Management Strategy Evaluation of the Torres Strait Prawn Fishery

A Final Report to AFMA

Project: 190829

July 2020

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Executive Summary

An age and size based tiger prawn simulation model for the Torres Strait brown tiger prawn stock was coded in the statistical programming language "R". The catchability, fishing selectivity, and recruitment model parameters were optimised by minimising the difference between the observed and predicted monthly catches and prawn grades for the years 2018 and 2019. The final fit of the model to the 2018-19 fishery data was used for the 5 closure simulations scenarios that were agreed at TSPMAC#20.

The rationale behind the proposed scenarios was to conduct a Management Strategy Evaluation of the potential impact of varying the season opening date over a three month period (1st February to 1st April) on the economics of the fishery and the tiger prawn stock. This was achieved by simulating the fishery opening on the 1st February, 1st March and 1st April using a number of monthly fishing patterns and two levels of annual fishing effort. A sensitivity analysis of the effect of the timing of prawn recruitment was done by running the simulations with the recruitment pattern shifted one month earlier and one month later.

The management strategy evaluation results support the view that season length and the season opening date per se does not have a measurable impact on the catch and stock biomass throughout the season. Any impact from the setting of a particular season date appears to be determined by the way the fishing fleet responds to the season date and the timing of prawn recruitment.

The only scenario simulation that indicated a negative impact on catches later in the season was scenario 2 and is a result of the high February effort and the available tiger prawn stock having a higher proportion of small prawn (21/30 grade). At the 2624 day level of annual fishing effort the impact was minimal and not detectable post June. Scenario 2 is highly unlikely given the current economics of prawn trawling in Australia.

The observed February grade proportions for 2016-19 have a higher proportion of U10 and lower proportion of 21/30 than the simulation results for 2019. This suggests that the vessels fishing in February are targeting areas that have a higher proportion of larger prawn and avoiding areas of small prawn. If there is concern that more vessels may start fishing in February and target the smaller size grades that occur close to the East of Warrior Closure (EWC) the option proposed by industry in 2005 for a one or two month extension to the EWC (O'Neill and Turnbull 2006, see extract in Appendix) could be considered as an alternative to shifting the season date back to the 1st March.

Introduction

The Torres Strait Prawn Fishery has been operating at less than 38% of available effort since 2009 and a number of mechanisms have been explored to try to encourage fuller utilisation of the fisheries resource, including changes to season length. Opening the season on the 1st February instead of the 1st March was trialled during 2016-19.

As a result of the ongoing discussion around the season dates at TSPMAC meetings, AFMA identified a research need to assess the impact that season dates may have on fishery catch rates and profitability.

Season length and dates are considered to have little effect on fishery sustainability as long as effort remains below 9,200 fishing days the maximum effort recommended by the harvest strategy. Furthermore, smaller prawns are protected through area closures and their recruitment into the fishery occurs throughout the year, both of which minimise the potential impacts of season length on harvest of juveniles (Turnbull and Watson, 1991).

Watson and Restrepo (1995) simulated seasonal closures in a tropical shrimp fishery that was loosely based on the tiger prawn fishery in Torres Strait. However there is little information on the effect season length and timing have on fishery economic performance of the TSPF, specifically relating to prawn sizes at different times of year, the relative value of the catch at different times of the year and the possible effects that catching smaller prawns at the start of the year could have on catches later in the season.

Objectives / performance indicators

a) Build a stochastic length based tiger prawn simulation model that can be used to investigate the impact of different season lengths and start/end dates.

b) Simulate different start/end dates to assess the impact on the relative value of the catch throughout the season and the possible effect that catching small prawns at the start of the season could have on catches later in the season.

c) Provide a report to the TSPMAC that includes the methodology, simulation results and recommendations on the optimal timeframe for the TSPF season.

Methods

Forward projection size based model for tiger prawn

An age and size based tiger prawn simulation model for the Torres Strait Prawn Fishery was coded in the statistical programming language “R”. The structure of the model is similar to a size-based model for abalone that Haddon (2011) details in chapter 13 of “Modelling and Quantitative Methods in Fisheries”. The process of fitting the model was adapted from Quinn et.al. (2009) who fitted a similar stochastic length base model to endeavour prawn catch and size frequency data collected from the Torres Strait prawn fishery for the years 1993-94.

The model was adapted to simulate the tiger prawn population in Torres Strait by using a monthly time step and allowing for separate growth and weight length parameters between male and female brown tiger prawns (*Penaeus esculentus)*. Based on the results of the research trawl surveys conducted in the Torres Strait prawn fishery during 2007-08 (Turnbull et.al. 2009) the brown tiger prawn comprises ~99% of the tiger prawn catch in Torres Strait.

The benefits of using a size base model instead of the delay-difference model used for the Stock Assessment update are that it can predict the prawn sizes and hence expected prawn grades. During each time step (month) in the model a growth transition matrix is used to stochastically increase the size of male and female tiger prawns in a way that allows variability in growth and hence simulates the distribution of prawn sizes that are observed in the fishery. In contrast the delay-difference model does not track prawn size and the average male and female growth parameters are combined into a generalised biomass growth function.

The model simulates the tiger prawn stock forward from the end of the 2018 season whilst applying one of the “simulation scenarios” proposed below. The effect of varying the timing of the season dates was then evaluated in terms CPUE, value of catch per unit of effort and the effect on the tiger prawn biomass and prawn sizes. The advantage of using 2018 as the starting point for forward simulations is that the model could be validated against the observed fishing data for the 2018 and 2019 seasons.

The prawn growth, length to weight and natural mortality parameter estimates used in the model were the same as those detailed in O’Neill and Turnbull 2006. The only change made to those parameters was to increase the L_{∞} estimate for male tiger prawn from 34.7 CL mm to 36 CL mm. This parameter is the asymptote in the growth equation and the change was needed to obtain a good fit of the model length frequency for males to the observed. The beach prices applied to the prawn grades in the analysis were: $22, $14, $11 and $8 for the “U10”, “10/20”, “21/30” and “30+” size grades respectively. These prices were obtained from industry member as being representative of the 2019 season.

Model fitting and validation

The model was initially fitted to 2007-08 monthly catches and length frequency data from the 2007-08 trawl research surveys conducted by QDPI (Turnbull, et.al. 2009). The model input parameter estimates for catchability, fishing selectivity, and recruitment were "fitted" or "optimised" to minimise the difference between the observed and predicted monthly catches and length frequency data. This was achieved using the optimisation function in 'R' to minimise the Residual Sums of Squares (RSS) for the difference between the observed and modelled catches and the observed and model size frequency data. Because the length frequency data are proportions they were scaled by 10,000 to ensure that catch and length data RSS were of a similar range and therefore providing an equal weighting during optimisation.

The model was then fitted to the 2018 and 2019 monthly catches and prawn grade data. The model parameters estimates for the best fit of the model to the 2018-19 data were used for the closure simulations.

The fitted model was reality checked and validated by comparing the observed and predicted monthly catch, CPUE and prawn grades. The model size frequency was checked against data from research trawls and where possible model outputs were compared with the results of the updated tiger prawn stock assessment.

Management Strategy Evaluation Simulation Scenarios

The response of the fishing fleet to the timing of a closure opening is the main determinate of annual catch rates, catches and the seasonal biomass trajectory. The monthly fishing effort will partly determine the extent to which the prawn biomass is fished down each month. This fish down will be reduced or negated during months of high prawn recruitment which is generally February to April based on the output of the tiger prawn stock assessment. Possible "fleet responses" to a closure opening can be quantified for input to the simulation in terms of: (1) annual fishing effort and (2) the proportion of fishing effort in each month.

There are an infinite number of variations on these quantities therefore the proposed monthly fishing effort scenarios were discussed at the TSPMAC#20 meeting held on the 29th and 30th January 2020. The five monthly fishing effort scenarios detailed below were discussed in terms of which are the most plausible or likely scenarios and which ones are more extreme and less likely but potentially bad for the fishery if they did occur. Investigation of changing the end of season date (30th November) was not considered necessary and the meeting supported the scenarios that were presented in the MAC agenda paper.

Figure 1 shows the observed monthly fishing proportions for the years 2016 to 2019 when February was open to fishing. The dashed black line is the mean or average pattern based on those years and is the basis of scenario 1.

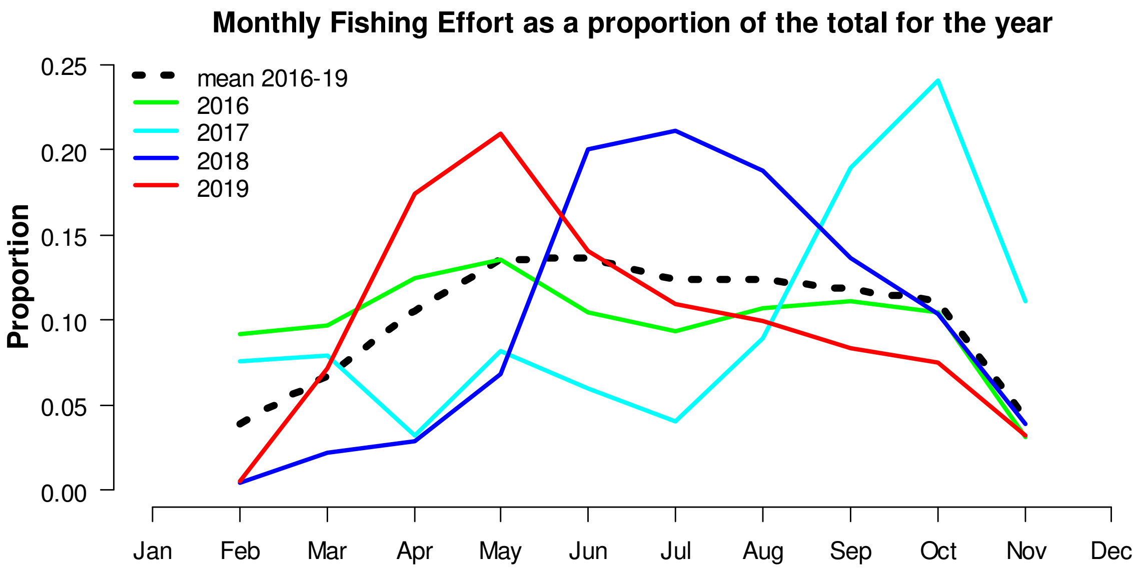

Figure 1 Observed monthly fishing effort as proportions of the annual totals for the years with February open (2016-2019). The dashed black line is the mean pattern for the four seasons.

The alternative season opening dates of 1st February (scenarios 1, 2 & 3), 1st March (scenario 4) and 1st April (scenario 5) were investigate using the five monthly fishing effort scenarios detailed below and shown as proportions of the annual catch in Figure 2. The sensitivity of the closure timing to the monthly effort patterns was checked by using three effort patterns for the February opening. Note that effort scenario 3 is the observed fishing effort for 2019.

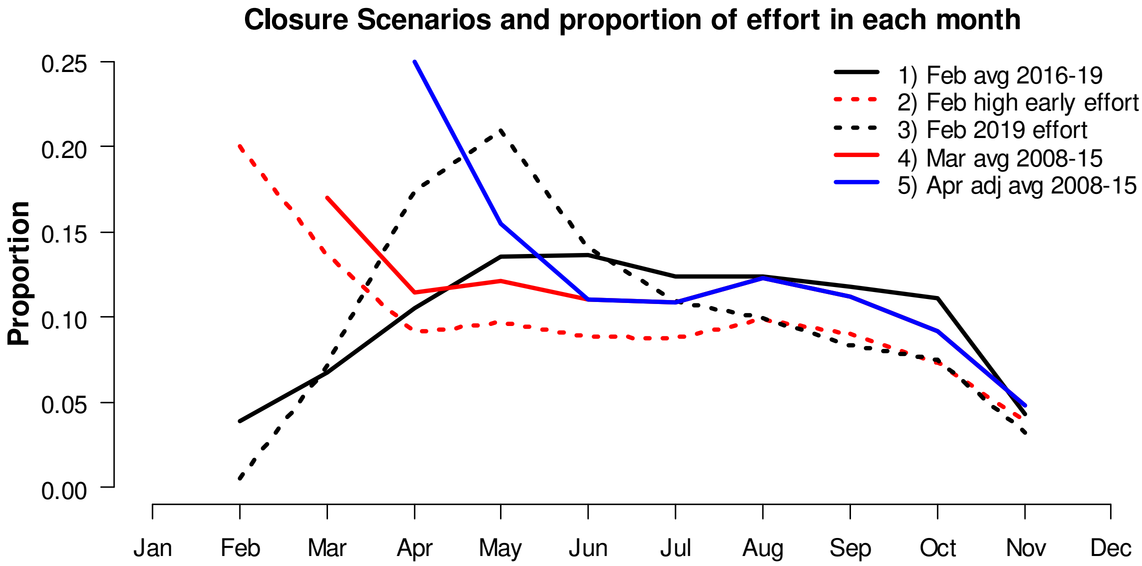

Figure 2 Monthly fishing effort as a proportion of the annual total for the proposed monthly fishing scenarios. Legend shows abbreviations of fishing scenarios. Refer to pages 7-8 for details of each scenario. Note: the proportions for each scenario sums to 1.

Season Opening dates and monthly Fishing effort scenarios

1. A 1st February season opening simulated using the mean monthly fishing effort of the years 2016-19 converted to proportions.
2. A 1st February season opening but with the highest proportion of effort in February then March. This simulates the "pulse fishing" at the start of a season that has frequently occurred after the introduction of a seasonal closure. This scenario has 0.2 as a proportion (or 20%) of the annual total in February. March to October use the proportions from scenario (4) x 0.8 to scale them down and the remainder (1 – sum (February to October) is in November.
3. A 1st February opening using the observed 2019 monthly fishing effort.
4. A 1st March season opening simulated using the mean monthly fishing effort of years the 2008-15 converted to proportions. All of these years had a 1st March opening.
5. A 1st April season opening simulated using the monthly fishing effort proportions in scenario (4) with the March effort redistributed into April and May; 80% to April and 20% to May.

The five monthly fishing effort pattern detailed above were simulated using two levels of annual fishing effort:

1. 2624 days which is the effort for 2019 and is close to the average for years 2009-2019 (2220 days, Turnbull and Cocking 2019) and
2. 6,000 days which is near the maximum days of fishing effort currently available to Australian operators (6,867).

These 10 simulations were run using 3 timings for the monthly recruitment pattern (Figure 10), to check the sensitivity of the results to the recruitment timing.

1. The fitted monthly recruitment which was obtained from the best fit of the model to the 2018-19 observed data.
2. The fitted recruitment pattern shifted to one month earlier and
3. The fitted recruitment pattern shifted to one month later.

Note that only the timing changed; the fitted estimate of the annual recruitment for 2019 was applied to the three recruitment timings.

The output of the 30 simulations estimates the fishery economic metrics: annual tiger prawn harvest, value of that harvest, the daily vessel income earned from the tiger prawn harvest, across the 3 closure options, variation of the monthly fishing proportions and a 3 month variation in the timing of the tiger prawn recruitment. The output also provides measures that relate to the impact of the season date on the prawn catches later in the season; monthly CPUE, the biomass available to fishing, monthly Fishing Mortality and prawn grades.

Results

Fit of the model to the observed catch and effort data for 2018-19

The annual and monthly catches are a close match to the observed (Figure 3). The annual tiger prawn catches predicted by the model for 2018 and 2019 are 325 and 526 tonne compared to the observed catches of 329 and 514 tonne.

The fit of the monthly model CPUE to the observed CPUE is not as close as for the monthly catch. The model CPUEs are a smooth curved line with the highest CPUEs in the first half of the season and lowest in the second half (Figure 4). Although the observed monthly CPUE roughly follows the trend line for the model CPUE there are large deviations. For example the 2018 April and May observed CPUE was much higher than the model CPUE and the fishing effort was low (Figure 4). Similarly February and November of 2019 have the largest differences between the observed and the model when fishing effort was lowest. The observed monthly CPUE is affected by which vessels in the fleet did most of the fishing and where they fished; therefore CPUE estimates from months of low fishing effort are more variable and may not reflect the true stock availability.

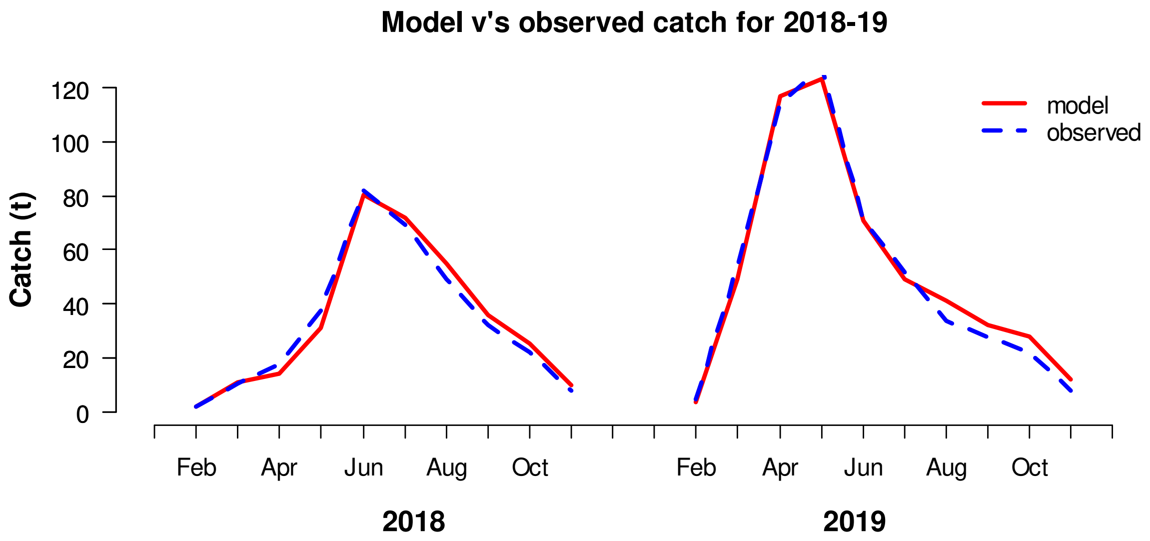

Figure 3 Comparison of the observed and predicted monthly catch for 2018 and 2019.

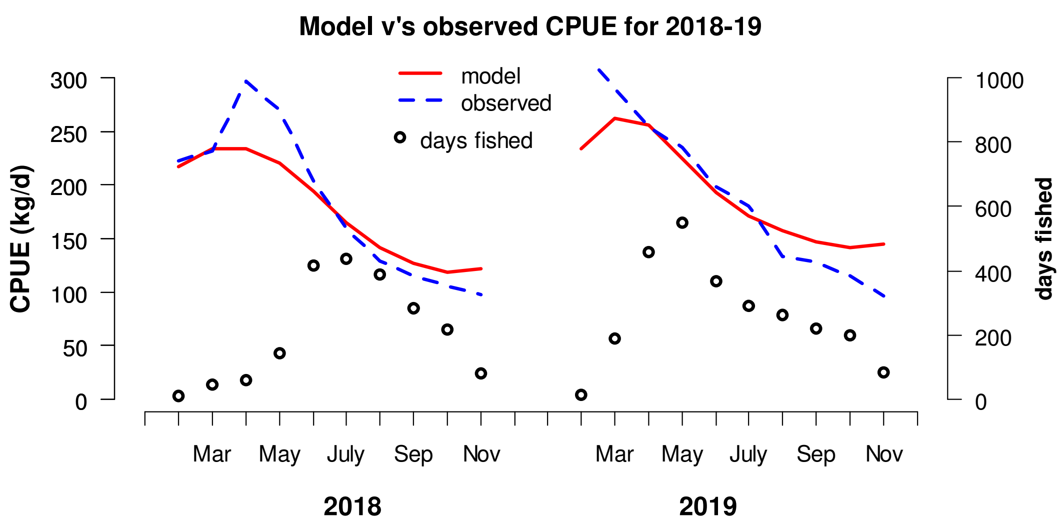

Figure 4 Comparison of observed and predicted monthly CPUE for the years 2018 and 2019. The circles indicate the monthly fishing effort in days and are scaled to the right y-axis.

The model annual catch divided into prawn grades (Figure 5) is a close match to the observed for 2018 and 2019. The largest difference occurs in 2018 where the proportion of U10 predicted by the model is larger than the observed. The observed and model catches by grade are a closer match for 2019.

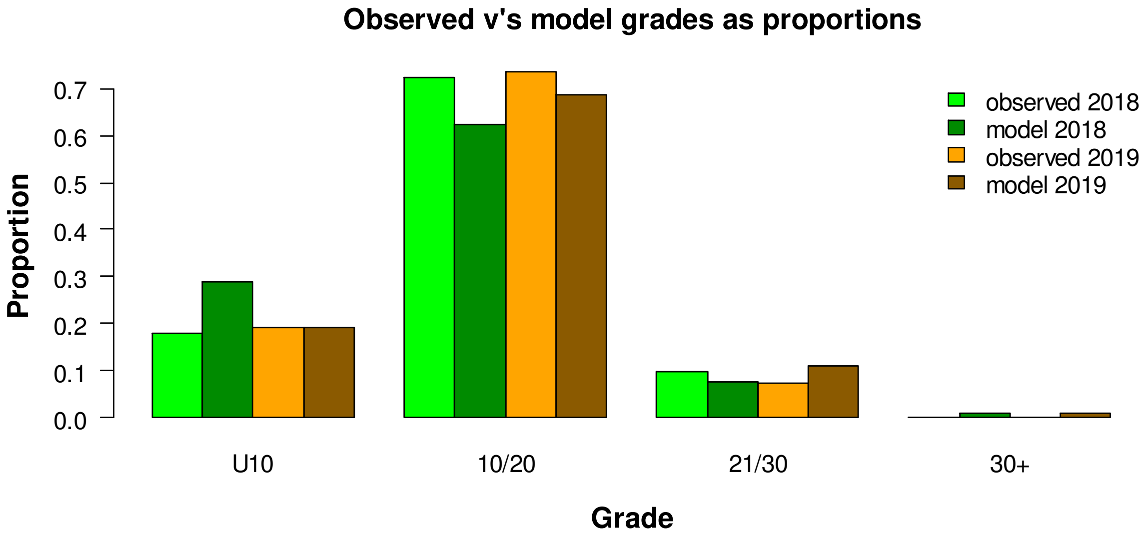

Figure 5 Comparison of the total observed and model grades for the years 2018 and 2019.

Figure 6 compares the mean monthly grades for the years 2016-2019 with the model monthly grades for 2018 and 2019. The plots on the right in figure 6 compare the grades as prawn weights. Note that the observed mean grade weights for 2016-2019 are not base on the entire catch, whereas all of the model catch is grouped in to one of the 4 prawn grades. In the logbook database some of the product is group into “soft and broken”, “ungraded” / “unknown” and other minor grades.

The observed monthly prawn grade data for 2016-19 (Figure 6) shows a higher proportion of 30+ and 21/30 prawn grades during March and to a lesser degree February and April. Conversely, the lowest proportion of the large prawns (U10 and 10/20) occurs during March and April. These results suggest that in the TPSF February to April is the main period of recruitment of small prawn into the fishery from the West and East of Warrior Closures. These closures were initiated by industry with the aim of reducing fishing mortality on small prawn; i.e. reduce “growth-overfishing” by increasing the size of the prawn at first harvest.

The observed data for February has higher proportion of U10 than March and April. These proportions however are based on small catches and could be biased by where the vessels were fishing. There is a trend in both the observed and model data (Figure 6) for the proportion of U10 grade to be highest in the second half of the season.

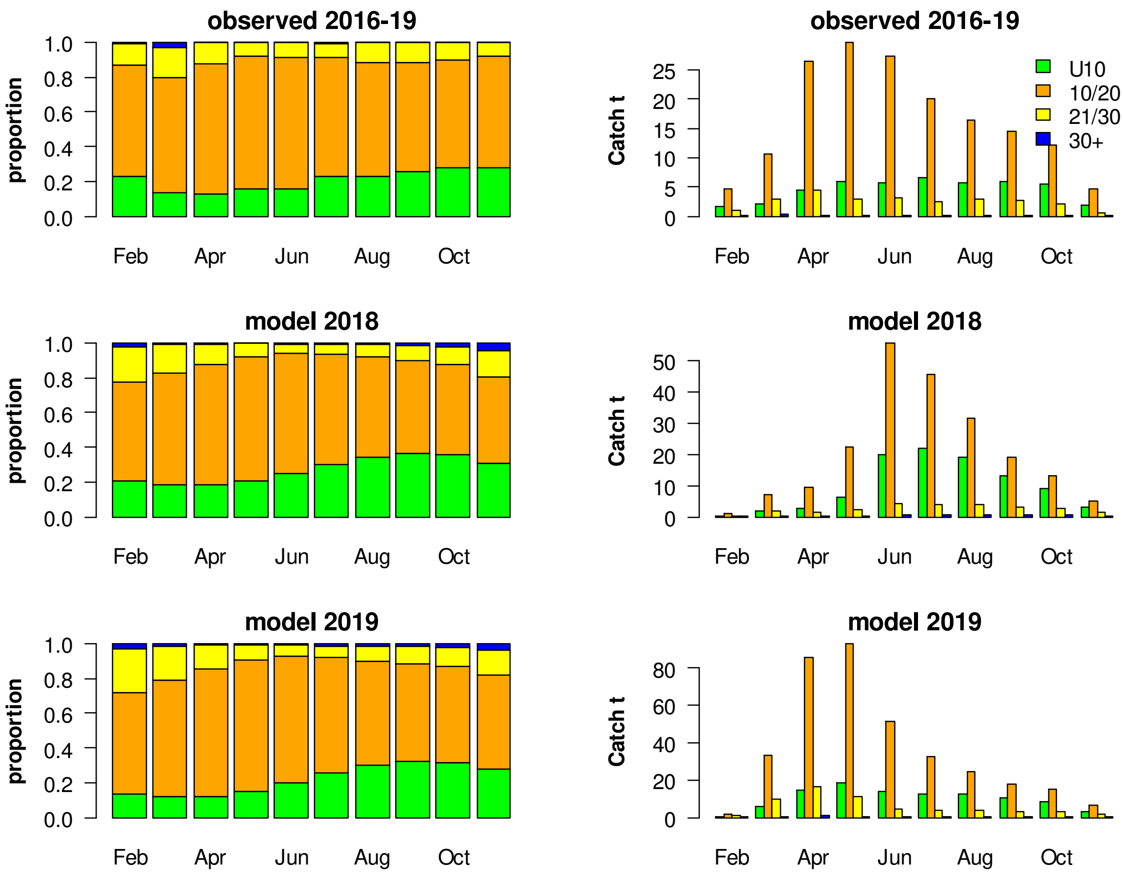

Figure 6 Observed v's Model catches by grade. The observed are the mean monthly grades for 2016-19. These are compared with the model grades for 2018 and 2019. The left-hand plots are as proportions. The right-hand plots are as catch weights in tonnes. Note that the observed catches as weights are smaller than the model catches because some of the observed catches were in the "other" categories whereas the model grades are based on the entire predicted catch.

Figure 7 compares the 2007-08 research trawl survey length frequency data with the model length frequency data for 2018-19 using the same months as for the trawl surveys (May, July, September and November). The model length frequencies are a good match with the trawl survey data. The observed data are the mean length frequencies as proportions selecting from trawls that were conducted in the area open to fishing for the whole season. The data is averaged over the eight surveys and is therefore that average length frequency over the season and the two survey years (2007-08). The similarity of the model and observed length frequencies for the female and male populations is confirmation that the model is a good simulation of the real fishery population and that the average size structure for 2007-08 is similar to that of 2018-19.

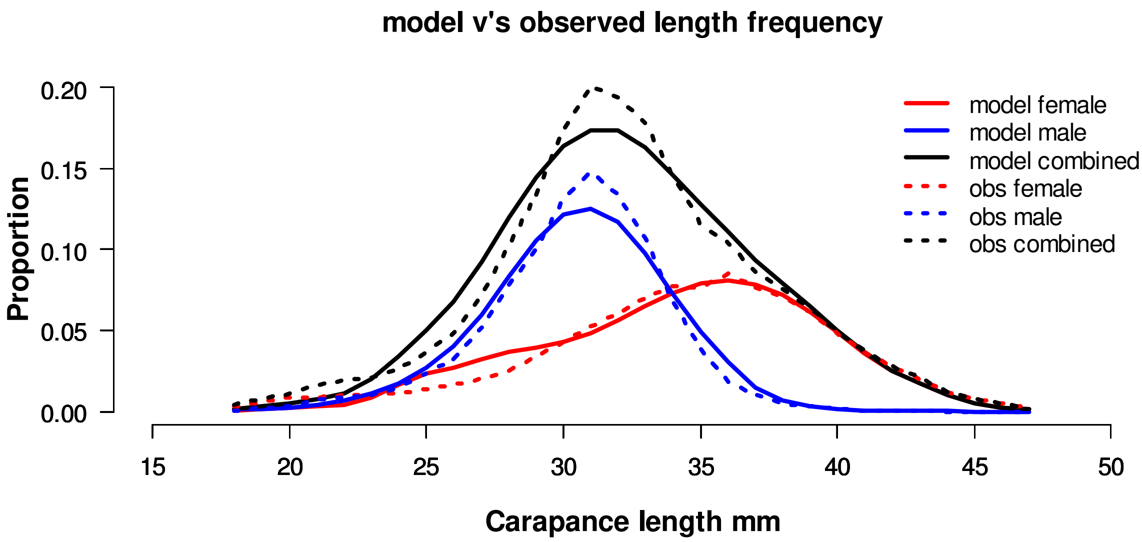

Figure 7 Comparison of the 2007-08 research trawl survey length frequency data with the model length frequency data for 2018-19 using the same months as for the trawl surveys (May, July, September and November).

In the Torres Strait most of the smaller prawns (30+ grade and smaller) are protected from fishing by the West and East of Warrior Reef area closures. The simulated prawn population however is not divided into areas that are open and closed to fishing. Instead the fishing selectivity curve parameters have been adjusted during the fitting of the model, to simulate these closures.

Figure 8 shows the initial selectivity curve which is based on the fishing selectivity for a standard prawn trawl net. The L50 is the size where 50 percent of the prawns are retained in the net; and for a trawl net L50 is 22 mm carapace length. Carapace Length (CP) is the length of the head of the prawn and is a standard method of measuring the size of prawns and other crustaceans.

The fitted selectivity curve simulates the area closures by moving the L50 to the right and increasing the parameter for the curve steepness. Therefore the prawn sizes between the two curves are less available to fishing within the model population. Note that prawns smaller than the fitted estimate of L50 (26 mm CP) are in the “30+” grade category.

Figure 9 shows the estimated monthly exploitable biomass as female, male and combined tiger prawn stock. The exploitable biomass is the section of the prawn stock that is in areas open to fishing and that is retained in a prawn trawl net. The estimates of biomass from the delay-difference stock assessment model, 766 and 769 tonnes using the Beverton Holt and Ricker Stock Recruitment Relationships, are close to the mean 2018 biomass estimate of 834 tonne from the length based model. The mean model biomass estimate for 2019 is 911 tonnes which would partly explain the higher CPUE, fishing effort and catches that were observed in 2019 compared with 2018.

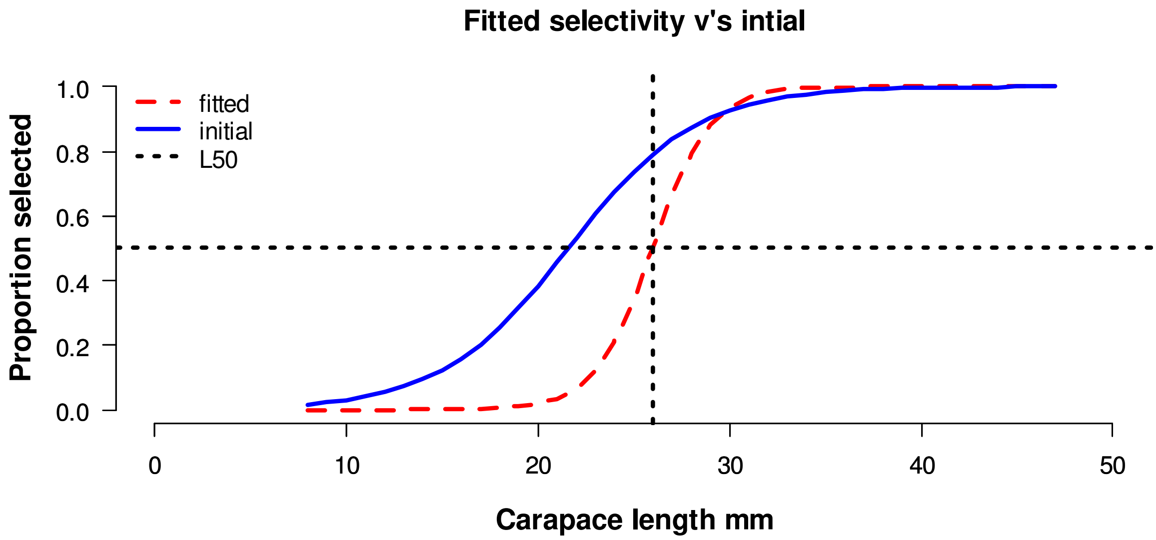

Figure 8 The initial and fitted fishing selectivity curves. The L50 is the size class were 50 percent of the prawns are selected by fishing. The blue line is the selectivity of a standard prawn trawl net. The red line is the fitted fishing selectivity curve used in the model and represents the combined effect of net selectivity and area closures to protect undersized prawn.

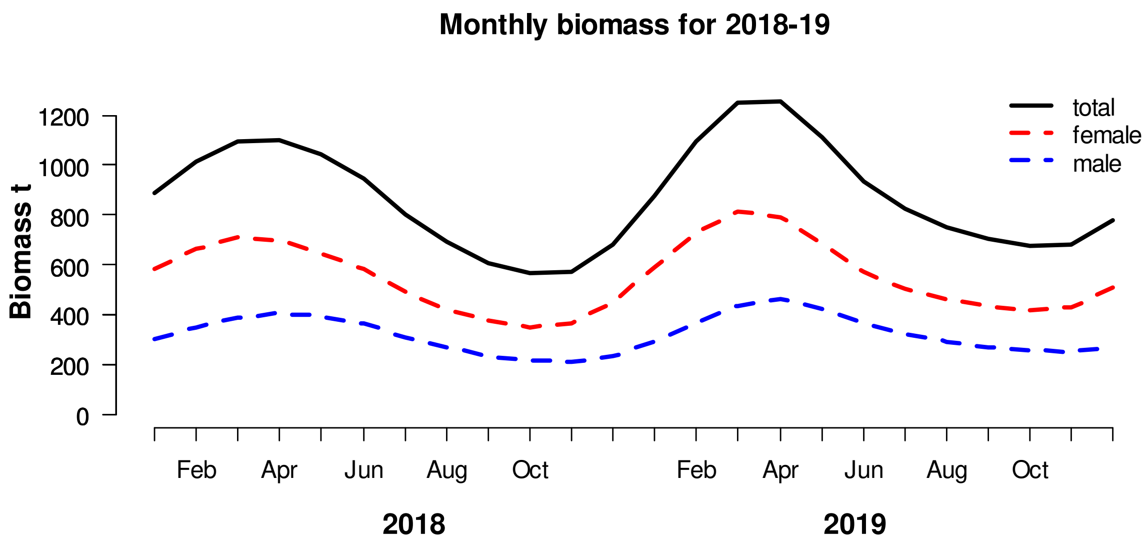

Figure 9 Model estimates of the exploitable biomass of female, male, and combined tiger prawns for each month of 2018-19.

Figure 10 shows the monthly recruitment pattern as a proportion of the total annual recruitment. Note that in the length based model recruitment is to the population at about 1 month of age and a carapace length of 8-10 mm carapace. In contrast recruitment in the delay-difference model is to the "fishery" (areas that are can be fished) at an age of about 6 months and a prawns size of around 20-30 mm carapace length.

The monthly proportion of recruitment each month is based on a bimodal normal distribution that allows for two peaks of recruitment within the year. The parameters that are estimated are the timing of each peak, a weighting between the peaks and spread of the normal distribution around the peaks. The total annual number of prawn recruits for the 2018 and 2019 seasons were also estimated during the fitting process.

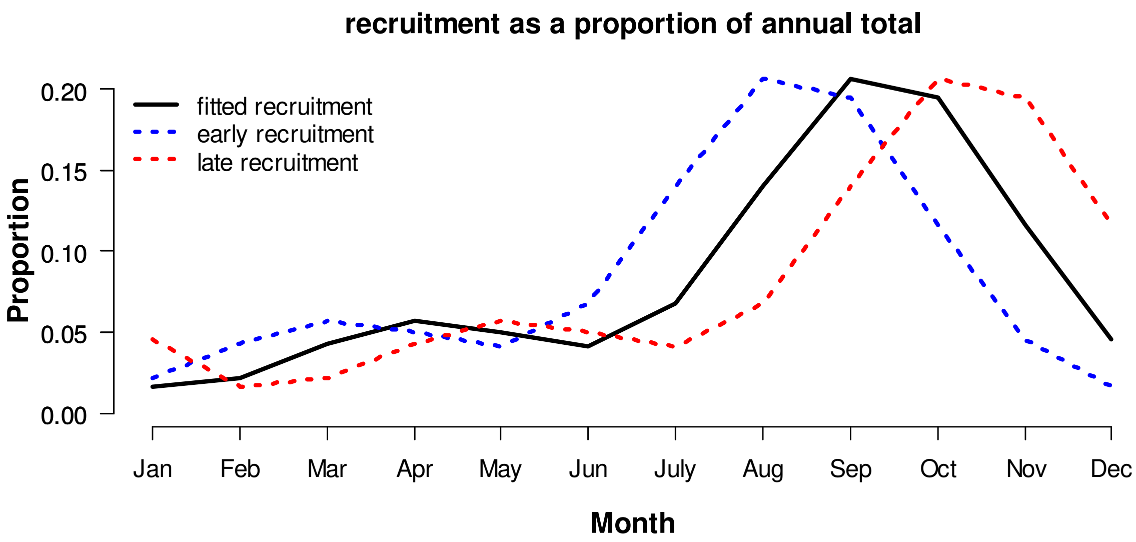

Figure 10 Monthly Recruitment as a proportion of the annual total.

Figure 10 shows the fitted recruitment curve and the same curve shifted to the left by one month to simulate early recruitment and shifted to the right one month to simulate late recruitment. In an early recruitment simulation prawns will tend to be larger at the season opening and conversely they will be smaller for late recruitment. The prawn stock you would expect to see at the start of March is there at the start of February for early recruitment but not there until the start of April for late recruitment.

The fitted recruitment curve is supported by the results of monthly research trawl surveys conducted during 1986-88 in Torres Strait by QDPI (Blyth, Watson and Sterling, 1990). The authors noted that based on their 1986 data *P. esculentus* had three major spawning periods in Torres Strait: January-March and August –September in the East, and October-November in the West (western side of Warrior Reef). These periods of spawning activity preceded peaks of larval settlement on Warrior Reef which forms the major juvenile nursery ground in the Torres Strait.

In figure 11 the monthly Fishing Mortality (F) for 2018-19 is plotted as the proportion of the monthly biomass that is removed during each month as a result of fishing. Fishing Mortality is also referred to as the 'Harvest Rate' (H) and is calculated as catch/biomass. In 2018 the number of vessel and fishing effort was low until May whereas in 2019 the number of vessels and fishing effort was highest in April-May. This explains why the monthly Fishing Mortality is different between the two seasons.

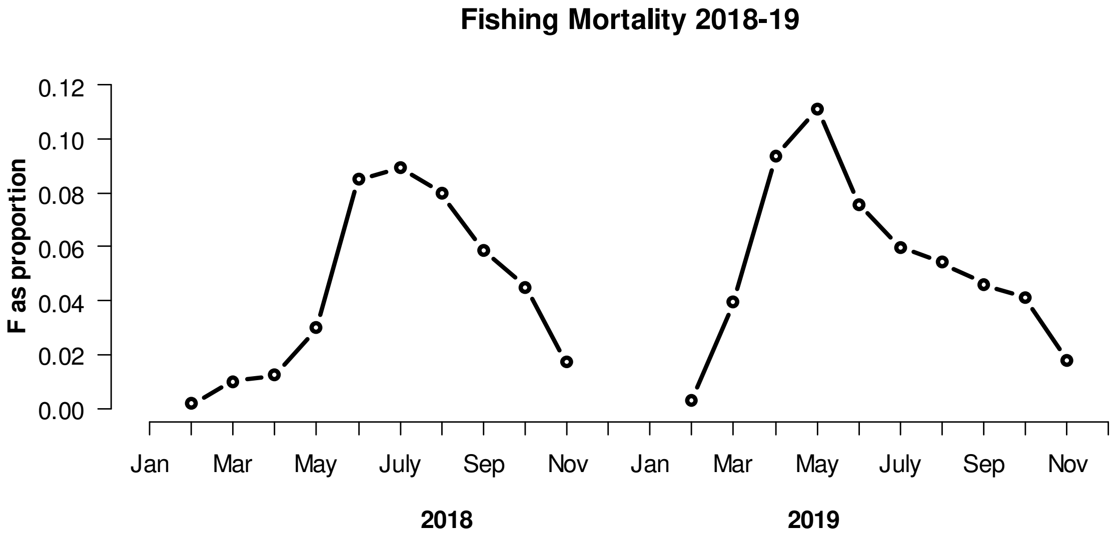

Figure 11 Fishing mortality (F) for years 2018 and 2019.

The results presented in this section indicate that the tiger prawn population in the model is correctly simulating the real tiger prawn population in terms of prawn growth, population size structure and fishing mortality, therefore the model and fitted (optimised) model parameters can be confidently used for the proposed season date simulations.

Results of the Season Date Simulation Scenarios

Annual Results

Table 1 Annual simulation output for season opening dates of 1st February, 1st March and 1st April. The February opening was run with 3 effort patterns; 1- average of 2016-2019, 2-highest effort in February then March, 3- 2019 effort. The scenarios were run with 2624 and 6000 days of annual effort across three recruitment patterns; the fitted pattern, one month early and one month later.

Effort		**2624**					**6000**				
Scenario		1	2	3	4	5	1	2	3	4	5
Opening		Feb	Feb	Feb	Mar	Apr	Feb	Feb	Feb	Mar	Apr
Harvest	Early	491	509	499	499	495	865	901	873	882	870
	Recruit	513	515	526	520	522	898	905	915	911	913
	Late	527	506	540	528	539	916	886	933	919	936
Value	Early	7.59	7.66	7.67	7.66	7.65	13.12	13.28	13.19	13.27	13.2
	Recruit	7.84	7.68	7.96	7.88	7.96	13.45	13.22	13.6	13.55	13.66
	Late	7.94	7.5	8.03	7.9	8.08	13.54	12.86	13.65	13.49	13.79
$ per day	Early	2894	2918	2924	2921	2915	2186	2214	2198	2212	2201
	Recruit	2988	2927	3033	3004	3033	2242	2203	2267	2258	2277
	Late	3025	2859	3062	3012	3080	2257	2143	2275	2249	2299
CPUE	Early	187	194	190	190	189	144	150	146	147	145
	Recruit	196	196	200	198	199	150	151	152	152	152
	Late	201	193	206	201	205	153	148	155	153	156
Mean Biomass	Early	934	899	923	926	935	779	714	765	765	785
	Recruit	924	889	911	915	924	760	695	742	744	764
	Late	906	877	889	896	902	733	678	710	717	731
Max Fishing Mortality	Early	0.07	0.11	0.11	0.09	0.13	0.16	0.23	0.24	0.2	0.27
	Recruit	0.07	0.11	0.11	0.09	0.13	0.16	0.23	0.24	0.2	0.28
	Late	0.07	0.11	0.11	0.09	0.13	0.16	0.23	0.24	0.2	0.28

The simulation estimates of: the annual catch of tiger prawn (harvest), the value of that harvest (Value), the daily vessel income from that harvest ($ per day), the nominal annual CPUE of tiger prawn (CPUE), mean annual biomass of tiger prawn (mean Biomass) and maximum monthly Fishing Mortality (Max Fishing Mortality) are presented in Table 1 and as bar plots in figures 12-14. “Opening” indicates whether the simulation is a season opening dates of 1st February (Feb), 1st March (Mar) or 1st April (Apr). The “Early”, “Recruit” and “Late” indicate the timing of the recruitment pattern used in the simulation; “one month earlier than the fitted or normal recruitment”, “normal timing” and “one month later than normal”.

Table 2 presents a summary of the information in Table 1 as the mean and range (minimum and maximum) for each fishery metric, grouped into the 2624 and 6000 day simulations.

Table 2 The mean and range of the annual data in table 1 grouped by the total annual effort.

Effort	2624			6000		
Fishery metric	**mean**	**minimum**	**maximum**	**mean**	**minimum**	**maximum**
Harvest	515	491	540	901	865	936
Value	7.8	7.5	8.08	13.39	12.86	13.79
Income per day	2973	2859	3080	2232	2143	2299
CPUE	196	187	206	150	144	156
Biomass	910	877	935	739	678	785
Fishing Mortality	0.1	0.07	0.13	0.22	0.16	0.28

Figures 12 and 13 compare the fishery metrics that relate to the economics of the fishery. The impact of season date is clearly smaller than the effects of; the total annual effort, the monthly pattern of fishing effort and the timing of the recruitment pattern. This is obvious by comparing the heights of the bars of each colour across the five scenarios for the 2624 and 6000 day simulations. The variation is insignificant compared to the heights of the bars. The variation in the mean biomass (Figure 14) is also insignificant compared to the heights of the bars. The larger variation in the maximum monthly Fishing Mortality is a result of the variation in the concentration of effort over the scenarios and hence the monthly Fishing Mortality plots are more informative about impact on the stock and catches later in the season.

Although the variation between the scenarios is relatively small there appears to be consistent trends in relation to the timing of recruitment. All of the scenarios except 2 (1st February opening with high fishing effort) show an increase in catch, CPUE and dollars per day as the recruitment timing shifts from being early to being late. In contrast, scenario 2 is flat in relation to recruitment timing. An explanation for this is that an early recruitment would result in more biomass that could be harvested in February.

The largest impact on the results is the total annual fishing effort. Although the higher effort simulations result in more harvest it results in a lower CPUE and hence lower "dollars per day".

The variation in the composition of the annual harvests in terms of prawn grades (Figure 15) are also relatively minor across the five scenarios at each level of annual total fishing effort. Scenario 2 has the highest proportion of small prawn (30+ grade) because the highest proportion of fishing occurs in February and March and this is the period of highest recruitment of the smaller grades of prawns into areas available to fishing.

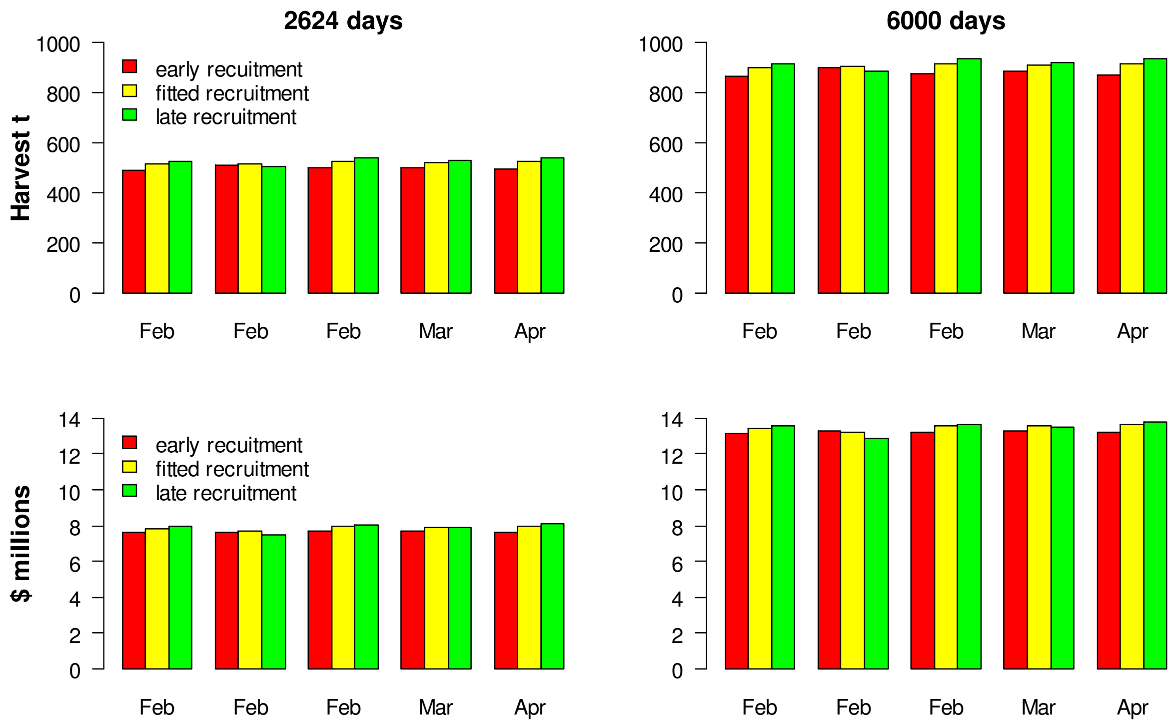

Figure 12 Harvest and value of harvest of tiger prawn.

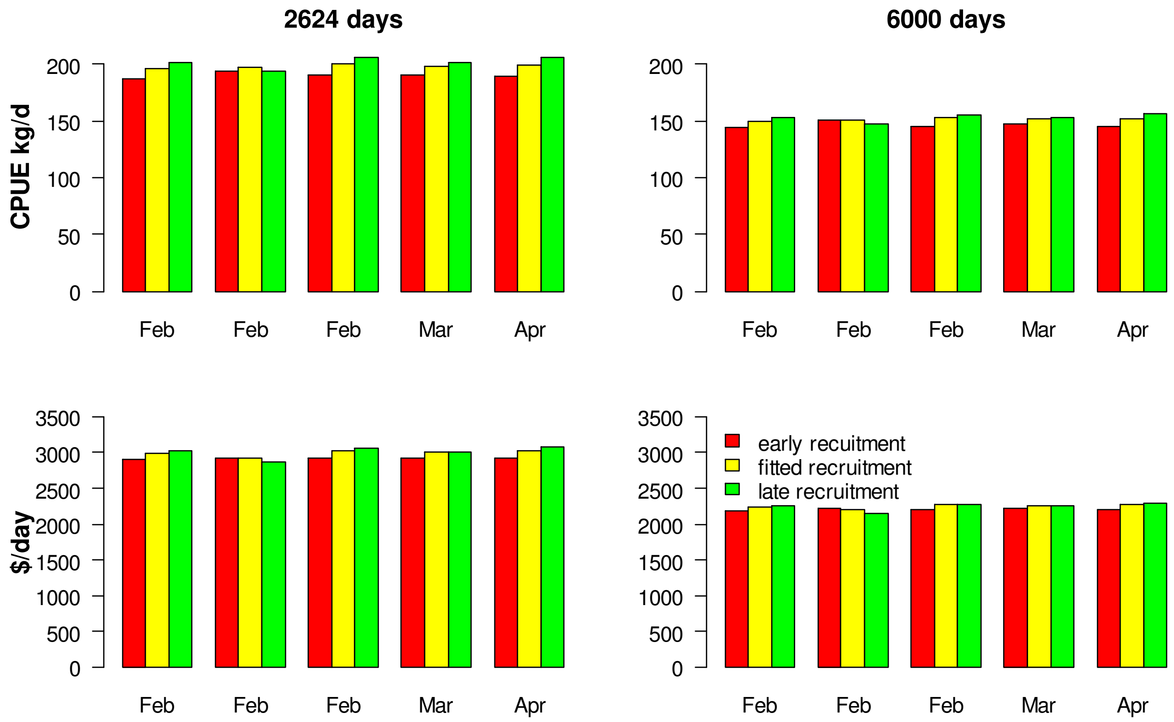

Figure 13 Tiger prawn CPUE and dollars / boat day.

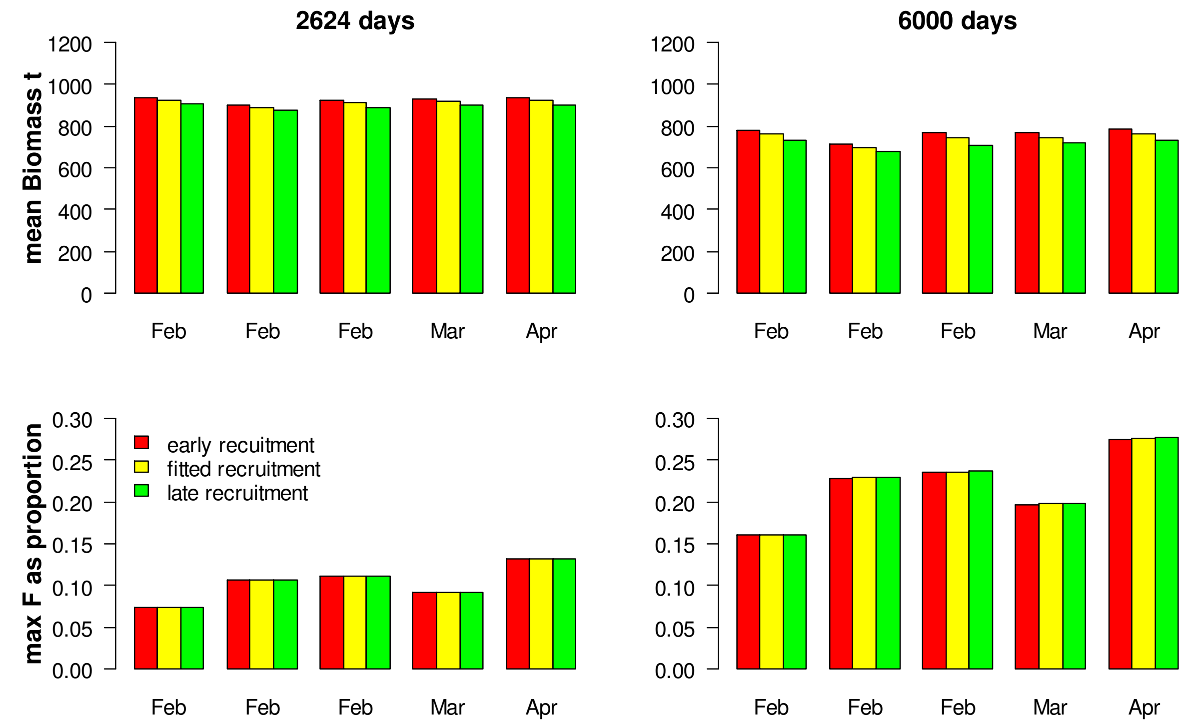

Figure 14 Mean Annual tiger prawn biomass and maximum monthly Fishing Mortality.

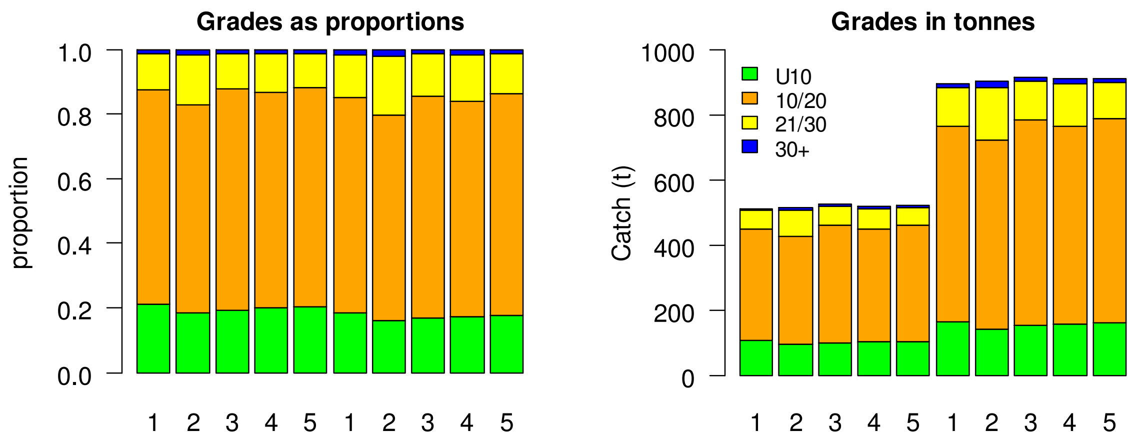

Figure 15 Annual catch divided into prawn grade as proportions of total catch (left plot) and as tonnes of catch (right plot).

Monthly Results

Figure 16 shows seasonality of the grade composition of the simulated catch; the left column of plots is from the 2642 fishing day simulations and the right column of plots is from the 6000 day simulations. Therefore the low to high annual fishing effort comparison is across the rows of plots and the between scenario comparison is down the columns of plots. All of the scenarios show the same pattern across the season. The proportion U10 is highest in second half of the season and the highest proportions of small prawns (21/30 and 21/30) occur during the early and later months of the season. The variation between scenarios in terms of the proportion of catch by grade for each month is small.

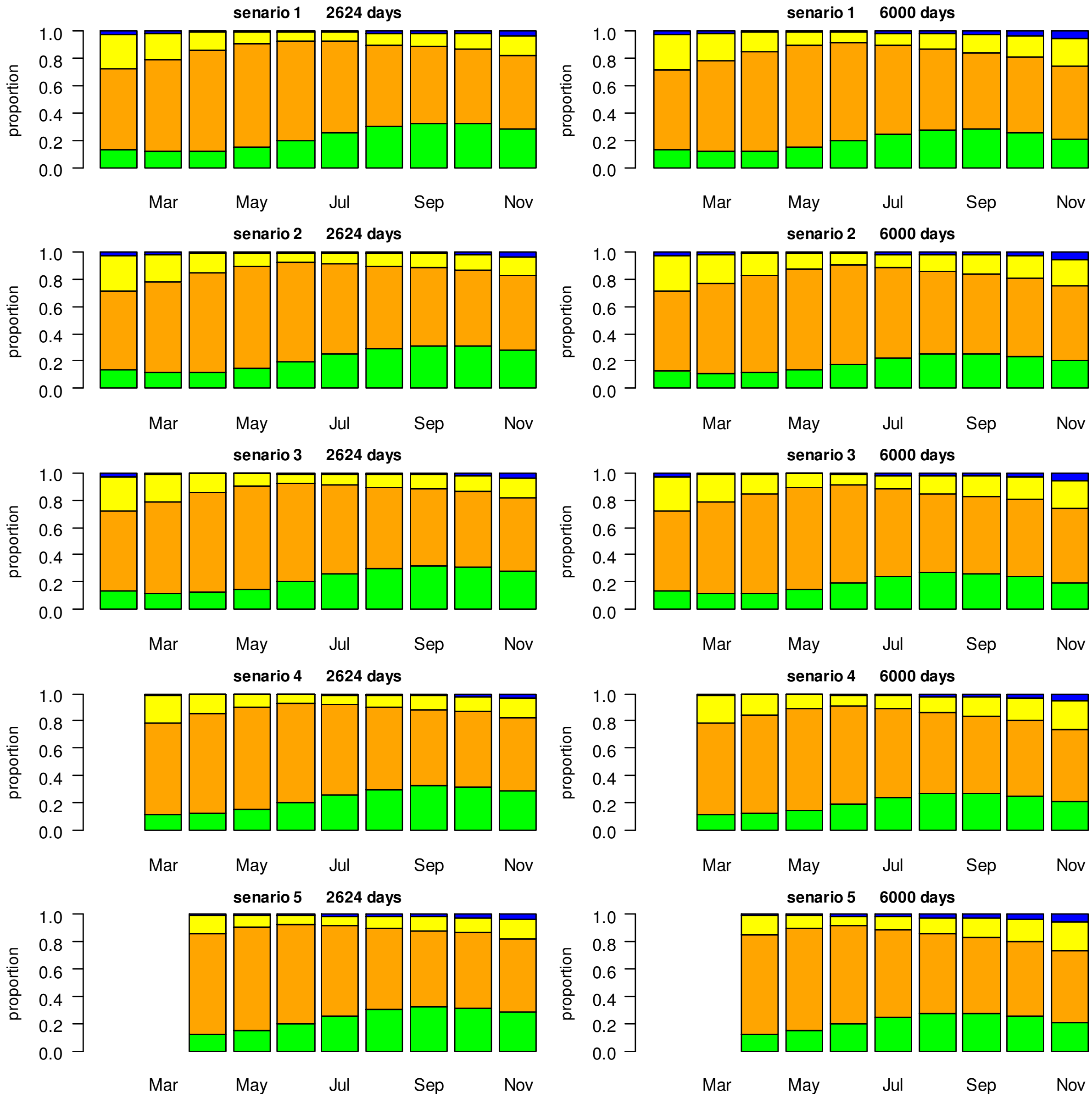

Figure 16 Monthly catches by grade for the 2624 effort scenarios on the left and the 6000 day effort scenarios on the right.

Figure 17 shows the monthly fishing effort applied to the five scenarios using 2624 days of annual fishing effort (the black lines) and the five 6000 day scenarios (the red lines). The individual scenarios are coded as different line types; ‘solid’ = scenario 1, ‘dashed’ = 2, ‘dotted’ = 3, ‘dot dash’ =4 and ‘long dashes’ = 5. The same coding is used in Figures 18 to 21. The data used for the plot is in Table 3.

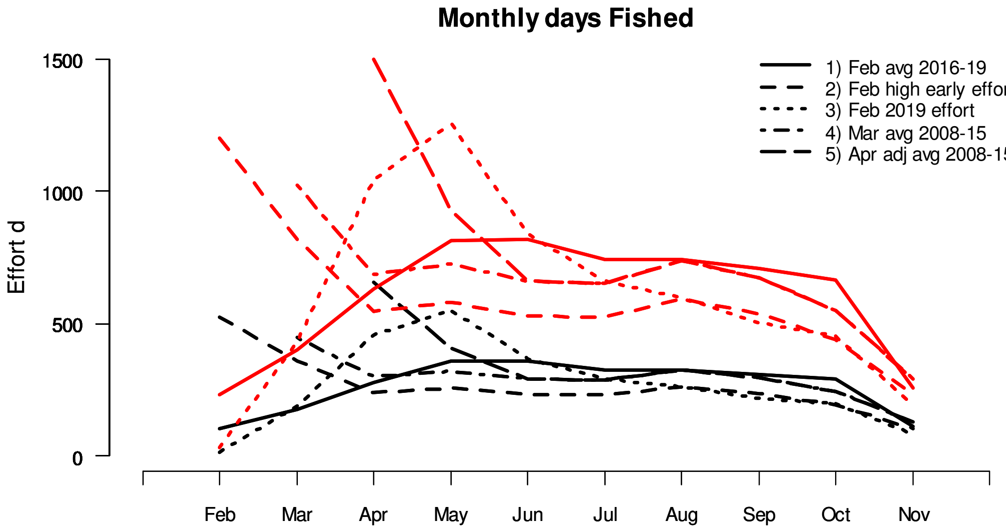

Figure 17 Monthly fishing effort; the 2624 day monthly effort patterns are “black” and the 6000 day monthly effort patterns are “red”. Legend shows abbreviations of fishing scenarios. Refer to pages 7-8 for details of each scenario.

Table 3 Monthly fishing effort as days fished under each scenario and total annual fishing effort. Note that the monthly effort values have been rounded to whole days for presentation as a table therefore some of the columns do not add exactly to 2642 or 6000.

effort	2624					6000				
Scenario	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Feb	101	525	14			230	1200	32		
Mar	176	357	188	446		402	817	430	1021	
Apr	276	239	457	299	656	630	547	1045	684	1501
May	356	254	549	318	407	815	581	1255	726	931
Jun	357	232	368	290	290	816	530	842	663	663
Jul	323	229	288	286	286	739	523	658	653	653
Aug	324	259	261	323	323	740	591	597	739	739
Sep	309	236	219	294	294	706	539	501	674	674
Oct	290	193	197	241	241	664	441	450	551	551
Nov	112	101	83	126	126	257	231	190	289	289

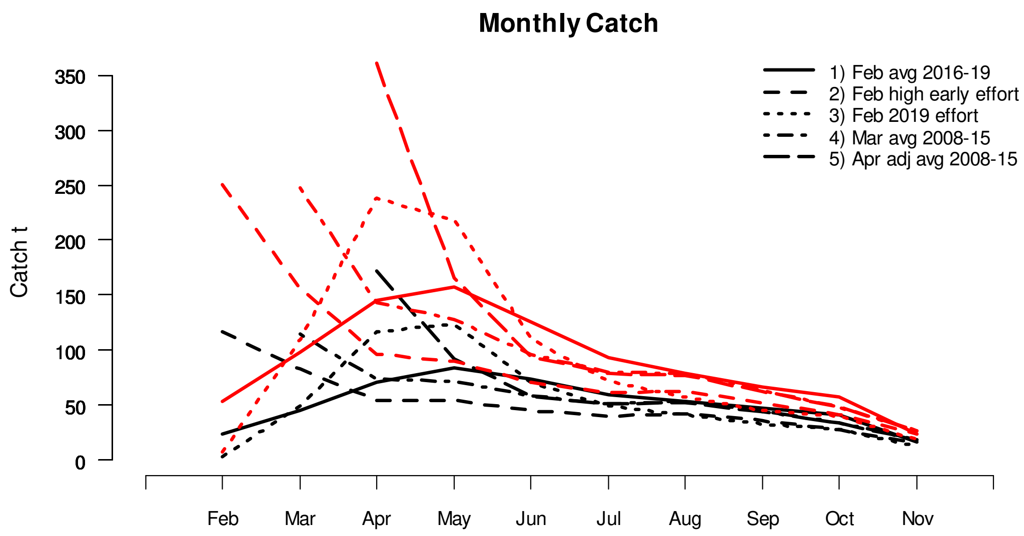

Figure 18 Monthly catches using the fitted recruitment timing. The 2624 day monthly effort patterns are "black" and the 6000 day monthly effort patterns are "red". Legend shows abbreviations of fishing scenarios. Refer to pages 7-8 for details of each scenario.

Table 4 Monthly catch in tonnes under each scenario and total annual fishing effort.

effort			**2624**					**6000**		
Scenario	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Feb	23.4	116.9	3.3			52.8	250.8	7.5		
Mar	45.3	82.7	49.3	114.4		98.5	156.7	109.6	247.1	
Apr	70.8	54.6	117	73.8	172	144.8	96	238	142.9	360.9
May	83.9	54.3	123.2	71.9	92.5	157.2	90.1	217.5	128.1	165.7
Jun	73.8	44.9	70.9	58.4	57.9	125.6	70.7	110.2	96.2	94.4
Jul	59	40.3	49.2	51.5	51.1	92.6	61.2	71.4	79.9	78.3
Aug	53.3	42.2	40.9	52.9	52.5	79	62.5	57.6	78.3	76.8
Sep	46.6	35.9	32.2	44.3	44	66.4	52.5	45.1	63.3	62.3
Oct	40.9	28	27.8	34.2	34	57.3	41.2	39.6	48.4	47.7
Nov	16	15	12	18.2	18.1	23.3	23.1	18.1	26.9	26.6

The 1st March (scenario 4) and 1st April (scenario 5) season date simulations both have the fishing effort highest in the opening month. Based on the historical fishing effort data this is the most likely reaction of the fleet to those season opening dates. Although less likely, fishing effort could be low during the first month or so of a March or April season opening. These scenarios were not explicitly simulated in the study but the fishing effort pattern of 2019 (scenario 3) could be considered as an example of a pseudo 1st March season opening because the February fishing effort, catch and Fishing Mortality (Figures 17, 18 and 21; Tables 3, 4 and 7) are almost negligible. Similarly the fitted simulation results for 2018 (Figures 2, 3 and 11) could be regarded as the results for a pseudo 1st April season opening because there was only a small amount of fishing during February and March with the maximum effort occurring in June and July.

The monthly catches (Figure 18) are largely driven by the fishing effort (Figure 17) which is why the plots are similar. The variation in monthly catches between scenarios rapidly decreases as the season progress indicting that the season opening date and fishing effort at the start of the season have minimal impact on catches later in the season.

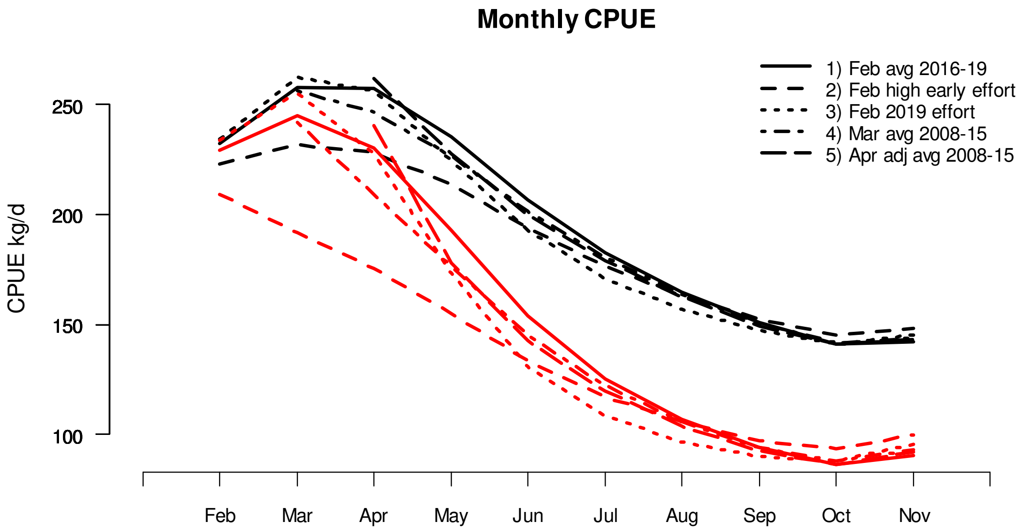

Figure 19 Monthly CPUE using the fitted recruitment timing. The 2624 day monthly effort patterns are "black" and the 6000 day monthly effort patterns are "red". Note that the y-axis (CPUE) starts at 100 kg/d. Legend shows abbreviations of fishing scenarios. Refer to pages 7-8 for details of each scenario.

Table 5 Monthly CPUE as kg/day under each scenario and total annual fishing effort.

effort			**2624**					**6000**		
Scenario	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Feb	232	223	234			229	209	234		
Mar	258	231	262	256		245	192	255	242	
Apr	257	228	256	247	262	230	175	228	209	241
May	235	214	224	226	227	193	155	173	176	178
Jun	207	194	193	202	200	154	133	131	145	142
Jul	182	176	171	180	179	125	117	108	122	120
Aug	165	163	157	164	162	107	106	97	106	104
Sep	151	152	147	151	149	94	97	90	94	92
Oct	141	145	141	142	141	86	93	88	88	87
Nov	142	148	145	144	143	91	100	96	93	92

The variation in CPUE, Biomass (Figures 19 and 20) and to a lesser extent, Fishing Mortality (Figure 21), rapidly decrease post April-May into two compact set of trajectories; for CPUE and Biomass the upper trajectory and for Fishing Mortality the lower trajectory are the 2624 day simulations. These trends also indicate that the impact of the season date on catches and biomass later in the season is minimal.

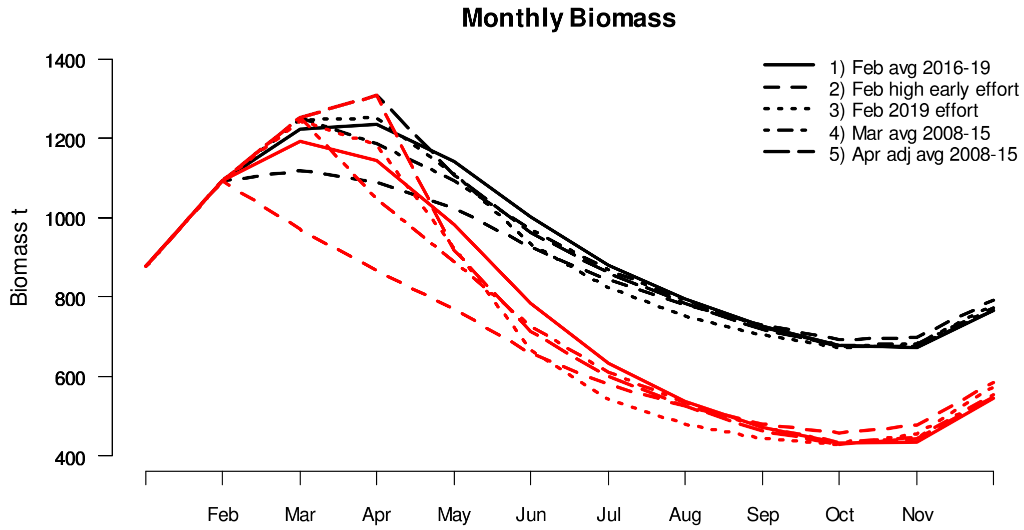

Figure 20 Monthly biomass using the fitted recruitment timing. The 2624 day monthly effort patterns are "black" and the 6000 day monthly effort patterns are "red". Note that the y-axis, biomass, starts at 400 t. Legend shows abbreviations of fishing scenarios. Refer to pages 7-8 for details of each scenario.

Table 6 Monthly biomass in tonnes under each scenario and total annual fishing effort.

effort			**2624**					**6000**		
Scenario	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Feb	1094	1094	1094	1094	1094	1094	1094	1094	1094	1094
Mar	1225	1119	1247	1251	1251	1191	971	1243	1251	1251
Apr	1235	1092	1253	1187	1309	1145	866	1184	1047	1309
May	1141	1024	1111	1093	1108	981	769	922	889	917
Jun	1003	927	935	970	963	783	659	668	727	714
Jul	881	844	823	868	861	632	578	542	612	599
Aug	795	782	753	791	784	538	525	479	534	524
Sep	727	729	703	725	719	472	480	443	470	462
Oct	678	692	673	679	674	431	455	429	433	427
Nov	672	699	682	680	676	434	476	454	446	442

Scenario 2 had the lowest CPUE and biomass until June, and this was more pronounced for the 6000 day simulation. This indicates that high fishing effort during February can impact the biomass available to fishing and hence CPUE until May-June, however, post June the impact is negligible.

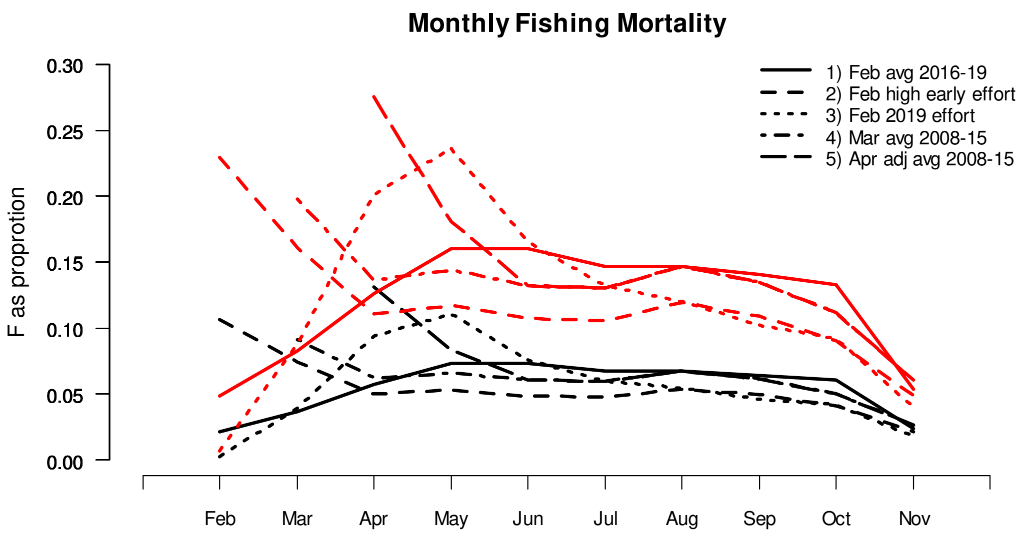

Figure 21 Monthly Fishing Mortality (F) using the fitted recruitment timing. The 2624 day monthly effort patterns are "black" and the 6000 day monthly effort patterns are "red". Legend shows abbreviations of fishing scenarios. Refer to pages 7-8 for details of each scenario.

Table 7 Monthly Fishing Mortality as the proportion of the biomass harvested each month under each scenario and level of annual fishing effort.

effort			**2624**					**6000**		
Scenario	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
Feb	0.021	0.107	0.003			0.048	0.229	0.007		
Mar	0.037	0.074	0.04	0.091		0.083	0.161	0.088	0.198	
Apr	0.057	0.05	0.093	0.062	0.131	0.126	0.111	0.201	0.137	0.276
May	0.074	0.053	0.111	0.066	0.084	0.16	0.117	0.236	0.144	0.181
Jun	0.074	0.048	0.076	0.06	0.06	0.16	0.107	0.165	0.132	0.132
Jul	0.067	0.048	0.06	0.059	0.059	0.147	0.106	0.132	0.131	0.131
Aug	0.067	0.054	0.054	0.067	0.067	0.147	0.119	0.12	0.147	0.147
Sep	0.064	0.049	0.046	0.061	0.061	0.141	0.109	0.102	0.135	0.135
Oct	0.06	0.041	0.041	0.05	0.05	0.133	0.09	0.092	0.112	0.112
Nov	0.024	0.021	0.018	0.027	0.027	0.054	0.048	0.04	0.06	0.06

Discussion

An age and size based tiger prawn simulation model for the Torres Strait Prawn Fishery was coded in the statistical programming language “R”. The model was initially fitted to 2007-08 monthly catches and length frequency data from the 2007-08 trawl research surveys conducted by QDPI. This was achieved by minimising the difference between the observed and predicted monthly catches and length frequency data to optimise the catchability, fishing selectivity, and recruitment parameters. Reality checking and validation of the model was done by comparing the observed and predicted monthly catch, CPUE and prawn grades. The final fit of the model to the 2018 and 2019 monthly catches and prawn grade data was used for the closure simulations.

The comparison of the model outputs with the observed fishery data for 2018-19 and trawl surveys length frequency data for 2007-08 indicates that the tiger prawn population in the model is correctly simulating the real tiger prawn population in terms of prawn growth, population size structure and Fishing Mortality. Therefore the model could be confidently used to simulate and compare the closure options and monthly fishing effort scenarios that were agreed at the January 2020 TSPMAC meeting.

The rationale behind the proposed scenarios was to conduct a Management Strategy Evaluation of the potential impact of varying the season opening date over a three month period (1st February to 1st April) on the economics of the fishery and the tiger prawn stock. This was achieved by simulating the fishery opening on the 1st February, 1st March and 1st April using a number of monthly fishing patterns and two levels of annual fishing effort. A sensitivity analysis of the effect of the timing of prawn recruitment was done by running the simulations with the recruitment pattern shifted one month earlier and one month later. The monthly fishing effort patterns for the March and April openings were based on the average (mean) of the years 2008-2015. During these years the season opened on the 1st March and is post the large decrease in fishing effort that occurred during 2003-2008.

The 1st February season date was simulated using three alternative responses of the fleet. The first and most likely is based on the average of the years 2016-19 (scenario 1). The alternate February scenario (2) has the highest effort in February then March. This is an unlikely scenario but serves as a sensitivity analysis of the model results to the pattern of monthly fishing. The third February scenario (3) uses the 2019 distribution of fishing effort.

Scenario 4 simulates a 1st March opening where the highest effort occurs at the start of the season; this is the typical effort distribution for a March opening based on the data for the 2009 to 2015 fishing seasons. Scenario 5 simulates a 1st April season opening with the highest fishing effort at the start of the season.

The less likely scenarios of low fishing effort at the start of a March or April opening were not explicitly simulated. However, the results of scenario 3 (the fishing effort pattern of 2019) can be regarded as a pseudo 1st March opening because the February fishing effort, catch and Fishing Mortality were negligible. In addition the 2018 model results serve as a pseudo 1st April season opening with low fishing effort because the February, March and April effort were low (8, 46 and 59 days respectively) with the highest effort being mid-season; June (415 d) and July (427 d).

The comparison in the results section of the fishery metrics suggests that the timing of the season opening has a minimal effect on the economics of the fishery and the tiger prawn stock. The impact of season date is smaller than the effects of variations in the total annual effort, the distribution of the fishing effort across the fishing season and a three month variation in the timing of the prawn recruitment. The total annual fishing effort has more impact on the economics of the fishery than the closure timing with high effort resulting in a greater harvest but lower CPUE and “dollars per day”. This supports industry observation that it is not currently economically viable to fish at the higher levels of effort that have historically occurred in this fishery.

The variations in the composition of the annual harvests in terms of prawn grades are also relatively minor across the five scenarios. Scenario 2 has the highest proportion of small prawn (30+ grades) because the highest proportion of fishing occurred in February and March which is the period of highest recruitment of the smaller grades of prawns into areas available to fishing.

Although the variation between the scenarios is relatively small there appears to be consistent trends in relation to the timing of recruitment. All of the scenarios except 2 (1st February opening with high fishing effort) show an increase in the monthly catch, CPUE and dollars per day as the recruitment timing shifts from being early to being late. In contrast, scenario 2 is flat in relation to recruitment timing. An explanation for this is that an early recruitment would result in more biomass that could be harvested in February.

The variation in the monthly catch, CPUE, Biomass and to a lesser extent, Fishing Mortality, rapidly decrease post April-May into two compact set of trajectories; for CPUE and Biomass the upper trajectory and for Fishing Mortality the lower trajectory are the 2624 day simulations. These trends indicate that the impact of the season date on catches and biomass later in the season is minimal. Scenario 2 (February open with high fishing effort) had the lowest CPUE and biomass until June, and this was more pronounced for the 6000 day simulation. This indicates that high fishing effort during February can impact the biomass available to fishing and hence CPUE until May-June; however, post June the impact is negligible.

In summary, the management strategy evaluation results support the view that season length and the season opening date per se does not have a measurable impact on the catch and stock biomass throughout the season. Any impact from the setting of a particular season date appears to be determined by the way the fishing fleet responds to the season date and the timing of prawn recruitment.

The only scenario simulation that indicated a negative impact on catches later in the season was scenario 2 and is a result of the high February effort and the available tiger prawn stock having a higher proportion of small prawn (21/30 grade). At the 2624 day level of annual fishing effort the impact was minimal and not detectable post June. Scenario 2 is highly unlikely given the current economics of prawn trawling in Australia.

Since 2016 when the season opening was first set to 1st February the proportion of the fishing effort in February has been below 0.1 (or 10%) and the highest monthly proportions (up to 0.2) have occurred during May to July. The observed February grade proportions for 2016-19 have a higher proportion of U10 and lower proportion of 21/30 than the simulation results for 2019. This suggests that the vessels fishing in February are targeting areas that have a higher proportion of larger prawn and avoiding areas of small prawn. If there is concern that more vessels may start fishing in February and target the smaller size grades that occur close to the East of Warrior Closure (EWC) the option proposed by industry in 2005 for a one or two month extension to the EWC (O'Neill and Turnbull 2006, see extract in Appendix) could be considered as an alternative to shifting the season date back to the 1st March.

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Appendix

Extracts from O'Neill and Turnbull 2006,

6 Alternative management strategy workshop

Introduction

The concept of convening an "Alternative Management Strategy Workshop" for the fishery arose from the David Die review. Recommendations 18 (high priority, Table 1.1.1) which suggests that the "Working Group should develop alternative management strategies to reach target reference points and that these strategies should be evaluated by the management strategy evaluation method". Implicit in this recommendation was the need to define clear reference points for the fishery that are agreed upon by the Prawn Working Group and to develop management strategies that could allow a diversion of effort to target endeavour prawns whilst ensuring that catch of tiger prawns is sustainable. Although the management agencies initially proposed that the workshop occur in mid-2004 as a component of the presentation of the updated stock assessment results, industry representatives were not prepared to participate in a workshop at that point in time.

In March 2005 industry representatives agreed to the concept of the workshop so an organising committee was formed consisting of representatives from the Management Agencies, industry and research. The workshop was held in late July 2005 and was immediately following by a Prawn Working Group meeting to consider the recommendations from the workshop.

6.5.2 New proposed closures

Following the workshop a small committee of industry members and researchers collaborated to define the location of the spatial/ temporal closures options proposed during the workshop. The location of the closure lines were based on an examination of logbook data for the whole fleet summarised by month and six-minute logbook grid, personal fisher records and local fisher knowledge.

Three new spatial/ temporal closures (Figure 6.5.1.) were proposed:

1. Tiger spawner closure

   This area is the deeper trawl ground on the eastern side of the fishery and would be closed when effort reaches the tiger prawn trigger point. Industry believes that this area contains the main tiger prawn spawning grounds. The results of monthly research surveys conducted by DPI&F during the late 1980's indicate that tiger prawns in this area have a high fecundity (Blyth *et al.* 1990).

2. Full moon closure (see results section 4.4, Figure 4.4.3)

   This area (which is a subset of the area encompassed by the "tiger spawner closure") would be closed for a period of about 10 days over the full moon during the latter months of the season (possibly August to November). This closure would be implemented independently of the effort applied in the fishery. The aim of the closure is to reduce targeting of large spawning tiger prawns over the full moon. Industry representatives noted that in recent years there has been a shift of fishing effort over the full moon periods from the shallower area on the eastern side of Warrior Reef to the deeper water east of Yorke Island. This shift in effort is a result of a decline in catch rates in the shallower areas whereas catch rates are maintained in the deeper water. This is possibly a result of the moonlight having less impact on prawn behaviour due to the increase in water depth.

3. An extension of the East of Warrior Closure (EWC)
This area is an extension of the east of Warrior Reef spatial/ seasonal closure and would be closed for the first month or two of the season (March and April?). Although this closure is mainly aimed at preventing growth-overfishing by reducing targeting of the smaller prawn grades (> 30 count per pound) it could also allow more tiger prawns to spawn prior to being harvested. Data from monthly DPI&F research surveys conducted during 1986-1991 indicate the average size of female tiger prawns inside the proposed closure would be less than 31 mm carapace length (CL). Research on the reproductive condition of Torres Strait tiger prawns (Keating *et al.* 1990) and the Gulf of Carpentaria (Crocos 1987) indicate female brown tiger prawns of less than 32 mm CL have a much lower fecundity due to reduced maturity and insemination rates.

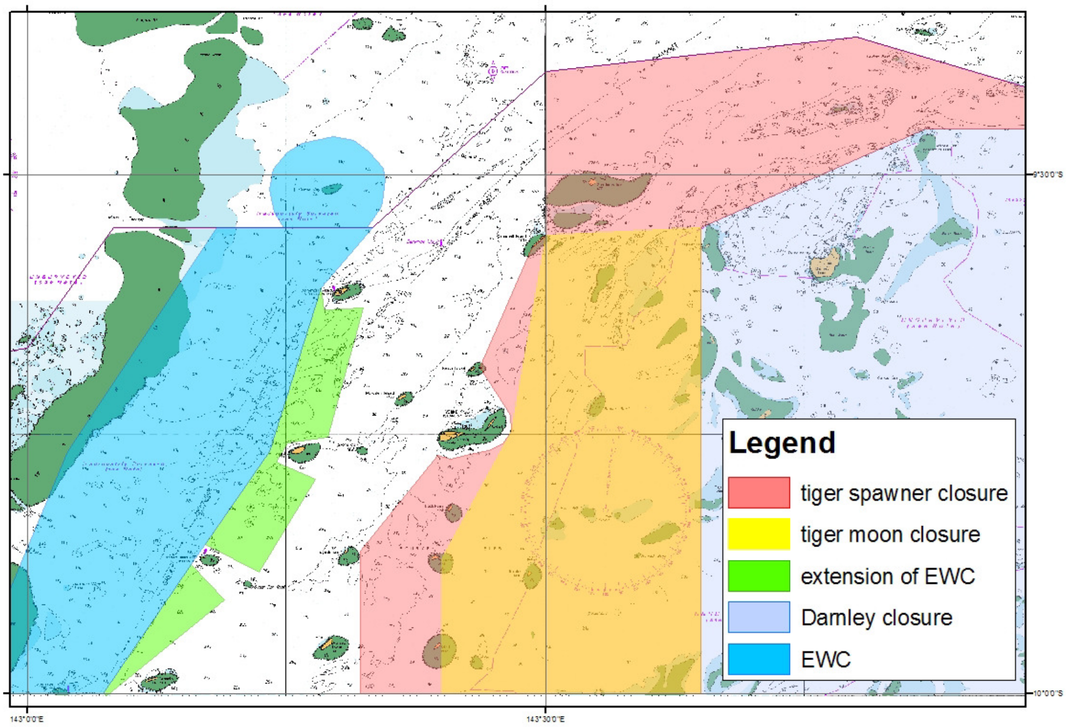

Figure 6.5.1 The new proposed closures. The existing East of Warrior and Darnley Closures are also shown.