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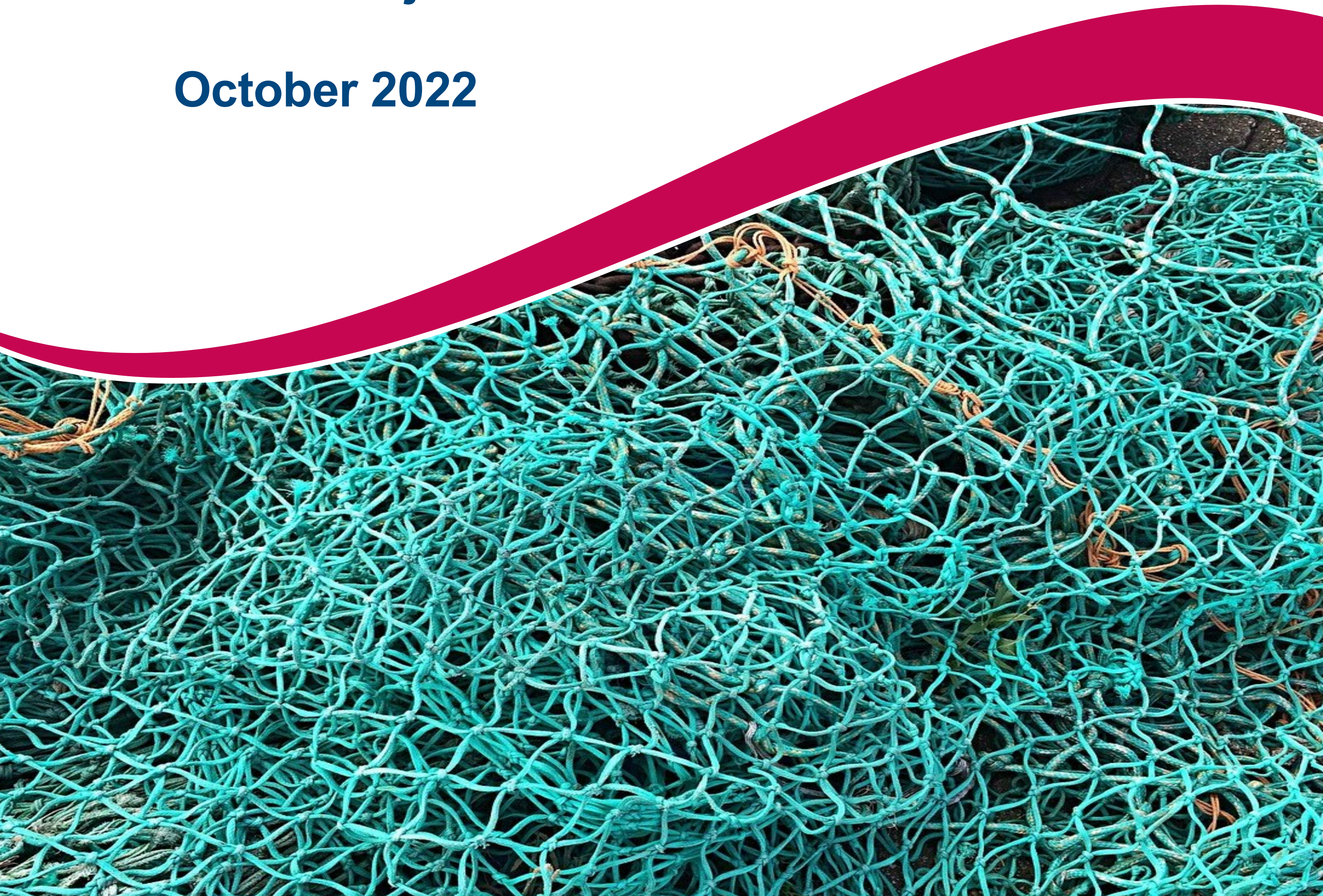
Stock assessment of the Joseph Bonaparte Gulf Redleg Banana Prawn (*Penaeus indicus*) Fishery to 2021, with TAE Recommendations for 2022

Final Report

AFMA Project No. 2020/0803

October 2022



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

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Acronyms

AAV	Average Annual Variability
AFMA	Australian Fisheries Management Authority
BOM	Bureau of Meteorology
CPUE	Catch Per Unit Effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
HCR	Harvest Control Rule
HS	Harvest Strategy
MEY	Maximum Economic Yield
MSE	Management Strategy Evaluation
MSY	Maximum Sustainable Yield
NPF	Northern Prawn Fishery
NPFI	Northern Prawn Fishery Industry
NPRAG	Northern Prawn Fisheries Resource Assessment Group
OM	Operating Model
SOI	Southern Oscillation Index
RAG	Resource Assessment Group
SFR	Statutory Fishing Right

Executive Summary

The assessment model for Redleg Banana Prawns (*Penaeus indicus*) utilising the additional data available for 2021 was updated. In this integrated model, quarterly time steps are used to represent the prawn dynamics. The model is fitted to available catch and effort data. We standardised effort data by applying the updated fishing power series derived for Redleg Banana Prawns. With the model, we calculated a 2022 Total Allowable Effort (TAE) recommendation for Redleg Banana Prawns (*Penaeus indicus*) in the Joseph Bonaparte Gulf (JBG) fishery.

In 2021, 95% of the fishing effort and 95% of the catch was in the JBG area, with the balance taken from Colville-Melville (CM) and with negligible amount from Fog Bay (FB) (total catch across all areas was 503 t). Effort in JBG 2021 was 415 boat-days (total effort across all areas was 438 boat days). Previously, most of the fishing effort was distributed in the second and third quarters (Apr-Sept), but given the harvest strategy change implemented in 2021 to permanently close the first season to Redleg Banana Prawn fishing, all of the 2021 fishing effort was in the second season.

Given that the 2021 JBG effort exceeded the data-sufficient number of 70 boat-days, this means that a stock assessment is conducted using the 2021 data updates. The number of boat-days in the 4th quarter was less than the 20 days required for using the CPUE in the stock assessment and hence only the 3rd quarter CPUE was used. The 2021 nominal CPUE observation for the third quarter was larger than the average (since the 2000s). The fishing power was estimated to have increased 4% in 2021 relative to 2020.

The stock assessment suggests an increase in the stock from 76% BMSY in 2020 to around 93% of the BMSY level in 2021, although the Spawning Biomass (2708 t) is still below (77%) the target BMEY level. Variability about BMSY is to be expected for a variable stock, but the biomass levels are estimated to have been below the target level for a number of recent years, hence it is encouraging that the stock appears to have increased in the recent year. This is consistent with the expected change under the revised HS as closing the first season is predicted to allow the stock to recover rapidly provided total effort doesn’t greatly exceed the TAE.

The Reference Case recommended TAE for 2022, under the new strategy of fishing only in the second season is 364 boat days (90% confidence interval [70;658]), with a corresponding catch prediction of 459 [0;960] tonnes. Thus, the predicted effort level to allow the stock to increase back towards the target level is 12% lower than the 2021 observed effort level (Table 1), noting that there is a wide confidence interval around this estimate.

Table 1. The change in nominal effort and catch over a two-year period (2020 observed versus 2021 model predicted) for the redleg banana prawn fishery in the JBG.

Factor (effort or catch)	Value	% difference
Effort 2021 – boat days	415	
Predicted effort 2022 – boat days (i.e. Recommended TAE)	364	-12
Catch 2021 - tonnes	479	
Predicted Catch 2022 - tonnes	459	-4

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, and financial support was provided by AFMA and the CSIRO Oceans & Atmosphere. We thank Shijie Zhou and Laura Blamey for constructive review comments on an earlier version of the report.

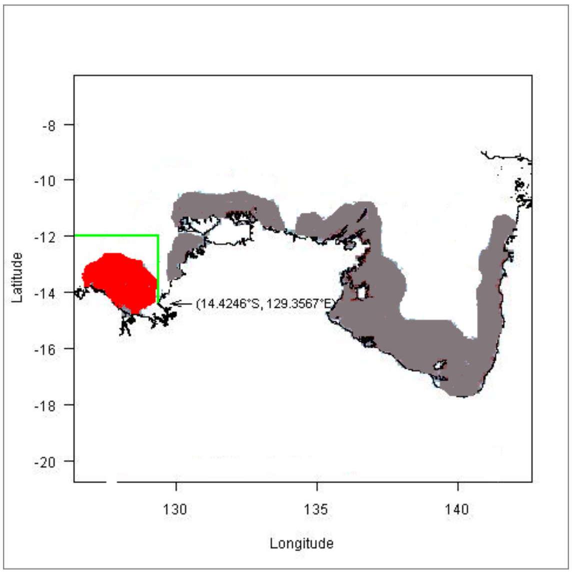
1 Background

The Northern Prawn Fishery (NPF), which commenced in the late 1960s, extends from Cape Londonderry in Western Australia to Cape York in Queensland (Gillett 2008). In some years it is the most valuable Commonwealth-managed fishery. The NPF targets at least nine species of prawns, the main species being White and Redleg Banana Prawns (*Penaeus merguiensis* and *P. indicus*), two Tiger Prawn species (*Penaeus semisulcatus*, *P. esculentus*) and two Endeavour Prawn species (*Metapenaeus endeavouri, M. ensis*). Commensurate with the data and available biological information, a suite of assessment methods have been applied to these species. They range from relatively simple biomass dynamic models (Zhou et al. 2009), through delay-difference models (Dichmont et al. 2003) to size-structured population dynamics model (Punt et al. 2010). A bio-economic model is used in the Tiger Prawn fishery, to predict catch and effort levels maximising net present value (Punt et al. 2011). For the Redleg Banana Prawn fishery of the Joseph Bonaparte Gulf (JBG), we apply an integrated model that represents dynamics on a quarterly time step.

Although fished extensively through southern Asia to East Africa, Redleg Banana Prawns are a relatively small percentage of the total NPF prawn catch (between 2011-2020, *P. indicus* were 4-17% of the total Banana Prawn catch). Most *P. indicus* within the NPF are caught in the Joseph Bonaparte Gulf (JBG). A Redleg Banana Prawn area (Figure 1), comprising the main fishing grounds where Redleg Banana Prawns are caught in the JBG, has been defined for management purposes. During the past 10-years (2012-2021), the average of White Banana Prawns caught in the JBG area is about 1% of the total NPF white banana catch whereas the average catch of Redleg Banana Prawns in the JBG area is about 83% of the total NPF Redleg Banana Prawn catch.

Figure 1. The area defined as the JBG fishery for Redleg Banana Prawns.

Boundaries were recommended by NPRAG and incorporated in the NPF Harvest Strategy. This figure is adapted from Dichmont et al. (2010, Figure 4). Figure production compliments of W.M. Venables (CSIRO) *pers. comm*.



The *P. indicus* fishery essentially developed in the early 1980s. The fishing grounds are in deeper waters than is the case for *P. merguiensis* (White Banana Prawns) and fishing takes place both day and night. Fishing centres on neap tides, as JBG has large tidal flows (tidal range is up to 7m) (Plagányi et al. 2020).

Substantial changes in fishing effort in the JBG fishery saw the number of days fished increase through the 1980s and 1990s, to a peak of about 2,471 boat days in 1997, but then falling to lows of just 161 and 149 boat days in 2008 and 2012, respectively. Effort has since climbed to 358 boat days, in 2013, and to 559 boat days (a 56% increase) in 2014, before decreasing to the lowest yet level of 79, 76 and 75 days in 2015, 2016 and 2019 respectively. Effort was high in 2017 (548 boat days), which corresponded to a period of high prices, but decreased to 195 days in 2020. Changes in effort over the entire period of the fishery reflect not only prawn catch rates but also historical management changes. These included large reductions in the number of vessels able to participate in the fishery and the introduction of seasonal closures (further detail is provided below). Inter-annual changes also reflect the response of operators to fluctuating catch rates, prices and values in other parts of the fishery (Pascoe et al. 2020), and more recently the role of environmental variability has also been explicitly recognized (Plagányi et al. 2020).

To account for the potential effects of environmental variability and extremes, Blamey et al. (2020, 2021) applied a management strategy evaluation (MSE) approach to test the robustness of the Redleg Banana Prawn harvest control rules to environmental variability. The MSE testing resulted in a plausible subset of management alternatives, and stakeholders selected a permanent closure of the first fishing season based on overall performance of this option; ability to reduce the risk of fishery closure and stock collapse; robustness to uncertainties; and ease of implementation (Blamey et al. 2020, 2021).

There are a number of implications for the harvest strategy and stock assessment arising from closure of the first fishing season, and these are discussed further in Plagányi et al. (2022). The Redleg Banana Prawn assessment relies on standardised CPUE data to serve as an index of stock abundance. In the first instance, closing the first season means that there will no longer be data available for the first season to fit the model to, and hence the model will rely on data obtained from the second season only. Moreover, in closure years or data-insufficient years when the fishing effort falls below 70 boat days, it won’t be possible to reliably update the assessment model.

2 Needs

Based on a set of short-lived, highly-variable species, management of the NPF requires detailed assessments to ensure maximal benefit. Specifically, under the Commonwealth Fisheries Harvest Strategy Policy, there is a need to set Total Allowable Effort (TAE) for Redleg Banana Prawns. Assessment is a core element of the Harvest Strategy for the fishery. Without regular, critical updates the Harvest Strategy would need considerable change and might be ineffectual.

This project is 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) provides harvest control rules (simply, ‘harvest strategies’) for two main species of Tiger Prawns, Blue Endeavour Prawns and Redleg Banana Prawns. There are separate assessments for these prawns.

The assessment of the Redleg Banana Prawn fishery, requires:

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

The Redleg Banana Prawn fishery models will provide TAEs and predicted corresponding catches, and thus make available all the information required for management. Furthermore, the continuous update to the harvest control rules for Redleg Banana Prawns given the recent evidence pointing to recent climate drivers which will need to be considered on an annual basis. This must be also undertaken to meet the requirements of the governments’ revised Harvest Strategy Guidelines, and this assessment supports that research and policy changes.

3 Objectives

The objectives as specified in the original proposal are:

1. Update the fishing power series incorporating data from gear surveys, annually (i.e. in this report 2022 for the preceding fishing years) for the Redleg Banana Prawn fishery;

2. Assess stock status of the Redleg Banana Prawn fishery (and relevant key environmental factors) and provide a TAE for Redleg Banana Prawns for 2022.

4 Method

The analyses presented in this report are based on those of Plagányi et al. (2010, 2022) and subsequent updates and the full details of the assessment model are given in Appendix 1, while Appendix 2 summarises key biological information. The data rules used in the current assessment are summarized in Appendix 3. Given recent strong environmental anomalies and indications that the stock may be influenced by a combination of environmental drivers, a summary of recent key environmental indicators is given in Appendix 4 (see Plagányi et al. 2020 for further details). The analysis of fishing power in the JBG fishery is presented in Appendix 5. The stock assessment described in this report was conducted in parallel with a Redleg Banana Prawn Stock Assessment Revision Project (Plagányi et al. 2022) which was necessary to take account of changes to the Harvest Strategy as described in Blamey et al. (2020).

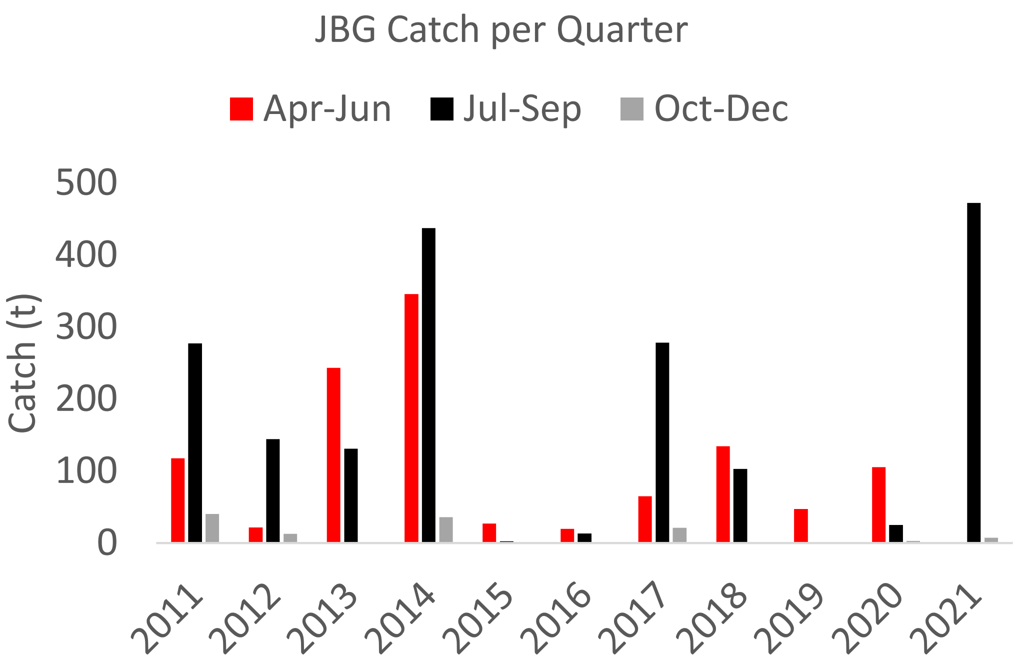
4.1 Catch, Effort and Biological Information

The JBG data were analysed per quarter, the four quarters being defined as those of a calendar year, i.e. Quarter 1 = January – March; 2 = April – June; 3 = July – September and 4 = October – December. A historical catch and effort series for each quarter, for the JBG sector only, from 1980 to 2021 was constructed using all available logbook information (Figure 2). Although sporadic catches were recorded in the area since the 1970s, the JBG prawn fishery essentially developed in the early 1980s. Catches peaked at around 977 t in 1997 but decreased to around 131t in 2007. Catches have been variable in subsequent years but the 2014 JBG banana prawn catch of 825.1t (including 819.5t of *P. indicus*) was the second highest annual catch in the history of the JBG fishery (Figure 2a). Catches then decreased substantially in 2015-2016, recovered during 2017-2018 but the 2019 catch was again anomalously low at 47t (Table 2). The 2020 JBG catch was 133.4 t and the 2021 catch has increased to 479.3t (Figure 2a). Seasonal catches in the fishery strongly reflect effort patterns (Figure 2).

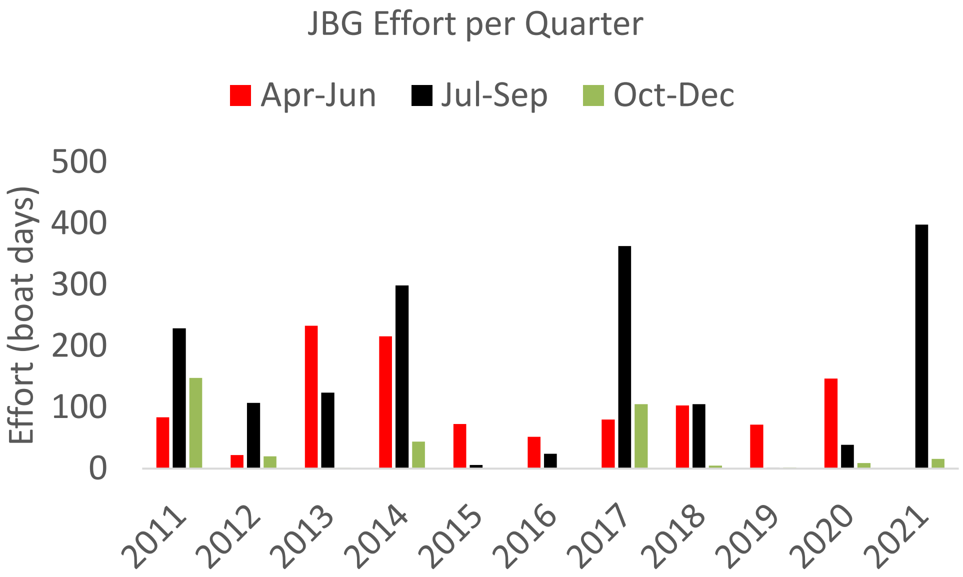
First quarter catches in JBG have never been substantial. JBG was fished in the first quarter in the early 1980s but catches and effort were small. Effort focused on the third and fourth quarters during the early years of the fishery. With the introduction of the seasonal closure from 1987, the first quarter was closed to fishing. Historically the larger catches during the year were from second quarter and from the mid-1980s, this quarter (now beginning the first season of the NPF) increased in importance. However, to address apparent reduced recruitment in JBG, this quarter was also subject to seasonal closure from 2007-2010. Following the removal of that closure in 2011, and with other fishery operational effects such as effort being directed to high abundances of White Banana Prawns elsewhere in the fishery, the annual pattern of catches over 2011-2020 has differed from the prior period, and has again changed since 2021 in response to the permanent closure of the first season to fishing Redleg Banana Prawns (Figure 2b). We accounted for this most recent change by adding a further (fifth) selectivity vector to the model for the period 2021 and subsequent assessments.

Figure 2. (a) Catch and (b) effort for Redleg Banana Prawns (*Penaeus indicus*) in the Joseph Bonaparte Gulf, shown per quarter for the period 2011-2021.

(a)



(b)



The Base Case model uses a standardised CPUE series which accounts for fishing power effects. Figure 3 summarises the fishing power input series for Redleg Banana Prawns based on the method described in Upston et al. (2019). A small increase in relative fishing power is estimated for 2021 (by ~4%) c.f. 2020 (Appendix 5).

Nominal CPUE for 2021 was above average (where average is computed over the period 2000 to 2020). However, we note the 2020 nominal CPUE average for the Harvest Strategy reference period, August to October, was larger than the pre-defined empirical CPUE limit reference point of 0.39 (tonnes/day) (Figure 4).

Figure 3. The updated Redleg Banana Prawn relative fishing power series (1981-2021).

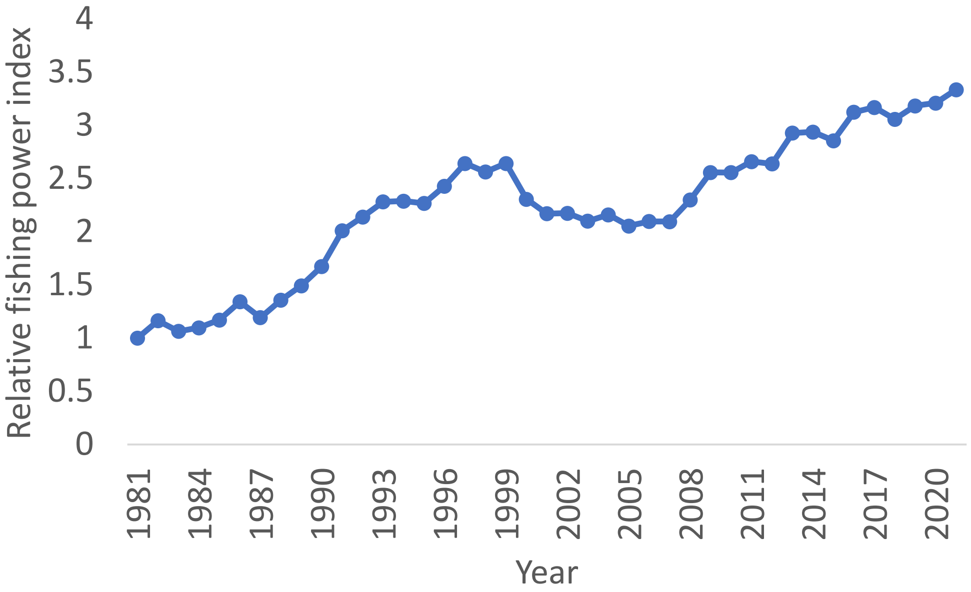
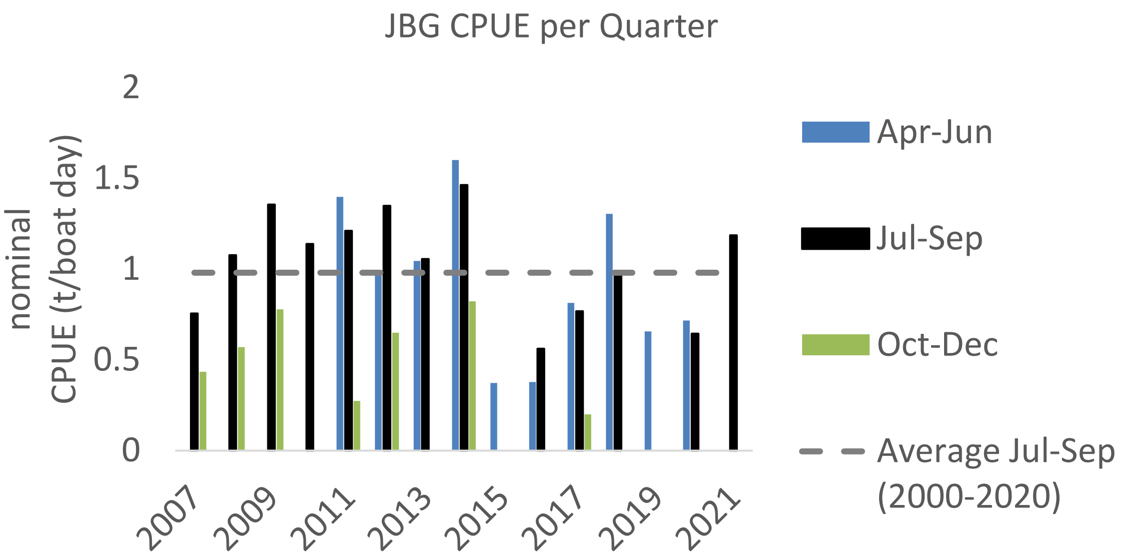


Figure 4. Comparison of the average nominal CPUE over August to October for years 2011 to 2021 with the average (2000-2020) for the third quarter (Jul-Sep) shown as a dashed line.



4.2 Closures in the NPF

A variety of spatial and temporal closures have been implemented over the years in the NPF. Substantial change was implemented in 1987, when an end of year (1 December to March/April) and a mid-year (22 June to 1 August) closure were introduced. The model accounts for the end of year closure by setting relative availability to zero for the first model quarter post-1987, and estimating separate availability parameters for the pre- and post-closure periods. The estimated availability parameters represent the combination of a variety of factors including reduced availability during a 3-month quarter due to partial closures, and fishing selectivity effects such as a proportion of the stock being too small to be fished.

During 2007-2010, the JBG was closed to prawn fishing during the first season (April to June). This corresponds to the second quarter in the model and is accounted for in the Base Case model by estimating a third quarter availability vector for 2007-2010 (discussed below). As the JBG was opened and fished during the first season from 2011-2020, a different availability vector is estimated for these years, and a fifth availability vector added for the period commencing in 2021 due to implementation of a permanent first season closure (Blamey et al. 2021).

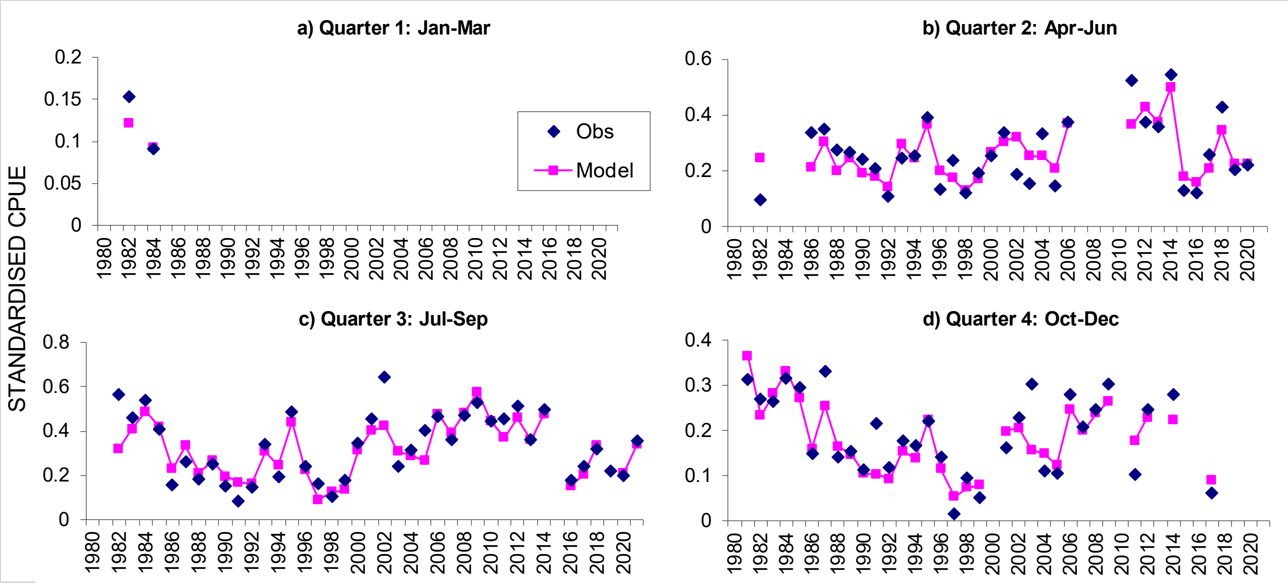
5 Results

5.1 Model fits and trajectories

Preliminary estimated parameter values are shown in Table 3 and Table 4. Comparisons between the observed and model-predicted CPUE values for each quarter are shown in Figure 5. The model fits to each of the quarters separately, and the fits are generally good, particularly for the most key reference fished quarters 2 and 3. For 2021, there were only adequate data (number of boat days > 20) to fit in quarter 3.

Estimates of availability per quarter (Figure 6) reflect the changing patterns of closures. The Base Case model estimates a single set of recruitment residuals associated with recruits that are spawned the previous October, recruiting to the fished population at the start of Quarter 2 (Figure 7). Although lower levels of recruitment are modelled to occur during the other quarters, accounting for the variability associated with just one (the major) of these events in Quarter 2, adequately represents resource dynamics.

Figure 5. Comparisons between the standardised CPUE data for each quarter and model-predicted CPUE values using the Base-Case model. Note that data are not included for the following quarters for which there was minimal fishing: Q4 in 2010, 2013, 2015-16, 2018-2021; Q3 in 2015, 2019.



In the plot of the stock-recruit residuals (Figure 7), the recruits in any quarter correspond to the spawning biomass half a year earlier. The residuals are random over time (runs test, n=41, p=0.34). Mostly positive residuals for 2006-14, correspond to higher-than-expected catch rates described above (i.e. observed catch rates greater than model estimates). However, the more recent data suggest a lower-than-average recruitment for four of the past six years (Figure 7). This might suggest that environmental drivers or other processes could be impacting on recruitment variability (Plagányi et al. 2020),

Figure 6. Schematic summary of Base Case model availability vectors for each quarter, for the five periods. a) 1980-1988, b) 1989-2006, c) 2007-2010, d) 2011-2020 and e) from 2021.

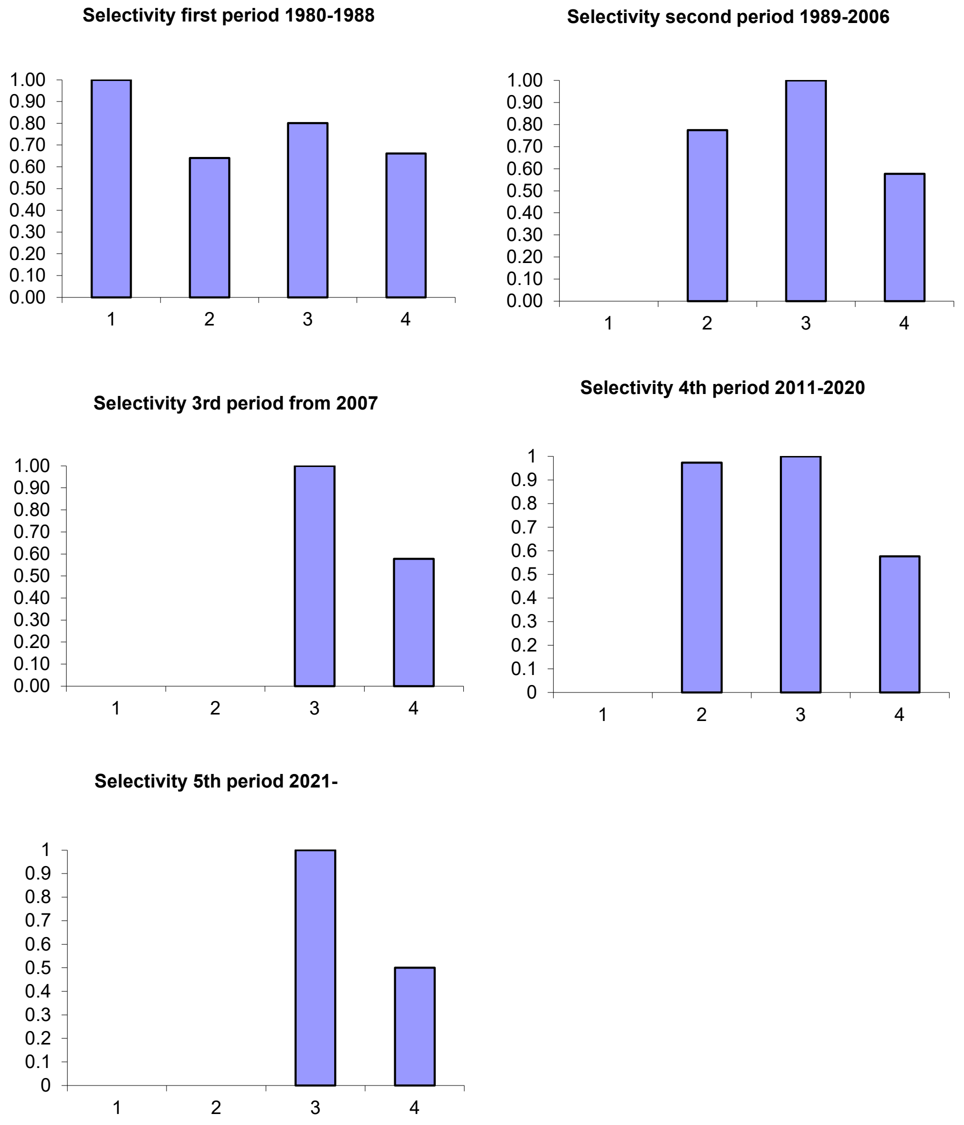
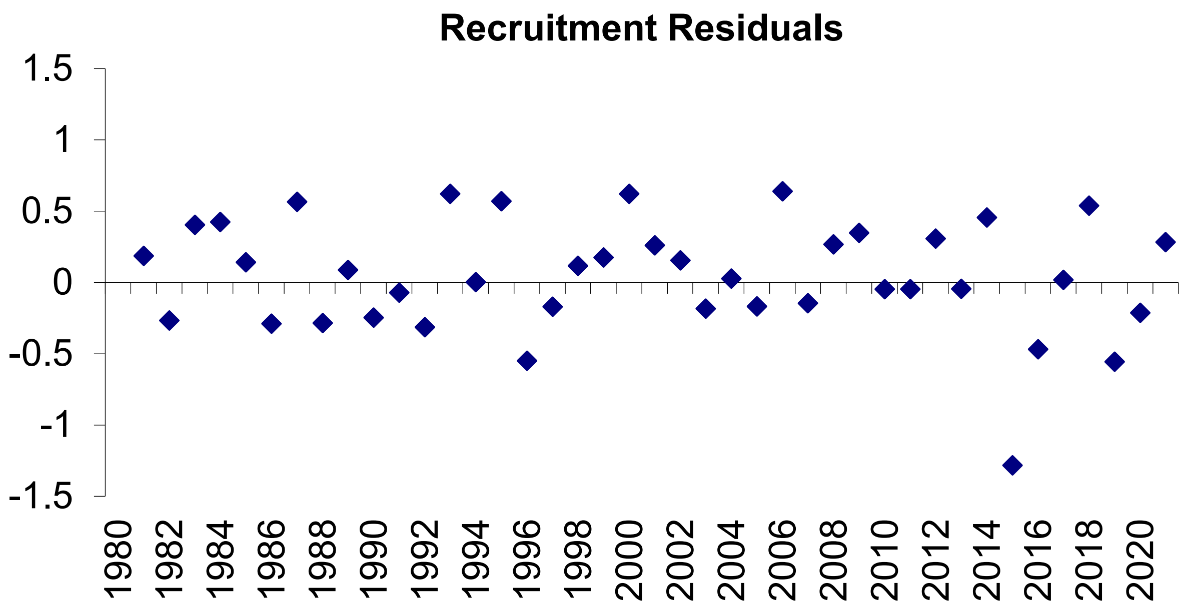


Figure 7. Recruitment estimates for Redleg Banana Prawns in Joseph Bonaparte Gulf, for the Base Case model. Plot shows estimated stock recruit residuals for the start of the second quarter for all years, 1981-2021.



The total annual spawning biomass trajectory is shown in Figure 8. The prawn population is predicted to have declined after 1995, but to have increased from around 2000 in response to lower catches and good recruitment, but then to have decreased again since 2014 toward the lower limit. However, based on limited CPUE data, the downward trend appears to have reversed briefly in 2018 when it tended back towards the target level, but the 2019-2021 spawning biomass is estimated to be below the BMSY level but the 2021 estimate is 93% of the BMSY level. The BMEY, BMSY and BLIM levels are respectively 3510t, 2925t and 1463t.

The stock size in the last year of the assessment is estimated to be greater than the Biomass Limit Reference Point (BLIM), i.e. B2021 > 0.5 BMSY, with B2021 ca. 1.85 times BLIM. However, B2021 is estimated to be below BMEY and slightly below BMSY, with depletion proportions (relative to BMSY) of 0.77 and 0.93 respectively.

The associated Hessian-based 90% confidence intervals as shown in Figure 9 highlight, nevertheless, the large uncertainty associated with model estimates of spawning biomass. Even considering the associated large uncertainty, there is some confidence that the stock declined substantially over 2015-2017 as evident from the upper confidence limit being below the target level for these years (Figure 9).

Similarly, the commercially available biomass (Bcomm) (see Appendix 1) is predicted to have decreased substantially in 2015-17 to a much lower level than in previous years, but has increased to 62% of the average in 2021 (Figure 10).

Figure 8. Total annual spawning biomass (t) trajectory using the Base Case model for 1980 to 2021. The plot also shows the target spawning biomass level (BMEY), the biomass level (BMSY) corresponding to Maximum Sustainable Yield (MSY) and limit reference level (BLIM)

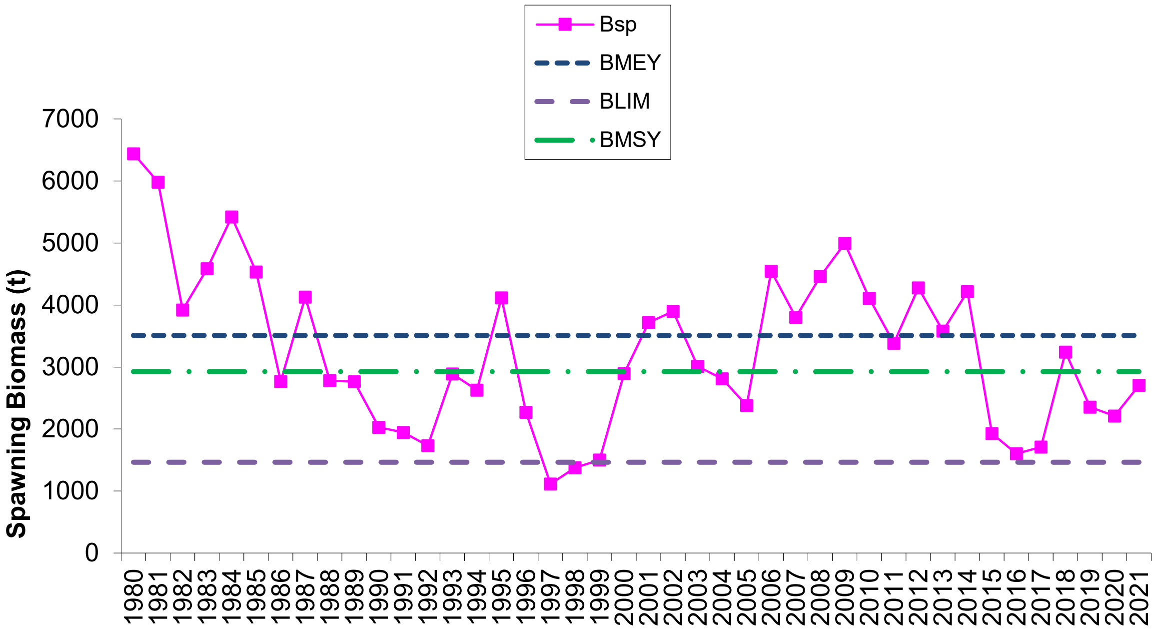


Figure 9. Base Case spawning biomass estimates for the period 1980 to 2021, and projected forward to 2022 (last point shown on right hand side of plot).

The shaded areas represent the associated Hessian-based 90% confidence intervals. The biomass is shown relative to model estimates of the biomass level (*BMEY*) corresponding to Maximum Economic Yield (*MEY*), which is used as the target biomass level.

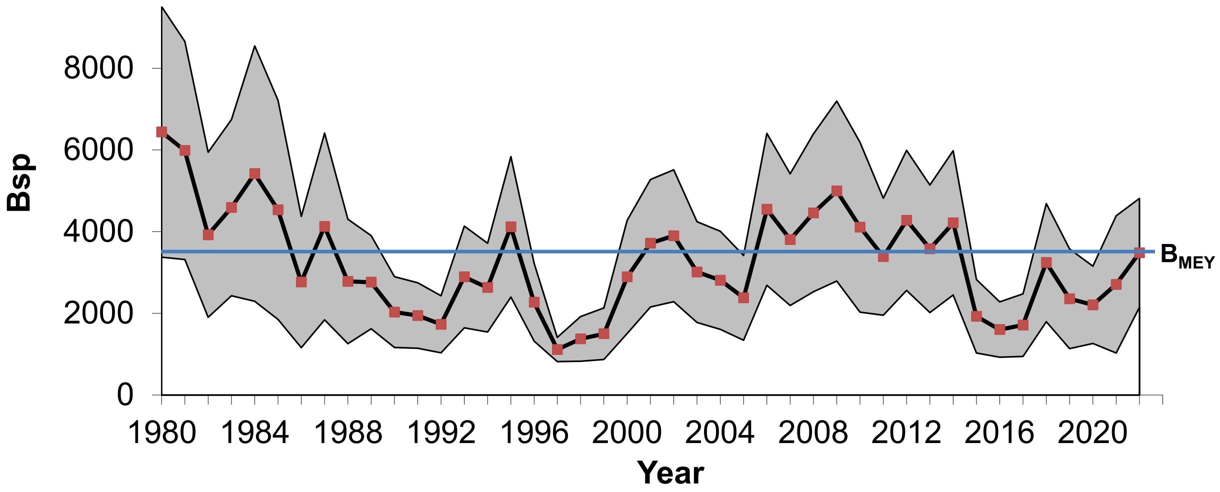
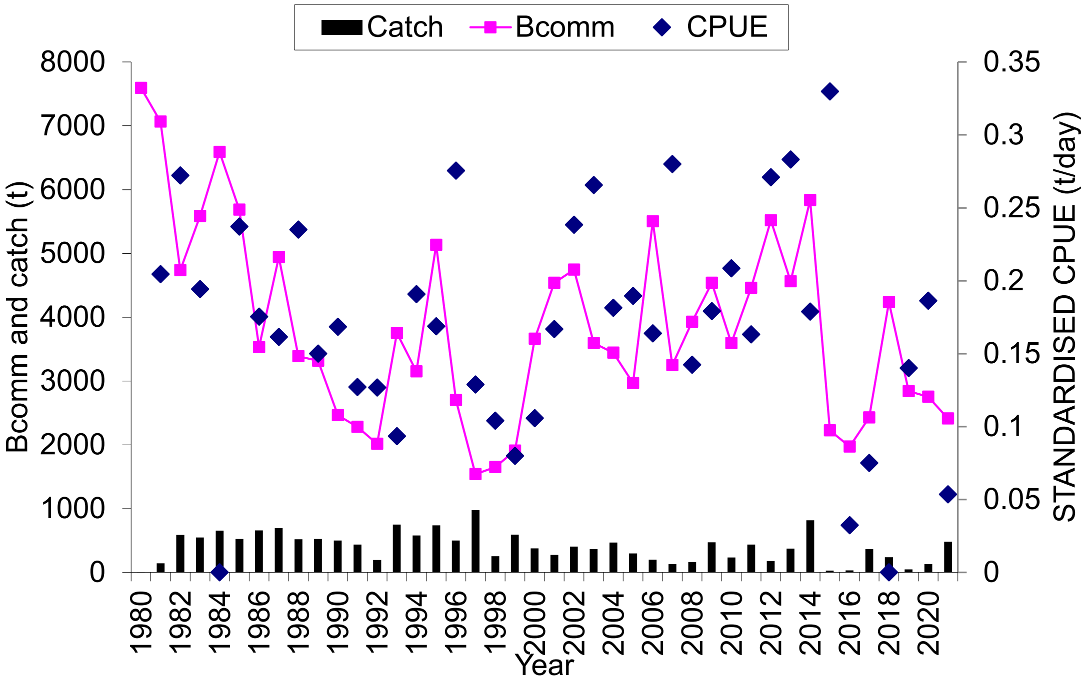


Figure 10. Total commercially available biomass (Bcomm) trajectory using the Base Case model, shown compared with the annual catch and annual averaged CPUE values.



5.2 Model predictions and sensitivity analyses

A number of sensitivity analyses were considered as part of the MSE project (Blamey et al. 2020, 2021) and the Redleg Banana Prawn stock assessment revision project (Plagányi et al. 2021). Here we present in Table 4 results of selected key sensitivity tests. The sensitivity tests use the same settings as the Reference Case model, including setting sigma=0.8, unless otherwise specified.

Based on earlier analyses, the Reference Case model uses a fixed stock-recruit steepness (*h*) value of 0.6. Steepness is a key parameter in stock assessments particularly when the stock has been estimated to decrease in abundance as has been the case for Redleg Banana Prawns since 2015, and hence sensitivity (B) allowed the model to estimate *h*. The model was able to successfully estimate h=0.55 with low associated Hessian-based standard deviation (0.05), but this did not significantly change the negative log likelihood, which is understandable given that the estimated value is close to the fixed value of 0.6. The Reference Case model thus remains the preferred model based on the AIC score, but the sensitivity is useful in confirming that steepness is likely to be relatively low for this species based on the median value of 0.7 from a meta-analysis (Myers et al. 1995).

Sensitivity (C) involved using a lower setting for sigma of 0.6 in place of the Reference Case value of 0.8. This sensitivity did not result in any major changes to the stock assessment.

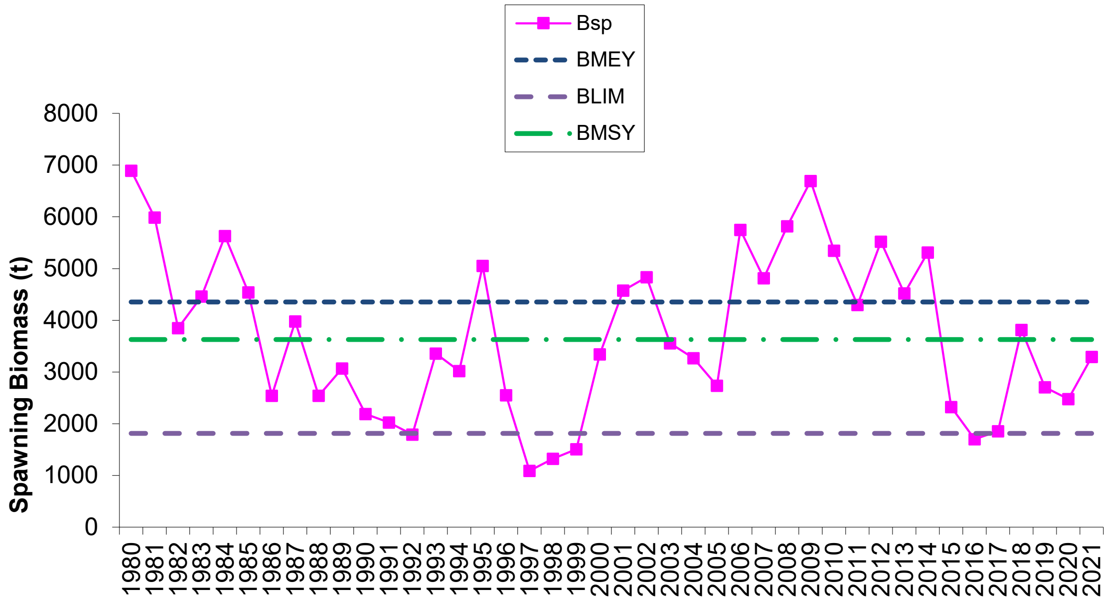
Sensitivity (D) tested the effect of assuming that the relationship between CPUE and stock abundance is hyper-stable rather than the assumption that CPUE is proportional to stock abundance (see e.g. Harley *et al.* 2001). The Reference Case assumes a linear relationship having a default value of hyps = 1. We therefore tested alternative settings for parameter *hyps,* and in partiuclar *hyps* = 0.8, where:

$$\left(\frac{C}{E}\right)_{y,s} = q_s qf_y \left(B_{y,s}^{\exp}\right)^{hyps}$$

where $B_{y,s}^{ex}$ is the model value for exploitable resource biomass corresponding to quarter *s*, q is the constant of proportionality which is assumed to be the same for each of the quarters, qf_y is the fishing power estimate for year y and *hyps* is the hyperstability parameter value.

Assuming a hyperstable relationship significantly worsened the model fit (Table 4) and hence is not the preferred model. If the hyperstability parameter is estimated in the model, the best fit corresponds to a value of 1 as is assumed in the Reference Case model. However, it is worth considering the possibility of a hyperstable relationship because as illustrated in Figure 11, it results in an estimation of the stock being more depleted during some past periods, and hence that the stock may have fallen below the BLIM level more frequently than is estimated by the Reference Case model.

Figure 11. Sensitivity Test assuming a hyperstable CPUE relationship and showing estimated total annual spawning biomass (t) trajectory for 1980 to 2021. The plot also shows the reference levels corresponding to Sensitivity (D) with hyperstability parameter set at 0.8: target spawning biomass level (BMEY), the biomass level (BMSY) corresponding to Maximum Sustainable Yield (MSY) and limit reference level (BLIM)



The Reference Case recommended TAE for 2022, with an associated fishing pattern (no fishing in first season) is 364 boat-days (90% confidence interval [70; 658]), with a corresponding catch prediction of 459 tonnes with wide confidence interval [0; 960] tonnes.

5.3 Environmental drivers and revisions to the Harvest Strategy

Previous work (Plagányi et al. 2016, 2020) hypothesized that low Redleg Banana Prawn catches in 2015-2016 could be explained by temporary drops in sea level and rainfall potentially reducing the ability of postlarvae to reach their nursery ground. It was proposed that notably poor prawn catch years may be predicted using two variables that are a sub-set of possible drivers of recruitment - the January Southern Oscillation Index and the combined January to February cumulative rainfall. However due to challenges in verifying and defining such environmental relationships for inclusion in a stock assessment, development of a harvest strategy framework was proposed to support management recommendations.

A Harvest Strategy framework was thus developed using two pragmatic empirical measures, SOI (January) and rainfall (cumulative January to February), as indicators of a poor prawn season. Uncertainty in the exact mechanism of these environmental drivers on the stock can be accounted for using a MSE framework, and uncertainty pertaining to prediction of future low catches can be accounted for as part of MSE testing (Blamey et al. 2020). The MSE testing can then evaluate the efficacy of alternative harvest strategies to reduce the risk of the stock decreasing below limit or target levels, as well as the risk of sub-economic fishing.

The MSE framework can also be used to simulation test whether the Harvest Strategy is sufficiently robust (e.g. reduces risk of stock decreasing below BLIM) to changes in fishing effort or fishing pattern, including anomalous scenarios for which there have previously not been data available to assess this. Based on the results presented in Blamey et al. (2020, 2021) and subsequent discussions with stakeholders, the first season was permanently closed to Redleg Banana Prawn fishing with effect from 2021.

As we collect more data over the next few years, our understanding of environmental drivers (Plagányi et al. 2020) and other effects such as economic factors (Pascoe et al. 2020), which are currently confounded, will improve and in turn will allow us to improve the models and better inform management of this fishery, especially under a changing climate. However, in the absence of a fishery-independent survey it will be very difficult to attribute the effects of multiple factors on the fishery.

Table 2. Summary of the recent Redleg Banana Prawn catch (tonnes) for Joseph Bonaparte Gulf and Total catch including areas Coburg-Melville and Fog Bay.

Year	JBG	Total
1980	2.5	30.8
1981	143.5	148.6
1982	588.6	596.7
1983	547.4	549.6
1984	653.5	666.5
1985	523.3	553.2
1986	657.6	675.1
1987	694.9	722.3
1988	520.6	535.1
1989	525.4	542.7
1990	500.3	519.8
1991	434.9	480.6
1992	193.4	222.0
1993	749.1	795.8
1994	581.1	592.7
1995	739.0	743.8
1996	498.4	527.8
1997	976.6	1126.3
1998	255.9	257.3
1999	590.5	625.1
2000	379.2	392.9
2001	274.2	306.0
2002	405.0	407.9
2003	364.9	376.2
2004	468.7	473.7
2005	299.9	308.1
2006	200.5	209.2
2007	130.9	159.0
2008	162.2	240.1
2009	471.8	510.3
2010	233.2	240.6
2011	435.3	475.2
2012	178.9	190.7
2013	374.3	380.6
2014	819.5	846.8
2015	29.5	55.7
2016	33.1	66.5
2017	364.6	430.2
2018	237.6	247.8
2019	47.3	66.7
2020	133.4	144.5
2021	479.3	502.7

Table 3. Summary of the parameters of the population dynamics model.

Parameter	**Treatment**
Pre-exploitation equilibrium spawning biomass, K_{1980}^{sp}	Estimate $K_{1980,1}^{sp}$ for first quarter, compute values for other quarters using equilibrium assumptions, and set $K_{1980}^{sp} = \sum_{seas} K_{1980,seas}^{sp}$
Natural mortality, *M*	Fixed at 0.05 wk^{-1}
Recruitment and spawning	
"Steepness", *h*, of the stock-recruitment relationship	Fixed at 0.6 (sensitivities tested)
Recruitment residuals , R_s for quarter 2	Estimated – 41 pars for 1981- 2021
Proportion of recruited stock that spawn each quarter, f_s	Assumed known [0.3; 0.05; 0.05; 0.6]
Stock-recruitment relationship parameters, α, β	Computed using estimated values of K_{1980}^{sp} and *h*
Variance in recruitment, σ_r	Fixed at 0.8 (sensitivities tested)
Fishing mortality related	
Catchability – *q (x10*$^{-4}$*)*	Computed, 2.4e-4
Availability during each quarter for period 1980-1988, $A_{y,s}$	Estimated [1.00 ; 0.64; 0.80; 0.66]
Availability during each quarter for period 1989-2006, $A_{y,s}$	Estimated *(except for pars in italics)* [*0*; 0.78; 1.00; 0.58]

Availability during each quarter for period from 2007-2010, $A_{y,s}$	Fixed at 1989-2006 estimates for quarters 3-4 [*0; 0*; *1.00; 0.58*]
Availability during each quarter for period from 2011-2020, $A_{y,s}$	Estimated *(except for pars in italics)* [*0*; 0.97; *1.00*; 0.58]
Availability during each quarter for period from 2021, $A_{y,s}$	Fixed [*0; 0; 1.00; 0.5*] Estimated *(except for pars in italics)* [*0* ; 0.97; *1.00*; 0.58]
Growth parameters	
Von Bertalanffy growth curve parameters	Assumed known
Length-weight regression	Assumed known
The observation model	
Observation error variance, σ	Estimated [0.29]

Table 4. Summary of (A) Reference Case model parameter estimates and sensitivity analysis with (B) stock-recruitment steepness parameter *h* estimated instead of being fixed at 0.6; (C) the sigma parameter controlling the extent of recruitment fluctuations reduced from 0.8 to 0.6 and (D) the CPUE-biomass relationship assumed to be hyperstable with hyperstability parameter 0.8

	(A) Reference Case (sigma 0.8)				(B) Estimate steepness h (sigma 0.8)				(C) Reference Case (sigma 0.6)				(D) hyperstability parameter 0.8 (sigma 0.8)			
K_{1980}^{sp}	6383				9823				5002				6827			
Steepness *h*	0.6 (fixed)				0.55	std (0.05)			0.6 (fixed)				0.6 (fixed)			
Availability during each quarter for period 1980-1988	1.00	0.64	0.80	0.66	1.00	0.55	0.72	0.61	1.00	0.65	0.81	0.68	1.00	0.75	1.00	0.77
Availability during each quarter for period 1989-2006	0.00	0.78	1.00	0.58	0.00	0.74	1.00	0.60	0.00	0.79	1.00	0.59	0.00	0.79	1.00	0.49
Availability during each quarter for period from 2007-2010	0.00	0.00	1.00	0.58	0.00	0.00	1.00	0.60	0.00	0.00	1.00	0.59	0.00	0.00	1.00	0.49
Availability during each quarter for period 2011-2020	0.00	0.97	1.00	0.58	0.00	0.93	1.00	0.60	0.00	0.97	1.00	0.59	0.00	0.98	1.00	0.49
Availability during each quarter for period from 2021	0.00	0.00	1.00	0.50	0.00	0.00	1.00	0.50	0.00	0.00	1.00	0.50	0.00	0.00	1.00	0.50
Catchability – *q*	2.4E-04				2.4E-04				2.5E-04				8.8E-04			
-lnL:overall	-70.4				-70.8				-67.4				-65.6			
Observation error variance	0.29				0.29				0.30				0.30			
Current depletion - Bsp(2021) relative to B_{MSY}	0.93				0.91				0.92				0.91			
Current depletion - Bsp(2021) relative to B_{MEY}	0.77				0.76				0.76				0.76			
Current depletion - Bsp(2021) relative to B_{1980}	0.42				0.29				0.51				0.48			
Fproj(2022) as proportion of Ftarg	0.93				0.91				0.92				0.91			
No. parameters	51	(41 recruit residuals)			52	(41 recruit residuals)			51	(41 recruit residuals)			51	(41 recruit residuals)		
AIC	-38.845				-37.505				-32.822	not comparable			-29.118			

6 Benefits and Adoption

The assessment provided estimates of stock status for the Redleg Banana Prawns. The outcome provided will be a demonstration of the sustainability of the NPF target species under current management. In accordance with the NPF Harvest Strategy the predictive component of the models supported recommendations for the Total Allowable Effort (TAE) for Redleg Banana Prawns (2022) (where previous years were published before), thus 2022 is presented in this report.

As the primary clients of this work are the management group of the fishery, that is AFMA, NORMAC, NPRAG and NPF Industry – principal methods were communicated via the provision of progress reports to meetings of these groups, and the use of the various forums to provide feedback on the project outputs. Presentations of all the work in this project were provided at all the NPRAG meetings during the time frame of this project. There is a public record of the minutes of the meetings, and the recommendations for the TAE for each year that were endorsed by the NPRAG and NORMAC, which would have been sent on to the AFMA Commission.

7 Further Development & Planned Outcomes

This project is in its first major phase of the three-year NPF Assessment project commenced in July 2021 (2021-2024). This project has been achieving the same set of objectives as outlined and delivered previously, although under new and different circumstances and challenges. Given the critical importance of this fishery to the nation as a key Commonwealth fishery its ongoing assessment in terms of biological sustainability needs to be maintained.

8 Conclusion and Recommendations

The objectives of this project were achieved, that is a completion of the Redleg Banana Prawn fishing power analysis and the assessment. On the basis of this work and the review and endorsement of the assessment by the NPRAG in May 2022, the Reference Case recommended TAE for 2022, with no fishing in first season is 364 boat days (90% confidence interval [70;658]), with a corresponding catch prediction of 459 tonnes. Thus, a predicted 12% decline in effort from the previous year (and a 4% decrease in catch assuming average recruitment).

Table 5. Summary of Redleg Banana Prawn stock status in 2020 AND 2021 relative to Reference levels

	Redleg Banana Prawn (JBG)
Steepness	0.6
Catch (2020)	479.4 t
BMEY/BMSY	1.20
B2020/BMSY	0.76
B2020/BMEY	0.63
B2021/BMSY	0.93
B2021/BMEY	0.77

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Appendices

Appendix 1. The Production Model

A discrete population model was constructed for Redleg Banana Prawns in the JBG as follows. The model time-step is quarterly (3 month quarters), with the number of prawns in year *y* and quarter *s* ($N_{y,s}$) given by:

$$N_{y,s+1} = N_{y,s}\,e^{-M_s} - C_{y,s} + R_{y,s+1} \qquad \text{for } s = 1 \text{ to } 3 \qquad (1)$$

and

$$N_{y+1,1} = N_{y,4}\,e^{-M_4} - C_{y,4} + R_{y+1,1} \qquad \text{for } s = 4 \qquad (2)$$

where

$N_{y,s}$ is the number of recruited and mature prawns (those corresponding to a size large enough to be fished) at the start of quarter *s* in year *y* (which refers to a calendar year),

$R_{y,s}$ is the number of recruits (number of 6-month old prawns) which are added to the population at the end of each quarter *s* in year *y*,

M_s denotes the natural mortality rate during quarter *s* (assumed in the Reference case to be constant throughout the year), and computed by multiplying the weekly natural mortality rate estimate by 13 (weeks) to reflect a quarterly mortality rate; and

$C_{y,s}$ is the predicted number of prawns caught during quarter *s* in year *y*, with catches arbitrarily assumed taken as a pulse at the end of each quarter.

Given catches are recorded in units of mass, the predicted number of prawns caught during quarter *s* in year *y* is computed from the following relationship:

$$C_{y,s} = A_{y,s} F_{y,s} N_{y,s} e^{-M_s} \qquad (3)$$

where

$A_{y,s}$ is the relative availability for quarter *s* and for year *y*, with one availability vector being applied to the early period 1970-1987, another vector to the period 1988-2006 (i.e. post end of year NPF closure) and 2007-2010 (first season closure) periods; and

$F_{y,s}$ is the fished proportion in quarter *s* and year *y* of a fully selected age class.

The fished proportion reflects the catch by mass ($C^{mass}{}_{y,s}$) in quarter *s* and year *y* as a proportion of the exploitable ("available") component of biomass:

$$F_{y,s} = C^{mass}{}_{y,s} \Big/ B^{ex}_{y,s} \tag{4}$$

with

$$B^{ex}_{y,s} = w_s N_{y,s} e^{-M_s} A_{y,s} \tag{5}$$

where

w_s is the average mass of prawns during quarter *s*.

One of the biggest challenges in constructing a realistic model of *P. indicus* relates to improved information on growth, and in particular quarterly changes in growth. Length frequency data that span a number of periods through the year are needed to better inform this aspect of the model. This model used the female (because the male growth is too slow on its own) von Bertalanffy growth parameters and assumed that individual mass increases through the year. An average length and mass of prawns was thus calculated for each quarter, assuming a median birth date of October.

The number of recruits at the end of quarter *s* in year *y* is assumed to be related to the spawning stock size six months previously (i.e. during two quarters previously) by a modified Beverton-Holt stock-recruitment relationship (Beverton and Holt, 1957), allowing for annual fluctuation about the deterministic relationship for Quarters 1 and 2:

$$
\begin{aligned}
R_{y,s+1} &= \frac{\alpha B^{sp}_{y,s-1}}{\beta + \left(B^{sp}_{y,s-1}\right)^{\gamma}} e^{(\varsigma_{y,s} - (\sigma_R)^2/2)} && s = 1, 2 \\
R_{y,s+1} &= \frac{\alpha B^{sp}_{y,s-1}}{\beta + \left(B^{sp}_{y,s-1}\right)^{\gamma}} && s = 3,4
\end{aligned} \tag{6}
$$

where

α, β and γ are spawning biomass-recruitment relationship parameters (note that cases with $\gamma > 1$ lead to recruitment which reaches a maximum at a certain spawning biomass, and thereafter declines towards zero, and thus have the capability of mimicking a Ricker-type relationship – the Reference Case has $\gamma=1$),

$\varsigma_{y,s}$ reflects fluctuation about the expected recruitment for year *y* and quarter *s*, which is assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process, and a single set of residuals is estimated for Quarters 1 and 2 because almost all recruitment is assumed to occur during this half of the year and is assumed driven by the same environmental influences each year;

$B^{sp}_{y,s}$ is the spawning biomass at the start of quarter *s* in year *y*, computed as:

$$
B^{sp}_{y,s} = f_s \cdot w_s \cdot N_{y,s} \tag{7}
$$

where

f_s is a relative index of the amount of spawning during quarter s.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, B^{sp}_o, and the "steepness", *h*, of the stock-recruitment relationship, which is the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass. Equation (6) can be rewritten in terms of the "steepness" *h,* defined as the fraction of pristine recruitment R_0 that results when spawning biomass drops to 20% of its pristine level, i.e.:

$$hR_0 = R\left(0.2B_0^{sp}\right) \tag{8}$$

which yields the following for the deterministic component of the formulation:

$$R\left(B_{y,s}^{sp}\right) = \frac{4h \cdot R_0 \cdot B_{y,s}^{sp}}{B_o^{sp}(1-h) + B_{y,s}^{sp}(5h-1)} \tag{9}$$

It follows that the total spawner stock size and recruitment for calendar year *y* are given respectively by:

$$B_y^{sp} = \sum_s B_{y,s}^{sp} \tag{10}$$

$$R_y = \sum_s R_{y,s} \tag{11}$$

The resource is assumed to be at the deterministic equilibrium (corresponding to an absence of harvesting) at the start of 1980, the initial year considered here. The model estimates the pre-exploitation quarter 1 spawning biomass, from which the starting number of prawns can be calculated using Equation (7), and it follows:

$$R_{0,1} = \left(1 - e^{-M_1}\right) \cdot B_{0,1}^{sp} / \left(f_1 \cdot w_1\right) \tag{12}$$

and similarly for the pristine numbers and recruitment levels in the remaining quarters, which can then be added together to provide total spawning biomass and recruitment values for the year. The model sets the starting spawning biomass in the first quarter $B_{0,1}^{sp} = K^{sp}$. Given the total pre-exploitation spawning biomass B_0^{sp}, it follows that:

$$B_0^{sp} = \frac{\sum_s f_s \cdot w_s \cdot R_{0,s}}{\left(1 - e^{-M_s}\right)} \tag{13}$$

which can be solved for *R₀*, and hence the stock recruit parameters.

Likelihood function

The model is fitted to all available CPUE data for each of the four quarters. The likelihood contribution is calculated assuming that the observed abundance index is log-normally distributed about its expected value:

$$I_y^s = \hat{I}_y^s e^{\varepsilon_y^s} \qquad \text{or} \qquad \varepsilon_y^s = \ln(I_y^s) - \ln(\hat{I}_y^s) \tag{14}$$

where I_y^s is the abundance index (with fishing power effect added) for year *y* and quarter *s*,

$\hat{I}_y^s = q^s B_{y,s}^{ex}$ is the corresponding model estimated value, where $B_{y,s}^{ex}$ is the model value for exploitable resource biomass corresponding to quarter *s*, given by equation (5).

q is the constant of proportionality which is assumed to be the same for each of the quarters, and

ε_y^s from $N\left(0,\left(\sigma_y^s\right)^2\right)$.

In cases where a hyperstability relationship is assumed, the hyperstability is implemented by modifying the relationship as follows $\hat{I}_y^s = q^s \left(B_{y,s}^{ex}\right)^{hyp}$, where *hyp* is the hyperstability parameter (which is set to unity in scenarios with no hyperstability).

The contribution to the negative of the log-likelihood function (after removal of constants) is given then by:

$$-\ln L = \sum_y \left[\sum_s \ln \sigma_y^s + \left(\varepsilon_y^s\right)^2 / 2\left(\sigma_y^s\right)^2 \right] \tag{15}$$

with the standard deviation of the residuals for the logarithms of the abundance series assumed to be independent of *y*, and set in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^s = \sqrt{\frac{1}{n} \sum_y \sum_s \left(\ln I_y^s - \ln \hat{I}_y^s\right)^2} \tag{16}$$

where n is the number of data points across all years and quarters.

The catchability coefficient q is also estimated using maximum likelihood:

$$\ln\hat{q} = \frac{1}{n}\sum_{y}\sum_{s}\left(\ln I_{y,s}^{s} - \ln\hat{B}_{y,s}^{ex}\right) \tag{17}$$

Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell nL^{pen} = \sum_{y=y1+1}^{y2} \left(R_{y,s}\right)^{2} \Big/ 2\sigma_{R}^{2} \tag{18}$$

where

σ_R is the standard deviation of the log-residuals, which is input.

Future projections

Resource biomass was projected forward under both input - and output control scenarios. A TAC was computed for each year based on a target total fishing mortality rate. However forward projections are complicated because of inter-annual changes in the fishing effort and hence mortality rate applied per season/quarter. The Reference Case model typically assumes that the future pattern of fishing effort per quarter will be similar to recent observed fishing effort distribution (e.g. the average of the last 3-years or 5-years) but this is reviewed annually in consultation with stakeholders as over time there have been changes to fishing operations and the opening of the first season. The target fishing mortality (see next section) per quarter s (F_s^{targ}) therefore depends on how the fishing effort is distributed each year.

The future projected number of prawns caught during quarter s in year y is therefore computed from the following relationship:

$$\hat{C}_{y,s} = F_s^{targ}\hat{B}_{y,s}^{ex} \tag{19}$$

Based on the above and Equation (14), an estimate of the predicted fishing effort (days) is thus calculated as follows:

$$\hat{E}_{y,s} = \frac{\hat{C}_{y,s}}{\theta_{y*} q \hat{B}^{ex}_{y,s}} \tag{20}$$

Where θ_{y*} is the fishing power for year y*, which represents the last year in the series (i.e. fishing power is held constant at the most recent level for future projections).

Table A1.1 Reference Case model recruitment residual parameter estimates and associated 90% confidence interval calculated using Hessian-based standard deviations

	Value	90% confidence interval	
1981	0.19	-0.51	0.88
1982	-0.27	-0.85	0.31
1983	0.40	-0.02	0.83
1984	0.42	-0.09	0.94
1985	0.14	-0.38	0.66
1986	-0.29	-0.78	0.20
1987	0.56	0.16	0.97
1988	-0.28	-0.74	0.17
1989	0.09	-0.43	0.61
1990	-0.25	-0.67	0.17
1991	-0.07	-0.48	0.34
1992	-0.31	-0.74	0.11
1993	0.62	0.26	0.98
1994	0.00	-0.41	0.41
1995	0.57	0.18	0.96
1996	-0.55	-1.02	-0.08
1997	-0.17	-0.62	0.27
1998	0.12	-0.25	0.48
1999	0.18	-0.18	0.53
2000	0.62	0.20	1.05
2001	0.26	-0.18	0.70
2002	0.16	-0.27	0.58
2003	-0.18	-0.62	0.25
2004	0.03	-0.39	0.44
2005	-0.17	-0.60	0.26
2006	0.64	0.24	1.04
2007	-0.15	-0.65	0.36
2008	0.27	-0.22	0.75
2009	0.35	-0.13	0.83
2010	-0.05	-0.67	0.58
2011	-0.05	-0.56	0.47
2012	0.31	-0.12	0.73
2013	-0.05	-0.53	0.44
2014	0.45	0.04	0.87
2015	-1.28	-2.07	-0.50
2016	-0.47	-1.01	0.08
2017	0.02	-0.40	0.43
2018	0.54	0.09	0.99
2019	-0.56	-1.25	0.14
2020	-0.21	-0.76	0.33
2021	0.28	-0.30	0.86

Appendix 2. Biological Information

Tag-recapture data are available from field tagging and release experiments in the JBG by Die et al. (2002). These data suggest fairly high natural mortality of ca. 0.05 wk^{-1}. The maximum age of Redleg Banana prawns is thought to be 12-15 months given no tagged prawns were caught in the year after tagging.

There are large differences between the growth rates for male and female *P. indicus*, with the latter growing much faster. Parameter estimates for males (κ = 0.0103; L_∞ = 34.05 mm and t_0 = -0.06) and females (κ = 0.0053; L_∞ = 49.64 mm and t_0 = -0.34) were obtained from Loneragan et al. (2002) who used the Wang (1995) growth model. Length-weight relationships are taken from Loneragan et al. (1997):

Females	Weight (g) = 0.000889 CL (mm) $^{2.914}$
Males	Weight (g) = 0.000372 CL (mm) $^{3.197}$

The average weights (grams) of *P. indicus* landed in the JBG by Newfishing Australia range from 25.6 to 40.7 g (Loneragan et al. 2002). The average weights per prawn recorded for six commercial categories ranged from 11g to 57g. Raw length frequency data would be highly informative in developing a model.

Loneragan et al. (2002) found no significant differences in the growth of the exploitable phase of *P. indicus* between two years characterised by very different recruitment levels, suggesting there are not overly strong density-dependent effects on growth for this species. The population dynamics are likely driven by variability in recruitment levels given the considerable distances between the recruitment and spawning grounds (Kenyon et al. 2004, Manson et al. 2001).

Spawning and maturity

The size of females at first maturity is 25 mm CL (and 23 mm for males) with the size at mass spawning (defined as corresponding to 50% of females having visible ovaries) is 44 mm CL (Taylor 2002). Female *P. indicus* carry fewer eggs than White Banana Prawns, and substantially less than Tiger Prawns.

Loneragan et al. (1997) analysed data on the stage of maturity for female *P. indicus* and concluded that the proportion of mature females is low during April to September and high over the period October to March. Using length frequency data from NT Fisheries, their rough analysis suggested that a peak in recruitment occurs in March, with 95% of recruits arriving between December and April. Based on the above, the model assumes peak spawning over October to March with substantially lower levels of spawning during the rest of the year.

The Reference Case model assumes that the proportion of the recruited population (i.e. individuals large enough to be recruited to the fishery) that spawn at the start of each of quarters 1-4 are as shown in Table 3. These proportions represent a combination of factors, including that not all prawns may be large enough to spawn and that not all mature prawns may spawn at that time. Assuming (based on the growth curve information) a roughly 6-month growth period before individuals are large enough to recruit to the fishery, this means that peaks in recruitment to the model population will occur at the ends of March and June. As this constitutes the bulk of the recruitment, recruitment residuals are estimated for the April to June quarter only.

Appendix 3. Data Inputs

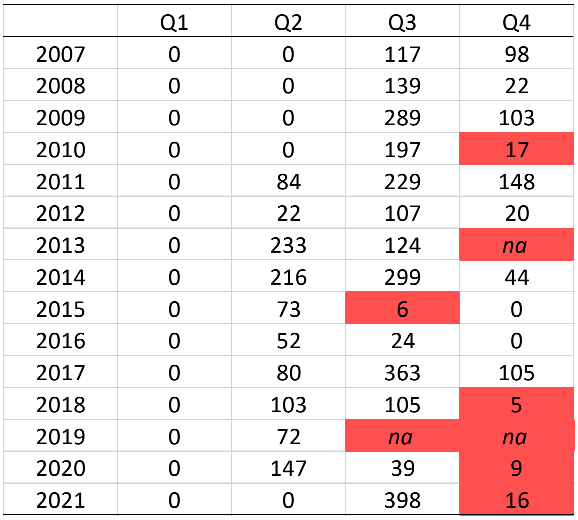
For May 2022 Reference Case assessment, we applied the following rules:

1. Require total annual Effort (boat days) >= 70 for a stock assessment to be conducted
2. Minimum quarterly total boat days = 20 for each of quarters 2 and 3 data, for the corresponding CPUE to be included in the assessment (this rule is applied retrospectively also in case a stock assessment is not run in any year not meeting criterion (1) above).
3. Minimum quarterly total boat days = 20 for quarter 1 historical data
4. Minimum quarterly total boat days = 20 for quarter 4 CPUE data to be included in the assessment

Application of the data rules in the current assessment resulted in excluding the following CPUE data from the model fitting process: 2013 quarter 4; 2015 quarter 3; 2018 quarter 4; 2019 quarters 3 and 4; 2020, 2021 quarter 4 (Table A3.1).

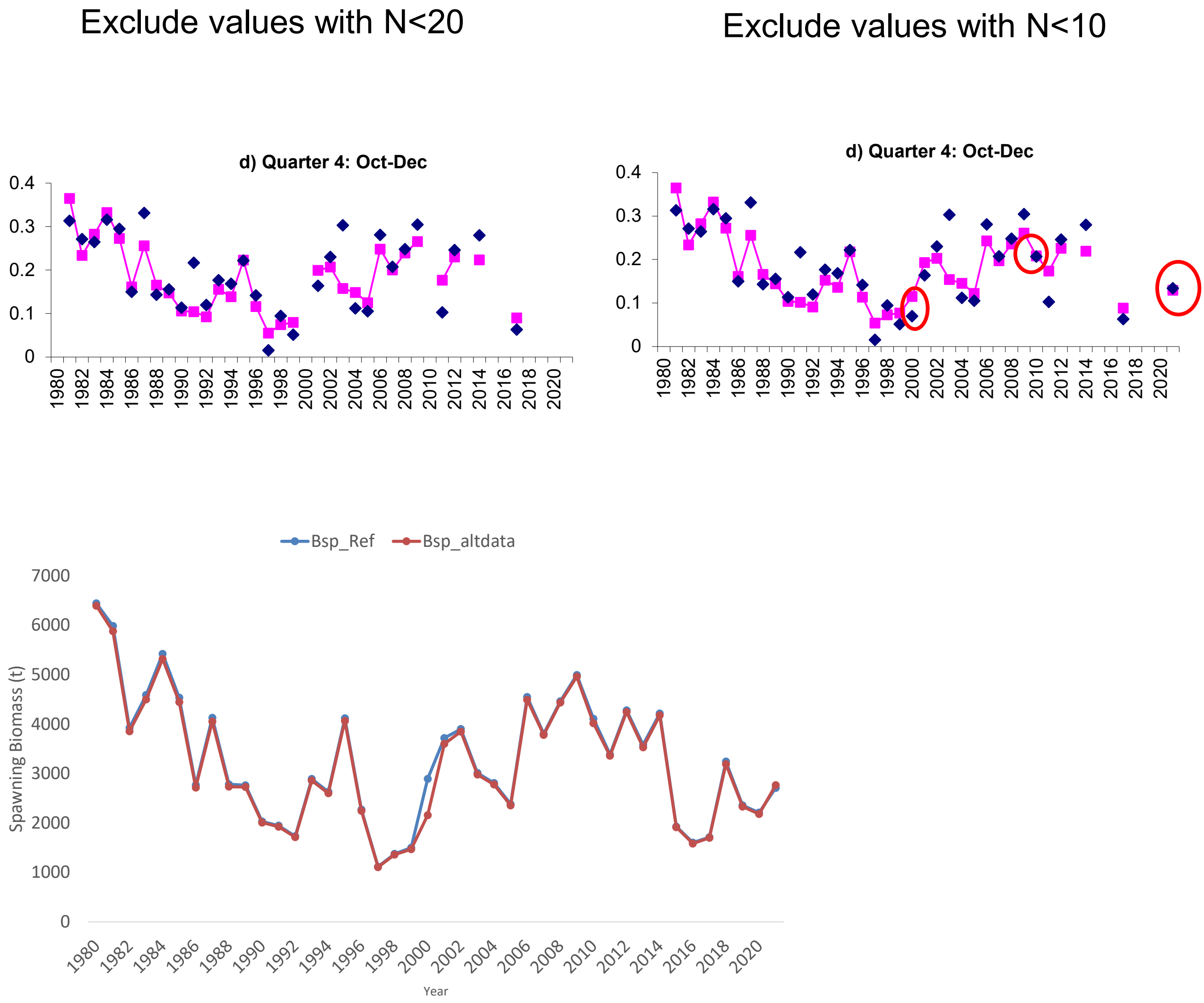
Some previous stock assessments have used a data cut-off of 10 boat days for the quarter 4 CPUE data, but as that is a very low number of boat days to base an estimate on, the current assessment used a cut-off of 20 days. However, this aspect is still being reviewed especially because excluding these data going forward means that there may often only be a single data point (CPUE for quarter 3) to fit the assessment model to. When comparing the model fits with and without these data (Fig. A3.1) there is a very minor difference only in the stock assessment, with the fourth quarter CPUE based on <20 boat days nonetheless being consistent with the model estimates of stock status. Hence, with more data in the future, it may be possible to revise this lower threshold (e.g., perhaps to n>=15) to check the representativeness of the corresponding CPUE.

Table A3.1. Summary of the number of boat days per quarter, highlighting cases with n<20. na represents confidential data due to less than 5-boat day rule.



	Q1	Q2	Q3	Q4
2007	0	0	117	98
2008	0	0	139	22
2009	0	0	289	103
2010	0	0	197	17
2011	0	84	229	148
2012	0	22	107	20
2013	0	233	124	*na*
2014	0	216	299	44
2015	0	73	6	0
2016	0	52	24	0
2017	0	80	363	105
2018	0	103	105	5
2019	0	72	*na*	*na*
2020	0	147	39	9
2021	0	0	398	16

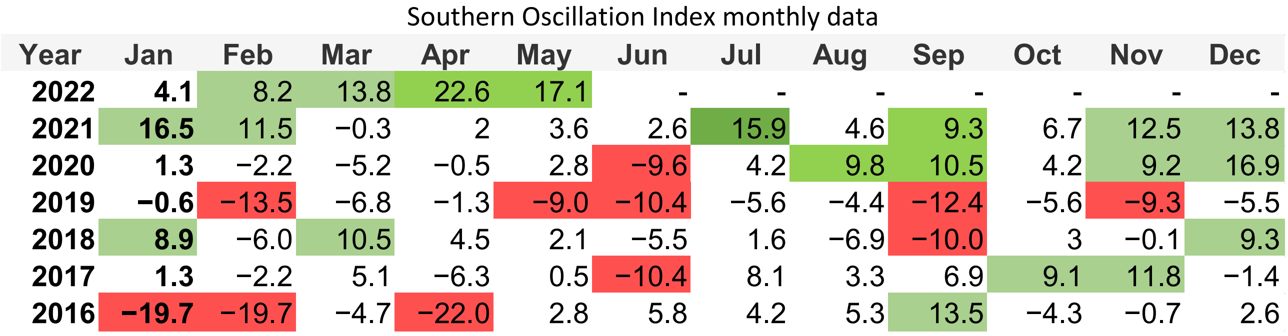
Fig. A3.1, Comparison of stock assessment model fit (pink line) to the standardised CPUE data (blue diamond symbol) when using a quarter 4 data cut-off rule that at least 20 boat days are required for the CPUE to be used (as per the current Reference Case) as compared with requiring at least 10 days only. The lower plot shows the minor difference in the estimated spawning biomass trend.



Exclude values with N<20

Exclude values with N<10

Appendix 4. Environmental Indicators



Southern Oscillation Index monthly data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2022	**4.1**	8.2	13.8	22.6	17.1	-	-	-	-	-	-	-
2021	**16.5**	11.5	−0.3	2	3.6	2.6	15.9	4.6	9.3	6.7	12.5	13.8
2020	**1.3**	−2.2	−5.2	−0.5	2.8	−9.6	4.2	9.8	10.5	4.2	9.2	16.9
2019	**−0.6**	−13.5	−6.8	−1.3	−9.0	−10.4	−5.6	−4.4	−12.4	−5.6	−9.3	−5.5
2018	**8.9**	−6.0	10.5	4.5	2.1	−5.5	1.6	−6.9	−10.0	3	−0.1	9.3
2017	**1.3**	−2.2	5.1	−6.3	0.5	−10.4	8.1	3.3	6.9	9.1	11.8	−1.4
2016	**−19.7**	−19.7	−4.7	−22.0	2.8	5.8	4.2	5.3	13.5	−4.3	−0.7	2.6

SOI (Jan 2022) = +4.1 (neutral but Feb-March (& Apr) La Nina)
2022 Update: Jan&Feb rainfall = 525.4 mm > median
Exceptional rules not triggered but perhaps expect average CPUE for 2022

- if SOI<-7 and rainfall <median: poor CPUE
- if SOI<-7 and rainfall>median: average to high CPUE
- if SOI>+7 and rainfall>median: very good CPUE
- if SOI>+7 and rainfall<median: low-average CPUE
- **neutral zone – (less certain) low to average CPUE**

	Argyle	Kingston Newry MtSanford
Median (1983-2015)	358	391.35 361.3 322.7

Note that the persistence of La Niña conditions in 2022 is unusual and the only year with some similarity was 1989 hence there is uncertainty as to what the implications might be. It is even more unusual that meteorologists are forecasting that a rare ‘triple’ La Niña climate event is considered likely and hence La Niña conditions could persist into 2023 (Jones 2022). This has happened only twice since 1950 and could be natural variability but climate change may also make these conditions more likely in future (Jones 2022).

Reference:

Jones, N., 2022. Rare 'triple' La Nina climate event looks likely-what does the future hold?. *Nature*.

Appendix 5. Northern Prawn Fishery: Update of the Redleg Banana Prawn fishing power time series for 2021

J. Upston, M. Miller, R. Deng, C. Moeseneder, and E. Plagányi.

CSIRO Oceans and Atmosphere

The relative fishing power time series for the Redleg Banana Prawn fishery in the Joseph Bonaparte Gulf (JBG) was extended to include information for 2021. We report on the 2021 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. The fishing power analysis method was developed by Janet Bishop, Bill Venables, Cathy Dichmont, André Punt, Charis Burridge, Eva Plagányi and other contributors (Annex 2 by Bishop et al. in Plagányi et al. 2010).

Relative fishing power was assessed by means of a delta-log normal model (Maunder & Punt, 2004), presented to the NPF RAG in August, 2011 (Plaganyi et al., 2011). This approach specifically accounts for search effort and harvest effort. The model coefficients were estimated from the 1981 - 2021 dataset. Changes in relative fishing power were obtained by making projections for a second dataset that consisted of the known and imputed fleet characteristics 1981 to 2021.

Overall, relative fishing power increased by 4% in 2021 relative to 2020 (Figure 5.1, Table 5.1). The estimated increase in relative fishing power coincided with a 3% increase in swept area compared to 2020 estimate, and an increase in average hours fished per day (geometric mean ~ 20 hours in 2021 c.f. 19 hours in 2020). Across the fleet fishing in JBG, the average swept area performance in 2021 was estimated to be 30.6 hectares per hour (100% of the fleet towing quad rig in 2021 c.f. 96% in 2017). Other gear inputs to the fishing power model were comparable on average in 2021 compared to 2020. There were 415 fishing days (and 18 vessels fishing) in 2021, up from 195 fishing days in 2020.

The overall trends in relative fishing powers (Figure 5.1) reflect changes in harvest power, with only a minor contribution due to search power. Harvest power increased up to the late 1990s to 2000, this was consistent with the increase in average hours fished per day (1985-97), fleet renewal (1988+) and within vessel change in technology, especially swept area rate, and innovations in electronics during the 1990s (see Annex 2 by Bishop et al. in Plagányi et al. 2010). The more recent increase in harvest power, since approximately 2011, is consistent with the increased allowance of headline per SFR unit (for second season 2011), and with the greater number of vessels towing quad rig (88% of fleet in 2011 and 100% in 2021 c.f. 43% of the fleet in 2010), with a corresponding increase in the average swept area performance across the fleet fishing in the JBG. We note that other factors used in the fishing power model can contribute to changes in harvest power, such as average hours fished per day and *inter alia* technology innovations.

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We are grateful to the fishers of the NPF who provided their logbook and gear data, and to Adrianne Laird and Josh Cahill (NPFI), and the 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 for the NPF fleet, and is thanked for valuable discussions regarding the PTPM results.

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Plagányi, É.E., Bishop, J., Miller, M., Punt, A.E., and T. Hutton. 2011. Assessment of the Joseph Bonaparte Gulf Red-legged Banana Prawn (Penaeus indicus) Fishery and preliminary TAC estimate for 2011. Australian Fisheries Management Authority Final Report. AFMA Project number: 2011/11. 25 p.

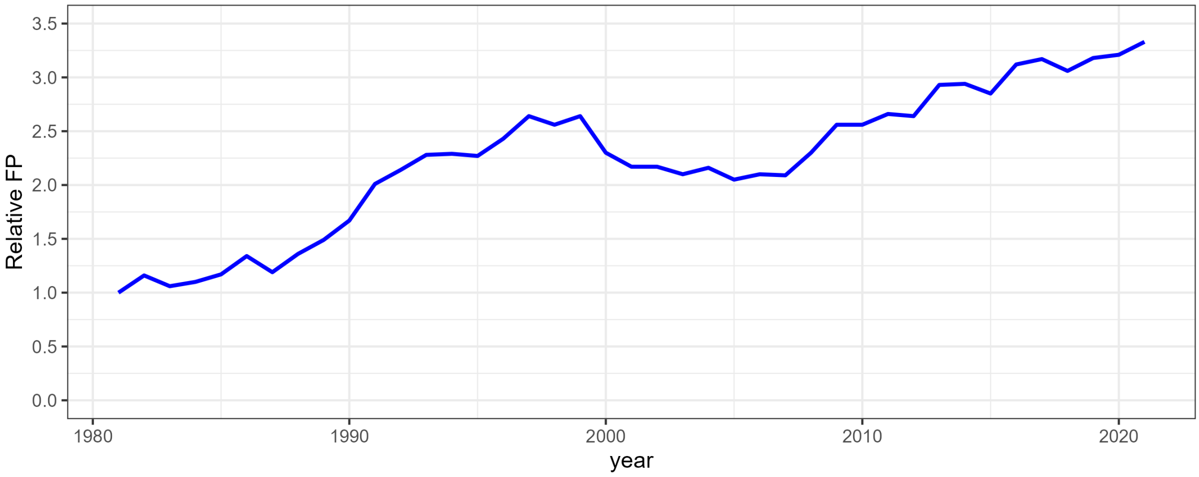

Figure 5.1 Estimates of relative fishing power trends in the Northern Prawn Redleg Banana Prawn Fishery. Relative fishing power series are daily catch rates relative to the fleet of 1981.

Table 5.1. Estimates of relative fishing power trends in the Northern Prawn Redleg Banana Prawn Fishery. Relative fishing power series are daily catch rates relative to the fleet of 1981, and q_{inc} are annual increments relative to the previous year.

	Relative Fishing Power	q_{inc}
1981	1.00	
1982	1.16	1.16
1983	1.06	0.91
1984	1.10	1.03
1985	1.17	1.07
1986	1.34	1.15
1987	1.19	0.89
1988	1.36	1.14
1989	1.49	1.10
1990	1.67	1.12
1991	2.01	1.20
1992	2.14	1.06
1993	2.28	1.07
1994	2.29	1.00
1995	2.27	0.99
1996	2.43	1.07
1997	2.64	1.09
1998	2.56	0.97
1999	2.64	1.03
2000	2.30	0.87
2001	2.17	0.94
2002	2.17	1.00
2003	2.10	0.97
2004	2.16	1.03
2005	2.05	0.95
2006	2.10	1.02
2007	2.09	1.00
2008	2.30	1.10
2009	2.56	1.11
2010	2.56	1.00
2011	2.66	1.04
2012	2.64	0.99
2013	2.93	1.11
2014	2.94	1.00
2015	2.85	0.97
2016	3.12	1.09
2017	3.17	1.01
2018	3.06	0.97
2019	3.18	1.04
2020	3.21	1.01
2021	3.33	1.04

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