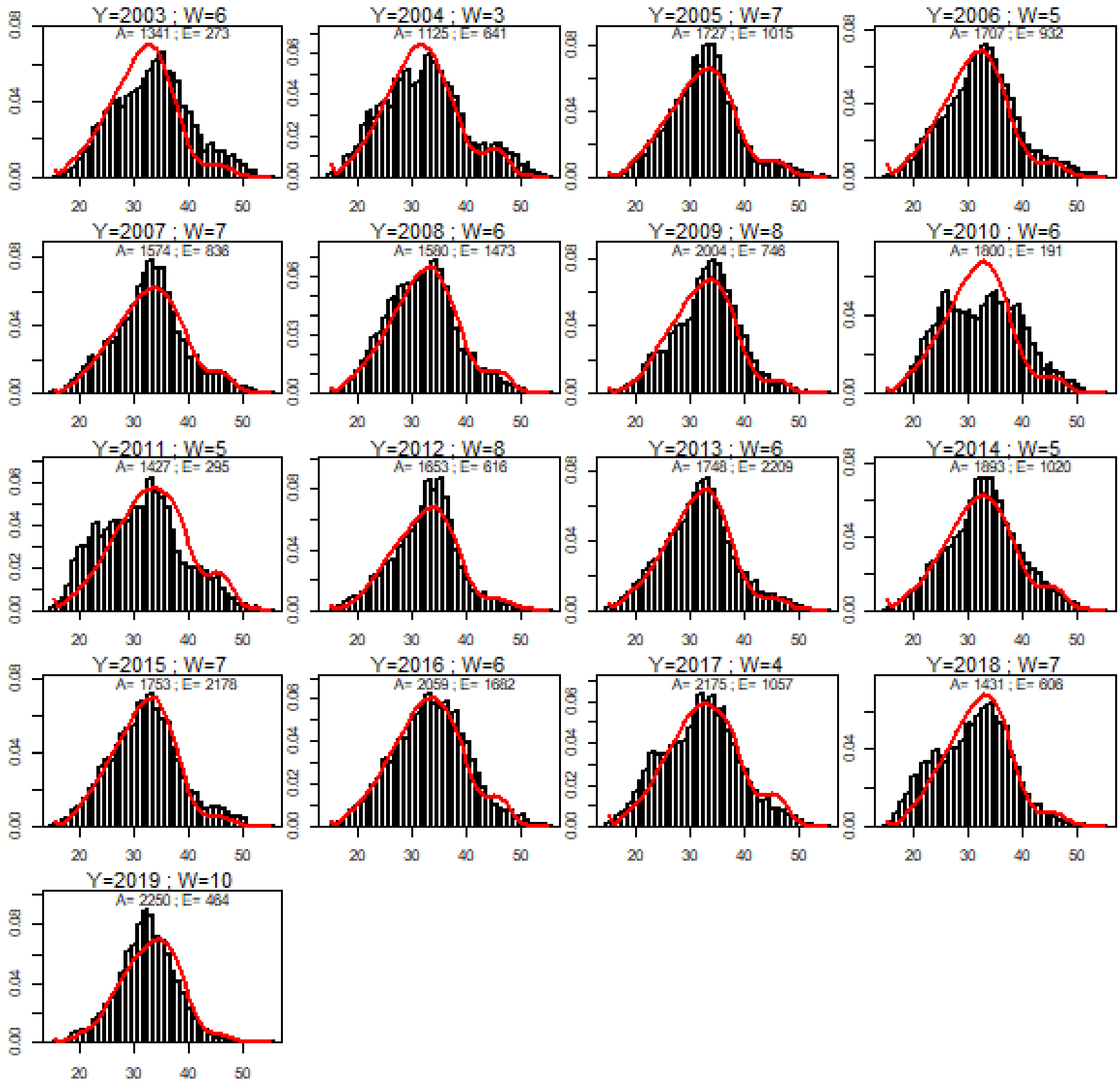

Y=2003 ; W=6
A= 1145 ; E= 178
Y=2004 ; W=3
A= 1135 ; E= 139
Y=2005 ; W=7
A= 1360 ; E= 1008
Y=2006 ; W=5
A= 1082 ; E= 275
Y=2007 ; W=7
A= 1074 ; E= 748
Y=2008 ; W=6
A= 1206 ; E= 347
Y=2009 ; W=8
A= 1206 ; E= 355
Y=2010 ; W=6
A= 1245 ; E= 702
Y=2011 ; W=5
A= 1159 ; E= 191
Y=2012 ; W=8
A= 1308 ; E= 411
Y=2013 ; W=6
A= 1428 ; E= 261
Y=2014 ; W=5
A= 1417 ; E= 371
Y=2015 ; W=7
A= 1338 ; E= 397
Y=2016 ; W=6
A= 1382 ; E= 249
Y=2017 ; W=4
A= 1200 ; E= 152
Y=2018 ; W=7
A= 1348 ; E= 702
Y=2019 ; W=10
A= 1443 ; E= 257

Figure 25. Estimated LF curves (red line) and observed recruitment survey composite data for Brown Tiger Prawns. a) female; b) male

a)



b)

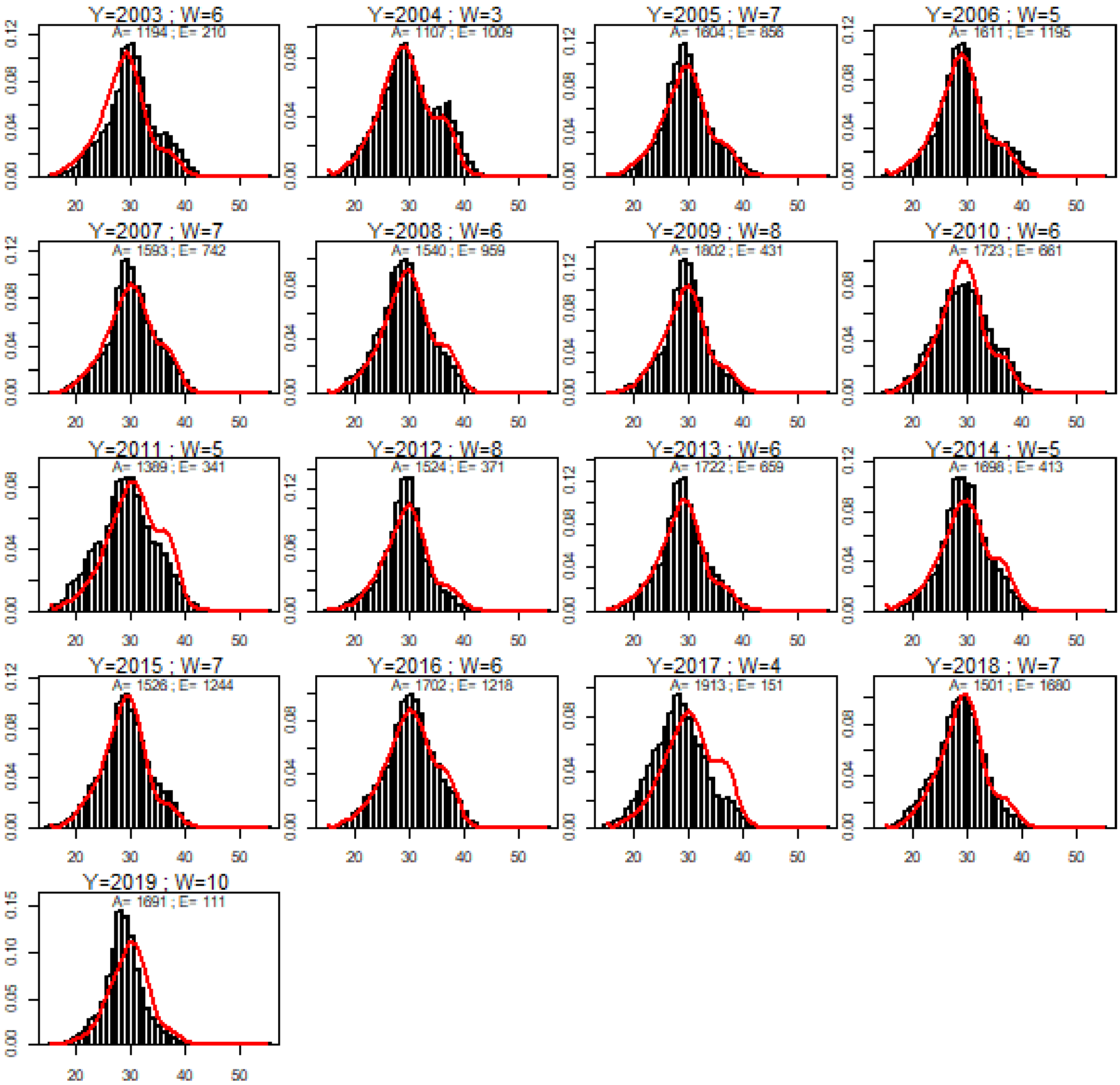
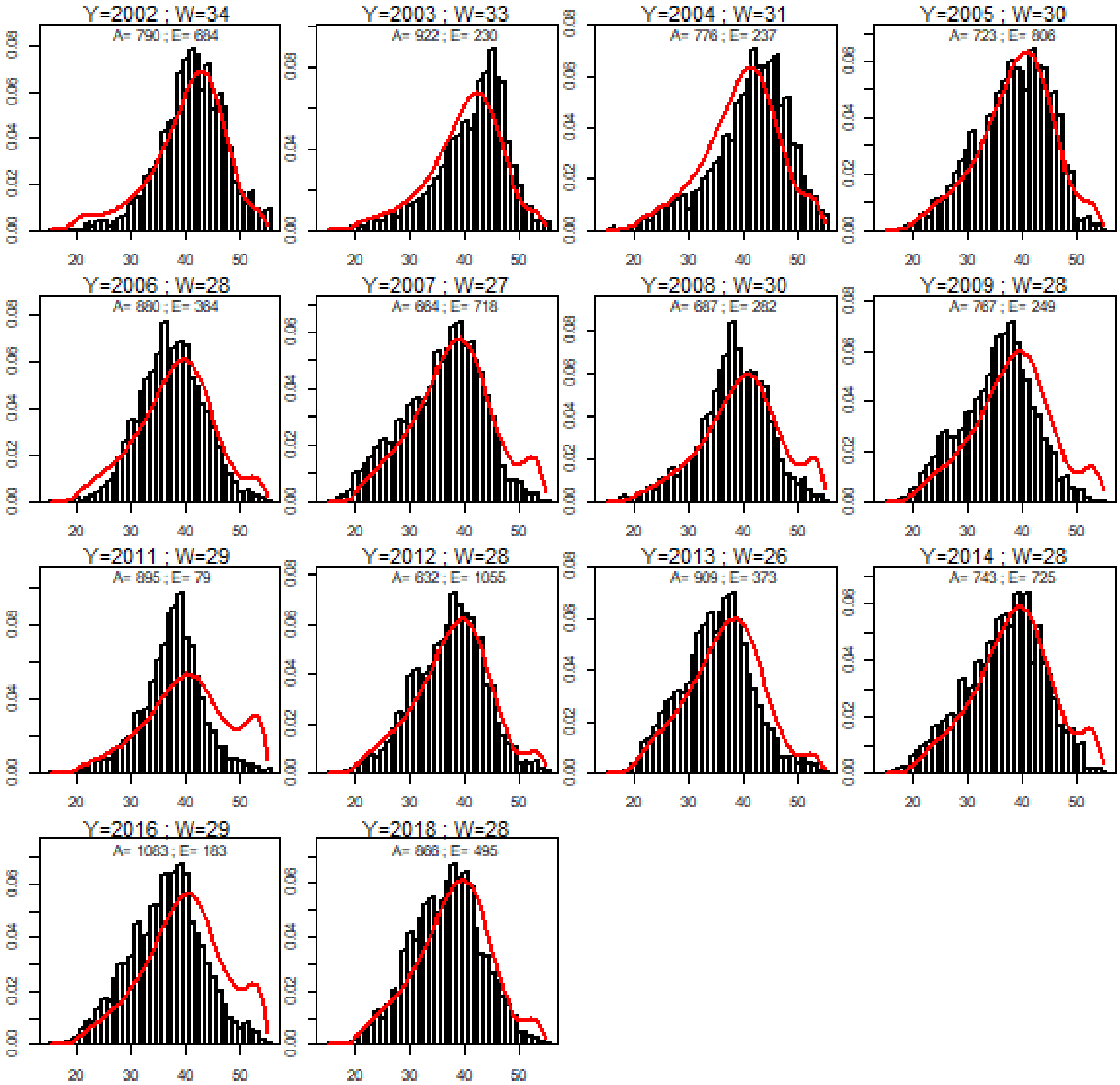
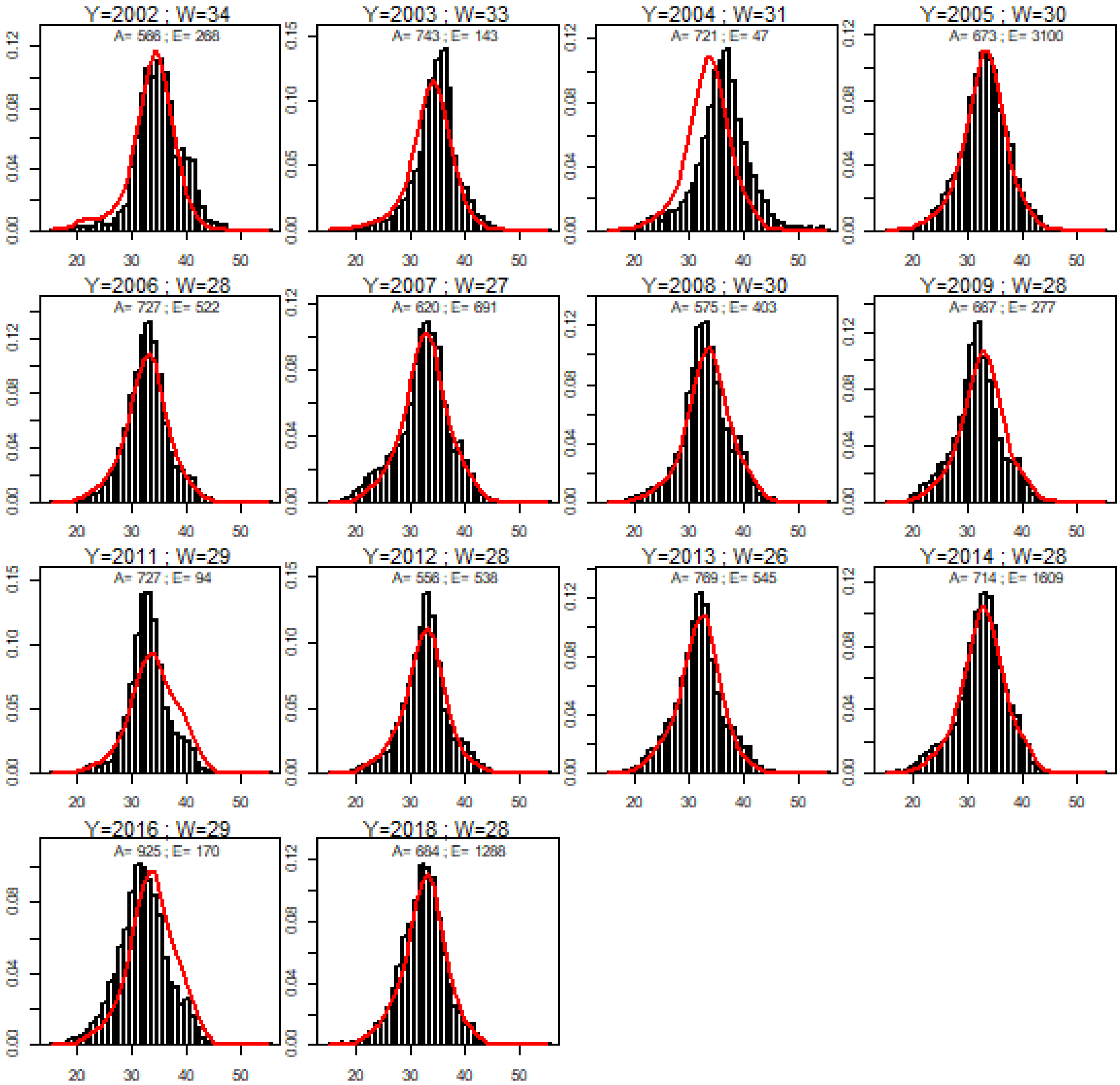

Y=2003 ; W=6
A= 1194 ; E= 210
Y=2004 ; W=3
A= 1107 ; E= 1009
Y=2005 ; W=7
A= 1604 ; E= 856
Y=2006 ; W=5
A= 1611 ; E= 1195
Y=2007 ; W=7
A= 1593 ; E= 742
Y=2008 ; W=6
A= 1540 ; E= 959
Y=2009 ; W=8
A= 1802 ; E= 431
Y=2010 ; W=6
A= 1723 ; E= 661
Y=2011 ; W=5
A= 1389 ; E= 341
Y=2012 ; W=8
A= 1524 ; E= 371
Y=2013 ; W=6
A= 1722 ; E= 659
Y=2014 ; W=5
A= 1698 ; E= 413
Y=2015 ; W=7
A= 1526 ; E= 1244
Y=2016 ; W=6
A= 1702 ; E= 1218
Y=2017 ; W=4
A= 1913 ; E= 151
Y=2018 ; W=7
A= 1501 ; E= 1680
Y=2019 ; W=10
A= 1691 ; E= 111

Figure 26. Estimated LF curves (red line) and observed spawning survey composite data for Grooved Tiger Prawns. a) female; b) male

a)



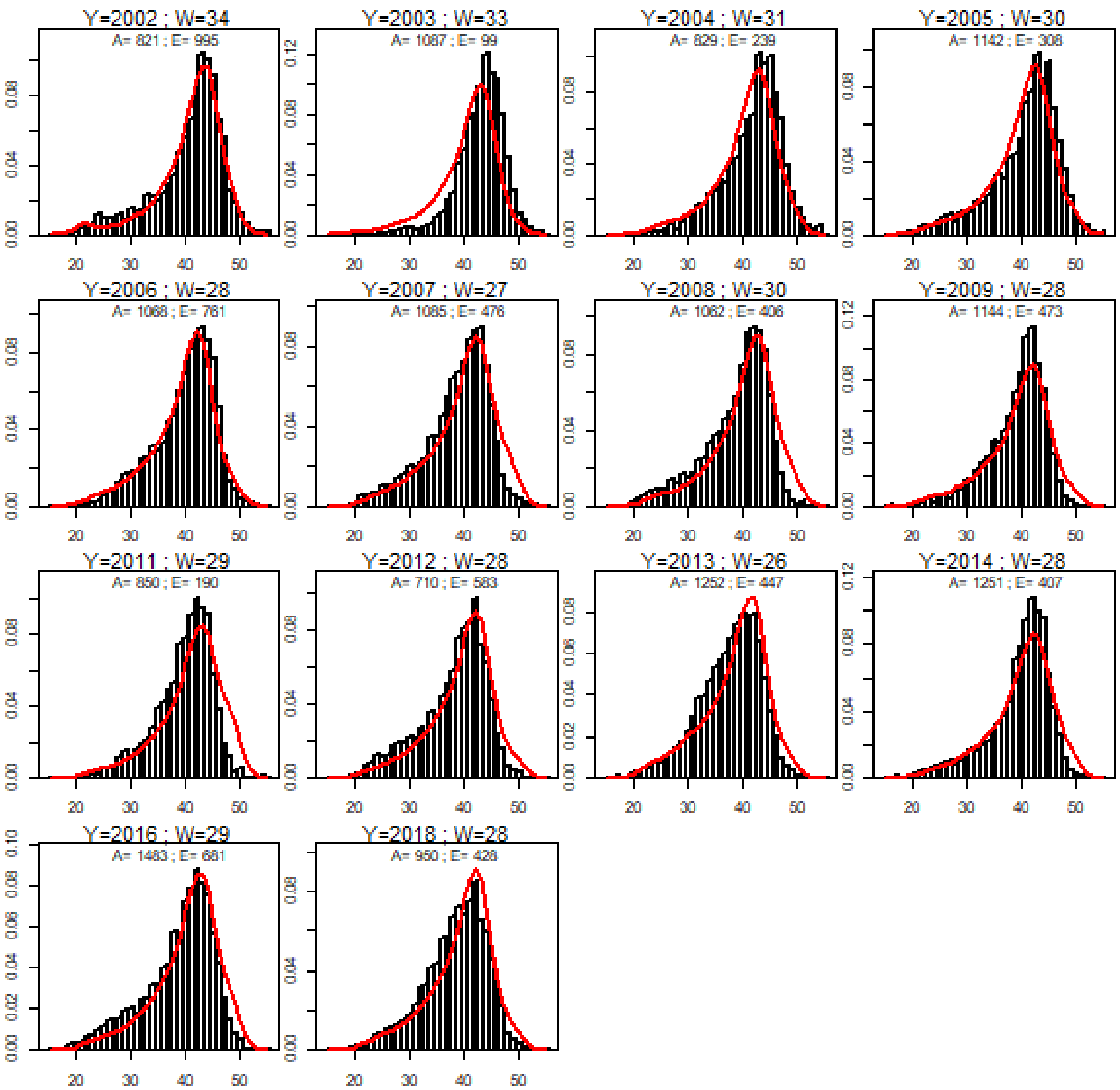
b)



Y=2002 ; W=34
A= 566 ; E= 268
Y=2003 ; W=33
A= 743 ; E= 143
Y=2004 ; W=31
A= 721 ; E= 47
Y=2005 ; W=30
A= 673 ; E= 3100
Y=2006 ; W=28
A= 727 ; E= 522
Y=2007 ; W=27
A= 620 ; E= 691
Y=2008 ; W=30
A= 575 ; E= 403
Y=2009 ; W=28
A= 667 ; E= 277
Y=2011 ; W=29
A= 727 ; E= 94
Y=2012 ; W=28
A= 556 ; E= 538
Y=2013 ; W=26
A= 769 ; E= 545
Y=2014 ; W=28
A= 714 ; E= 1609
Y=2016 ; W=29
A= 925 ; E= 170
Y=2018 ; W=28
A= 684 ; E= 1288

Figure 27. Estimates LF curves (red line) and observed spawning survey composite data for Brown Tiger Prawns. a) female; b) male

a)



b)

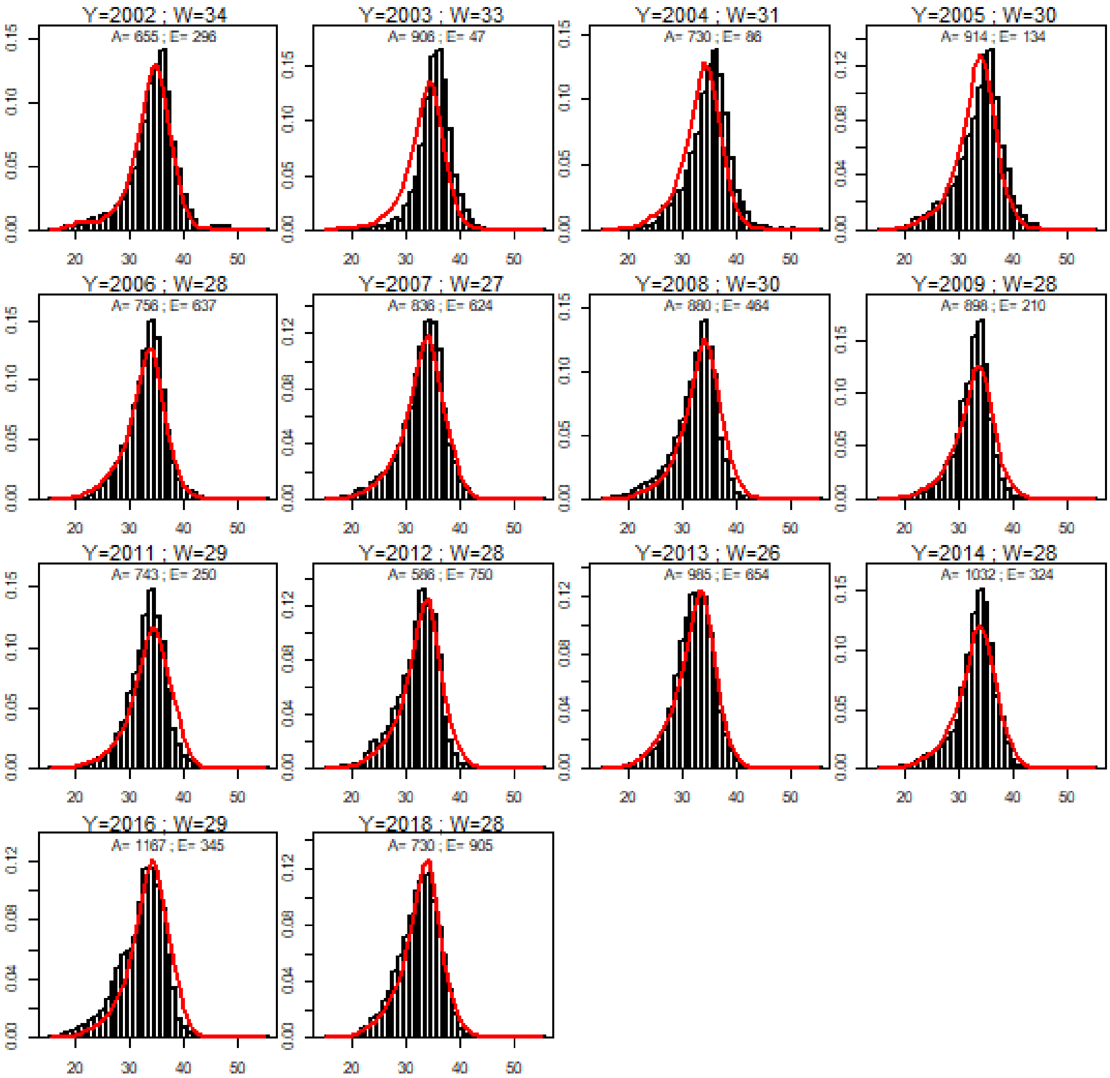
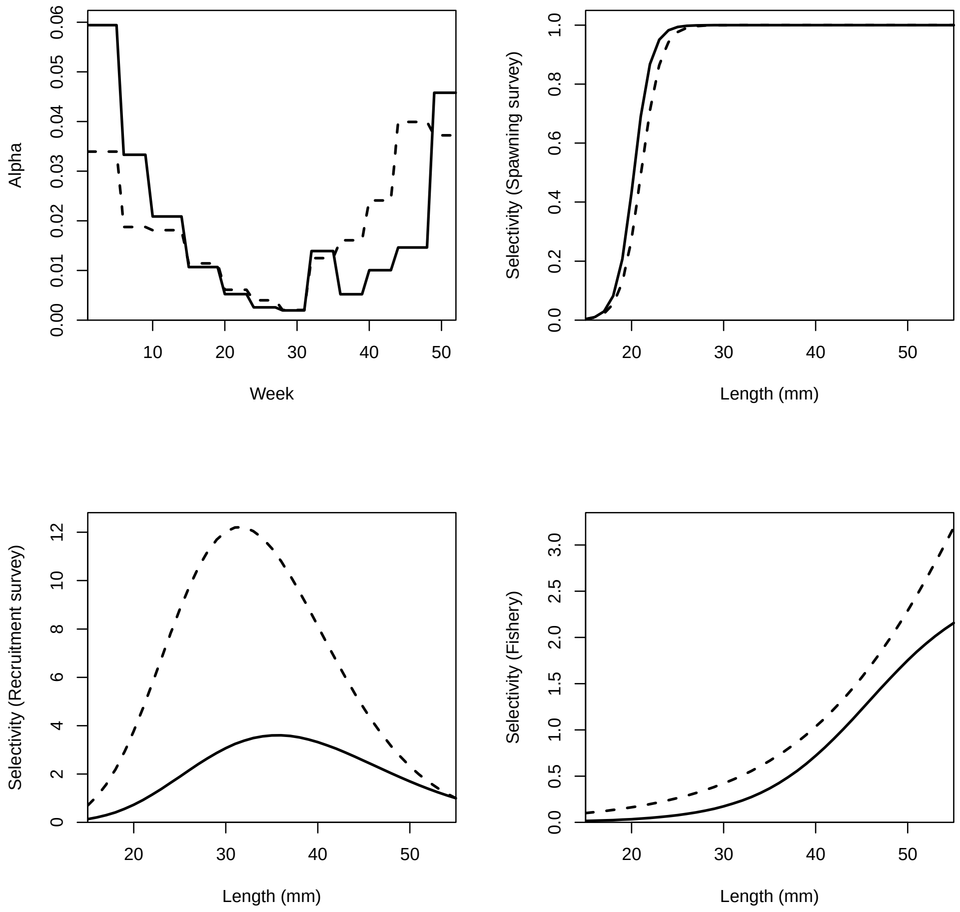

Y=2002 ; W=34
A= 655 ; E= 296
Y=2003 ; W=33
A= 906 ; E= 47
Y=2004 ; W=31
A= 730 ; E= 86
Y=2005 ; W=30
A= 914 ; E= 134
Y=2006 ; W=28
A= 756 ; E= 637
Y=2007 ; W=27
A= 836 ; E= 624
Y=2008 ; W=30
A= 880 ; E= 464
Y=2009 ; W=28
A= 898 ; E= 210
Y=2011 ; W=29
A= 743 ; E= 250
Y=2012 ; W=28
A= 586 ; E= 750
Y=2013 ; W=26
A= 985 ; E= 654
Y=2014 ; W=28
A= 1032 ; E= 324
Y=2016 ; W=29
A= 1167 ; E= 345
Y=2018 ; W=28
A= 730 ; E= 905

Figure 28. Estimates of biological and fishery parameters for the base-case size-structured population model.

Solid line for Grooved Tiger Prawns and dash line for Brown Tiger Prawns: (top left) monthly recruitment pattern, (top right) selectivity to the spawning survey, (bottom left) selectivity to the recruitment survey, and (bottom right) selectivity to the fishery.



5.4 Economics

Present and predicted prawn prices and fuel prices (Table 9) were provided by Prof. Tom Kompas (University of Melbourne). Average prawn prices (Table 9a) related to 2019–2020. The price ratio split across the different size grades was based on information provided by David Carter (Austral Fisheries Pty Ltd.) in February 2014.

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

Opportunity cost of capital and the economic depreciation rate were unchanged from the last year's assessment. Opportunity cost of capital is the "normal" expected rate of return on investment in the fishery and is equivalent to the discount rate used in the analysis. Economic depreciation rate measures how much capital depreciates each year when fishing, after allowing for repairs and maintenance. 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 2026 (Table 11 and Table 12). Stock size of blue endeavour prawns would be close to S_{MSY} but would need further time to reach the estimated SMEY (Figure 16 and Table 13).

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)[7]

Species Group	All sizes	< 40 mm	40-45 mm	45-50 mm	50-55 mm	> 55 mm
Tiger prawns	21.6	17.06	22.25	24.47	28.92	34.12
Endeavour prawns	8.8					

(b) Cost variables[8]

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

(c) Prawn prices and fuel costs index[9]

Year	Prawn prices index	Fuel costs index
2020	100	100
2021	102.2	101.2
2022	103.1	101.8
2023	103.9	102.4
2024	104.8	102.5
2025	105.8	102.8
2026	106.5	103.2

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

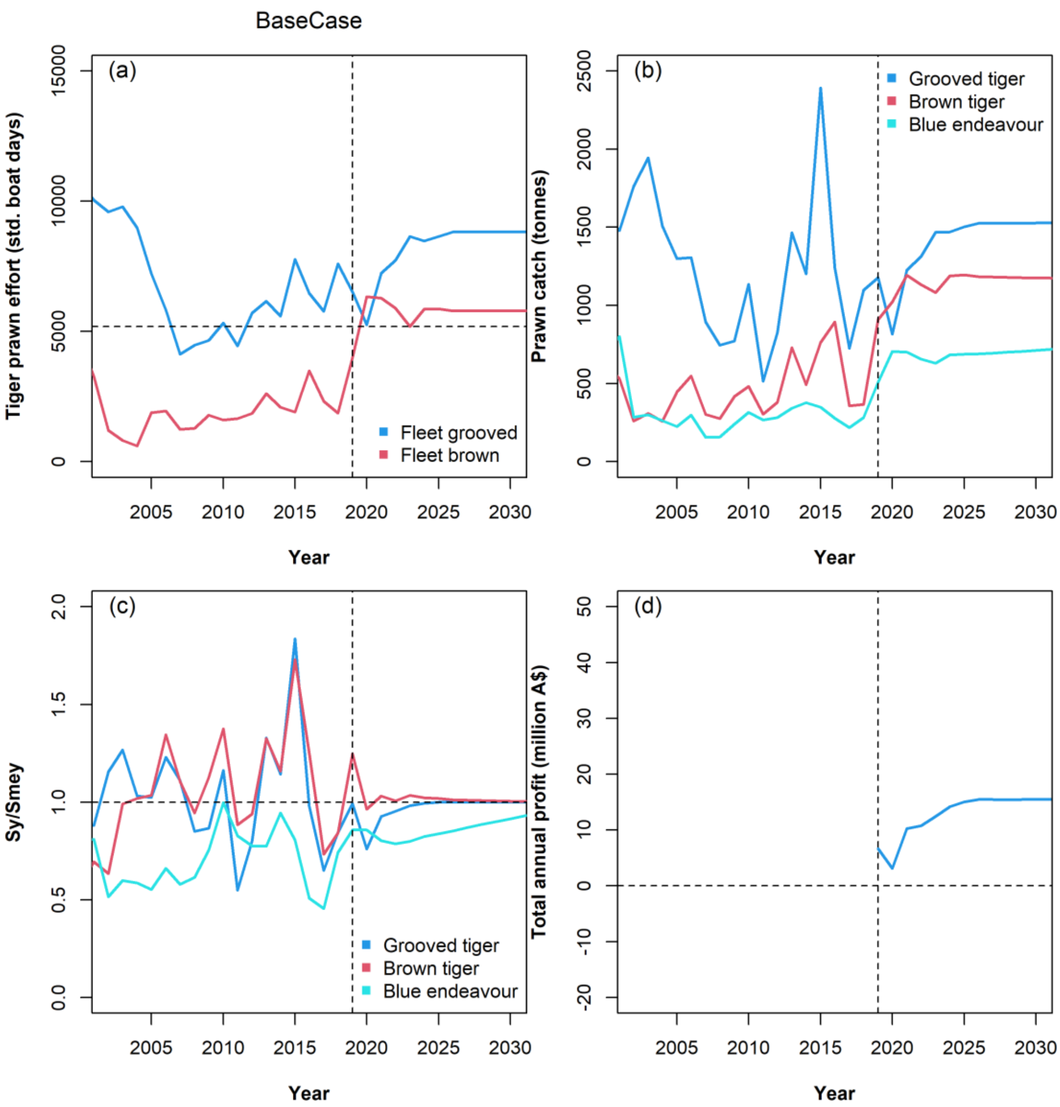
[8] provided by Sean Pascoe and Tom Kompas;

[9] provided by Tom Kompas;

Projected effort moved up or down in the first couple of years and then stabilized as stock sizes approach the target reference levels (Figure 29), ($S2019/S_{MEY}$ is 99% and 125% for grooved and brown tiger prawn, respectively), and reached equilibrium effort in the last few years of the projection (Figure 29). As per the NPF 2020 assessment the predicted future catches, SY/S_{MEY}, and profit for the Base Case along with the effort trends (as discussed) are predicted to improve out to 2030 (Figure 29) given the optimality constraint as set.

Figure 29. 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 SSB assessment using the Base Case assessment 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 2020 modelled effort levels were 2816 boat days for grooved tiger prawns and 3390 boat days for brown tiger prawns (a total of 6206 boat days), given the RAG-approved distribution of relative effort in 2020. This was an 8.6% increase on total actual effort of 2019. It was equivalent to a 36% gear size increase. The 2021 model estimated effort levels were 3877 and 3363 boat days, respectively, for grooved tiger prawns and brown tiger prawns (a total of 7059 boat days). The 2021 levels were a 27% increase on total actual effort of 2019 and equivalent to a 137% gear size increase.

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. The assessment predicted profit improvement from 2020 to 2025 and a maintained level of higher profit to 2030. 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; 2019 and 2020, and 2021) (full assessment in 2020 only).
2. The TAE for redleg banana prawns (2019, 2020 and 2021) (published as a separate report).
3. The estimation of trigger catch rate limits for the white/common banana prawn fishery for 2019, 2020 and 2021 (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

A further three-year NPF Assessment project commenced in July 2021 (2021-2024), after the completion of the project reported here and the new project will achieve the same set of objectives as outlined and delivered by this project, 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 species of the prawns have highly variable populations, subject to annual tropical-extreme, monsoon-pulsed environmental drivers and on-going harvest pressure. The assessment was critical to the NPF Harvest Strategy by several measures. The Harvest Strategy mandated that an assessment will be conducted biennially. In addition, the assessment provided key metrics for input. 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) predicted 2020 optimal effort levels of 2816 boat days for grooved tiger prawns and 3390 boat days for brown tiger prawns (a total of 6206 boat days). The optimal total effort estimated in the various sensitivity tests ranged from 5966 to 6830 boat days (excluding the lower effort scenario). The model estimated effort levels for the 2021 tiger prawn fishing season were 3877 and 3363 boat days, respectively, for grooved tiger prawns and brown tiger prawns (a total of 7059 boat days). The predicted effort was a 27% increase on total actual effort of 2019 and equivalent to a 137% gear size increase. By these measures, the assessment supported sustainable management of the NPF via the Harvest Strategy.

Actual effort deployed in 2020 was 4080 boat days for grooved tiger prawns and 1309 boat days for brown tiger prawns. Actual effort deployed to fish each tiger prawn species in 2020 was distinctly different to predicted optimal effort. The total effort in 2020 (5389 boat days) was only 13% lower than model-estimated effort for 2020; but the actual distribution between species was considerably different and skewed by species relative to the model-estimated effort (145% for grooved tiger prawns and 39% for brown tiger prawns). Further research will evaluate the possible reasons for this.

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Appendices

Appendix A. Summary tables for base case and sensitivity tests

Table 10. Results of relevant management measures and parameter estimates for all three species for the Base Case (SSB - "low" fishing power, the average of last two years' effort patterns).
E_{MSY} was the effort level (expressed in terms of 2019 days) at which MSY was achieved and S_{MSY} was the spawner stock index at which the (deterministic) MSY was achieved.

Name	Grooved tiger prawns	Brown tiger prawns	Blue Endeavour prawns
Steepness	0.394	0.341	NA
$Catch_{2020}$	816	1022	705
Observed C_{2019}	1178	908	509
MSY	1687	1113	808
MEY	1526	1170	747
SMEY/SMSY	122	112	100
S_{2019}/S_0 (%)	63	67	48
S_{2019}/S_{MSY} (%)	121	139	86
S_{2019}/S_{MEY} (%)	99	125	86
5-year mav($S_{2015\text{-}2019}/S_{MSY}$) (%)	129	130	68
S_{2026}/S_{MEY} (%)	100	101	85
Observed nominal E_{2019}	3535	2181	NA
Estimated nominal E_{2020}	2816	3390	NA
E_{MSY}	7163	2665	NA
E_{MEY}	4723	3099	NA
E_{MEY}/E_{MSY}(%)	66	116	NA

E_{2019}/E_{MSY} (%)	49	82	NA
E_{2019}/E_{MEY} (%)	75	70	NA
Standardised E_{2019}/E_{MSY} (%)	49	80	NA
Standardised E_{2019}/E_{MEY} (%)	74	69	NA
Profit (estimated) 2019 ($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.	6.7		

Table 11. Sensitivity test outputs for Grooved Tiger Prawns.

E_{MSY} was the effort level (expressed in terms of 2019 boat days) at which MSY was achieved and S_{MSY} was the spawner stock index at which the (deterministic) MSY was achieved. Constrained – Constrnd. Threshold – thrshd (for all tables).

	Base Case	**Mid - High**	**DDD**	**Fixed effort pattern**	**Est - Pattern**	**Constrnd effort change**	**Lower effort thrshd**	**Four species**	**No eff thrshd**
Steepness	0.394	0.39	0.362	0.394	0.394	0.394	0.394	0.394	0.394
$Catch_{2020}$	816	798	851	830	984	885	816	861	816
Observed C_{2019}	1178	1178	1178	1178	1178	1178	1178	1177	1178
MSY	1687	1662	1561	1695	1676	1687	1687	1693	1687
MEY	1526	1526	1475	1542	1627	1526	1526	1529	1526
S_{MSY}	0.294	0.283	0.532	0.288	0.316	0.294	0.294	0.289	0.294
S_{MEY}	0.357	0.347	0.595	0.355	0.401	0.357	0.357	0.356	0.357
S_{MEY}/S_{MSY}	122	123	112	123	127	122	122	123	122
S_{2019}/S_0 (%)	63	62	57	63	63	63	63	63	63
S_{2019}/S_{MSY} (%)	121	122	103	123	112	121	121	123	121
S_{2019}/S_{MEY} (%)	99	100	92	100	88	99	99	100	99
5-year mav($S_{2015-2019}/S_{MSY}$) (%)	129	130	110	131	120	129	129	131	129
S_{2026}/S_{MEY} (%)	100	101	100	101	86	100	100	100	100
Observed nominal E_{2019}	3535	3535	3535	3535	3535	3535	3535	3535	3535

Estimated nominal E_{2020}	2816	2777	2777	2874	3821	3254	2816	3060	2814
E_{MSY}	7163	7209	5063	7437	6322	7163	7163	7408	7163
E_{MEY}	4723	4819	4089	4862	4935	4722	4723	4744	4723
E_{MEY}/E_{MSY}(%)	66	67	81	65	78	66	66	64	66
E_{2019}/E_{MSY} (%)	49	49	70	48	56	49	49	48	49
E_{2019}/E_{MEY} (%)	75	73	86	73	72	75	75	74	75
Standardised E_{2019}/E_{MSY} (%)	49	48	69	47	55	49	49	47	49
Standardised E_{2019}/E_{MEY} (%)	74	73	85	72	71	74	74	74	74
Standardised E_{2019}	6513	6385	6513	6513	6513	6513	6513	6513	6513
Standardised E_{2020}	5258	5070	5186	5367	7135	6077	5259	5715	5255
Total profits to that of Base Case(%)[1]	100	98	95	100	112	100	100	111	100

[1] This does not apply to the Grooved Tiger Prawns only. It was the sum for all Tiger Prawn fishery fleets and species included in this 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 12. Sensitivity test outputs for Brown Tiger Prawns.

E_{MSY} was the effort level (expressed in terms of 2019 days) at which MSY was achieved and S_{MSY} was the spawner Stock index at which the (deterministic) MSY was achieved**.**

	Base Case	**Mid - High**	**DDD**	**Fixed effort pattern**	**Est - Pattern**	**Constrnd effort change**	**Lower effort thrshd**	**Four species**	**No eff thrshd**
Steepness	0.341	0.34	0.289	0.341	0.341	0.341	0.341	0.341	0.341
$Catch_{2020}$	1022	946	931	1012	1017	897	1021	1035	1022
Observed C_{2019}	908	908	908	908	908	908	908	910	908
MSY	1113	1101	1127	1097	1216	1113	1113	1106	1113
MEY	1170	1138	1167	1139	1201	1170	1170	1169	1170
S_{MSY}	0.214	0.212	0.524	0.225	0.248	0.214	0.214	0.229	0.214
S_{MEY}	0.239	0.251	0.547	0.249	0.25	0.239	0.239	0.239	0.239
S_{MEY}/S_{MSY}	112	118	104	110	101	112	112	104	112
S_{2019}/S_0 (%)	67	66	60	67	67	67	67	67	67
S_{2019}/S_{MSY} (%)	139	138	109	133	120	139	139	130	139
S_{2019}/S_{MEY} (%)	125	117	105	120	119	125	125	125	125
5-year mav($S_{2015-2019}/S_{MSY}$) (%)	130	127	106	123	112	130	130	121	130
S_{2026}/S_{MEY} (%)	101	96	101	98	90	102	101	102	101
Observed nominal E_{2019}	2181	2181	2181	2181	2181	2181	2181	2181	2181
Estimated nominal E_{2020}	3390	3146	2777	3307	3092	2777	3385	3372	3387
E_{MSY}	2665	2619	3034	2391	3506	2665	2665	2420	2665

E_{MEY}	3099	2777	3070	2777	3304	3101	3098	3096	3098
E_{MEY}/E_{MSY}(%)	116	106	101	116	94	116	116	128	116
E_{2019}/E_{MSY} (%)	82	83	72	91	62	82	82	90	82
E_{2019}/E_{MEY} (%)	70	78	71	78	66	70	70	70	70
Standardised E_{2019}/E_{MSY} (%)	80	82	70	89	61	80	80	88	80
Standardised E_{2019}/E_{MEY} (%)	69	77	70	77	65	69	69	69	69
Standardised E_{2019}	3994	3921	3994	3994	3994	3994	3994	3994	3994
Standardised E_{2020}	6331	5745	5186	6176	5775	5186	6322	6298	6325

Table 13. Sensitivity test outputs for Blue Endeavour Prawns**.**

E_{MSY} is the effort level (expressed in terms of 2019 boat days) at which MSY is achieved and S_{MSY} is the spawner stock index at which the (deterministic) MSY is achieved.

	Base Case	Mid - High	DDD	Fixed effort pattern	Est - Pattern	Constrnd effort change	Lower effort thrshd	Four species	No eff thrshd
$Catch_{2020}$	705	649	411	696	717	633	704	668	704
Observed C_{2019}	509	509	509	509	509	509	509	509	509
MSY	808	809	542	803	818	808	808	733	808
MEY	747	734	552	733	759	747	747	726	747
S_{MEY}/S_{MSY}	100	104	104	102	103	100	100	105	100
S_{2019}/S_0 (%)	48	47	40	48	48	48	48	48	48
S_{2019}/S_{MSY} (%)	86	85	113	84	92	86	86	98	86
S_{2019}/S_{MEY} (%)	86	82	109	83	89	86	86	94	86
5-year mav($S_{2015-2019}/S_{MSY}$) (%)	68	66	87	66	72	68	68	77	68
S_{2026}/S_{MEY} (%)	85	82	100	84	85	85	85	92	85

Table 14. Sensitivity test outputs for Red Endeavour Prawns**.**

E_{MSY} is the effort level (expressed in terms of 2019 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	Red endeavour prawns (four species sensitivity test)
$Catch_{2020}$	NA	277
Observed C_{2019}	NA	147
MSY	NA	348
MEY	NA	260
S_{MEY}/S_{MSY}	NA	90
S_{2019}/S_0 (%)	NA	53
S_{2019}/S_{MSY} (%)	NA	113
S_{2019}/S_{MEY} (%)	NA	126
5-year mav($S_{2015-2019}/S_{MSY}$) (%)	NA	104
S_{2026}/S_{MEY} (%)	NA	114

Appendix B. Fishing Power Analysis

Northern Prawn Fishery: Update of the tiger prawn fishing power time series for 2019.

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

CSIRO Oceans and Atmosphere

The fishing power analysis method was developed by Janet Bishop, Bill Venables, Cathy Dichmont, and other contributors (Dichmont, Bishop, Venables 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 2018 (there was no formal stock assessment for the 2018 fishing season) and 2019. We report on the 2019 model estimates in this document. The fishing power estimates account for changes in vessels and gear, and any 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 a couple of years in the early 1970s. No further changes to the historical series were made in the current year, however a project that aims to revise the historical fishing power series is currently under way (AFMA project 170836, Revision of NPF fishing power data series and model, Upston et al).

Fifty-two vessels fished for tiger prawns in 2019. 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 2019 gear survey of each vessel (an annual survey was implemented by AFMA 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 Dichmont et al., 2010). In both regression models, the coefficients were estimated from the 1970 - 2017 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 2019.

Since 2006 quad-rig trawl gear has been allowed in the NPF, and an increasing number of vessel operators have converted to quad-rig. In 2019 approximately 96% of the fleet towed quad-rig gear 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 2019 was estimated to be 28 hectares per hour (like 2018). Greater average swept area performance in the last eight years may be explained, in part, by more boats towing quad-rig gear (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.

Other gear inputs to the fishing power model were comparable, on average, between 2018 and 2019. However, there were marked changes in the spatial pattern of fishing, with less effort in North Groote, South Groote and Weipa regions (approximately half the effort in 2018) and more in Karumba and West Mornington regions. Overall, the relative fishing power increased by 5-6% in 2019 relative to 2018 (Figure B.1.; Table B.1.).

Figure 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.

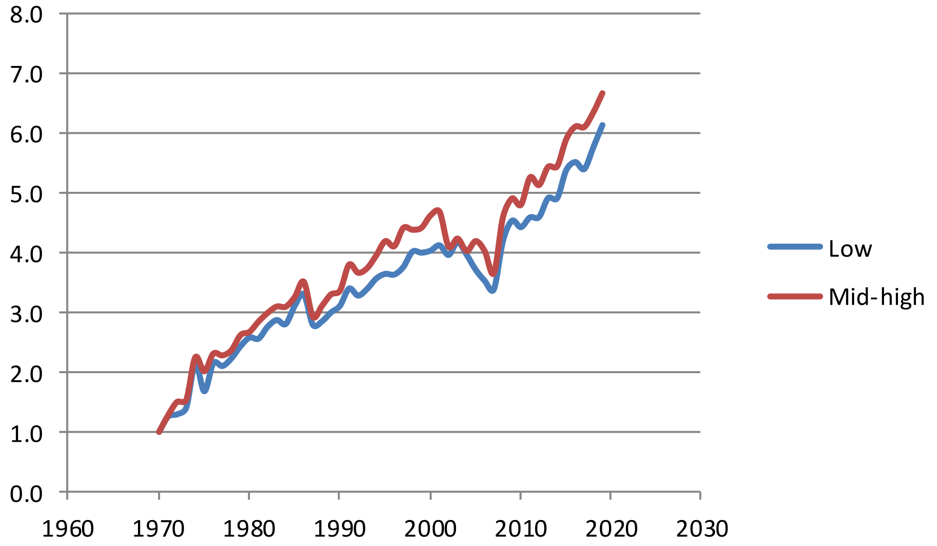

Table B.1. Estimates of relative fishing power trends in the NPF tiger prawn fishery. Relative fishing power units are daily catch rates relative to the fleet of 1970, and q_{inc} are annual increments relative to the previous year.

	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	1.51	1.18
1973	1.40	1.08	1.53	1.02
1974	2.16	1.53	2.25	1.47
1975	1.68	0.78	2.02	0.90
1976	2.16	1.28	2.32	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	2.63	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	3.12	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	4.39	0.99
1999	4.01	1.00	4.43	1.01
2000	4.05	1.01	4.63	1.05
2001	4.14	1.02	4.70	1.01
2002	3.97	0.96	4.11	0.87
2003	4.19	1.05	4.25	1.03
2004	3.98	0.95	4.04	0.95
2005	3.73	0.94	4.20	1.04
2006	3.54	0.95	4.03	0.96
2007	3.40	0.96	3.67	0.91
2008	4.20	1.24	4.60	1.25
2009	4.55	1.08	4.92	1.07
2010	4.44	0.98	4.81	0.98
2011	4.61	1.04	5.27	1.10
2012	4.61	1.00	5.15	0.98
2013	4.93	1.07	5.45	1.06
2014	4.93	1.00	5.46	1.00
2015	5.40	1.10	5.91	1.08
2016	5.54	1.03	6.13	1.04
2017	5.42	0.98	6.12	1.00
2018	5.79	1.07	6.36	1.04
2019	6.16	1.06	6.69	1.05

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We are grateful to the fishers of the NPF who provided their logbook and gear data, and to Adrianne Laird (NPFI), AFMA Data Section for collecting and collating the gear survey and catch and effort data. David Sterling of DJ Sterling Trawl Gear Services provided the predictions of the swept area performance for the NPF fleet. He is thanked for valuable discussions regarding the PTPM results.

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Appendix C. Summary of catch and effort data and the fishery independent survey data up to 2020

Summary of the NPF Tiger Prawn catch and effort data and the fishery independent survey data up to 2020

Deng, R., Hutton, T., Punt, A., Upston, J., Miller, M., Moeseneder, C., Pascoe, S.

Background

Data were provided by Roy Deng, Rob Kenyon and Margaret Miller (and NPF CSIRO Assessment Team and Monitoring Team). Methods and data were checked by Trevor Hutton.

Fishery catch and effort data from 1970 to 2020 for each tiger prawn species and for each endeavour prawn were extracted from AFMA's database and the species split data that were stored in CSIRO logbook database (Table 15)

Compared with the data in 2019, the grooved tiger prawn catch and the brown tiger prawn catch decreased about 18.8% and 55% respectively; the tiger prawn species-combined catch decreased (about 34.5%, Table 15) while corresponding total effort decreased by only 5.7% in 2020. Similarly, the blue endeavour prawn catch and the red endeavour prawn catch decreased by 54.2% and 15.0% respectively. The nominal effort targeting grooved tiger prawns increased by about 15.4%, but that targeting brown tiger prawns decreased 40% from 2019 to 2020.

Table 15. 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	Brown	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	2,087	5,716

2020	957	409	233	125	4,080	1,309	1,366	5,389

Figure 30 and Table 16 and Table 17 present the latest survey information for input into the assessment (Rob Kenyon per com, and permission: NPF Monitoring Project). In addition see Figures 2, 3, and 4 for catch by year, effort and CPUE.

With great thanks to Adrianne Laird, NPF Industry Pty Ltd for the logbook data (collection, correction and guidance). Without the extensive support of the NPFI and Industry the collation of data would not be possible.

Figure 30. Catch-per-unit effort index and abundance indices from the surveys. From top to bottom-panels: Grooved Tiger Prawns, Brown Tiger Prawns, Blue Endeavour Prawns and Red Endeavour Prawns from 1993 to 2020 calculated using nominal effort. The mean survey recruitment and spawning indices are also provided for each stock (with an extension to include the 2021 recruitment survey indices).

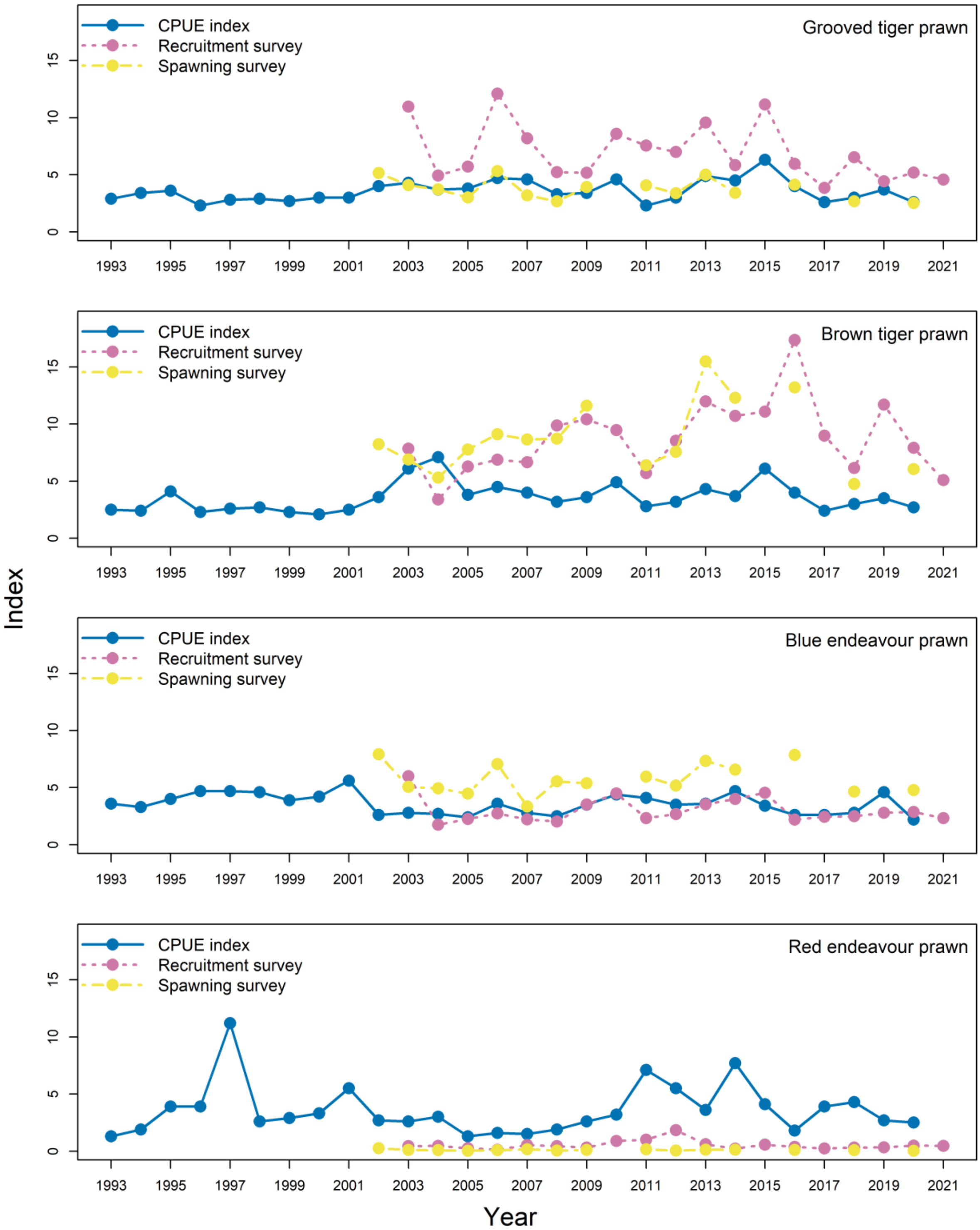


Table 16. Survey recruitment index series

	Grooved Tiger Prawns		Brown Tiger Prawns		Blue Endeavour Prawns		Red Endeavour Prawns	
Year	Recruitment index	CV	Recruitment index	CV	Recruitment index	CV	Recruitment index	CV
2003	10.96	0.096	7.85	0.107	6.00	0.059	0.43	0.118
2004	4.94	0.076	3.40	0.074	1.75	0.070	0.45	0.129
2005	5.71	0.054	6.29	0.096	2.25	0.070	0.26	0.172
2006	12.11	0.218	6.87	0.071	2.74	0.056	0.12	0.197
2007	8.19	0.071	6.66	0.087	2.21	0.079	0.54	0.154
2008	5.23	0.072	9.87	0.091	2.03	0.061	0.44	0.168
2009	5.18	0.071	10.41	0.087	3.51	0.088	0.31	0.162
2010	8.58	0.069	9.47	0.063	4.49	0.049	0.89	0.163
2011	7.56	0.143	5.71	0.090	2.33	0.066	1.00	0.171
2012	7.00	0.073	8.54	0.087	2.68	0.064	1.84	0.171
2013	9.56	0.092	11.98	0.097	3.54	0.057	0.60	0.168
2014	5.84	0.061	10.71	0.103	4.00	0.063	0.22	0.181
2015	11.16	0.078	11.09	0.086	4.55	0.056	0.56	0.117
2016	5.95	0.077	17.37	0.096	2.20	0.063	0.36	0.171
2017	3.85	0.061	8.99	0.088	2.42	0.080	0.23	0.146
2018	6.54	0.066	6.15	0.091	2.49	0.065	0.31	0.136
2019	4.42	0.067	11.7	0.085	2.8	0.083	0.33	0.174
2020	5.19	0.072	7.93	0.077	2.86	0.058	0.47	0.121
2021	4.58	0.067	5.1	0.074	2.32	0.069	0.45	0.100

Table 17. Survey spawning index series

	Grooved Tiger Prawns		Brown Tiger Prawns		Blue Endeavour Prawns		Red Endeavour Prawns	
Year	**Spawning index**	**CV**	**Spawning index**	**CV**	**Spawning index**	**CV**	**Spawning index**	**CV**
2002	5.16	0.104	8.24	0.090	7.92	0.088	0.25	0.182
2003	4.09	0.094	6.90	0.072	5.07	0.063	0.10	0.265
2004	3.72	0.087	5.47	0.104	5.03	0.076	0.09	0.250
2005	3.02	0.098	7.77	0.078	4.46	0.060	0.03	0.258
2006	5.33	0.103	9.12	0.117	7.06	0.075	0.09	0.346
2007	3.19	0.086	8.65	0.098	3.35	0.081	0.15	0.274
2008	2.68	0.135	8.72	0.072	5.54	0.058	0.05	0.315
2009	3.92	0.107	11.61	0.082	5.38	0.068	0.10	0.363
2010	NA	NA	NA	NA	NA	NA	NA	NA
2011	4.08	0.099	6.39	0.092	5.95	0.065	0.15	0.259
2012	3.38	0.116	7.56	0.108	5.16	0.065	0.05	0.288
2013	5.01	0.080	15.48	0.106	7.34	0.070	0.12	0.364
2014	3.43	10.7	12.3	10.6	6.57	0.085	0.12	0.384
2015	NA	NA	NA	NA	NA	NA	NA	NA
2016	4.13	0.082	13.22	0.092	7.86	0.183	0.10	0.367
2017	NA	NA	NA	NA	NA	NA	NA	NA
2018	2.67	0.107	4.76	0.098	4.66	0.121	0.08	0.470
2019	NA	NA	NA	NA	NA	NA	NA	NA

2020	2.53	0.111	0.606	0.142	4.79	0.067	0.03	25

Figure 2. Catch by year.

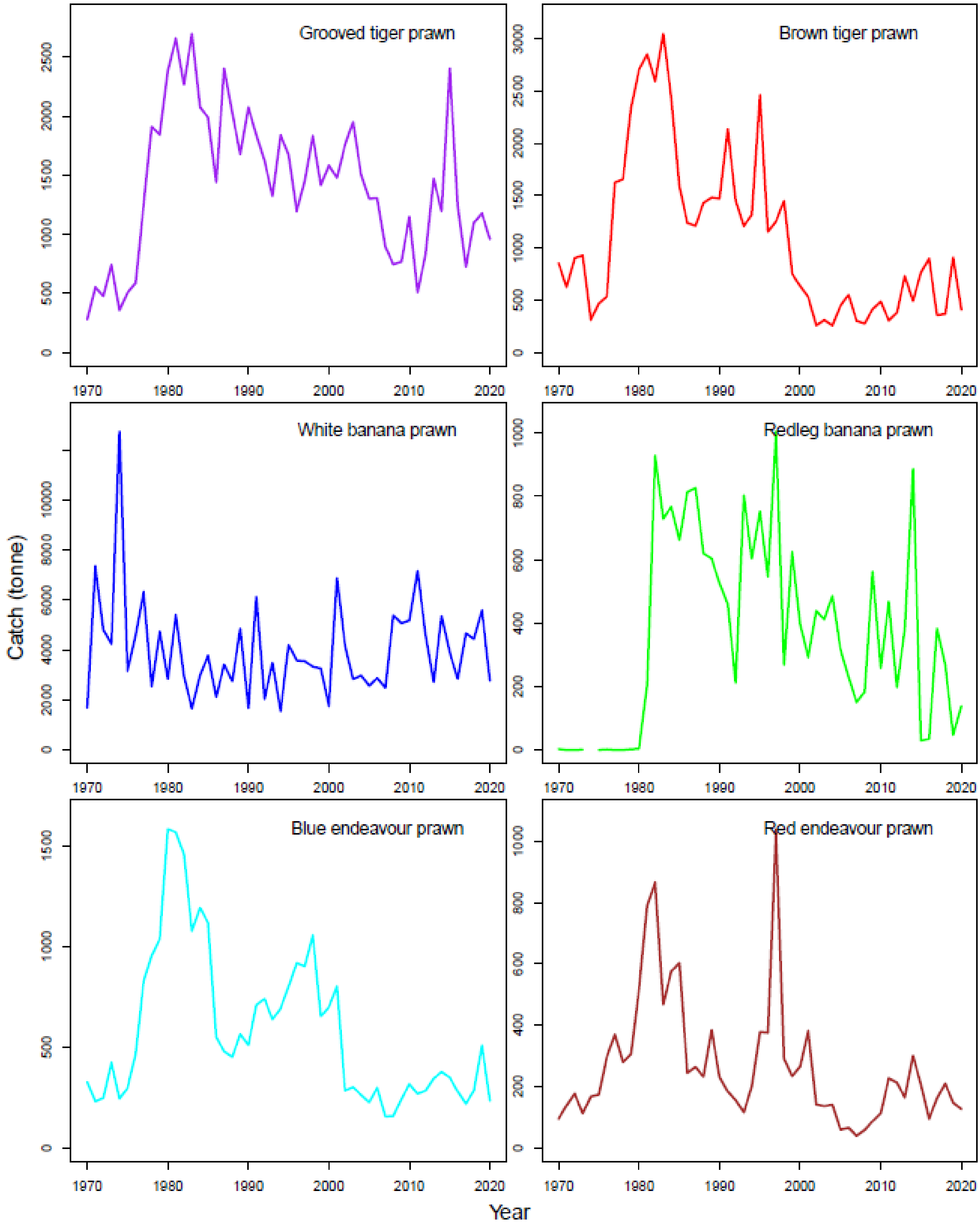


Figure 3. Effort by year.

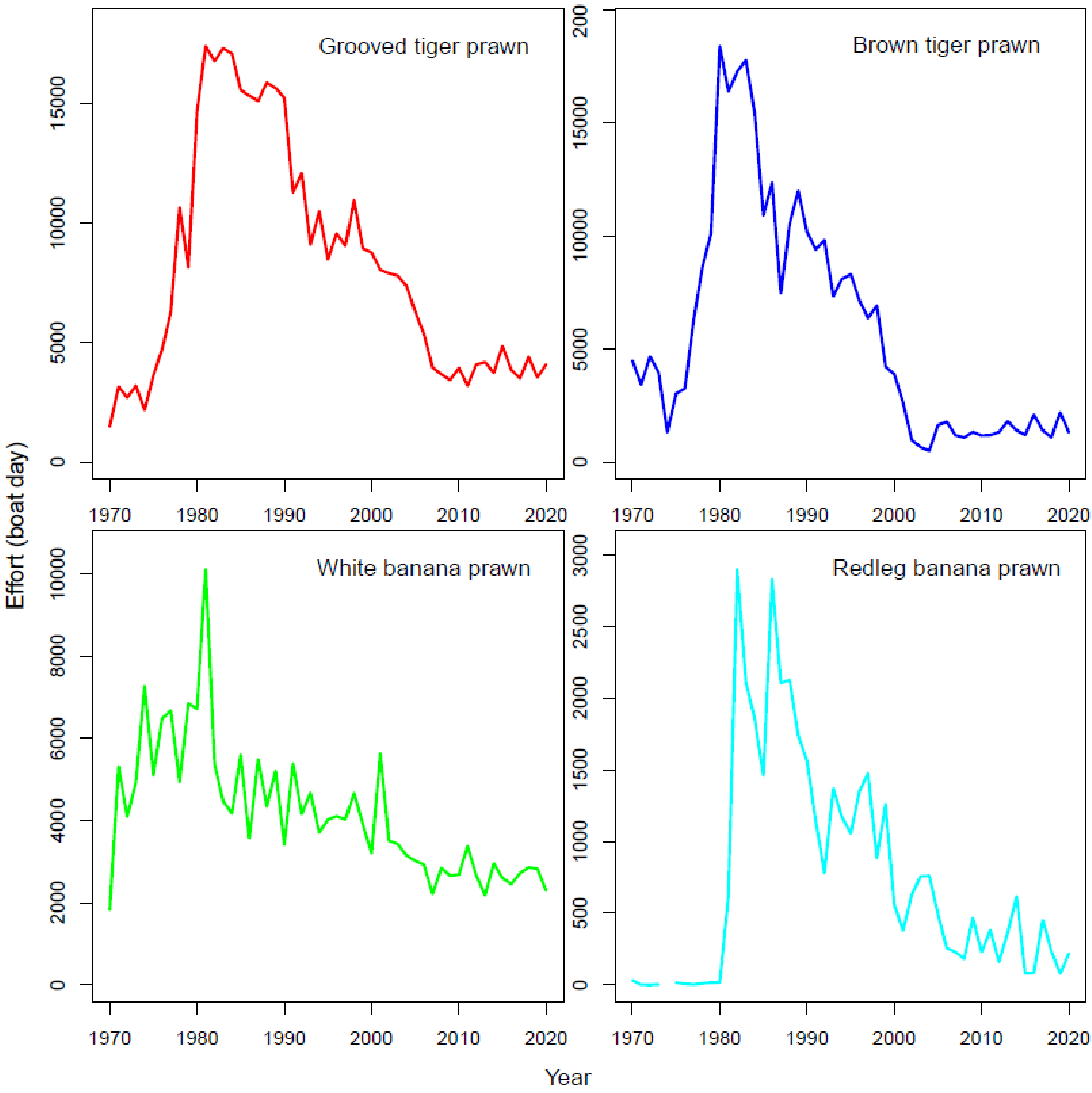
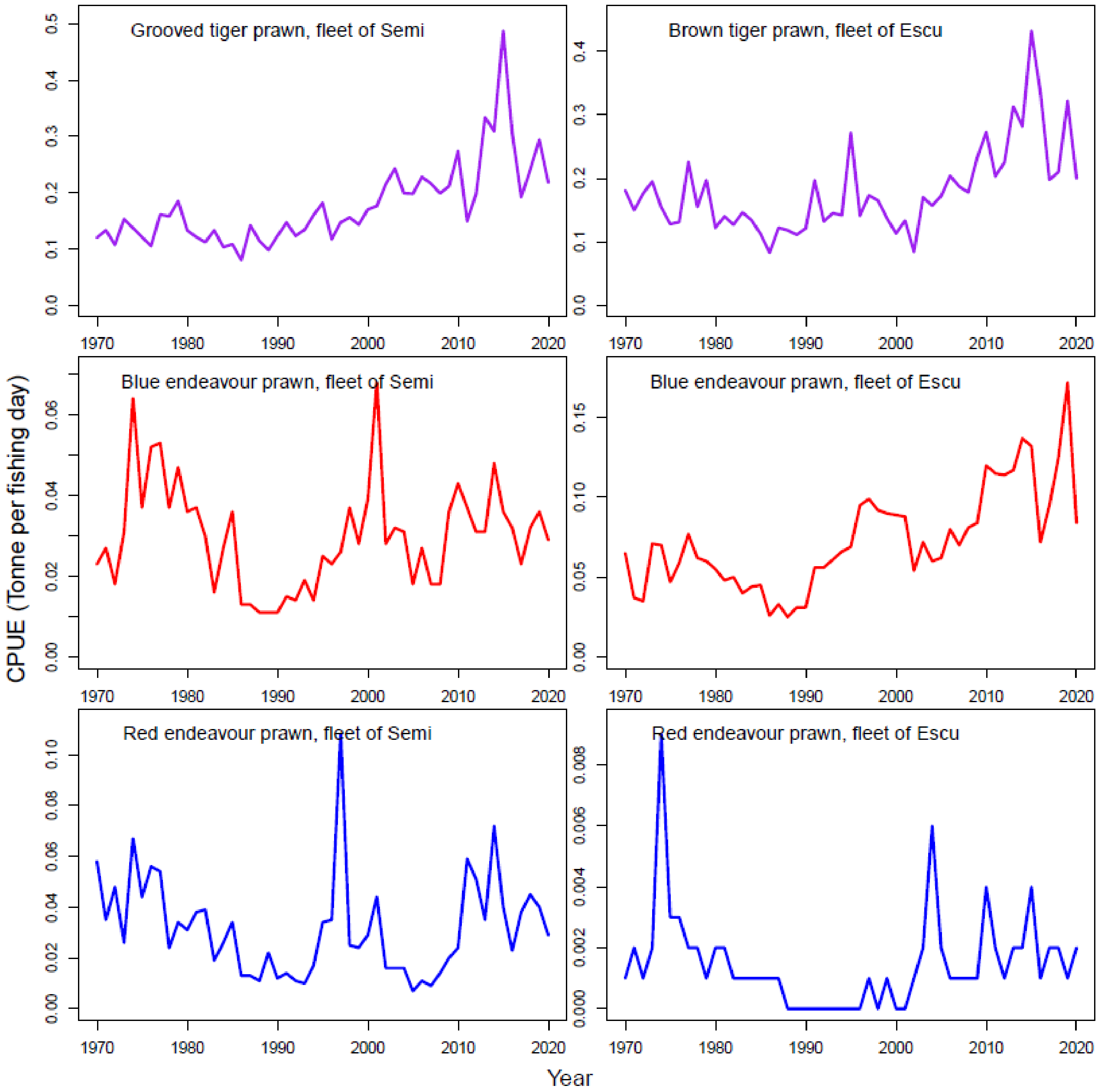


Figure 4. CPUE by year.



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Enquiries should be addressed to:

Dr Trevor Hutton
CSIRO Oceans and Atmosphere
Phone: 07 3833 5931 or e-mail: trevor.hutton@csiro.au