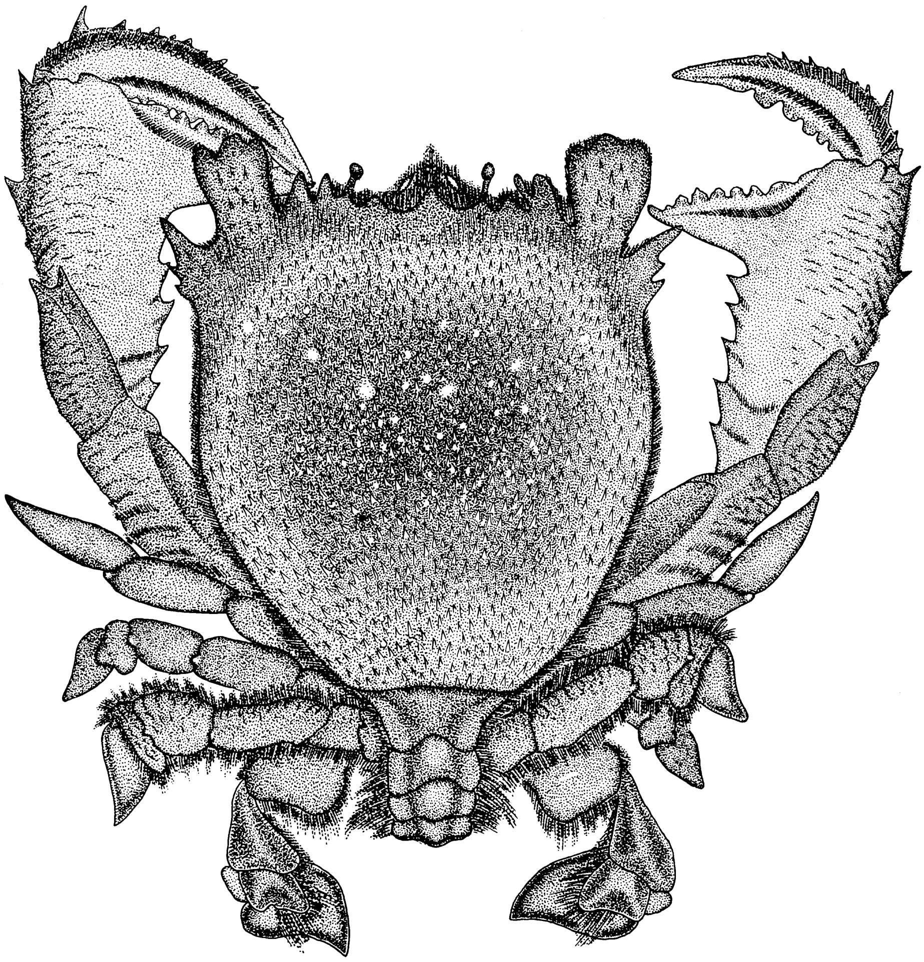

Total allowable commercial catch review for Queensland spanner crab (*Ranina ranina*), with data to December 2023

March 2024

Queensland
Government

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Contents

Summary

The Australian east coast fishery for spanner crab is the largest in the world, with the Queensland commercial sector landing approximately 85% of the annual Australian harvest.

The Queensland sector operates primarily in offshore waters between Rockhampton and the New South Wales border; called management area A. In these waters, spanner crab are managed by a harvest strategy (Department of Agriculture and Fisheries 2020b).

The harvest strategy employs standardised commercial (sCPUE) and fishery independent survey (sFIS) catch rates from two years, compared against target rates, to calculate total allowable commercial catch. Only catch data from management area A is used in total allowable commercial catch calculations; this excludes catch data from New South Wales and Queensland waters outside management area A.

The aim of the harvest strategy and total allowable commercial catch process was to rebuild the Queensland spanner crab resource to 60% of the pre-fishery exploitable biomass (legal-sized crabs), while simultaneously improving the economic performance of the fishery.

In the 2022 and 2023 calendar years, commercial spanner crab harvest in managed area A was 597 t and 592 t respectively. These harvests equated to about 70% of the 847 t total allowable commercial catch being caught and a gross value of production (GVP) of around $8.8 million using the BDO 2020/21 estimated average beach price of $14.90/kg (BDO EconSearch 2023).

The average 2022–2023 catch rate indicators from two years, standardised using generalised linear models, were: sCPUE = 0.754 kilograms per dilly-net lift and sFIS = 5.913 crab per ground-line.

The harvest strategy target catch rates were 95% of 2006–2010 average catch rates: target sCPUE = 1.38 kilograms per dilly-net lift and target sFIS = 10.435 crab per ground-line.

The stock indices were the ratio of the indicators compared to their targets. The calculated stock indices were less than 1, signalling catch rates were below target: sCPUE ratio = 0.546 and sFIS ratio = 0.567.

The pooled index was 0.556 (average of the two stock indices). The pooled index means that the fishery was at 56% of its target.

By referencing the pooled index against the harvest strategy (Appendix D), a **797 t total allowable commercial catch was calculated**. The figure results directly from activating rule 5.1, triggered by a three-year consecutive decline in the pooled index. Using data from previous economic analysis, this harvest strategy is estimated to potentially yield a GVP of approximately $11.9 million per year, assuming fully caught.

Acknowledgements

We thank monitoring staff and fishers who provided valuable assistance during the FIS and data collation.

The harvest strategy would not be possible without the logbook catch rate data provided by fishers, and their engagement to build the management procedure.

The authors acknowledge the fishers and scientists who have contributed to past research on Spanner crab.

Finally, we would like to thank Fisheries Queensland staff for reviewing and providing comments on the draft report.

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Glossary

BDO	Independent business for economic research and analysis.
boat day	A single day of fishing by a primary vessel operation.
CI	Confidence interval.
CL	Rostral carapace length in centimetres (cm).
DAF	Department of Agriculture and Fisheries, Queensland.
FIS	Fishery independent survey, conducted by FM.
FM	Fisheries Monitoring (managed by Fisheries Queensland).
FP	Fishing power measured the annual fleet of fishing operations effectiveness at catching crab. More generally, fishing power refers to a measure of deviation in actual fishing effort from the standard unit of effort.
FQ	Fisheries Queensland.
FRDC	Fisheries Research and Development Corporation.
GFP	General fisheries permit.
Git	Version control system used for the spanner crab project. The open source software tracks code history in any set of files for data analysis integrity.
GLM	Generalised linear model.
GVP	Gross Value of Production. The value of the total annual catch for the fishing sector as a whole.
Harvest	Retained catch of legal sized crab.
ITQ	Individual transferable quota.
kg	Weight measured in kilograms.
MAA	Managed area A.
MEY	Maximum economic yield.
MLS	Minimum legal size CL (10 cm).
NSW	New South Wales.
QLD	Queensland.
Quantile	A set of values which divide a frequency distribution into equal groups.
R	Open source free computer programming language for statistical computing and graphics.
REML	Restricted maximum likelihood. Type of linear mixed model used in statistics.
SAFS	Status of Australian fish stocks (www.fish.gov.au).
sCPUE	Standardised commercial catch rate of legal sized spanner crab. Units were kg per dilly lift.
sFIS	Standardised fishery independent survey catch rate of legal sized spanner crab. Units were number of crabs per ground-line.
t	Metric unit of weight equal to 1000 kilograms.
TACC	Total allowable commercial catch. The maximum annual harvest of legal sized crab, in tonnes t.
TAFC	Total Allowable Fishing Committee (New South Wales).
Year	The assessment year was defined as a calendar year.

1 Introduction

Spanner crabs (*Ranina ranina*) sustain an important offshore commercial fishery along Australia's east coast. The crab species belong to a single biological population (stock), shared by New South Wales and Queensland between approximately 22 and 30°S (or Rockhampton to Coffs Harbour) (Brown et al. 1999; Roelofs et al. 2021). Their range has been observed to extend further south than previously documented, reaching as far south as Broulee (35°S) (Atlas of Living Australia 2024).

Fishing is concentrated in south-east Queensland and northern New South Wales waters, with over 95% of spanner crab harvest by commercial fishing and about 80% of harvest from Queensland waters.

The fishing gear is designed specially for catching spanner crab by entangling their legs on tightly strung mesh over a flat metal frame with an area of about 1 m^2. The meshed frames are called dilly-nets, dillies or sometimes generally as pots.

The establishment of a live-crab Asian market was a significant turning point in the early growth of the fishery. An increasing proportion of vessels became dedicated to spanner crabbing and the fleet grew rapidly, with a trend towards larger vessels similar to those used in the Western Australia rock-lobster fishery.

The total allowable commercial catch (TACC) was set at 847 tons for the 2018–2019 season and remained unchanged through to the 2022–2023 season, down from 1631 tons in the 2017–2018 season.

In southern Queensland waters, commercial fishing for spanner crabs is managed under a licence marked with a C2 fishery-symbol for managed area A (Department of Agriculture and Fisheries 2020b). The managed area A fishery (Figure A.1, Appendix A) is fully developed and accounts for over 95% of the total harvest of spanner crabs from Queensland. The TACC is reviewed every two years in line with the harvest strategy for managed area A, with vessel catch allocations determined annually by individual transferable quota (ITQ) ownership and leasing.

For waters north of about Rockhampton (north of 23°S), a C3 symbol is required for spanner crabbing in managed area B (Figure A.2) (Department of Agriculture and Fisheries 2020b). No TACC applies to managed area B, and is managed using a catch limit of 16 prescribed containers (about 1 t) of crab per vessel per trip (Department of Agriculture and Fisheries 2020a).

As of February 2024, 235 C2 and 180 C3 licence symbols were registered and there were 41 quota account holders for fishing or leasing quota in managed area A.

Gear limits changed from 1 September 2019, where the number of spanner crab dilly nets per licence was limited to 45 for one person on board a vessel, or 75 for two or more people on board. General fisheries permits (GFP) allowing vessels to use excess dilly nets expired 1 January 2020.

In Queensland, a closed fishing season for spanner crab is enforced from 1 November to 15 December. This closure aims to coincide with the main part of the species' spawning period (Brown 1986). Additionally, females carrying eggs must always be returned to the ocean.

This report was prepared to inform Fisheries Queensland and stakeholders on retained commercial catch and catch rate levels to estimate annual TACC of spanner crabs in managed area A for July 2024 to June 2026. The TACC setting process is outlined in the harvest strategy (Department of Agriculture and Fisheries 2020b).

2 Methods

2.1 Brief

The commercial data was extracted from Fisheries Queensland logbook databases, representing daily commercial spanner crab harvests in kg per fishing operation from 1 January 1988 to 31 December 2023. The data was extracted on 23 February 2024.

All fishery-independent survey data from Queensland, in units of numbers of spanner crab per ground line, were collated for years 2000 to 2023.

Standardised catch-rate indicators, commercial (sCPUE) and survey (sFIS) for managed area A, were estimated for 2000–2023. These catch rates formed the annual indicators of legal sized spanner crab abundance in management area A.

Spanner crab catch rates were standardised using generalised linear models (GLM) (McCullagh et al. 1989). The models were fitted using the programming language R. The importance of individual model terms were assessed formally using F statistics by dropping individual terms from the full models.

Th GLM models employed a quasi-Poisson method. This method assumed a linear mean-variance relationship of the response variable, $E[Y] = \theta Var[Y]$, where $\theta \in \mathbb{R}$ is estimated. This allows for more flexibility than a more traditional Poisson model with a mean-variance relationship of unity (i.e., $E[Y] = Var[Y]$). This flexibility is useful in cases where the data exhibits overdispersion ($Var[Y] > E[Y]$), a common phenomena in ecological abundance data (Lindén et al. 2011).

The GLM models assumed over dispersed Poisson error using a log link function. The GLMs standardised catch rates for temporal and spatial changes in fishing effort, different fishing vessels and aspects of crab catchability such as fishing power.

Predictions of standardised catch rates were formed following the methods from previous spanner crab analyses and reports (Campbell et al. 2016a; O'Neill et al. 2022).

The missing 2020 survey was estimated using the same technique used in the 2022 TACC review (O'Neill et al. 2022).

2.2 In detail

2.2.1 Commercial catch rates

The commercial spanner crab GLM response variable consisted of the daily catch (kg) taken by each fishing-operation (boat). Explanatory model terms included interactions between fishing years and regions, seasonality and region, and the natural logarithm (log) of the number of dilly lifts by type of general fishery permit (GFP).

As well, GLM main effects were fitted for catch rate differences between fishing operations and the lunar cycle.

The same fishing power offset was used as detailed in the previous TACC review (O'Neill et al. 2022). The offset accounted for three variables: skipper experience, use of advanced/integrated computer mapping software, and staying at-sea overnight.

The R equation form of the commercial GLM was:

$$
\begin{aligned}
\text{kg} \sim \exp(&\text{boat} + \text{year} * \text{region} + \text{region} : \text{s1cos} + \text{region} : \text{s1sin} + \text{region} : \text{s2cos} + \text{region} : \text{s2sin} + \\
&\text{region} : \text{s3cos} + \text{region} : \text{s3sin} + \text{gfp} + \text{gfp} : \log(\text{netlifts}) + \\
&\text{lunar} + \text{lunaradv} + \text{offset}(\log(\text{fishingpower})))
\end{aligned}
\tag{2.1}
$$

where the GLM type and variables were:

- *kg*: daily harvest per boat of spanner crab (kg)
- *boat*: authority chain numbers (ACNs) for different boats (factor)
- *year*: calendar year 2000 to 2023 (factor)
- *region*: spatial zones 2 to 6 within management area A (factor)
- *s1 to s3*: six seasonality variables defined by cosine and sine functions (variates)
- *gfp*: fishing under a GFP permit, where yes = 1 and no = 0 (factor)
- *netlifts*: number of net lifts for the boat day (variate)
- *lunar*: luminance measure followed a sinusoidal pattern (variate)
- *lunaradv*: lunar copied and advanced 7 days for a quarter lunar cycle (variate)
- *fishingpower*: annual proportional increase (variate; log transformed and offset)
- *GLM family and link function*: quasi-Poisson and log link

The seasonality of spanner crabs in each region was modelled using sinusoidal data to standardise catch rates for the time of year. The approach reduce the number of parameters in analysis. In total six trigonometric covariates were used (Marriott et al. 2013):

$$
\begin{aligned}
s1cos &= cos(2\pi d_y/T_y),\ s1sin = sin(2\pi d_y/T_y) \\
s2cos &= cos(4\pi d_y/T_y),\ s2sin = sin(4\pi d_y/T_y) \\
s3cos &= cos(6\pi d_y/T_y),\ s3sin = sin(6\pi d_y/T_y)
\end{aligned}
$$

The d_y numbers were the cumulative day of the year $(1 \cdots T_y)$, and T_y was the total number of days in the year (365 or 366 for a leap year). The reason for using cosine and sine data together was similar to modelling lunar phases, where the data operated together in pairs to identify the period in the cycle. The pairs of data were in order such that s1 first tested for a 12-month cycle, s2 for a 6-month cycle, and s3 for a 4-month cycle. The result of combining the three pairs of data quantified the seasonal patterns of spanner crab catch rates (Figure A.8, Appendix A).

The lunar phase (luminance) data was a calculated measure of the moon cycle with values ranging between 0 = new moon and 1 = full moon for each day of the year. The luminance measure (lunar) followed a sinusoidal pattern and was copied and advanced 7 days (for a quarter lunar cycle) into a new variable (lunaradv) to quantify the cosine of the lunar data (O'Neill et al. 2006). The two variables were modelled together to estimate the variation of spanner crab catch rates according to the moon phase (i.e. contrasting waxing and waning patterns of the moon, Figure A.9, Appendix A).

The fishing dates joined the corresponding sinusoidal and lunar data to catch rate data table. The GLM only analysed daily catch reports and removed 'bulk' trip harvests of more than one day. Harvest summaries used all daily and bulk catch data.

The five fishing regions, zones 2 to 6 in management area A south of 23°S, were calculated using latitude and longitude data as follows : region 2 = between 23°S inclusive and 24°S, region 3 = between 24°S inclusive and 25°S, region 4 = between 25°S inclusive and 26.5°S, region 5 = between 26.5°S inclusive and 27.5°S, and region 6 = between 27.5°S inclusive and 28.2°S (Figure A.3, Appendix A). Data outside management area A was excluded.

General fishery permits (GFP) were coded from a table listing the fishing operations using more than 45 dillies. A fishing operation was coded as GFP = 1 if their catch dates were between the GFP start and valid-to dates. If not, then the operation was not fishing with excess gear and coded as non GFP = 0.

GFP allocations finished 1 January 2020. Post GFP, and to be consistent with the previous factor coding, operations using up to 45 dillies were coded as non GFP, and those using between 46 and 75 dillies were factored as GFP. The GFP factor was interacted with the log of fishing effort: log(number of dilly-lifts).

In 2012, fishers highlighted a catch rate bias to the department due to the discarding of legal sized crabs, which led to the formation of a working group to investigate the issue (Brown 2013). Consequently, adjustments were made to the spanner crab logbook by mid-2012 to address discrepancies where the reported kilograms of legal catches did not align with the actual amount landed. The key modification in logbook SC06 included a mechanism for estimating the quantity of legal crabs discarded on days when a buyer imposed a landing limit.

It was thus important to remember that discards reported in logbook versions prior to SC06 referred to undersized crab. While, discards in logbooks from SC06 and after refer exclusively to legal sized crab.

To account for the phase-in time to introduce the SC06 logbook, and, as a result, mixed reporting of legal and undersized discards in regions 4 and 5, the following procedure was used to adjust catch weights, described in Brown (2013) and Campbell et al. (2016b):

- Catch records in the 2009-10 financial year, from 01/07/2009, for regions 4 and 5 were adjusted upward by a factor of 1.1543.
- Likewise for regions 4 and 5, in the 2010-11 financial year, the adjustment factor was 1.3073.
- The estimated high-grading gradually declined between 01/07/2011 and 30/09/2012 (in regions 4 and 5 only), and was linearly modelled ($Y = a + bX$) with parameters $a = 0.7414$ and $b = -0.0181$, and Y was the ratio of estimated discards to landings and X the sequential month number commencing from July 2011.
- Catches reported on logbook version SC06 and after were calculated as the sum of the reported catches and discards.
- Logbook versions prior to SC06 in the same period 'catches' were scaled up by the monthly means from SC06 (i.e. multiplied by 1.0491 and 1.0635 respectively).

Further consideration for the commercial data was the pooling of 'multiple set' records. Some fishers occasionally reported separate catch and effort statistics for two or more fishing sets on a given day. As the lowest level of temporal separation in analysis was a fishing operation day, these records were pooled. This was done by summing the catches and efforts over all fishing sets on the fishing operation day. Fishing grids were selected using a first command.

From the GLM, standardised catch rates were formed following GenStat's PREDICT procedure (VSN International 2021). This was done in R by using two steps, to ensure consistency with previous analyses and reports spatial averaging and averaging the appropriate way over levels of factors. Prediction of a full interaction table was formed in step A. Secondly this table was then averaged in step B.

The first step A, was to calculate the full table of predictions using R's PREDICT command, classified by every factor in the GLM. For any variate in the model, the predictions were formed at its mean, unless they were specified for the prediction table. If so, the variate values were then taken as a further classification of the full table of predictions. By default, the predictions were made to the last year of the log fishing power offset.

The second step B, was to average the full table of predictions from step A. Factors that were not specified in prediction, were averaged by what was called marginal weights applied to each factor level. That was, by the number of data occurrences, scaled to proportions, of each of it's factor levels in the whole dataset. This averaging is the appropriate statistical way of combining predicted values over levels of a factor (VSN International 2021).

The resulting predictions from step B were standardised kg per boat-day (the logbook reporting unit). Units of kg per dilly-lift, used by the harvest strategy, were calculated by standardising for the mean log dilly-lifts per boat-day used in analysis (= 255 dilly-lifts per boat-day):

$$\text{kgperdillylift} = \exp(\log(\text{kgperboatday}) - \log(\text{mean}(\text{dillyliftsperboatday}))) \tag{2.2}$$

A demonstration of the code used to predict standardised catch rates can be found in the previous review, O'Neill et al. (2022, Table 2.2).

2.2.2 Survey catch rates

Since 2000, annual fishery independent surveys (FIS) of spanner crab were conducted in Queensland waters during May, except for 2004, 2012 and 2020. Catch rate measures of abundance were collected from 25 areas (6 × 6 minute grids) across the fishery (Figure A.3); 5 areas per region. In all, 15 individual ground-lines (the sampling units), each consisting of ten dilly nets, were set in each area. The net soak times, typically 40–60 minutes, with the number of spanner crabs caught, their sex, and size (rostral carapace length cm) were recorded.

In 2023, in Region 4, two aspects of the FIS changed: 1) sampling was delayed and extended into June, and 2) a different vessel and skipper were employed. Historically, similar vessels had been used in each region to ensure continuity. Any effects of this change, if present, were not detected. Survey methodology and gear remained consistent.

The survey spanner crab GLM response variable consisted of the number of legal crab per ground-line. Explanatory model terms included the interaction between years and regions, plus the log of the number of net hours (soak time) per ground-line.

The R equation for the survey GLM was:

$$\text{NumLegalSize} \sim \exp(\text{year} * \text{region} + \log(\text{nethours})) \tag{2.3}$$

where the GLM type and variables were:

- *NumLegalSize*: number of legal sized crab per ground-line (number)
- *year*: calendar year 2000 to 2023 (factor)
- *region*: spatial zones 2 to 6 within management area A (factor)

- *nethours*: hours soak time for the ground-line (variate)
- *GLM family and link function*: Over dispersed (quasi) poisson and log link

From the survey GLM, standardised catch rates were formed following GenStat's PREDICT procedure (VSN International 2021).

2.2.3 TACC

Performance indicators

Two annual indicators were selected in the harvest strategy to describe fishery performance in managed area A:

- standardised catch rate of legal-sized spanner crabs from commercial fishing (labelled: sCPUE).
- standardised catch rate of legal-sized spanner crabs from survey fishing (labelled: sFIS).

The harvest strategy averaged the annual sCPUE and sFIS from two years, and then converted into a 'stock index' ratio by dividing by their respective target catch rate. The stock index ratios were then averaged together into a 'pooled index'. This was used to inform the TACC, for the reference points in Table 2.1.

Target catch rates

The target catch rates for sCPUE and sFIS were set at 95% of the average of the reference years, 2006–2010. The harvest strategy aim was to return spanner crab catch rates to more profitable levels experienced during the reference years. These years were when the harvest strategy assumed the spanner crab legal stock was near 60% biomass, and this aligned to the target reference point in the Queensland Sustainable Fisheries Strategy: 2017–2027 (Department of Agriculture and Fisheries 2017).

Table 2.1: Performance indicators and reference points.

Aspect	Reference point	Reference level
Standardised commercial catch rate of spanner crabs in kilogram per dilly lift (sCPUE)	Target reference point proxy for 60% biomass	95% of the 2006–2010 average standardised catch rate
Catch rate of spanner crabs from the standardised fishery independent survey in legal crabs per ground line (sFIS)	Target reference point proxy for 60% biomass	95% of the 2006–2010 average standardised catch rate
sCPUE of spanner crabs averaged over two consecutive years	Limit reference point proxy for 20% biomass	0.5 kg per dilly lift
Pooled index – average of the sCPUE and sFIS stock index ratios	Target reference point	1
TACC	TACC upper limit	1300 tonnes
TACC	TACC minimum if above limit reference point	300 tonnes
TACC	Minimum change buffer	50 tonnes
TACC	Maximum change buffer	200 tonnes

Missing indicators

In May 2020 no FIS was conducted due to COVID-19. However, the harvest strategy required the average FIS catch rate from two years: mean(sFIS_{2020} and sFIS_{2021}). For this reason, the missing sFIS_{2020} required an estimate. The same log 'proportional gap' estimation method detailed in the previous TACC review was used (O'Neill et al. 2022).

The method assumed the annual survey catch rate sFIS was proportional to annual commercial sCPUE (correlation $\approx$ 0.71), based on mean log differences between sFIS and sCPUE. The method was a log variant of the proportional gap scheme (Filar et al. 2021a):

$$\begin{aligned} \text{sFIS}_{2020} &= \exp(\log(\text{sCPUE}_{2020}) + \omega), \text{where the mean } \omega \text{ was} \\ \omega &= 0.5 \sum_{i=2019,2021} \log(\text{sFIS}_i) - \log(\text{sCPUE}_i) \end{aligned} \tag{2.4}$$

The equations steps were:

1. Calculate differences log(sFIS) - log(sCPUE) for 2019 and 2021.
2. Average the two values from step 1.
3. Exponential back-transform log(sCPUE_{2020}) plus step 2.

3 Results and discussion

3.1 Commercial catch rates

Figure 3.1 shows the annual commercial standardised catch rate of spanner crab since 2000 in managed area A. The results were:

- Catch rates experienced various trends: an initial increase from 2000–2008, a decline from 2009–2017, followed by an increase from 2018–2020, and then a slight decline in 2021, stabilising from 2021–2023.
- The magnitude of the decline in catch rate from 2009–2017 was near 60%.
- Between 2000 and 2017, the fishing power offset increased by about 12% ± 4% for the 95% confidence interval (Figure 3.2).
- The measures of statistical error on the mean catch rates was a coefficient of variation CV of ≈ 4–5%, and 95% confidence intervals about ± 0.1 kg (Figure 3.1). The low error-precision in standardised catch rates was sufficient for use in the harvest strategy.
- In general, over the years since 2000, the GLM predicted higher catch rates associated with Spring and Autumn (Figure A.8), on the waxing moon phase (Figure A.9), and for region 4 of the fishery (Figure A.4). These figures were presented in Appendix A.
- In 2023, regional catch rates varied, with some regions experiencing increases and others decreases when compared to 2022. Despite these variations, a general downward trend in catch rates across all regions has been observed since approximately 2009. The magnitude of this decline varies across regions, highlighting the importance of continuous monitoring across regions and adaptive management strategies (Figure A.4).
- The plot of the model residuals appeared satisfactory to show no lack of model fit (Figure A.5, Appendix A).
- The model percentage of mean deviance accounted for was 55%, with a dispersion of 77 kg.
- Nominal fishery statistics are summarised in Appendix C.

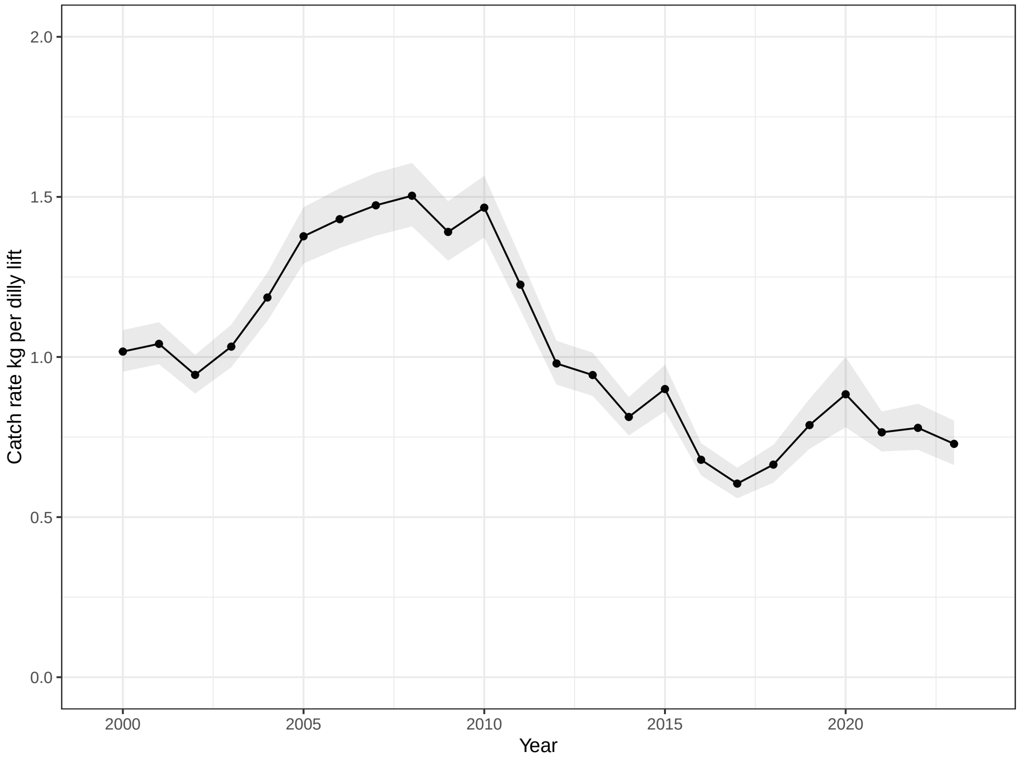

Figure 3.1: Standardised commercial catch rates (sCPUE) of spanner crab by year for managed area A. The ribbon shading illustrated the 95 percent CI.

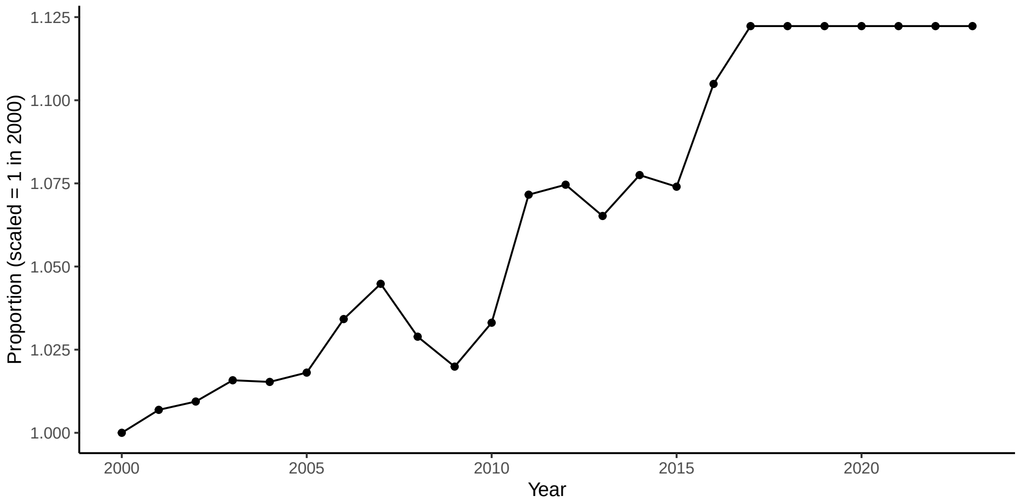

Figure 3.2: Fishing power applied in the commercial catch rate standardisation. Values since 2017 were unchanged.

3.2 Survey catch rates

Figure 3.3 illustrated the survey standardised catch rate of legal-sized spanner crabs since 2000 in managed area A. Analysis results showed:

- Survey ground-lines showed a success rate of 66% in catching legal-sized crabs across all years, with variations between years. Success rates ranged from 62–81% from 2000 to 2016, then decreased to 46–59% from 2017 to 2023, indicating a notable decline in catches of legal-sized crabs in the recent period.

- Survey catch rates exhibited fluctuating trends, with an increase observed from 2000–2008, followed by variable rates between 2009 and 2016, and a decrease to around 6 legal crabs per ground line from 2021–2023. The year 2023 recorded the lowest catch rate since the beginning of the surveys.
- The catch rate decline post-2015 was approximately 33%, with region 3 consistently recording low catch rates (Figure B.1).
- Residuals appeared satisfactory (Figure B.2, Appendix B).
- The model percentage of mean deviance accounted for was 30.4%, with a dispersion of 10.6 crabs.
- Statistical error metrics for the mean catch rates, including a CV of approximately 13% and 95% confidence intervals of approximately ± 2 crabs, were presented in Figure 3.3. The low error-precision in standardised catch rates was sufficient for use in the harvest strategy.

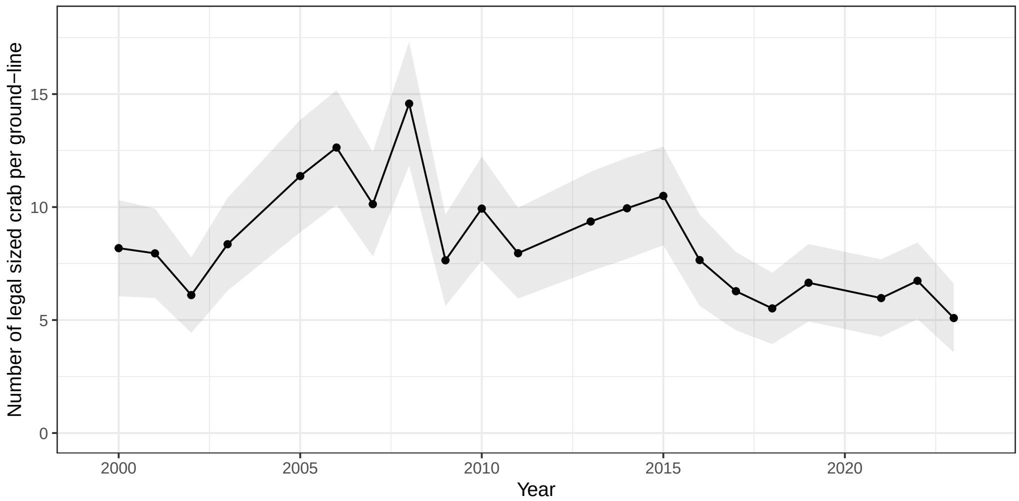

Figure 3.3: Survey standardised catch rates (sFIS) of spanner crab by year for managed area A.

3.3 TACC

The spanner crab harvest strategy sets out decision rules to determine the appropriate level of commercial harvest. This was based on the status of two spanner crab catch rate indicators, labelled sCPUE for commercial standardised catch rates and sFIS for the survey standardised catch rates.

The calculated TACC results were as follows:

2023–2024 TACC: 847 t

Catch rate targets: Target sCPUE = 1.38 kg per dilly lift and target sFIS = 10.435 crabs per ground-line. In Table 3.1.

Catch rate indicators: The 2022–2023 averages were: sCPUE = 0.754 kg per dilly lift and sFIS = 5.913 crabs per ground-line. In Table 3.1.

Stock indices: The stock index was the ratio of the indicator compared to the target. The calculated indices for 2022–2023 were: sCPUE = 0.546 and sFIS = 0.567. In Table 3.1.

Pooled index: The 2022–2023 pooled index was 0.556, being the average of the two stock index ratios. The pooled index indicates that the fishery was at 56% of its target in 2023. In Table 3.2.

Recommended new TACC for 2024–2025 and 2025–2026: By referencing the indicators against the decision rules (Table 2.1 and Appendix D), the following annual TACC was calculated: 797 t.

Table 3.1: TACC indicators.

Indicator	sCPUE	sFIS
Year 2020	0.884	7.177
Year 2021	0.765	5.972
Year 2022	0.779	6.737
Year 2023	0.729	5.089
2020 - 2021 mean	0.824	6.575
2021 - 2022 mean	0.772	6.355
2022 - 2023 mean	0.754	5.913
Target ref pt, 95% 2006 - 2010	1.380	10.435
2020 - 2021 mean stock index	0.597	0.630
2021 - 2022 mean stock index	0.559	0.609
2022 - 2023 mean stock index	0.546	0.567

Table 3.2: TACC pooled index and result.

Indicator	Result
Year 2021 pooled index	0.614
Year 2022 pooled index	0.584
Year 2023 pooled index	0.556
Rule 3.1, close MAA	No
Rules 1., increase TACC	No
Rules 2., decrease TACC	Yes
Rule 4.2, TACC change within 50 tonnes	Yes
Rule 5.1, 3 yr trend in pooled index	Yes
Rule 5.2, 40% decrease in regional sCPUE	No
New TACC tonnes	797

The TACC of spanner crab in management area A was calculated at 797 t, following Rule 5.1 of the harvest strategy. This rule was activated due to a three-year consecutive decline in the pooled index.

This result was influenced by the high sCPUE in 2020 and it's influence on the estimated sFIS in 2020. The magnitude of the three declines in the pooled index was however, marginal.

Retroactively applying either the mean or the median of the sFIS values from 2019 and 2021 to estimate the missing sFIS for 2020 would still result in the activation of Rule 5.1.

The TACC rules included revised reference points as defined in the harvest strategy, to improve sustainable stock management. They were generated from standardisation of catch rates and MSE tested (O'Neill et al. 2010; O'Neill 2015; Department of Agriculture and Fisheries 2020b; O'Neill et al. 2022). For Queensland spanner crabs, the new reference points were successfully brought together in the harvest strategy that permitted simple and rapid quota setting.

Ongoing review and checks on standardised catch rates are recommended to ensure reliable and sustainable fishery. Aspects of note to check and improve future analysis were:

- New fishing power data or offset is required for 2017 onwards. Data pre 2017 chronicles the history of change in fishing vessels, skippers and technologies (O'Neill et al. 2022). Ideally, the collection of updated data on relevant fishing technologies could verify gear related fishing-power assumptions (via annual fishing gear log). An alternative to collecting gear data from fishers, might be to review and update the annual gear fishing-power offset with insights from the fishery working group.
- The use of logbook authority chain number (ACN) as a 'boat' identifying term in the commercial analysis generated many parameters. The high number of ACNs has caused some aliasing when testing certain model-term interactions. This leads to difficulties when predicting finer scale catch rates by each region, year and season. The number of boats (ACNs) in the analysis now totals 273. Modelling of ACNs as random effects or simplifying their factor coding to fewer levels should be tested.
- More aspects on crab catchability should be tested in the standardisation. This includes information on daily average wind speed and direction, sea current speed and direction, swell height, and cross latitude-longitude environmental aspects associated to crab catchability (Filar et al. 2021b).
- The correlation between crab catchability, recruitment, and various oceanic and climate-related indices—including El Niño, chlorophyll concentration (indicative of upwelling), sea level anomalies, and temperature—has been researched (Filar et al. 2021b). While this study has found correlations, the potential changes in these phenomena due to climate change and their subsequent positive or negative impacts on the fishery fall outside this report's scope. Nevertheless, it is clear that climate driven changes in environmental factors might play a crucial role in influencing the fishery's future.
- Herein, over dispersed Poisson GLMs were used to pragmatically analyse and predict standardised catch rates. This was effective, but the performance of the Poisson GLMs should be monitored. Other methods have been tested in the past, such as using hierarchical generalised mixed models (O'Neill 2015; VSN International 2021) or two component models (Campbell et al. 2016b) to improve goodness of fit statistics and better account for the annual changes in frequency of zero or small catches. However, the use of such models in R might be complicated and need custom prediction code.
- As noted in methods, the number of steps in the 2012 and 2013 catch adjustments for discarding legal crab were complex. This should be reviewed and simplified. In addition, unload reports (catch disposal records: CDR) should be used to verify logbook harvest tonnages and/or catch rates where available. CDR reports were only recently available, and any catch adjustments suggested by the data should be reviewed to ensure time series consistency and no bias.
- A formal stock model should be researched and management strategy evaluation (MSE) tested, building in the BDO economic data for MEY calculations. This could act as a complimentary tool to monitor biomass trend and allow reference point checks for future harvest strategies beyond 2025. Also, ongoing complimentary modelling can add to the support, like in the last harvest strategy review for staying within a empirical catch rate framework to maintain understandings and learning's that have been built so far. Example stock models were presented to the working group in 2018, and a model was published by Filar et al. (2021b). To facilitate development, an MSE can support stock model decisions in how to deal with uncertainties in spanner crab longevity and natural mortality. An MSE simulation model was developed for testing the new harvest strategy, and can be extended to pipe simulation data into a stock assessment model.

In summary, indices across regions were generally below target catch rates. Annual harvests in the last four years were less than the TACC (Figure C.1). The next two years of monitoring stock indices are important, as the harvest strategy will expire after 2025. If stock indices do not improve, then additional scientific work might be required to review methods, target indicators, and management procedures.

3.4 New South Wales Spanner Crab Fishery

This section outlines recent developments within the New South Wales spanner crab fishery.

In August 2023, NSW implemented a new spanner crab harvest strategy with the goal of maintaining sustainable stocks through cooperation with Queensland (Department of Regional NSW 2023). The strategy employs the sFIS indicator for standardised catch rates, leveraging data from fishery-independent surveys conducted across both states.

Subsequent to the implementation of this strategy, the Total Allowable Fishing Committee (TAFC) established the NSW TACC at 100 t for the 2023–24 fishing period (New South Wales Total Allowable Fishing Committee 2023). This represented a decrease from the 135 t quota set in 2020–21 (NSW Department of Primary Industries 2021).

Observations indicate that recent landings in NSW have consistently been below this adjusted quota (Johnson 2023). This scenario, alongside TAFC's recognition of the potential need for further adjustments to the TACC, highlights the ongoing challenges in managing spanner crab populations effectively. To address these issues, the TAFC has called for enhancement of management dialogue between NSW and QLD to better harmonise their harvest strategies (New South Wales Total Allowable Fishing Committee 2023).

Reinforcing the necessity for a collaborative approach, recent research highlights substantial connectivity between QLD and NSW spanner crab stocks, attributed to pelagic larval dispersal driven primarily by the East Australian Current (Schilling et al. 2022). This research suggests that recruitment within NSW and the southern QLD regions is dependent on larval influx from the north, with northern regions being largely self-recruiting. The study stresses the importance of adopting cooperative interstate management strategies.

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A Appendix - Commercial catch rates

Figures A.1, A.2 and A.3 show maps of the managed areas and fishing regions.

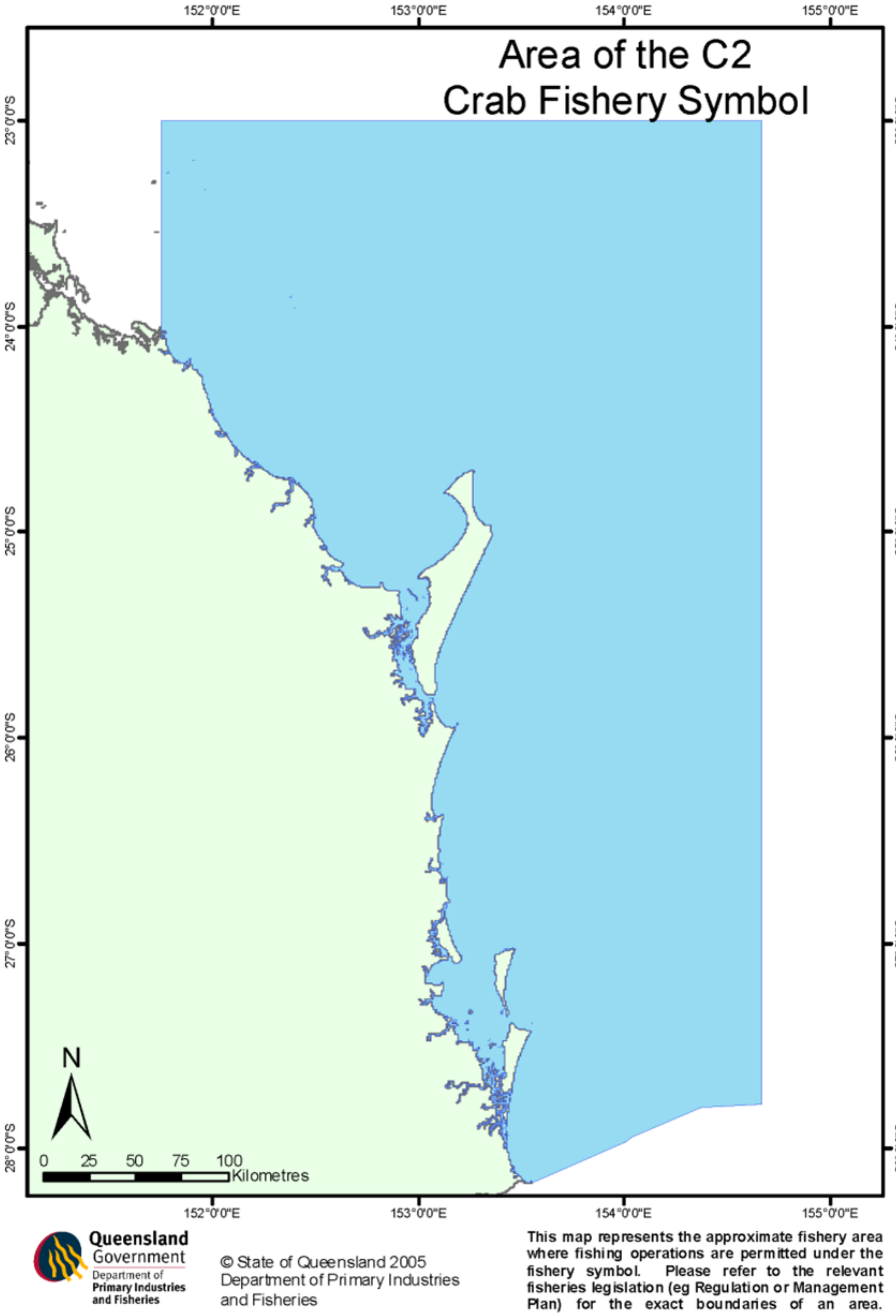

Figure A.1: Spanner crab managed area A for a C2 spanner crab licence.

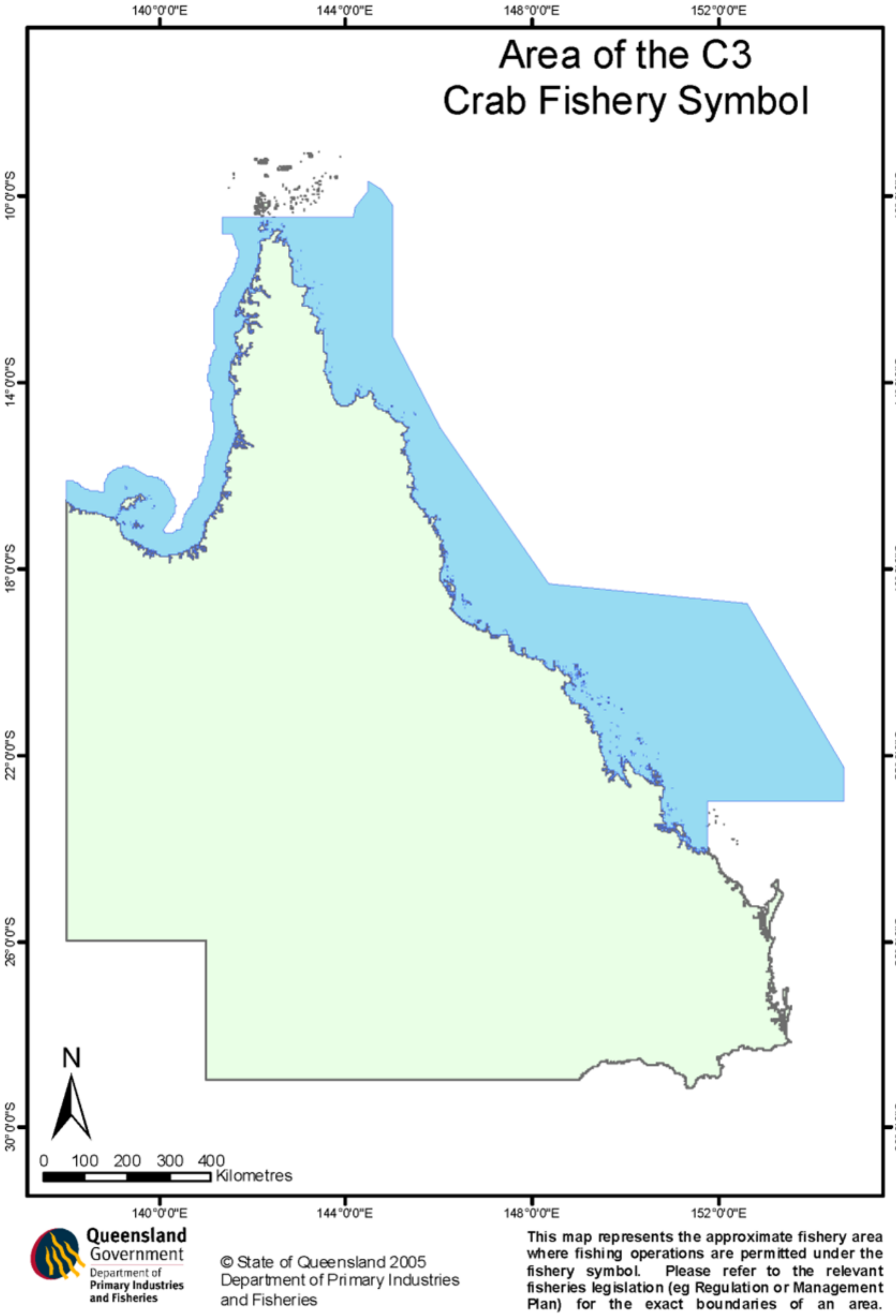

Figure A.2: Spanner crab managed area B for a C3 spanner crab licence.

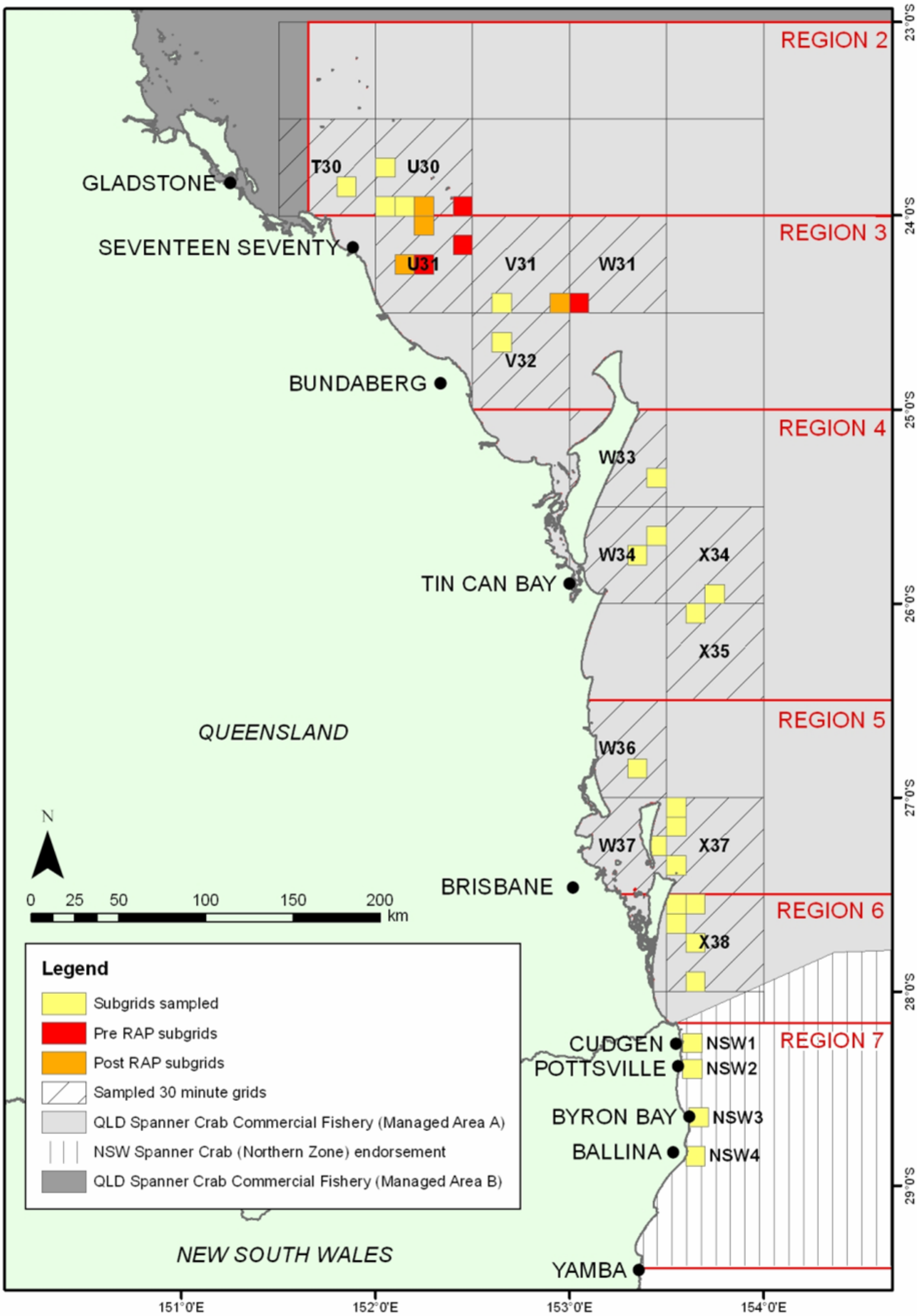

Figure A.3: Chart of the spanner crab fishery, showing the location of fixed 30 x 30 minute grids within regions and fixed 6 minute subgrids within grids for the extended monitoring (FIS) survey.

Regional catch rates in 2023 showed an upturn in region 3, steady and low in regions 2 and 4, and downturns in regions 5 and 6,Figure A.4.

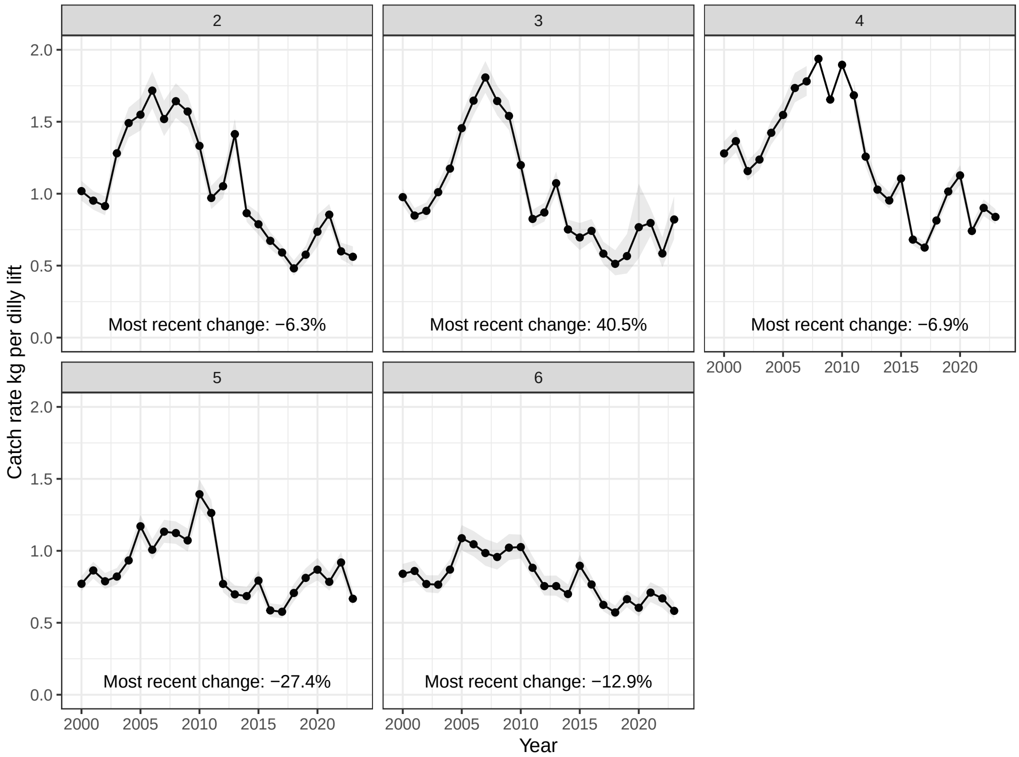

Figure A.4: Standardised commercial catch rates (sCPUE) of spanner crab by year and regions 2 to 6 for managed area A. Annotations denote the percentage change from the previous year.

An analysis of variance table, A.1, showing the model terms and their statistical significance. The table generated by dropping model terms from the full model (R procedure: drop1). The residual degrees of freedom was 97903.

Table A.1: Analysis of variance table for the commercial catch rate (sCPUE) analysis. Model term significance was p ¡ 0.001, except for lunar. F statistics were derived from the R drop1 procedure.

term	Df	Deviance	F value	Pr(>F)
residual	97903	7543192		
boat	275	8921294	65.041	0.000
lunar	1	7543233	0.529	0.467
lunaradv	1	7548832	73.199	0.000
year:region	92	7861495	44.905	0.000
region:c12	5	7830069	744.675	0.000
region:cs12	5	7715800	448.056	0.000
region:c6	5	8007399	1204.989	0.000
region:cs6	5	7599245	145.503	0.000
region:c4	5	7570645	71.264	0.000
region:cs4	5	7569087	67.219	0.000
gfpid:potliftslog	2	8730784	7706.872	0.000

The residuals showed an acceptable model fit, Figure A.5. There were few large residuals below -1 and above 1, relative to the total number of data. The residuals were standardised by the fitted values, called ”working” residuals in R. Working residuals were sufficient to illustrate goodness-of-fit, given the broad range of small and large catches per boat-day and units in kg. The boxplot illustrated the interquartile range of the data, so that the middle 50% of the data lie within the box, with a horizontal line indicating the median residual near zero. The vertical lines extended to a distance of 1.5 times the interquartile range. Outlying residuals were plotted with a circle symbol.

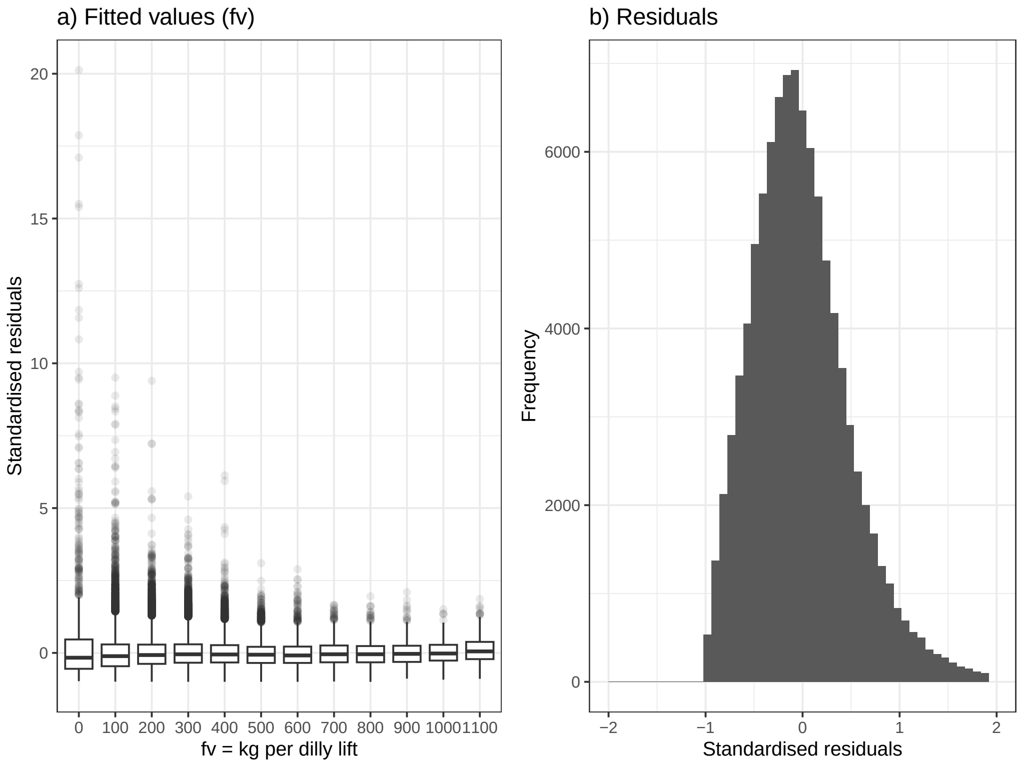

Figure A.5: sCPUE goodness of fit plots for a) box plot of fitted values and residuals, and b) histogram of residuals. Fitted values > 1000 were grouped.

Figure A.6, Influence plot illustrating the key boat and fishing power effects on sCPUE.

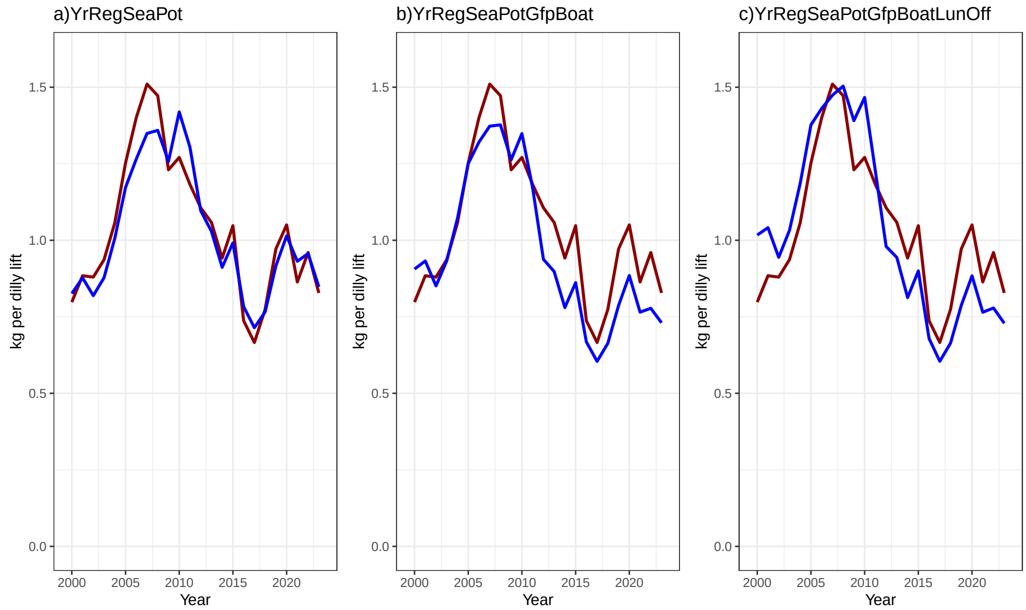

Figure A.6: Influence plot comparing the effects on sCPUE against the nominal mean catch rate (red line). Subplot a) compares sCPUE for a year (Yr), region (Reg), seasonality (Sea) and dilly lifts (Pot) model; b) compares sCPUE for a year, region, seasonality, dilly lifts, GFP and boat model; c) compares sCPUE for the full standardisation model by adding lunar (Lun) and the fishing power offset (Off).

Figure A.7, The fleet-average fishing-power measure jumped and declined over the 2020–2023 period.

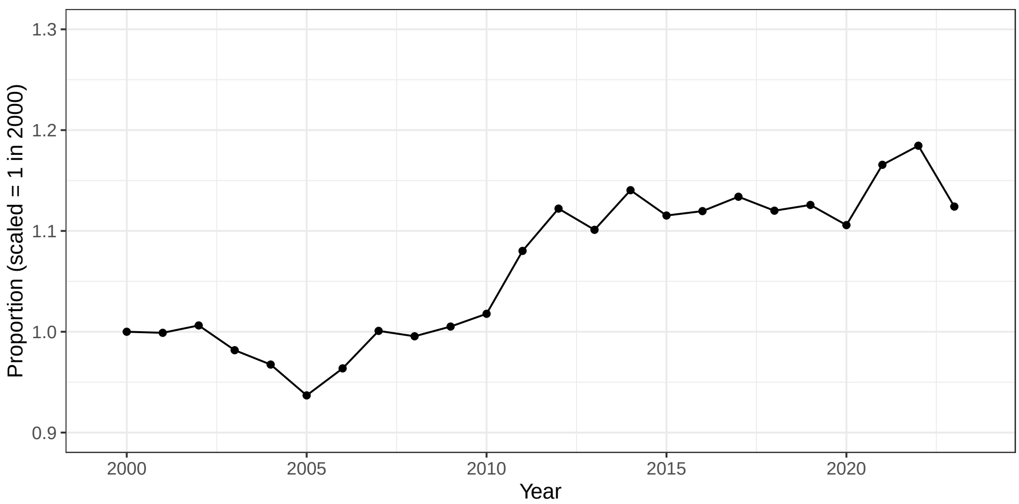

Figure A.7: Relative average boat fishing power by year as estimated from the GLM boat factor.

Figure A.8, The seasonal co-variate variables modelled the monthly trends in each region well.

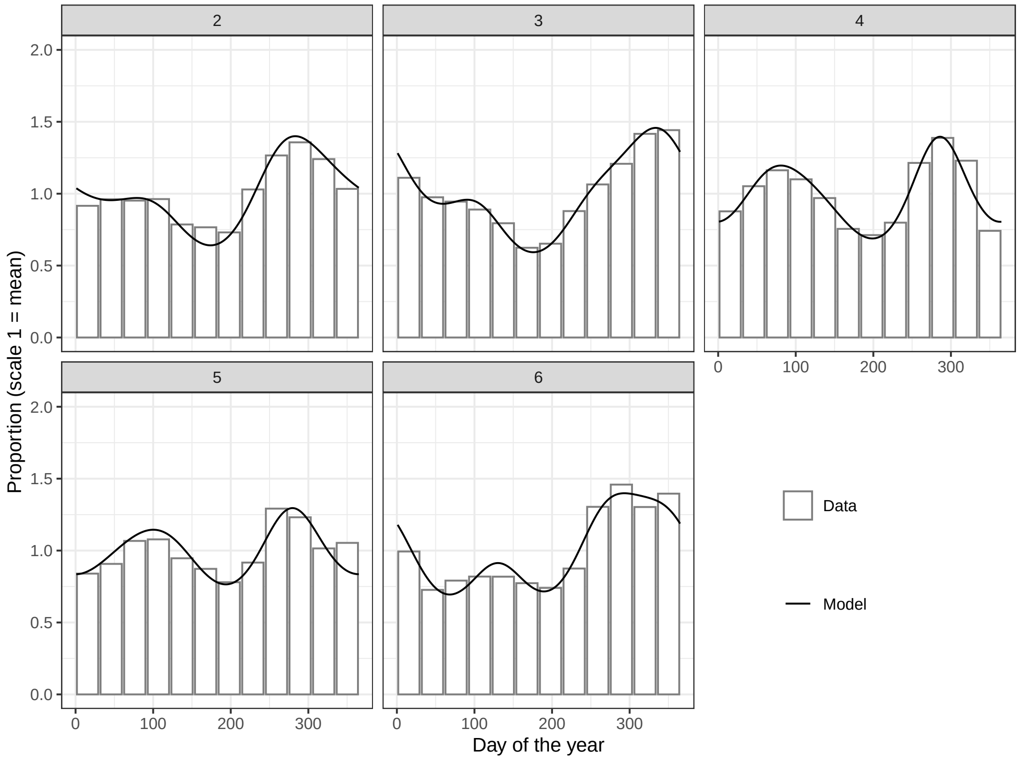

Figure A.8: Relative sCPUE by time-of-year and regions 2 to 6 for managed area A. The bar graph illustrates the monthly average, and the model fit (line) matched this well.

Figure A.9, Lunar cycle was associated with sCPUE, but the magnitude was small. The result showed that a mean catch rate could vary by about 4% between the waxing and waning moon phases.

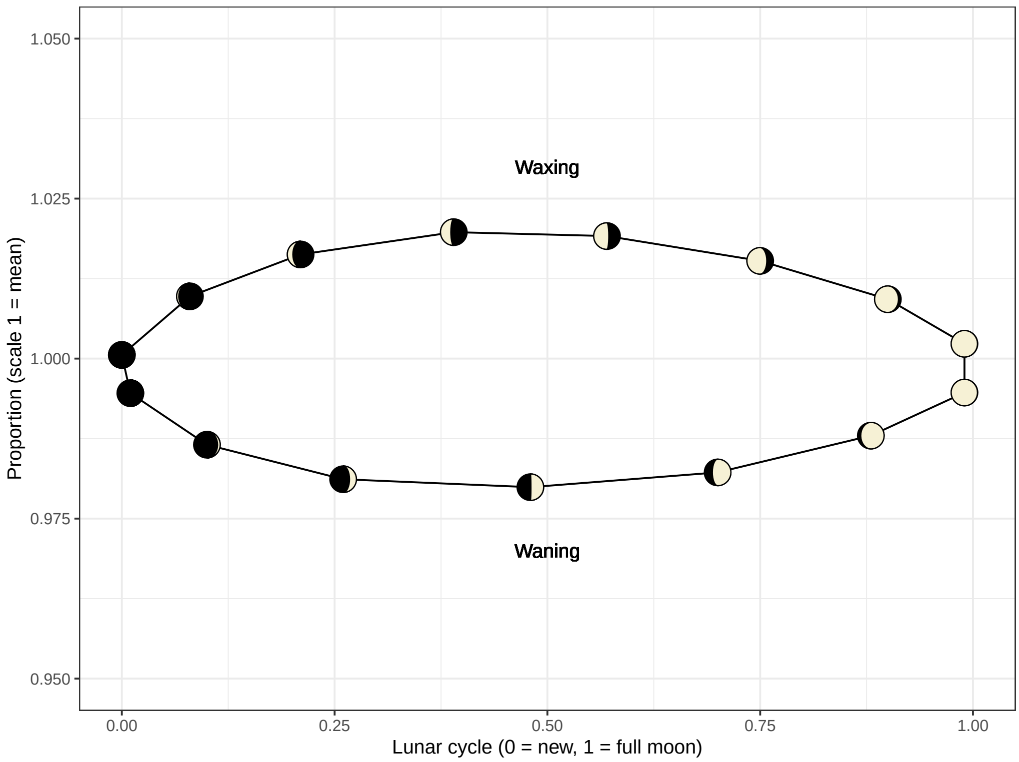

Figure A.9: Relative catch rate by lunar cycle.

Figure A.10, The allowance of general fishery permits (GFP) introduced a cryptic per-dilly-lift relationship. The figure showed the transition to use more dillies. This improved the catch per boat-day, but the catch rate per dilly-lift was less. Catch and dilly-lifts per boat-day were not proportional, with parameter estimates for non GFP gfpid0:potliftslog = 0.583, and for GFP gfpid1:potliftslog = 0.685.

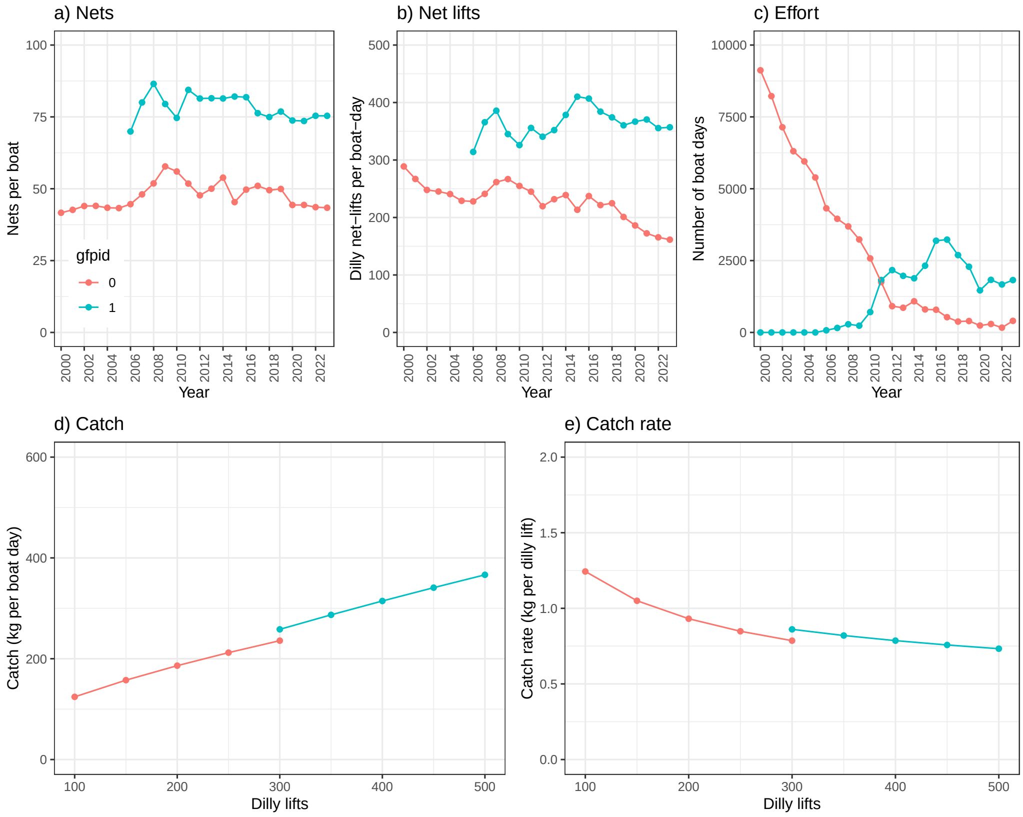

Figure A.10: Influence plot comparing the net lift effects by GFP on sCPUE. Subplot a) mean number of nets per boat by year; b) mean number of net lifts per boat-day by year; c) nominal total effort by year; d) mean catch per boat day relationship; e) mean catch rate by dilly lift relationship.

B Appendix - Survey catch rates

Appendix B presents supplementary figures and tables to detail the survey catch rate (sFIS) results.

Figure B.1, Regional catch rates for 2023 have mostly remained low. Region 4 did experience a downturn although there is more variance in region 4's survey catch rates.

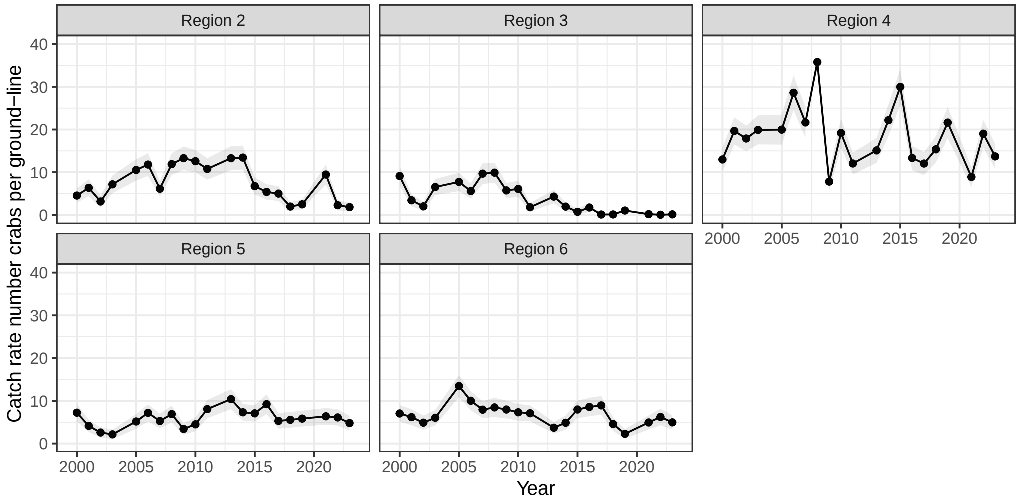

Figure B.1: Standardised survey catch rates (sFIS) of legal sized spanner crab by year and region for managed area A.

Table B.1, The survey nominal catch statistics per year showed the FIS caught fewer crab in total since 2017 and reduced catch rate (CatchLegalMean: number of crabs per ground-line).

Table B.1: Catch statistics for the fishery independent survey. Units for CatchLegalMean = number of crabs per ground-line, else the units were total numbers of crab. MLS = 10 cm.

SamplingYear	Catch	CatchLegal	CatchUnderSize	CatchLegalMean
2000	5630	3093	2537	8.248
2001	5494	3243	2251	8.648
2002	3788	2544	1244	6.784
2003	5071	3169	1902	8.451
2005	7537	4356	3181	11.616
2006	8135	4912	3223	13.099
2007	6963	3852	3111	10.272
2008	9040	5453	3587	14.541
2009	5636	2946	2690	7.753
2010	6972	3755	3217	10.013
2011	7500	3171	4329	8.479
2013	7400	3639	3761	9.704
2014	7457	3683	3774	9.821
2015	7372	3941	3431	10.537
2016	6936	2854	4082	7.611
2017	4579	2337	2242	6.232
2018	4405	1968	2437	5.248
2019	4760	2403	2357	6.391
2021	4253	2222	2031	5.925
2022	4638	2526	2112	6.736
2023	3398	1838	1560	4.901

Table B.2, Analysis of variance showing the model terms and their statistical significance. The table was generated by dropping model terms from the full model (R procedure: drop1). All model terms were significant. The residual degrees of freedom was 7773.

Table B.2: Analysis of variance table for the FIS catch rate analysis. Model term significance was $p < 0.001$. F statistics were derived from the R drop1 procedure.

term	Df	Deviance	F value	Pr(>F)
residual	7773	82281		
lognethrs	1	83782	141.828	0.000
year:region	80	92219	11.735	0.000

Figure B.2, The residuals showed an general acceptable model fit. The residuals were mostly between -2 and 2, relative to the total number of data. The residuals were standardised by the square-root of the dispersion factor and standard error of the fitted values, called ”deviance” residuals. Deviance residuals were shown as count data were analysed, with the range of counts generally small with a median catch rate per ground-line equal to 3 crabs, with a number of zero catches (34%).

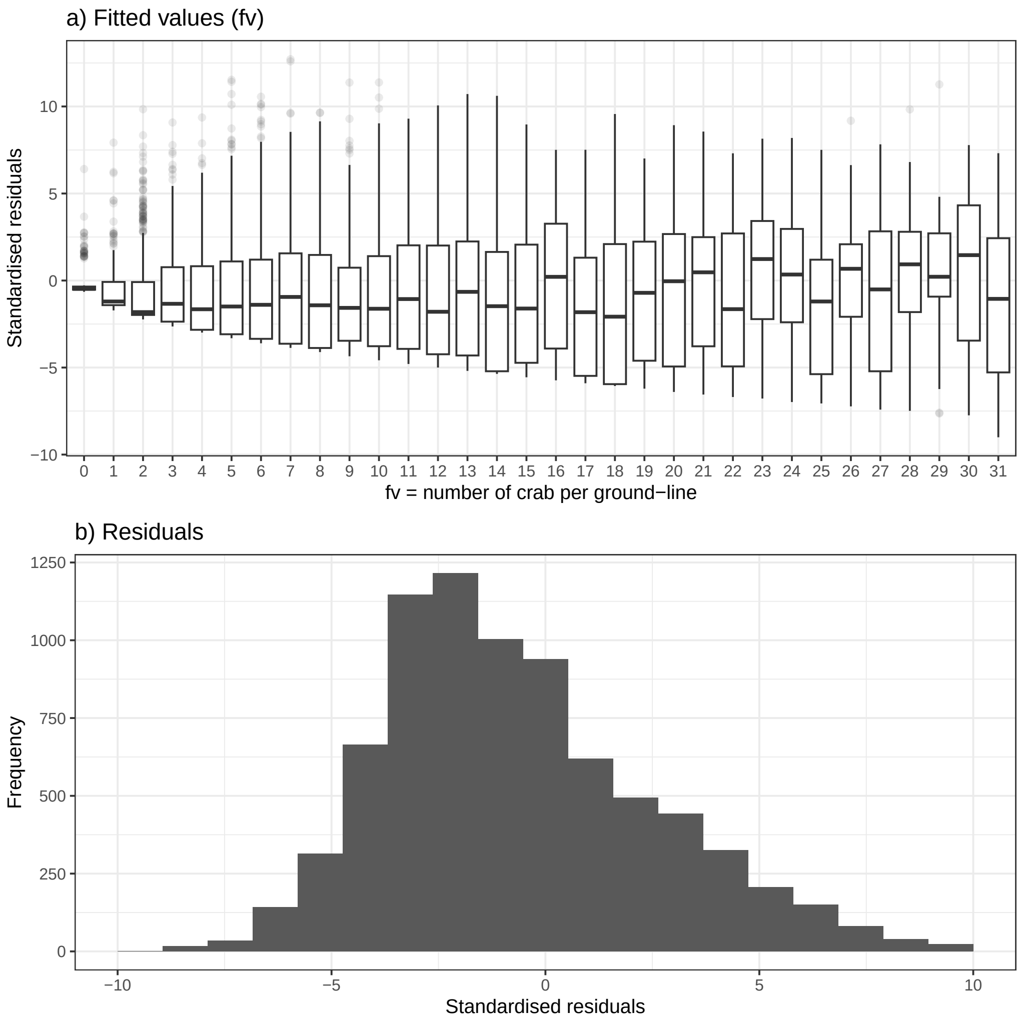

Figure B.2: sFIS goodness of fit plots for a) box plot of fitted values and residuals, and b) histogram of residuals. Fitted values > 30 were grouped.

C Appendix - Harvest summary

The total reported harvest was 596.5 t and 592.3 t for 2022 and 2023, respectively (Table C.1 and Figure C.1).

The 2022 and 2023 harvest resulted from 621.3 and 715.4 thousand net-lifts (Figure C.2), by 36 and 40 vessels respectively (Table C.1).

In the last four years, higher nominal catch rates in region 4 attracted more fishing effort and vessels (Table C.2). No fishing occurred in managed area B.

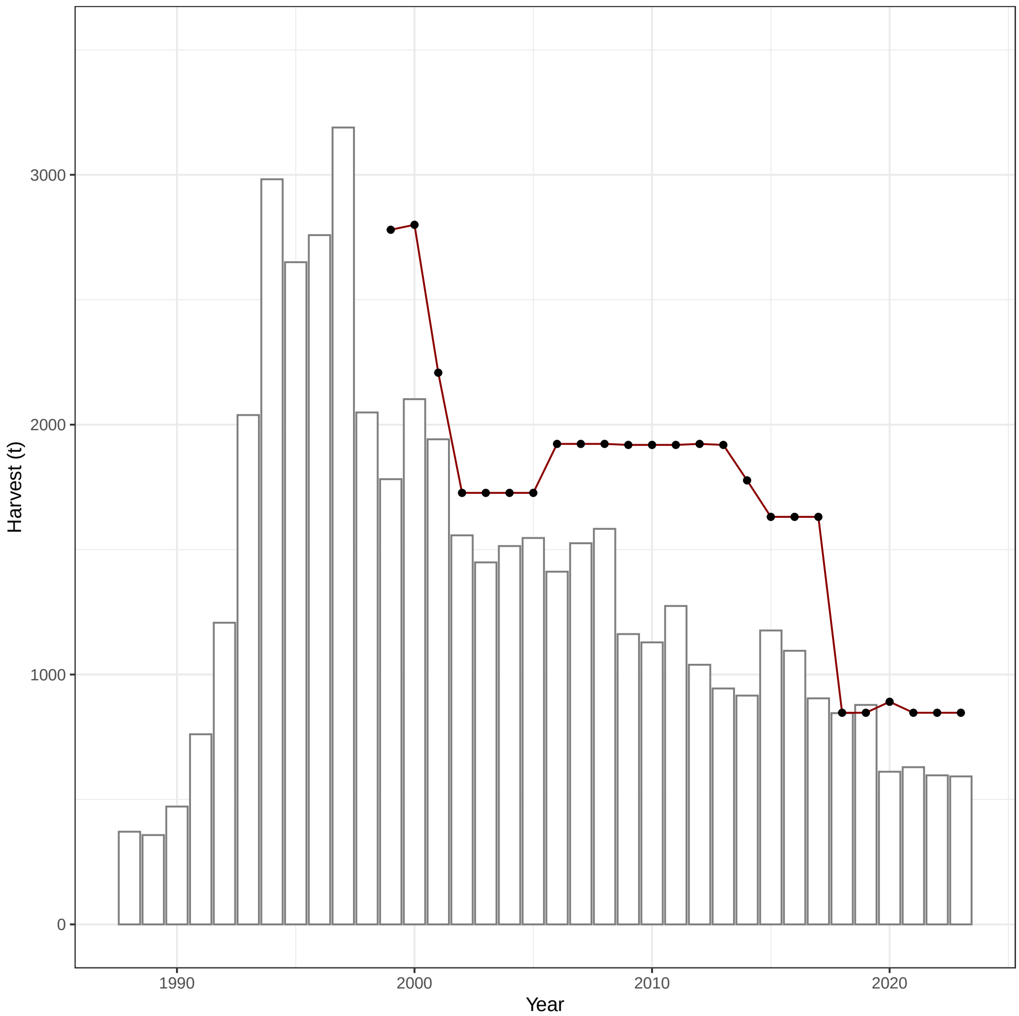

Figure C.1: Annual spanner crab harvest landings (tonnes) from managed area A (bar graph), compared against the TACC settings (line graph).

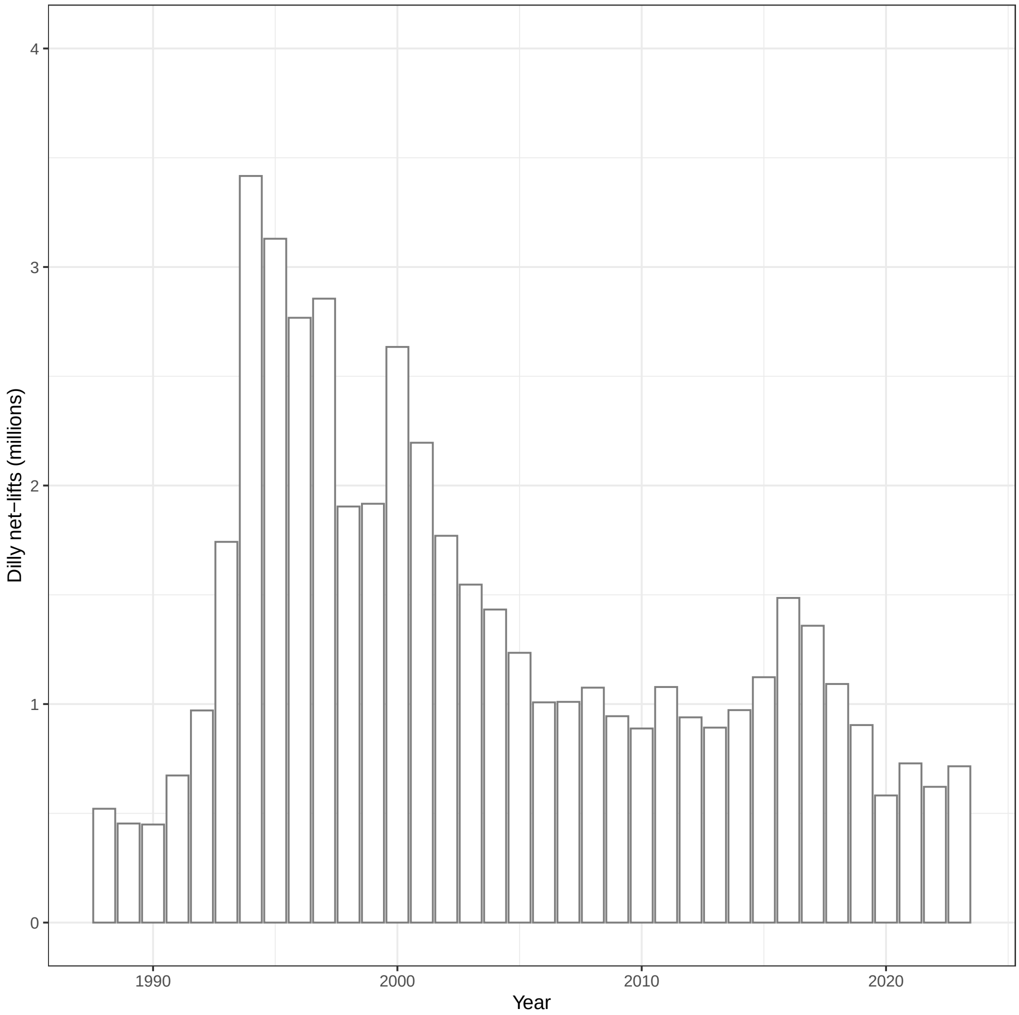

Figure C.2: Annual spanner crab fishing effort (millions of net-lifts) in managed area A.

Table C.1: Annual nominal logbook statistics for managed area A.

Year	Tonnes	NetLifts	KgPerNetLift	BoatDays	Boats
1988	370.987	520955	0.712	2578	93
1989	357.571	453406	0.789	2151	85
1990	471.649	448822	1.051	2216	68
1991	760.989	673245	1.130	2883	73
1992	1207.386	970827	1.244	4014	82
1993	2038.493	1742344	1.170	7627	166
1994	2982.158	3416658	0.873	14864	248
1995	2650.259	3129380	0.847	12766	213
1996	2758.618	2767703	0.997	12805	198
1997	3189.290	2855169	1.117	14624	196
1998	2048.914	1903962	1.076	8734	163
1999	1781.834	1916659	0.930	7056	138
2000	2102.097	2634286	0.798	9135	135
2001	1941.495	2195885	0.884	8241	131
2002	1557.056	1770127	0.880	7154	125
2003	1448.752	1546630	0.937	6319	113
2004	1514.213	1432599	1.057	5989	97
2005	1546.481	1234644	1.253	5416	92
2006	1411.636	1007884	1.401	4403	87
2007	1525.459	1010134	1.510	4119	71
2008	1583.091	1075170	1.472	3994	73
2009	1161.897	944522	1.230	3471	66
2010	1128.651	888224	1.271	3300	62
2011	1274.359	1078068	1.182	3586	61
2012	1039.131	939286	1.106	3086	63
2013	944.170	892212	1.058	2832	60
2014	915.742	972347	0.942	2975	56
2015	1176.312	1122919	1.048	3130	55
2016	1095.101	1485686	0.737	3994	72
2017	904.655	1358439	0.666	3788	60
2018	845.619	1091908	0.774	3080	51
2019	878.277	903915	0.972	2696	47
2020	611.042	581835	1.050	1715	38
2021	629.259	728600	0.864	2134	41
2022	596.543	621345	0.960	1868	36
2023	592.278	715381	0.828	2247	40

Table C.2: Annual nominal logbook statistics by region for the last four years.

Year	Region	Tonnes	NetLifts	KgPerNetLift	BoatDays	Boats
2020	2	17.246	22345	0.772	54	5
2020	3	2.929	3840	0.763	12	5
2020	4	475.072	409866	1.159	1102	28
2020	5	70.124	78505	0.893	281	24
2020	6	45.670	67279	0.679	266	10
2021	2	96.348	117033	0.823	253	7
2021	3	30.248	38367	0.788	86	6
2021	4	347.358	401273	0.866	1084	29
2021	5	97.387	107959	0.902	428	27
2021	6	57.918	63968	0.905	283	13
2022	2	56.405	83332	0.677	204	7
2022	3	11.260	18723	0.601	50	6
2022	4	345.839	327127	1.057	886	24
2022	5	134.269	131520	1.021	465	21
2022	6	48.769	60643	0.804	263	16
2023	2	30.684	56155	0.546	135	9
2023	3	11.232	14421	0.779	42	7
2023	4	403.046	439125	0.918	1208	28
2023	5	85.750	107675	0.796	414	26
2023	6	61.566	98005	0.628	448	11

D Appendix - TACC rules

TACC rules for managed area A.

The decision rules below were designed to provide guidance for the TACC-setting process by defining how changes in the pooled index should be interpreted and by linking them to a set of decision rules for adjusting the TACC (Table D.1 and Figure D.1).

Table D.1: TACC decision rules.

Increase in the TACC
The TACC is increased when the following conditions are met in a TACC-setting year:
1.1 The pooled index is greater than 1 and the current index is above the previous year's index.
If the above conditions are met, the TACC increase will be equal to:
1.2 the proportion of change between the current index and the previous year index, with
1.3 a limit of no more than 200 tonnes to be issued in any given year, and notwithstanding that
1.4 the new TACC must not exceed 1300 tonnes.

Decrease in the TACC The TACC is decreased when the following conditions are met in a TACC-setting year:
2.1 The pooled index is less than 1 and the current index is below the previous year's index.
If the above conditions are met, the TACC decrease will be equal to:
2.2 the proportion of change between the current index and the previous year index, with
2.3 a limit of no more than 200 tonnes to be issued in any given year, and notwithstanding that
2.4 the new TACC must not be less than 300 tonnes.

Closure of managed area A (this rule takes precedence)
The TACC for managed area A will be equal to zero if:
3.1 the average sCPUE is less than 0.5 kg per dilly lift.

No change in the TACC
The TACC is to remain unchanged if:
4.1 none of the above conditions are met in a TACC-setting year, or
4.2 the new TACC is within 50 tonnes of the current TACC.

Review of TACC or decision rules
5.1 If the pooled index has either increased or decreased consecutively over each of the three most recent years and no change to the TACC has occurred, the TACC for the forthcoming year must be adjusted by 50 tonnes to reflect the recent trend, or
5.2 If the commercial index in any monitoring region is 40% or more below the previous year's index, it must be determined why the decline occurred and whether further management intervention is required to reduce the risk of localised depletion, or
5.3 If any new information becomes available indicating that the assessment and TACC setting arrangements are not consistent with the sustainable management of the fishery, the decision rules must be reviewed and, if appropriate, the reference points must be adjusted.

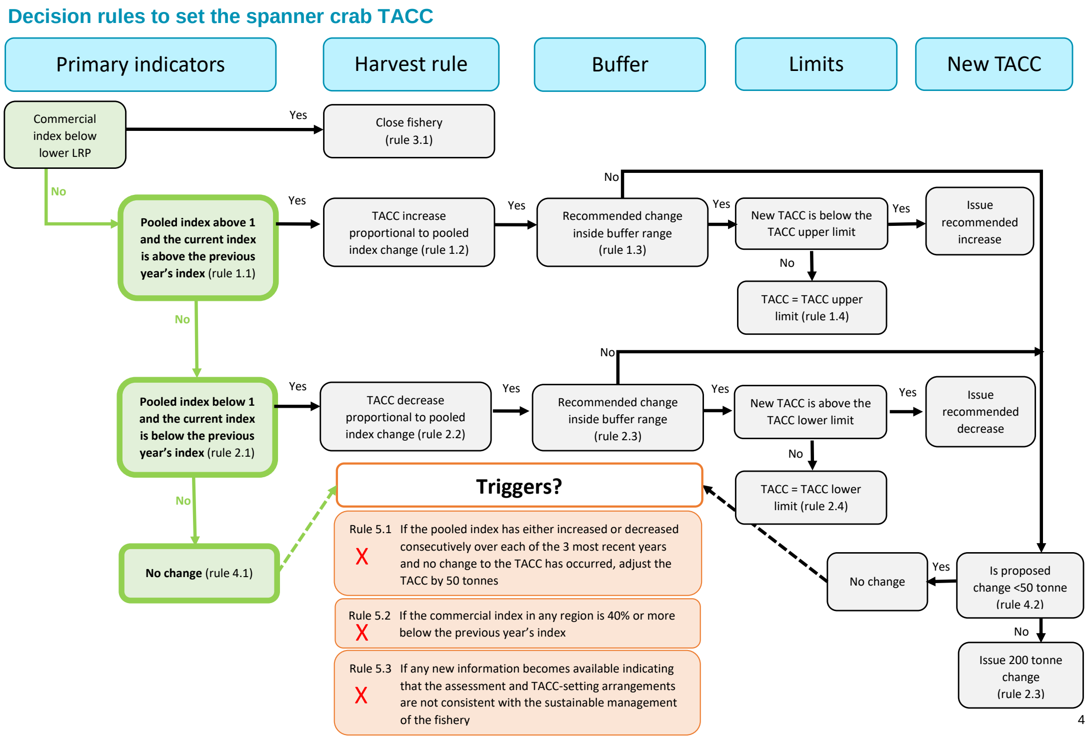

Figure D.1: Decision rules to set the spanner crab TACC.