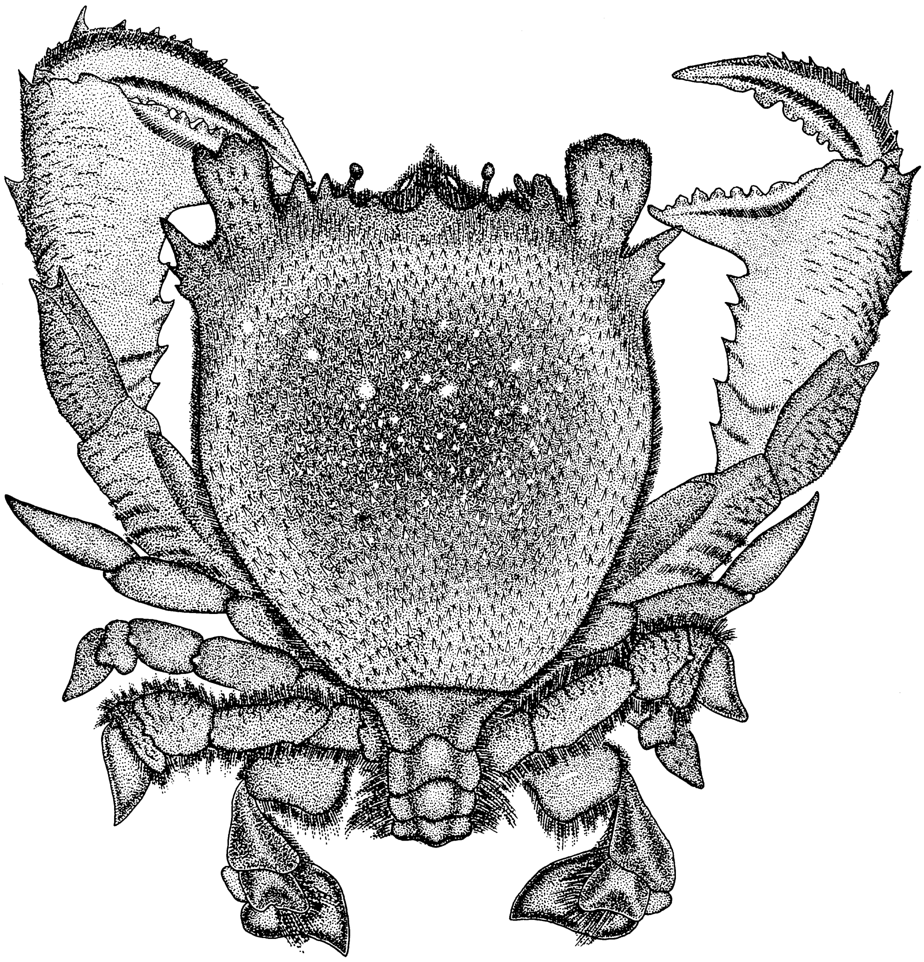

Total allowable commercial catch review for Queensland spanner crab (*Ranina ranina*), with data to December 2021

March 2022

Queensland Government

This publication has been compiled by M. F. O'Neill, A. B. Campbell and J. G. McGilvray of Fisheries Queensland, Department of Agriculture and Fisheries.

Enquiries and feedback regarding this document can be made as follows:

Email:	info@daf.qld.gov.au
Telephone:	13 25 23 (Queensland callers only)
	(07) 3404 6999 (outside Queensland)
	Monday, Tuesday, Wednesday and Friday: 8 am to 5 pm, Thursday: 9 am to 5 pm
Post:	Department of Agriculture and Fisheries GPO Box 46 BRISBANE QLD 4001 AUSTRALIA
Website:	daf.qld.gov.au

Interpreter statement

The Queensland Government is committed to providing accessible services to Queenslanders from all culturally and linguistically diverse backgrounds. If you need an interpreter to help you understand this document, call **13 25 23** or visit **daf.qld.gov.au** and search for 'interpreter'.

Contents

Summary

The Australian east coast fishery for spanner crab is the largest in the world, with the larger Queensland commercial sector landing in order of 80 per cent of annual harvests.

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 2020c).

The harvest strategy uses standardised commercial (sCPUE) and fishery independent survey (sFIS) catch rates from two years, compared against target rates, to calculate total allowable commercial catch (TACC).

The harvest strategy and TACC process aim was to rebuild the Queensland spanner crab resource to 60 per cent of the pre-fishery exploitable (legal sized crab) biomass, while improving economic performance for fishing.

For 2018/19, published economic data showed the Queensland commercial spanner crab fishery gross value of production (GVP) was around $8 million (BDO EconSearch 2020); for a harvest of about 846 t. The average beach price for spanner crab was estimated to be $9.40/kg in 2018/19.

Additionally, in the 2018/19 financial year the commercial spanner crab fishery contributed an estimated $13.2m in gross state product (from direct fishery and flow-on effects into other sectors) and 123 full-time equivalent jobs to the Queensland economy (BDO EconSearch 2020). The BDO report estimated net economic return, defined as the long-run profit from the fishery after all costs had been met, was marginal at 4.3 per cent.

This report was prepared to inform on estimated TACC of spanner crabs and potential economic GVP in managed area A for the forthcoming two quota years 1 July 2022 to 30 June 2023 and 1 July 2023 to 30 June 2024. The following paragraphs summarise key indicators for TACC.

For the recent calendar years 2020 and 2021 the total commercial spanner crab harvest was 611 t and 629 t respectively. These harvests equated to about 73 per cent of the 847 t TACC being caught, and a GVP of around $5.8 million.

The average 2020–2021 catch rate indicators from two years, standardised using generalised linear models, were: sCPUE = 0.823 kilograms per dilly-net lift and sFIS = 6.623 crab per ground-line.

The harvest strategy target catch rates were 95% of 2006–2010 average catch rates: target sCPUE = 1.37 kilograms per dilly-net lift and target sFIS = 10.489 crab per ground-line.

The stock indexes were the ratio of the indicators compared to their targets. The calculated stock indexes were less than 1, signalling catch rates were below target: sCPUE ratio = 0.6 and sFIS ratio = 0.631.

The pooled index was 0.616 (average of the two stock indexes). The pooled index means that the fishery was at 62% of its target.

By referencing the pooled index against the harvest strategy (Appendix D), no change in the 847 t TACC was suggested. This TACC corresponded to a potential GVP of around $8 million per year if fully caught.

Acknowledgements

The work was overseen by a project team committee that consisted of the authors and the following scientists, data specialists and managers: Carlie Heaven, Sue Helmke, Sam Williams, Matthew Campbell, Nancy Trieu, Eddie Jebreen, Anthony Roelofs, Darren Roy, Samantha Miller and Ian Jacobsen. The role of the committee was collaborative to share interpretation and decision making on data, methods and results.

Carlie Heaven supplied valuable data to cross check GFP data and we thank her for answering calls in a busy time for Fisheries Queensland. We also 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 members of the project team committee, for reviewing and providing comments on the draft report through Overleaf. The assessment was supported by the Queensland Department of Agriculture and Fisheries.

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 centimeters (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.
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	Generalized linear model.
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.
Overleaf	Overleaf is an online LaTeX (software for document preparation) editor that enables writing, reviewing and publication to take place in one space.
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.
RStudio	The integrated development environment (interface) used to run R code, Git, and the spanner crab project.
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.
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 (Brown et al. 1999; Roelofs et al. 2021).

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 small-mesh over a flat metal frame with an area of about 1 m^2 (Figure 1.1). 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 (WA) rock-lobster fishery.

Fishing effort increased exponentially between 1990 and 1994 as operations expanded their fishing grounds, harvesting in excess of 2000 t per year. Annual harvests ranged around 1500 t between 2002 and 2008, and 1000 t per year between 2009 and 2017 (Appendix C).

In 2018, concern about low catch rates led to a reduced TACC (Department of Agriculture and Fisheries 2020a; Department of Agriculture and Fisheries 2020d). In 2020–2021 the annual TACC of spanner crab was 847 t, down from 1631 t in 2017–2018.

Since 2020 the fishery has had some instability in markets. Local, interstate and international market demands have varied, with transport issues a challenge for selling live crab, which in turn has limited the annual fishing effort. International trade issues have posed additional challenges for some seafood exporters (Mobsby et al. 2021). Reliance on overseas markets for seafood export was a risk that has been highlighted during the COVID-19 pandemic (Mobsby et al. 2021).

In response, some spanner crab processors have looked to diversify to explore different markets, including new domestic options and product-forms (e.g. high quality crab meat). Market diversification can be expected in the medium term as processors seek to balance profit and risk during the COVID-19 pandemic (Mobsby et al. 2021).

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 2020c). 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 2020c). No TACC applies to managed area B, and is managed using a catch limit of 16 containers (about 1 t) of crab per vessel per trip (Department of Agriculture and Fisheries 2020b).

As of December 2021, 236 C2 and 194 C3 licence symbols were registered and there were 41 quota account holders for fishing or leasing TACC in manged area A. Individual TACC holdings (ITQ) can be traded between licence symbols in managed area A. Licences holding a C2 symbol can only harvest spanner crabs in managed area A if they hold or lease unused TACC.

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.

Throughout Queensland a closed spawning season applies to spanner crab from 1 November to 15 December. This no-fishing closure aimed to covered the main part of the species' spawning period in Queensland waters (Brown 1986). Also, egg carrying females must be returned to the ocean.

This report was prepared to inform Fisheries Queensland, Department of Agriculture and Fisheries, and stakeholders on harvest and catch rate levels to estimate annual TACC of spanner crabs in managed area A for July 2022 to June 2024. TACC results recommended no change in the annual 847 t TACC of spanner crab.

Figure 1.1: Entangled spanner crabs on a flat dilly net.

2 Methods

2.1 Brief

The commercial data were extracted from the Fisheries Queensland logbook databases, representing daily spanner crab harvests in kg per fishing operation from January 1988 to 31 December 2021. The data was extracted on 3 February 2022.

All fishery-independent survey data from Queensland, in units of numbers of spanner crab per ground line, were collated for 2000–2021.

Standardised catch-rate indicators, commercial (sCPUE) and survey (sFIS) for managed area A, were estimated for 2000–2021. The results were used in the TACC setting process outlined in the harvest strategy (Department of Agriculture and Fisheries 2020c). The catch rates formed the annual indicator of legal sized spanner crab abundance.

Spanner crab catch rates were standardised using generalised linear models (GLM) (McCullagh et al. 1989). The models were fitted using the computer software R in RStudio. The importance of individual model terms were assessed formally using F statistics by dropping individual terms from the full models (Type II tests). 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). They were verified against the statistical software GenStat (VSN International 2021).

The missing 2020 survey was estimated to enable TACC calculations in the harvest strategy (Department of Agriculture and Fisheries 2020c) (Appendix F).

All analysis code and report generation was version controlled using Git, through RStudio.

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 net 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.

An annual gear-only fishing-power effect was log offset, noting, no additional fishing power data were available since 2017. No increase from the 2017 fishing power level was used for subsequent years.

The fishing power data was collected from an updated fleet gear survey for 2000–2017 (Appendix E). The survey data and results were presented to industry on 19 December 2017 in Mooloolaba. The 2017 survey data represented 41 boat owners out of 66. The target sample number was 92, with 26 operators not working, and 25 operators unable to participate.

The fishing power offset was estimated by adding the 2017 survey information to that collected originally in 2007 (O'Neill et al. 2010). The data was then matched to logbooks for each vessel to quantify the effect of each fishing characteristic on catch rate, by using a statistical linear mixed model REML in GenStat (VSN International 2021). The fishing power offset was documented in Appendix E, and consisted of three variables: 1) skipper experience, use of advanced/integrated computer mapping software, and staying at-sea overnight.

The R equation form of the commercial GLM was:

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

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 2021 (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*: Over dispersed (quasi) poisson and log link

The seasonality of spanner crabs in each region was modeled 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 both 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 data were from the Department of Agriculture and Fisheries (DAF), Queensland Government. 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 modeled 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 calculated and 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 (Figure A.3, Appendix A): 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.

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 advised the department on a catch rate bias as a result of discarding legal sized crab (Brown 2013). A working group was convened to review the matter, triggered by a change in export market demand.

As a result, through which the reported kg of legal catches were not necessarily equal to the amount hauled, modifications were made to the spanner crab logbook in mid-2012. The principal change in the logbook SC06 was provision for an estimate of 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 new 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 (Table 2.1) (Brown 2013):

- 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 modeled ($Y = a + bX$) 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).

A description of this issue, as well as the methodology used to account for discarding of legal-size crabs, can be found in Brown (2013) and Campbell et al. (2016b).

Table 2.1: Catch adjustment code for discarding legal sized crab.

```
MoNum = ifelse(interval(ymd(”20090701”),StartDate) %/% months(1)¡0,
        -1,interval(ymd(”20090701”),StartDate) %/% months(1)),

CritMoScalar = ifelse(MoNum in 0:11,1.1543,
ifelse(MoNum in 12:23,1.3073,
ifelse(MoNum in 24:38,1+(0.7414-0.0181*MoNum),
ifelse(MoNum==39,1.0491,
ifelse(MoNum==40,1.0635,
ifelse(MoNum>41 & LogVersion != 6 & region==4,1.085,1))))))

WtAdj = ifelse(LogVersion==6,wt+DiscardsWt,
ifelse(region in 4:5,wt*CritMoScalar,wt))
```

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 a) consistency with previous analyses and reports, b) appropriate spatial averaging, and c) 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 usually the appropriate 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 (= 254 dilly-lifts per boat-day):

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

The following code demonstrates a prediction of standardised catch rates by year (Table 2.2):

Table 2.2: Example prediction code.

Prediction settings for the annual commercial catch rate, standardised using a marginal weights policy of averaging over factor levels for region, boat, and GFP. Mean variate values were used for seasonality, dilly net-lifts, lunar and fishing power. glmfinal was the dataframe of the GLM data.

```
ndata = glmfinal %>%
# note "nesting" clause
expand(year, nesting(region, boat, gfpid)) %>%
# Attach columns for other variables
bind_cols(
c4 = mean(glmfinal$c4),
cs4 = mean(glmfinal$cs4),
c6 = mean(glmfinal$c6),
cs6 = mean(glmfinal$cs6),
c12 = mean(glmfinal$c12),
cs12 = mean(glmfinal$cs12),
potliftslog = mean(glmfinal$potliftslog),
lunar = mean(glmfinal$lunar),
lunaradv = mean(glmfinal$lunaradv),
log_offset_exp1 = 0.11538) # last year
```

Form predictions using ndata

```
ndata = bind_cols(ndata, as_tibble(predict(glm.mod, ndata, se.fit = TRUE)[1:2]))
```

Summarise the annual predictions for average region, boat and gfpid data

```
ComCatchRateYear = glmfinal %>%
group_by(region, boat, gfpid) %>%
summarise(wg=n(), .groups = "drop") %>%
mutate(wg = wg/sum(wg)) %>%
right_join(ndata) %>%
mutate(
predlink = fit * wg,
predlb = (fit - 1.96*se.fit)*wg,
predub = (fit + 1.96*se.fit)*wg
) %>%
group_by(year) %>%
summarise( # per pot results
pred = exp(sum(predlink) - mean(glmfinal$potliftslog)),
predlb = exp(sum(predlb) - mean(glmfinal$potliftslog)),
predub = exp(sum(predub) - mean(glmfinal$potliftslog))
) %>%
mutate(year = as.integer(year))
```

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 May 2005, the survey was extended south into northern New South Wales, with the placement of four new areas (Kennelly et al. 2002; Brown et al. 2008). The extended survey aimed to provide a more representative perspective on spanner crab distribution and size than can be obtained from commercial logbooks. The New South Wales data was not reported or used in the current harvest strategy, due to different trends compared to Queensland (Campbell et al. 2016a).

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 2021 (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 2.3.

Target catch rates

The targets were based on the reference years of 2006 to 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).

The target catch rates for sCPUE and sFIS were set at 95% of the 2006–2010 average.

Table 2.3: 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 (Appendix F).

A log 'proportional gap' method was selected to estimate sFIS_{2020}. The method was reviewed by the project team on 16 December 2021 and the fishery working group on 4 February 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.

Note that the equations above were fit-for-purpose for estimating sFIS_{2020}. However, the equations could be generalised for other scenarios, where surveys might be missing in two years, or if forward estimation was required (e.g. if 2020 was present and 2021 was missing). The method can accommodate as required (Filar et al. 2021a).

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 illustrated increasing and decreasing trends. This started with an up cycle for 2000–2008, then declined 2009–2017, and a upturn after 2017.
- The catch rate increased 2018–2020, but declined in 2021.
- The magnitude of decline in catch rate 2009–2017 was near 60%.
- 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 55.6%, with a dispersion of 76.1 kg.
- The inclusion of boat effects were important in the standardisation of catch rates (Figure A.6, Appendix A).
- Between 2000 and 2017, the fishing power offset increased by about 12% $\pm$ 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 $\approx$ 4–5%, and 95% confidence intervals about $\pm$ 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.
- Region 4 mean catch rates fell significantly between 2020 and 2021 by 35% (Figure A.4, Appendix A). This was the largest regional fall in 2021 catch rate, and was close to triggering harvest strategy rule 5.2.

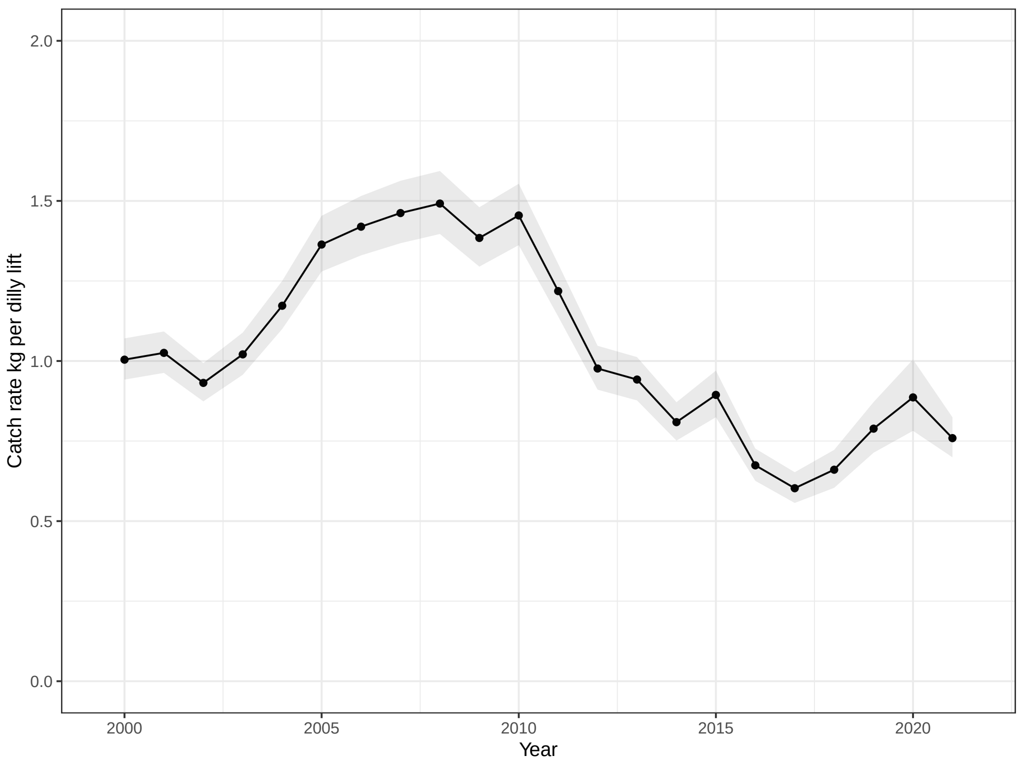

Figure 3.1: Standardised commercial catch rates (sCPUE) of spanner crab by year for managed area A. The ribbon shading illustrated the 95 percent CI.

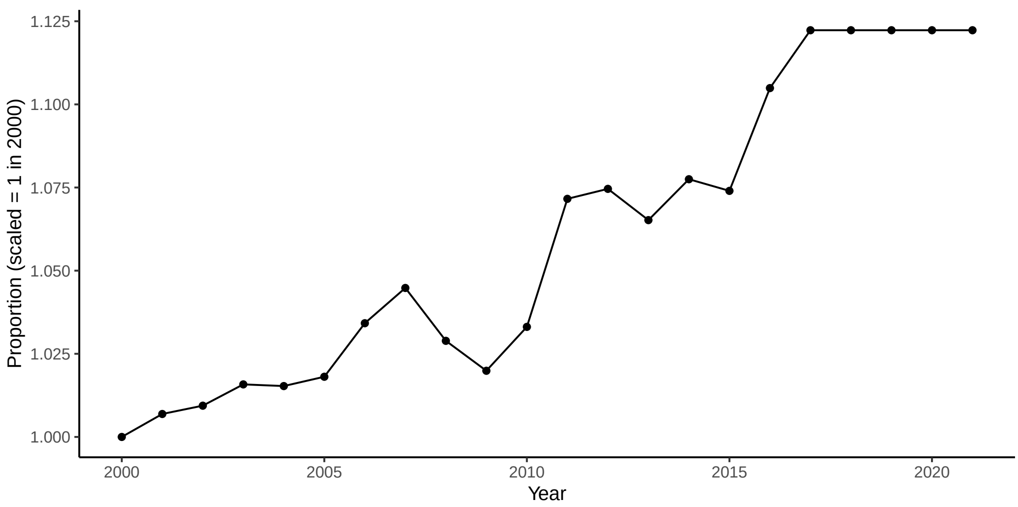

Figure 3.2: Fishing power applied in the commercial catch rate standardisation. Values since 2017 were unchanged.

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:

- Overall, 68% of survey ground-lines caught legal sized crabs. The percentages varied between years. They ranged 62–81% between 2000 and 2016. Less legal crabs were caught 2018–2021, with lower nonzero-catch percentages ranging 49–59%.

- Like for commercial, survey catch rates illustrated increasing and decreasing trends.
- Mean catch rates increased 2000–2008 from 6–8 legal crabs to 10–15 crabs per ground line.
- Mean catch rates varied between 8–11 legal crabs between 2009 and 2016.
- Mean catch rates declined to around 6 legal crabs per ground line 2017–2021.
- The magnitude of decline in catch rate after 2015 was near 33%.
- Analysis residuals appeared satisfactory (Figure B.2, Appendix B).
- The model percentage of mean deviance accounted for was 29%, with a dispersion of 10.8 crabs.
- The measures of statistical error on the mean catch rates in Figure (3.3) were a CV $\approx$ 13%, and 95% confidence intervals about $\pm$ 2 crabs. The low error-precision in standardised catch rates was sufficient for use in the harvest strategy.

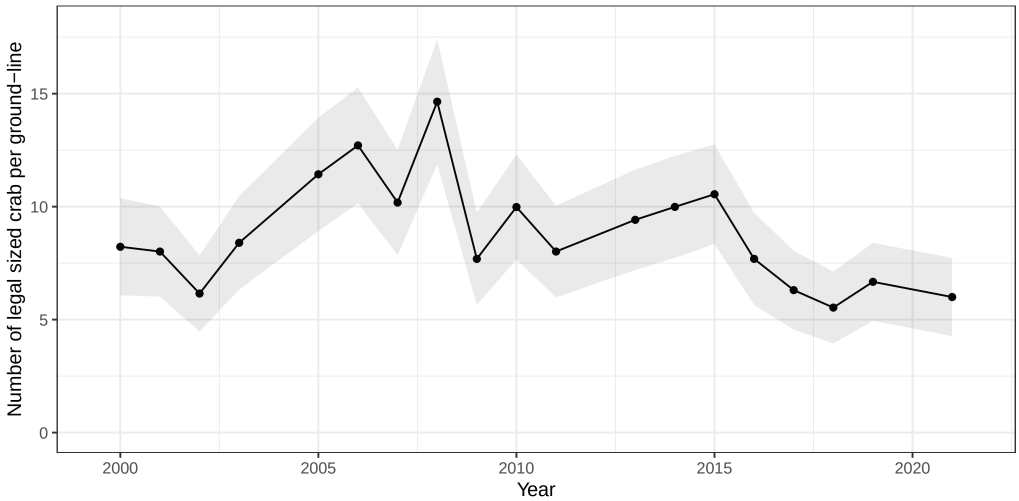

Figure 3.3: Survey standardised catch rates (sFIS) of spanner crab by year for managed area A.

3.3 TACC

The spanner crab harvest strategy set out decision rules to determine the appropriate level of commercial harvest. This was based on the status of two spanner crab catch rate indicators, labeled sCPUE for commercial standardised catch rates and sFIS for the survey standardised catch rates. The TACC rules were described in Methods and in Appendix D. The calculated TACC results were as follows:

2021–2022 TACC: 847 t

Catch rate targets: The target catch rates were 95% of 2006–2010 average catch rates: target sCPUE = 1.37 kg per dilly lift and target sFIS = 10.489 crabs per ground-line. In Table 3.1.

Catch rate indicators: The harvest strategy averaged sCPUE and sFIS from two years. The calculated performance indicators for 2020–2021 were: sCPUE = 0.823 kg per dilly lift and sFIS = 6.623 crabs per ground-line. In Table 3.1.

Stock indexes: The stock index was the ratio of the indicator compared to the target. The calculated indexes for 2020–2021 were: sCPUE = 0.6 and sFIS = 0.631. In Table 3.1.

Pooled index: The 2020–2021 pooled index was 0.616, being the average of the two stock index ratios. The pooled index indicates that the fishery was at 62% of its target in 2021. In Table 3.2.

Recommended new TACC for 2022–2023 and 2023–2024: By referencing the indicators against the decision rules (Table 2.3 and Appendix D), the following annual TACC was calculated: 847 t. In Table 3.2.

Table 3.1: TACC indicators.

Indicator	sCPUE	sFIS
Year 2018	0.661	5.532
Year 2019	0.789	6.674
Year 2020	0.886	7.248
Year 2021	0.759	5.999
2018 - 2019 mean	0.725	6.103
2019 - 2020 mean	0.838	6.961
2020 - 2021 mean	0.823	6.623
Target ref pt, 95% 2006 - 2010	1.370	10.489
2018 - 2019 mean stock index	0.529	0.582
2019 - 2020 mean stock index	0.611	0.664
2020 - 2021 mean stock index	0.600	0.631

Table 3.2: TACC pooled index and result.

Indicator	Result
Year 2019 pooled index	0.555
Year 2020 pooled index	0.637
Year 2021 pooled index	0.616
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	No
Rule 5.2, 40% decrease in regional sCPUE	No
New TACC tonnes	847

The TACC result of 847 t for managed area A spanner crab was unchanged from the previous quota. The TACC rules did signal the fishery performance indices were below target and less compared to the previous year. As the 2021 pooled index was less than 1 and below the previous year index, harvest strategy rule 2.1 suggested the TACC be reduced by 28 t. However, the 28 t decrease was cancelled out by buffer rule 4.2, for the new TACC being within 50 tonnes of the current TACC.

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

Ongoing review and checks on standardised catch rates were recommended to ensure reliable and sustainable TACC. Aspects of note to check and improve analyses 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 (Appendix E) (O'Neill et al. 2010). 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. Industry had questioned components of the offset (Appendix G).
- 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, and cross latitude-longitude environmental aspects associated to crab catchability (Filar et al. 2021b).
- 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 generalized 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 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.

References

BDO EconSearch (2020). *Economic and social indicators for the Queensland spanner crab fishery, 2017/18 and 2018/19. A report to Fisheries Queensland*. Tech. rep. URL: https://www.daf.qld.gov.au/business-priorities/fisheries/monitoring-research/data/economic-and-social-data.

Brown, I., J. Kirkwood, S. Gaddes, C. Dichmont, and J. Ovenden (1999). *Population dynamics and management of spanner crabs (Ranina ranina) in southern Queensland. Project report QO99010, FRDC project 1995/022. Department of Primary Industries, Queensland*. Tech. rep. URL: https://www.frdc.com.au/sites/default/files/products/1995-022-DLD.pdf.

Brown, I. W. (1986). *Population biology of the spanner crab (Ranina ranina) in south-east Queensland. Final report on project 81/71 to the Australian Fishing Industry Research Committee (FIRC), Canberra*. Tech. rep. Department of Primary Industries, Queensland.

— (2013). *Queensland spanner crab annual status report 2013: mid-cycle review for TAC period June 2012 – May 2014. Department of Agriculture, Fisheries and Forestry*. Tech. rep.

Brown, I. W., J. Scandol, D. Mayer, M. Campbell, S. Kondylas, M. McLennan, A. Williams, K. Krusic-Golub, and T. Treloar (2008). *Reducing uncertainty in the assessment of the Australian spanner crab fishery. FRDC project 2003/046. Department of Primary Industries and Fisheries, Queensland*. Report.

Campbell, M. J., M. F. O'Neill, and J. G. McGilvray (2016a). *Queensland spanner crab fishery: commercial quota setting for June 2016 – May 2018. Department of Agriculture and Fisheries, Queensland*. Tech. rep. URL: http://era.daf.qld.gov.au/id/eprint/5059/.

Campbell, M. J., M. F. O'Neill, and J. G. McGilvray (2016b). *Queensland spanner crab fishery: commercial quota setting for June 2015 – May 2016. Department of Agriculture, Fisheries and Forestry*. Tech. rep. URL: https://era.daf.qld.gov.au/id/eprint/5060/.

Department of Agriculture and Fisheries (2017). *Queensland sustainable fisheries strategy 2017-2027*. Tech. rep. URL: https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable/sustainable-fisheries-strategy-overview.

— (2020a). *Management advice. Spanner crab fishery 2020*. Tech. rep. URL: https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable/harvest-strategy/spanner-crab-fishery-management.

— (2020b). *Spanner crab fishery commercial fishing rules in Queensland*. Tech. rep. URL: https://www.daf.qld.gov.au/%5C_%5C_data/assets/pdf%5C_file/0003/1569108/Spanner-crab-fishery%5C_fact-sheet%5C_July-edits.pdf.

— (2020c). *Spanner crab fishery harvest strategy: 2020-2025*. Tech. rep. URL: https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable/harvest-strategy.

— (2020d). *Spanner crab fishery working group communique, 24 February 2020*. Tech. rep. URL: https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable/fishery-working-groups/spanner-crab-working-group/communiques/communique-24-february-2020.

— (2022). *Spanner crab fishery working group communique, 4 February 2022*. Tech. rep. URL: https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable/fishery-working-groups/spanner-crab-working-group/communiques/communique-4-february-2022.

Filar, J., S. Helmke, M. Holden, T. Martin, M. Mendiolar, M. F. O'Neill, D. Teixeira, and J. Webley (2021a). *Estimating Queensland's recreational catch between statewide recreational fishery surveys. The University of Queensland.* Tech. rep.

Filar, J. A., A. J. Courtney, L. J. Gibson, R. Jemison, S. Leahy, Y. S. Lei, M. Mendiolar, J. Mitchell, B. Robson, C. Steinberg, S. Williams, W.-H. Yang, and N. Ye (2021b). *Modelling environmental changes and effects on wild-caught species in Queensland. Department of Agriculture and Fisheries, Queensland, The University of Queensland and the Australian Institute of Marine Science. FRDC project 2019-013*. Tech. rep.

Kennelly, S. J. and J. P. Scandol (2002). "Using a fishery-independent survey to assess the status of a spanner crab *Ranina ranina* fishery: Univariate analyses and biomass modelling". In: *Crustaceana* 75, pp. 13–39.

Marriott, R. J., M. F. O'Neill, S. J. Newman, and C. L. Skepper (2013). "Abundance indices for long-lived tropical snappers: estimating standardized catch rates from spatially and temporally coarse logbook data". In: *ICES Journal of Marine Science* 71.3.

McCullagh, P. and J. A. Nelder (1989). *Generalized linear models.* 2nd ed. London: Chapman and Hall.

Mobsby, D., A. H. Steven, R. Curtotti, and M. Dylewski (2021). *Australian fisheries and aquaculture: Outlook to 2025–26, ABARES research report, Canberra*. Tech. rep. URL: https://daff.ent.sirsidynix.net.au/client/en%5C_AU/search/asset/1031681/0.

O'Neill, M. F. (2015). "Improving the effectiveness of age-abundance indicators in the management of fisheries in Queensland, Australia. The University of Queensland, PhD". Thesis. URL: https://espace.library.uq.edu.au/view/UQ:373922.

O'Neill, M. F., A. B. Campbell, I. W. Brown, and R. Johnstone (2010). "Using catch rate data for simple cost-effective quota setting in the Australian spanner crab (*Ranina ranina*) fishery". In: *ICES Journal of Marine Science* 67.8, pp. 1538–1552.

O'Neill, M. F. and G. M. Leigh (2006). *Fishing power and catch rates in the Queensland east coast trawl fishery. Department of Primary Industries and Fisheries, Queensland. Report QI06051*. Tech. rep.

— (2007). "Fishing power increases continue in Queensland's east coast trawl fishery, Australia". In: *Fisheries Research* 85.1-2, pp. 84–92.

Roelofs, A., D. Johnson, and J. G. McGilvray (2021). *Spanner crab. In Toby Piddocke, Crispian Ashby, Klaas Hartmann, Alex Hesp, Patrick Hone, Joanne Klemke, Stephen Mayfield, Anthony Roelofs, Thor Saunders, John Stewart, Brent Wise and James Woodhams (eds) 2021, Status of Australian fish stocks reports 2020, Fisheries Research and Development Corporation, Canberra*. Tech. rep. URL: https://www.fish.gov.au/report/298-Spanner-Crab-2020.

VSN International (2021). *GenStat Statistical Software*. Tech. rep. URL: http://www.vsni.co.uk/software/genstat.

A Appendix - Commercial catch rates

Appendix A presents supplementary figures and tables to detail the commercial catch rate (sCPUE) results. They are listed as follows:

1. Figures A.1, A.2 and A.3 were maps showing the managed areas and fishing regions.
2. Figure A.4, Regional catch rates for 2021 showed an upturn in regions 2 and 3, steady and low in region 6, and a downturn in regions 4 and 5.
3. Table A.1, Analysis of variance table showing the model terms and their statistical significance. The table was for type II tests, for dropping model terms from the full model (R procedure: drop1). The residual degrees of freedom was 93840.
4. Figure A.5, The residuals showed an acceptable model fit, and were typical for Poisson type models. 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.
5. Figure A.6, Influence plot illustrating the key boat and fishing power effects on sCPUE.
6. Figure A.7, The fleet-average fishing-power of a boat increase by about 10% post 2010, as fewer lower catching vessels fished. The fishing power measure jumped to 17% in 2021.
7. Figure A.8, The seasonal co-variate variables modeled the monthly trends in each region well.
8. 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.
9. 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 = 0.585, and for GFP gfpid1:potliftslog = 0.72.

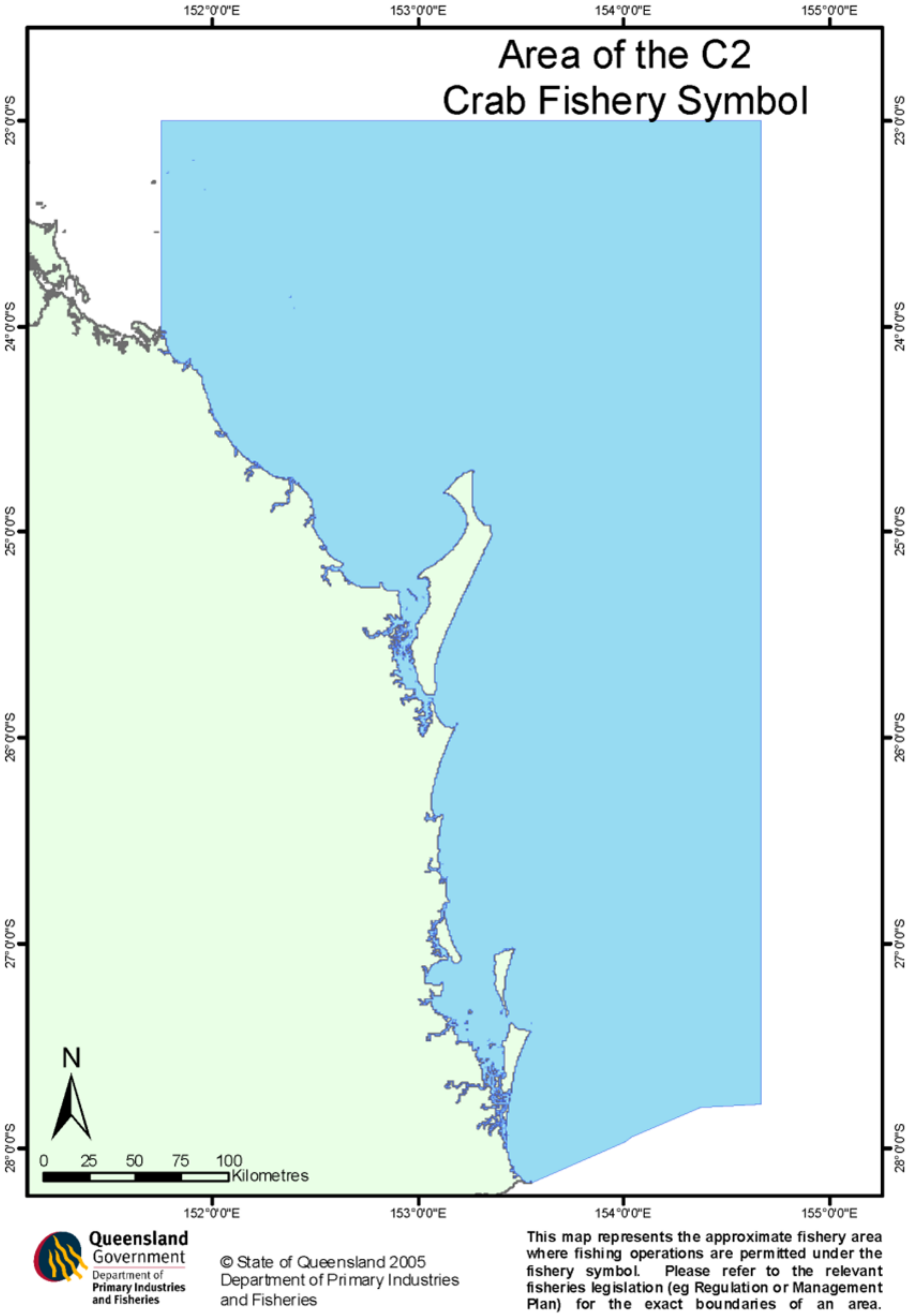

Figure A.1: Spanner crab managed area A for a C2 spanner crab licence.

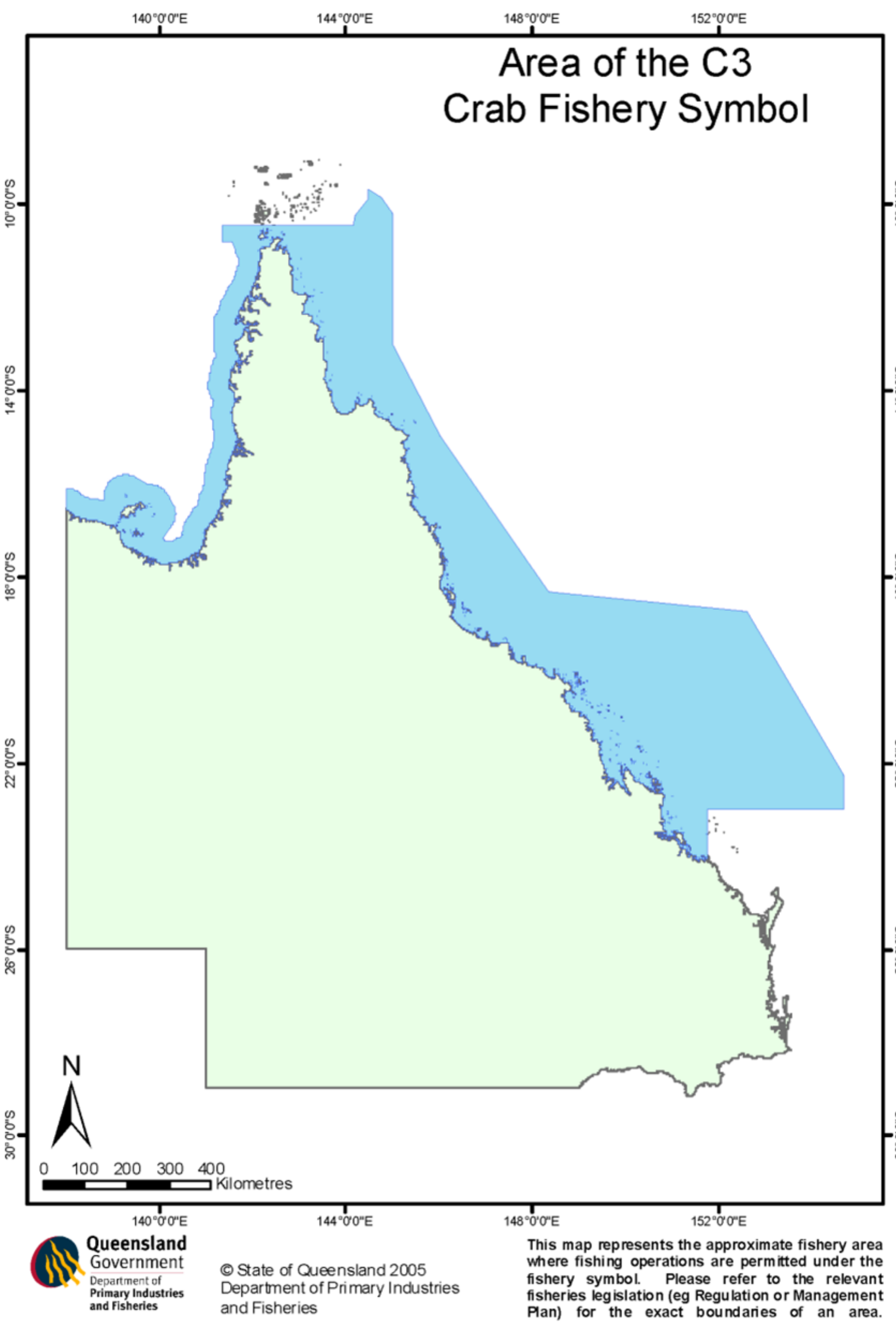

Figure A.2: Spanner crab managed area B for a C3 spanner crab licence.

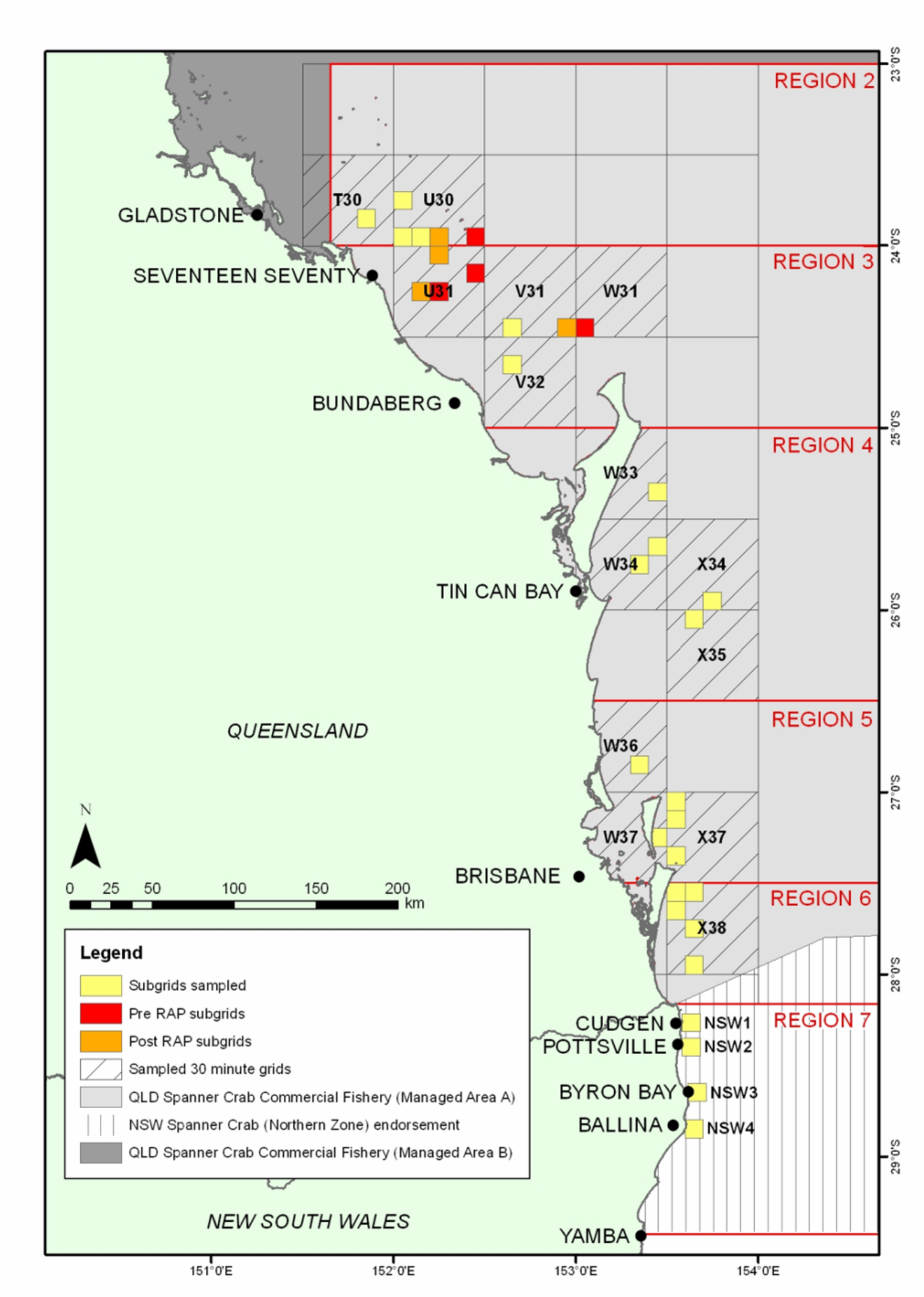

Figure A.3: Chart of the spanner crab fishery, showing the location of fixed 30 x 30 minute grids within regions and fixed 6 minute subgrids within grids for the extended monitoring (FIS) survey.

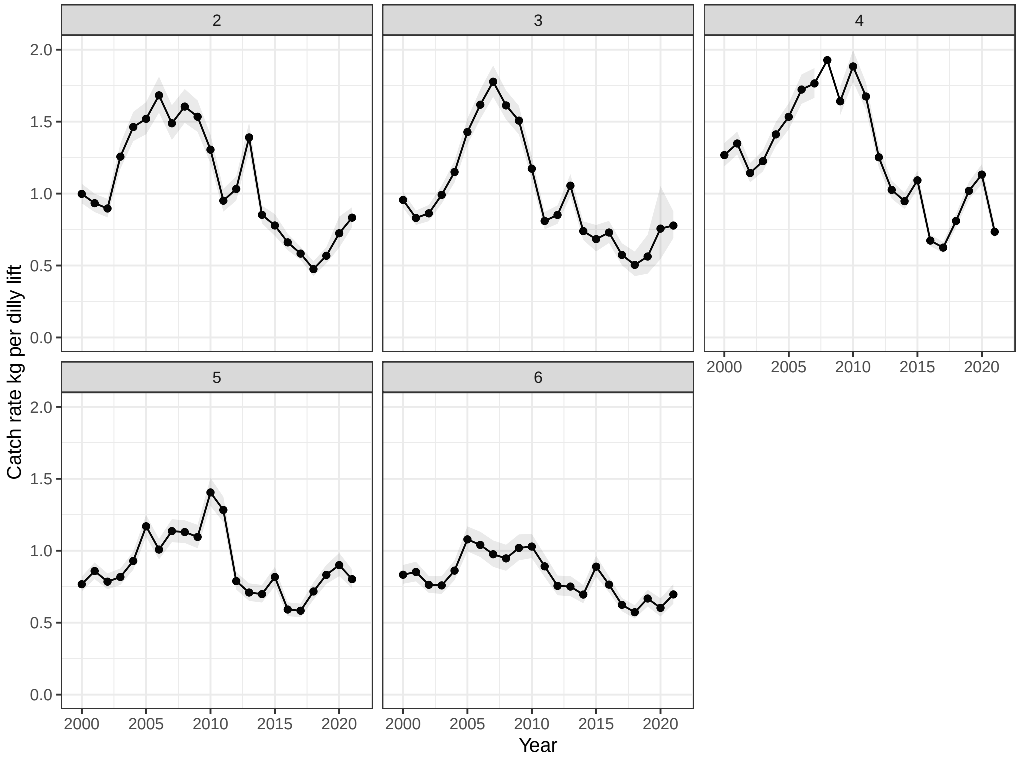

Figure A.4: Standardised commercial catch rates (sCPUE) of spanner crab by year and regions 2 to 6 for managed area A.

Table A.1: Anaylsis 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		7140604		
boat	272	8439874	62.775	0.000
lunar	1	7140649	0.596	0.440
lunaradv	1	7145755	67.700	0.000
year:region	84	7440979	46.994	0.000
region:c12	5	7419846	733.947	0.000
region:cs12	5	7309778	444.650	0.000
region:c6	5	7584435	1166.543	0.000
region:cs6	5	7193835	139.911	0.000
region:c4	5	7168011	72.037	0.000
region:cs4	5	7167972	71.933	0.000
gfpid:potliftslog	2	8294522	7582.254	0.000

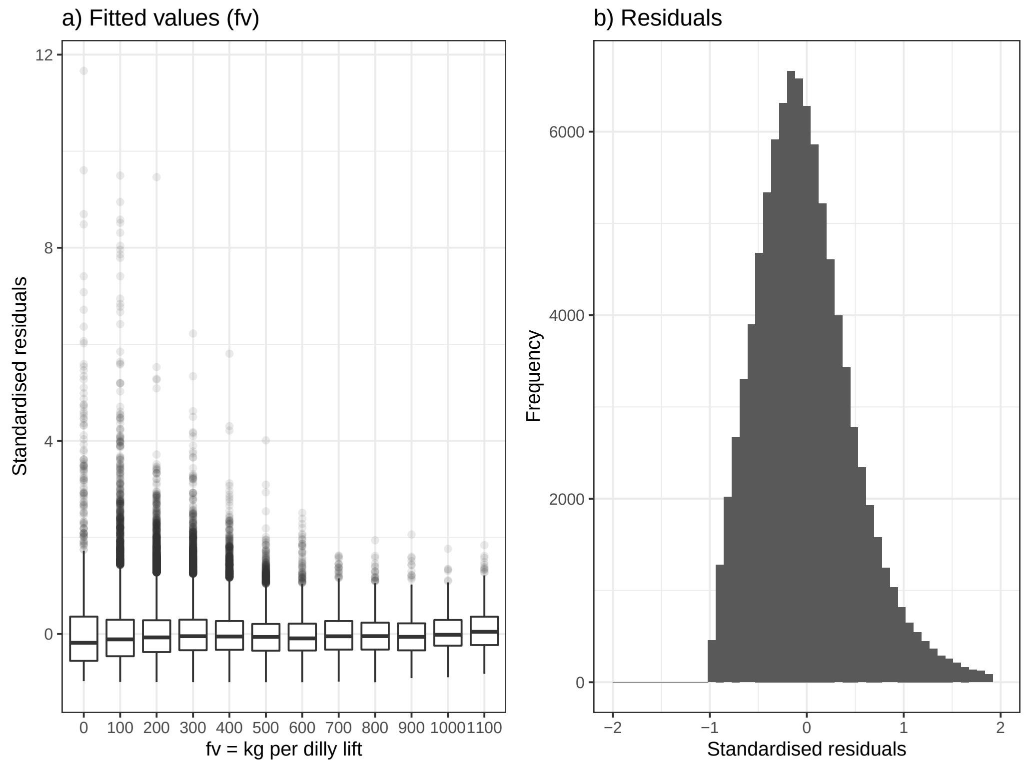

Figure A.5: sCPUE goodness of fit plots for a) box plot of fitted values and residuals, and b) histogram of residuals. Fitted values > 1000 were grouped.

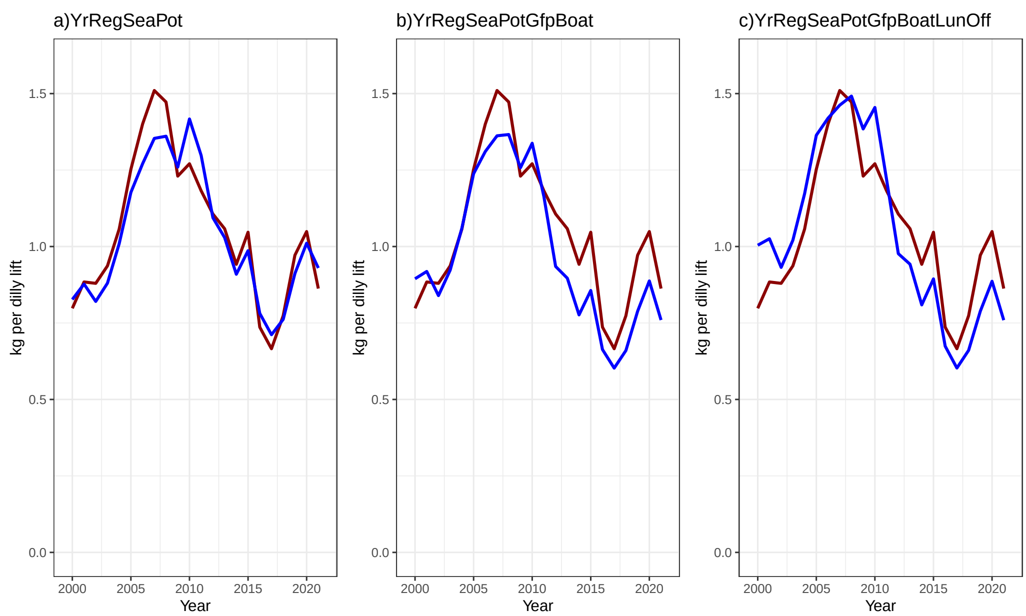

Figure A.6: Influence plot comparing the effects on sCPUE against the nominal mean catch rate (red line). Subplot a) compares sCPUE for a year (Yr), region (Reg), seasonality (Sea) and dilly lifts (Pot) model; b) compares sCPUE for a year, region, seasonality, dilly lifts, GFP and boat model; c) compares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

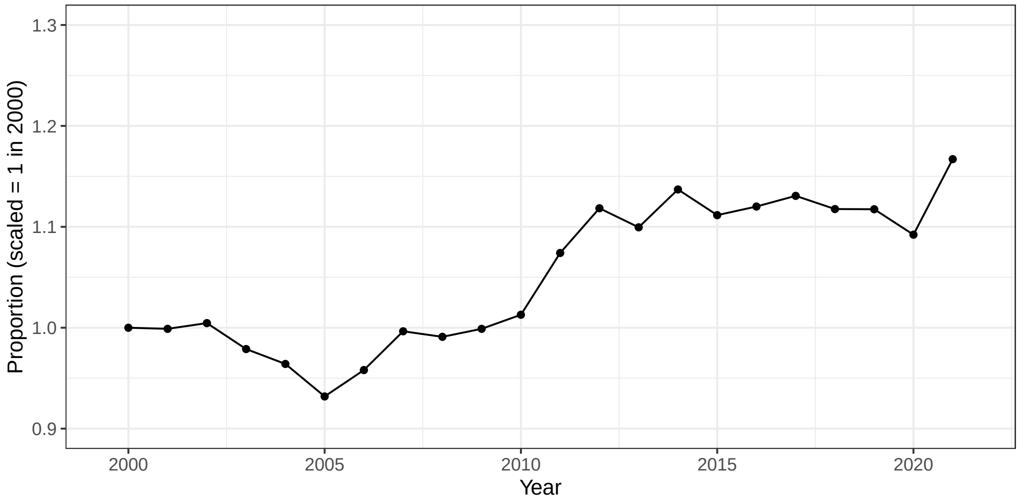

Figure A.7: Relative average boat fishing power by year as estimated from the GLM boat factor.

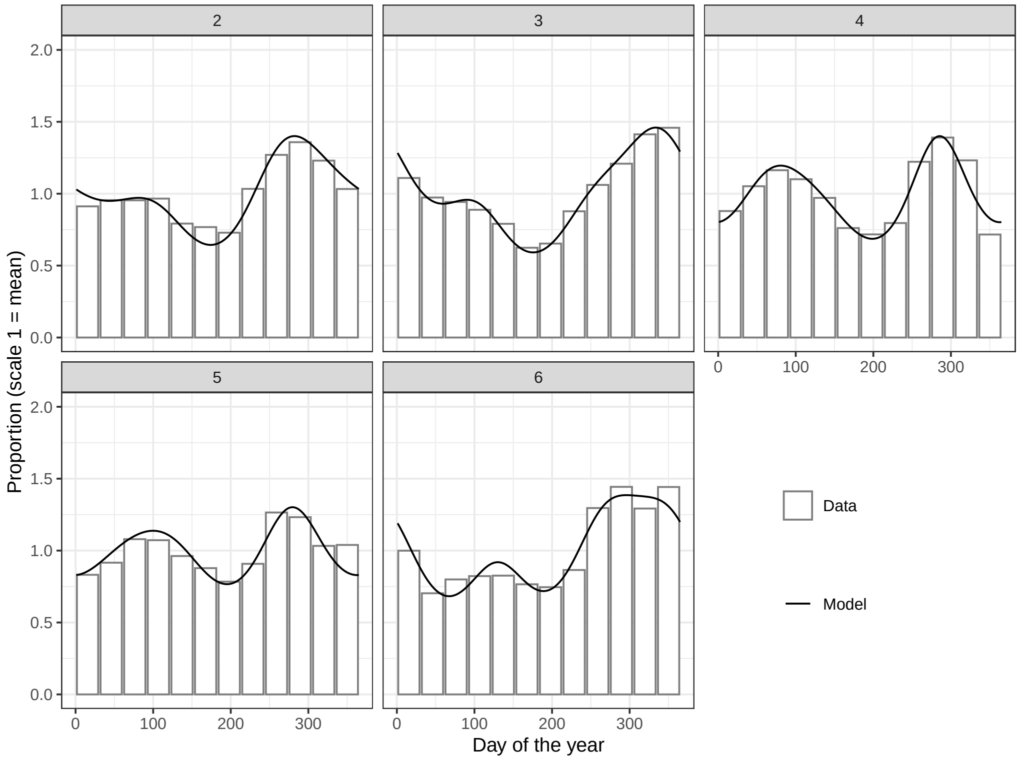

Figure A.8: Relative sCPUE by time-of-year and regions 2 to 6 for managed area A. The bar graph illustrates the monthly average, and the model fit (line) matched this well.

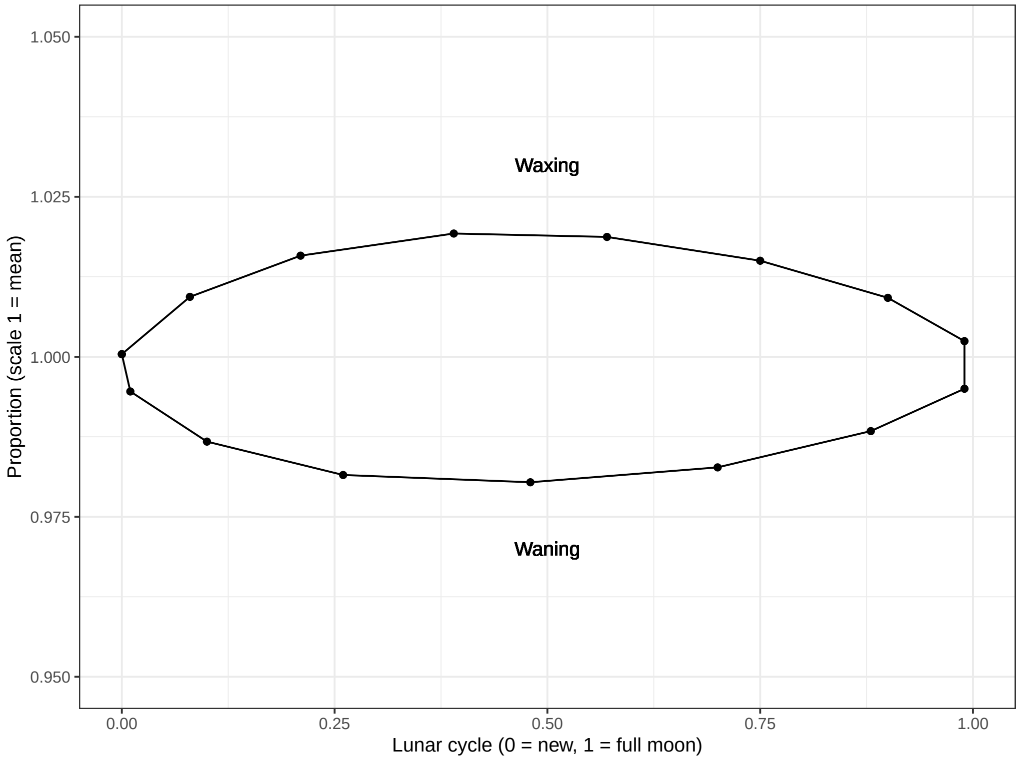

Figure A.9: Relative catch rate by lunar cycle.

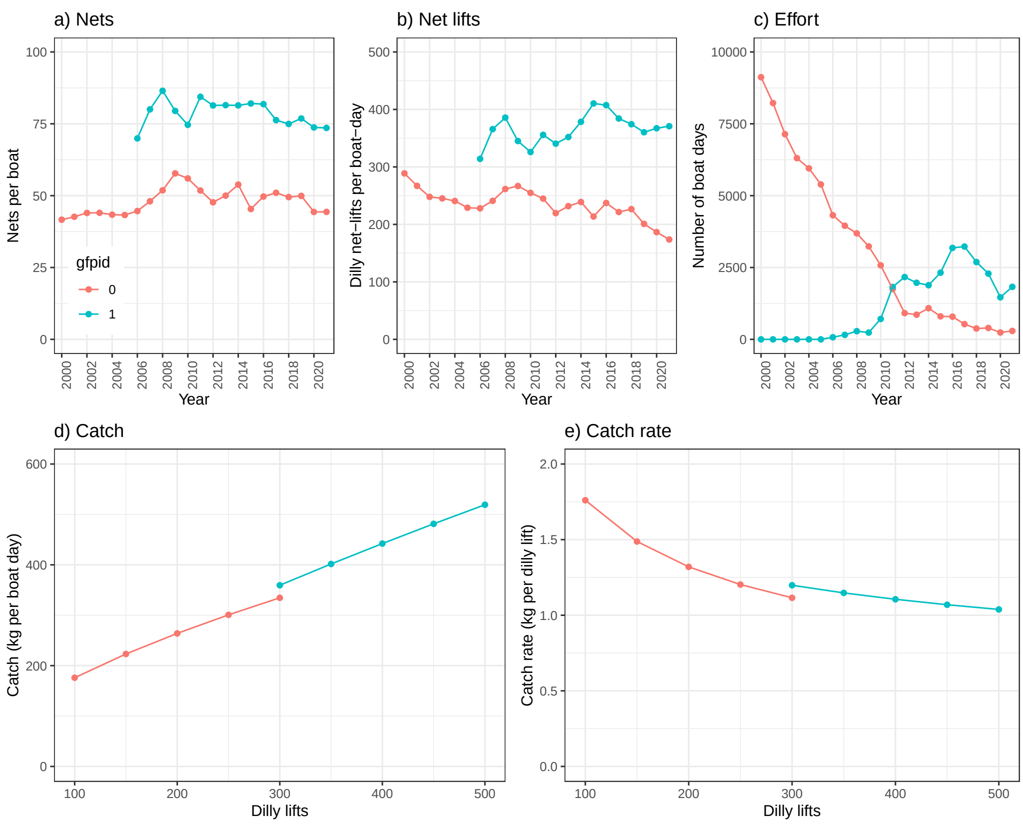

Figure A.10: Influence plot comparing the net lift effects by GFP on sCPUE. Subplot a) mean number of nets per boat by year; b) mean number of net lifts per boat-day by year; c) nominal total effort by year; d) mean catch per boat day relationship; e) mean catch rate by dilly lift relationship.

B Appendix - Survey catch rates

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

1. Figure B.1, Regional catch rates for 2021 showed an upturn in region 2, steady or low in regions 3, 5 and 6, and a downturn in region 4.
2. 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).
3. Table B.2, Analysis of variance showing the model terms and their statistical significance. The table was for type II tests, for dropping model terms from the full model (R procedure: drop1). All model terms were significant. The residual degrees of freedom was 7033.
4. 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 (32%).

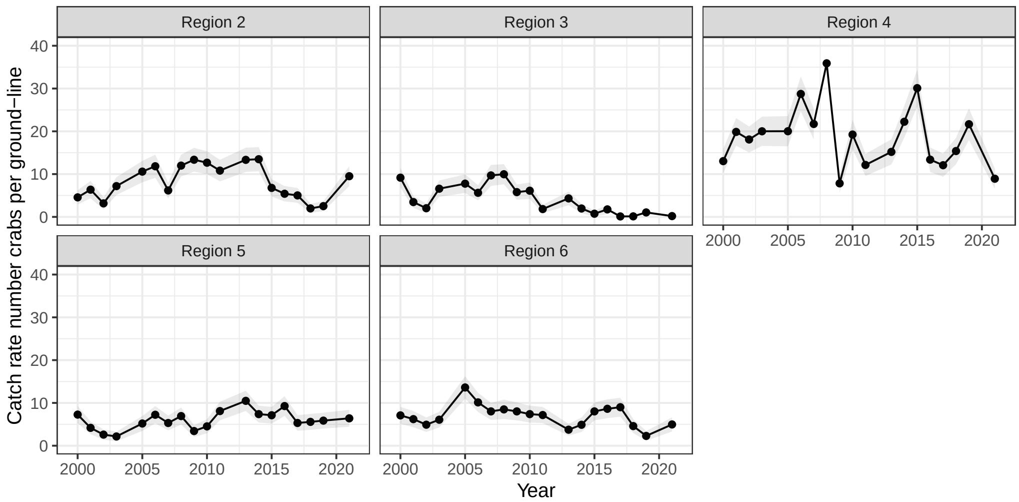

Figure B.1: Standardised survey catch rates (sFIS) of legal sized spanner crab by year and region for managed area A.

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

Table B.2: Anaylsis 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		75694		
lognethrs	1	77018	123.059	0.000
year:region	72	84395	11.229	0.000

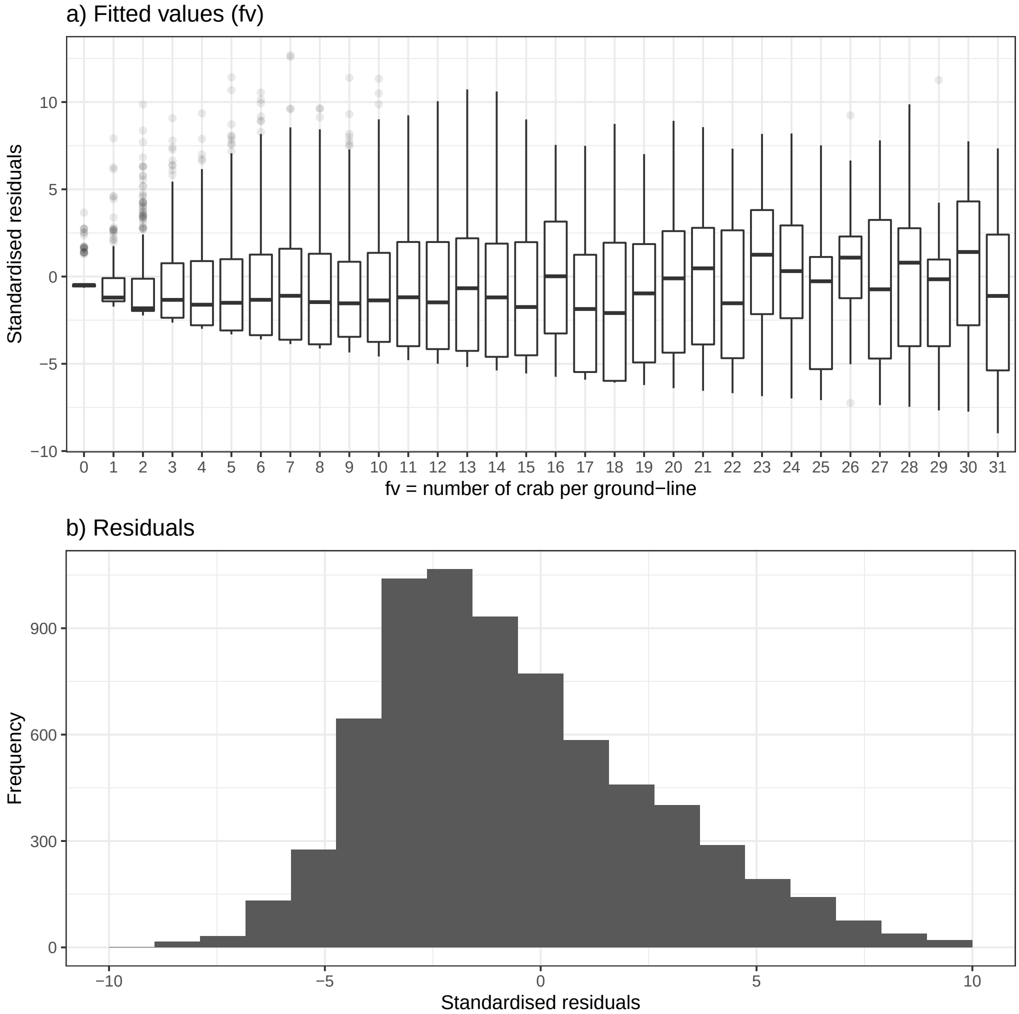

Figure B.2: sFIS goodness of fit plots for a) box plot of fitted values and residuals, and b) histogram of residuals. Fitted values > 30 were grouped.

C Appendix - Harvest summary

The total reported harvest was 611 t and 628.7 t for 2020 and 2021, respectively (Table C.1 and Figure C.1).

The 2020 and 2021 harvest resulted from 582.5 and 728.9 thousand net-lifts (Figure C.2), by 38 and 41 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.

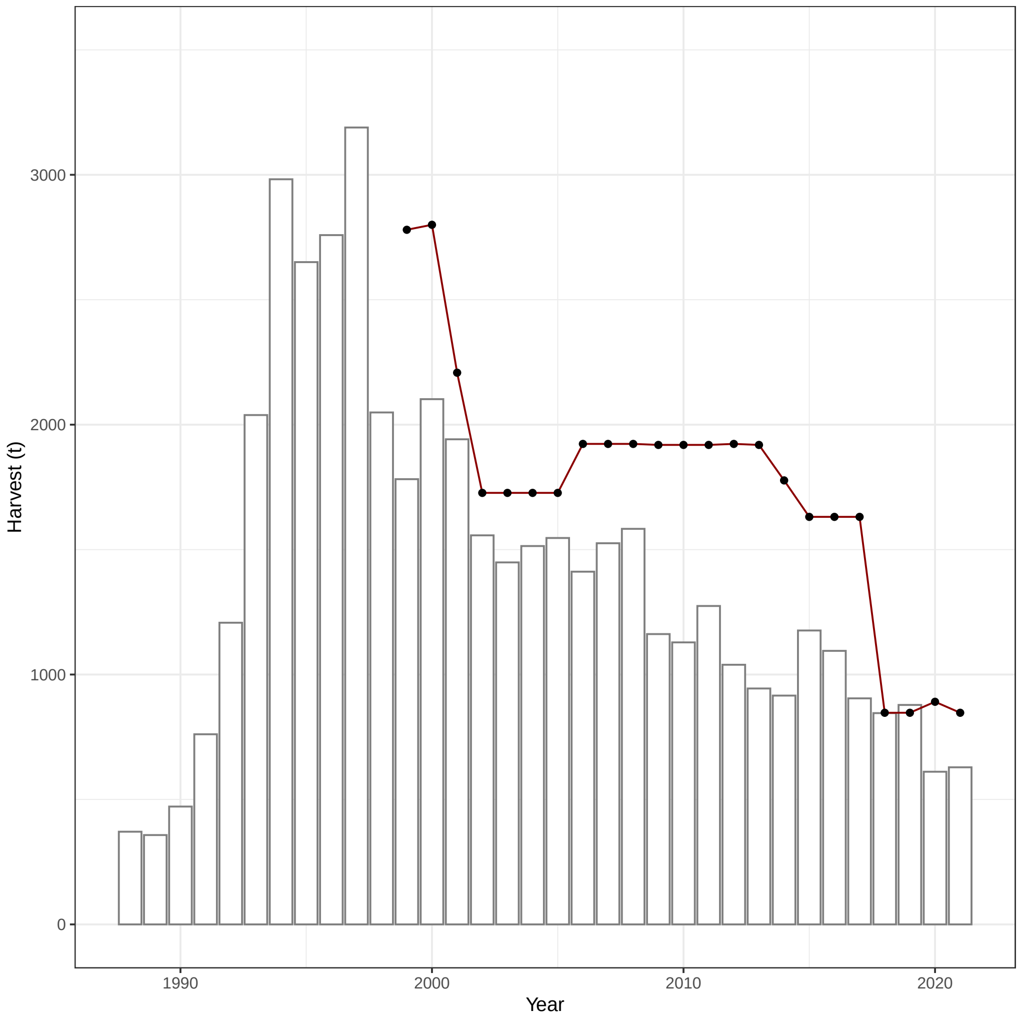

Figure C.1: Annual spanner crab harvest landings (tonnes) from managed area A (bar graph), compared against the TACC settings (line graph).

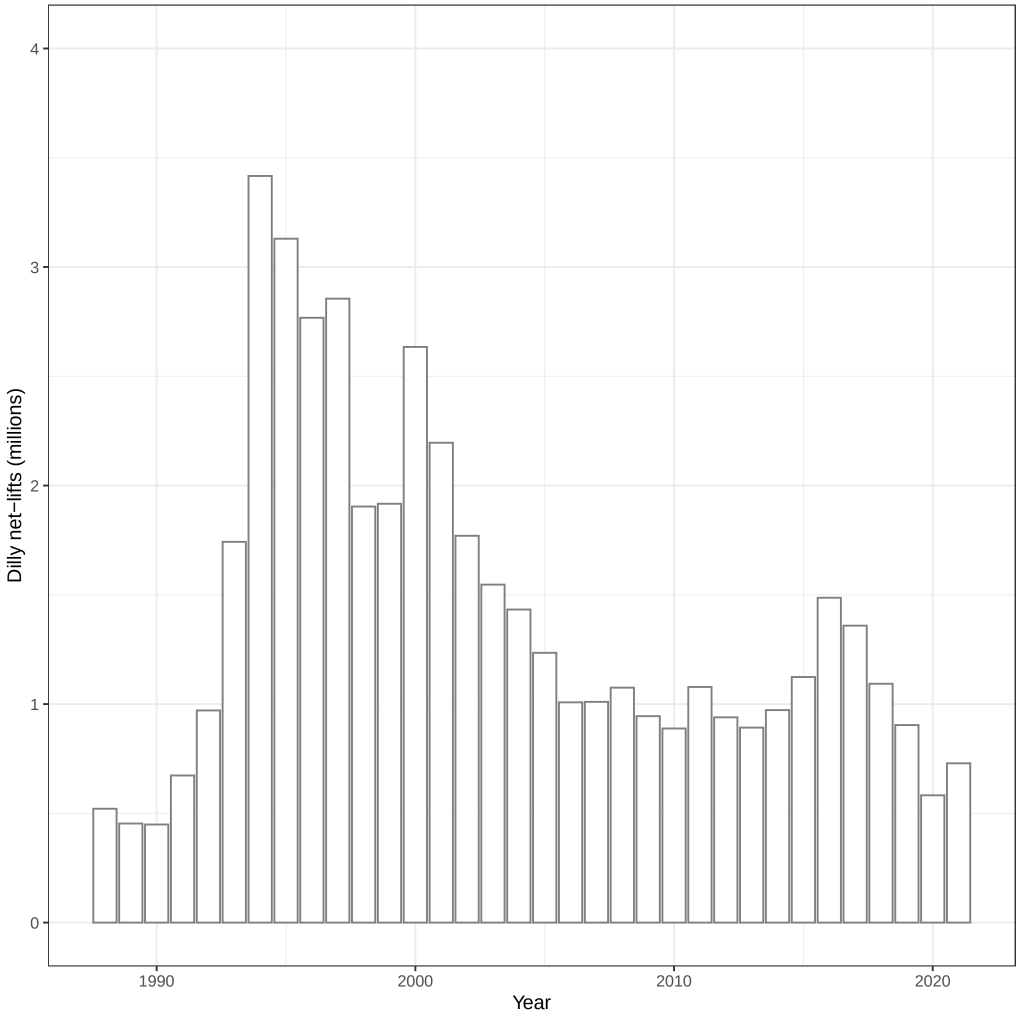

Figure C.2: Annual spanner crab fishing effort (millions of net-lifts) in managed area A.

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	2650.559	3129560	0.847	12767	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	1123739	1.047	3133	55
2016	1094.821	1486571	0.736	3997	72
2017	904.655	1358814	0.666	3789	60
2018	845.619	1092958	0.774	3083	51
2019	878.277	903915	0.972	2696	47
2020	611.042	582510	1.049	1717	38
2021	628.715	728940	0.863	2136	41

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

Year	Region	Tonnes	NetLifts	KgPerNetLift	BoatDays	Boats
2018	2	38.815	73780	0.526	188	10
2018	3	12.862	25140	0.512	62	16
2018	4	591.258	691165	0.855	1734	32
2018	5	87.058	118908	0.732	411	32
2018	6	115.626	183965	0.629	688	18
2019	2	50.614	85075	0.595	217	10
2019	3	5.824	11760	0.495	32	10
2019	4	630.604	563124	1.120	1513	34
2019	5	105.760	131558	0.804	474	29
2019	6	85.475	112398	0.760	460	9
2020	2	17.246	22345	0.772	54	5
2020	3	2.929	3840	0.763	12	5
2020	4	475.072	410541	1.157	1104	28
2020	5	70.124	78505	0.893	281	24
2020	6	45.670	67279	0.679	266	10
2021	2	95.318	116308	0.820	251	7
2021	3	30.248	38367	0.788	86	6
2021	4	347.358	401648	0.865	1085	29
2021	5	97.387	108139	0.901	429	27
2021	6	58.404	64478	0.906	285	13

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.

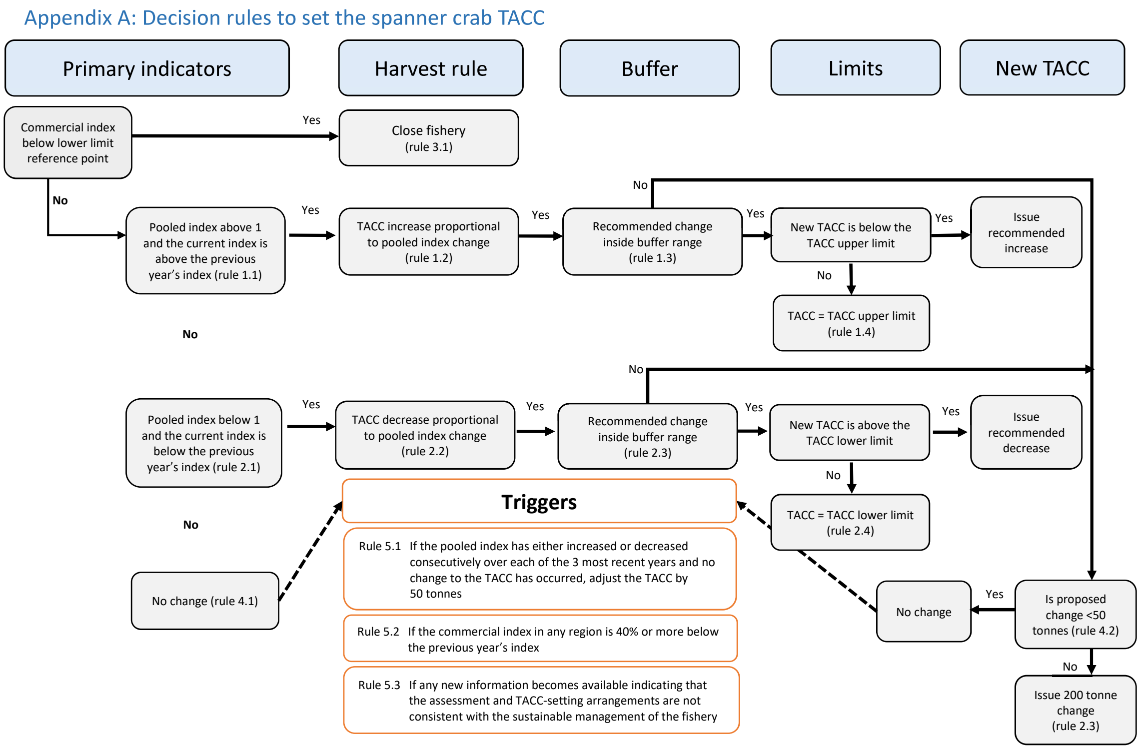

Figure D.1: Decision rules to set the spanner crab TACC.

E Appendix - Fishing power offset

The fishing power offset was estimated by matching gear survey information and logbook catches for each vessel to quantify the effect of each fishing characteristic on catch rate, by using REML (VSN International 2021). This appendix documents key information from the analysis in 2017. The fishing power calculations followed methods from O'Neill et al. (2006) and O'Neill et al. (2007).

The fishing power offset consisted of three variables: 1) skipper experience, use of advanced/integrated computer mapping software, and staying at-sea overnight. Between 2000 and 2017, the combined fishing power offset increased by about 12% (Figure E.1).

Over two surveys, a total of 137 fishing operations (boats) provided fishing power data (Figure E.2). This data showed a general steady, but broadening range of years of fishing experience (Figure E.3), more fishing effort associated with boats integrating computer mapping with improved software (Figure E.4; improved computer mapping was also correlated with between 20–40% use of seabed discrimination systems since 2010), and more fishing effort by boats staying at-sea overnight (Figure E.5).

The log scale parameter estimates from REML, associating with higher catch rates (fishing power), were: 1) 0.026 and standard error se = 0.006 for years of fishing experience, 2) 0.097 and se = 0.051 for seabed discrimination systems (SDS), 3) 0.229 and se = 0.025 for computer mapping, and 4) -0.036 and se = 0.019 for over-nighting. SDS was excluded from the combined fishing power estimates (Figure E.1) due to correlation with computer mapping.

The GenStat REML code, for the 2000–2017 analysis with residual df = 42380 and variance = 0.354, was:

```
VCOMPONENTS [FIXED=lunar+lunaradv7+loglifts+ year*region+region.c12+region.cs12+region.c6+region.cs6
+region.c4+region.cs4+ overnight+compmap+sds+logyrsexp;FACTORIAL=2] RANDOM=acn; INITIAL=1;
CONSTRAINTS=positive REML [PRINT=model,components,effects,vcovariance, deviance,waldTests,
covariancemodel,means; PSE=allestimates; MVINCLUDE=*; method=ai;] logkg
```

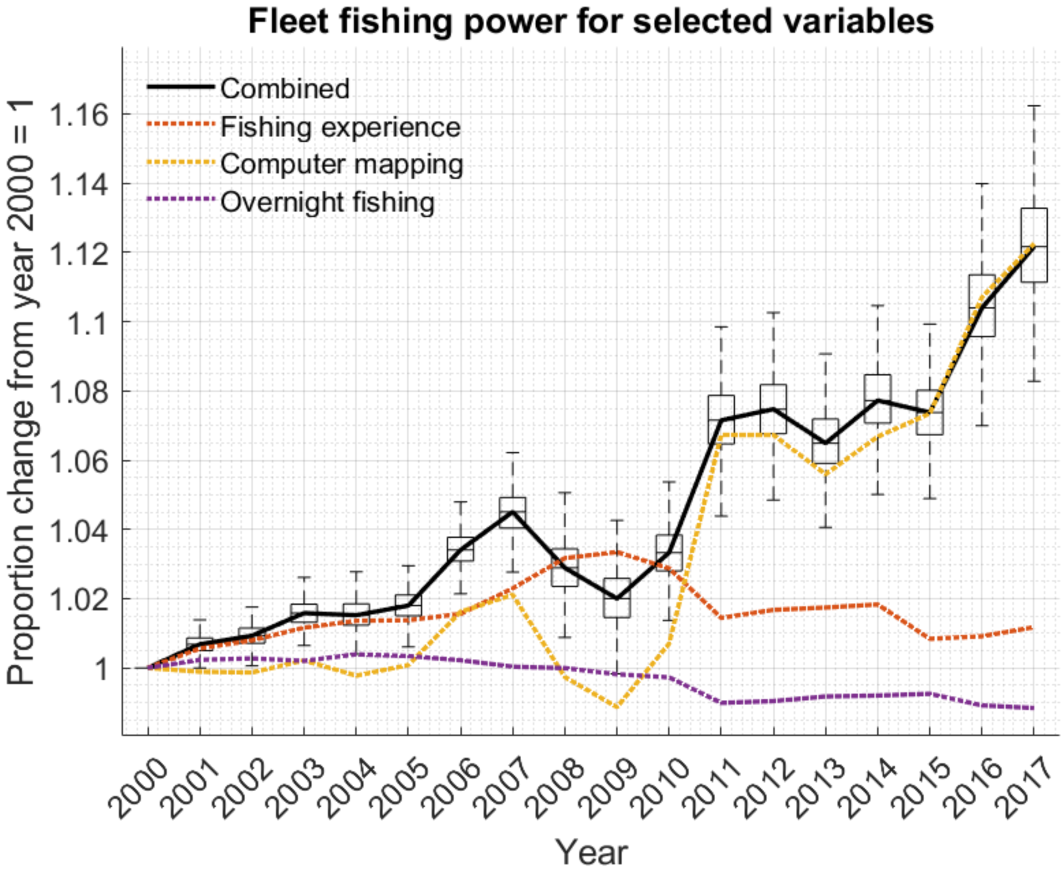

Figure E.1: Estimated fishing power offset (combined - black line), with a boxplot plot illustrating the range of estimates, and fishing power seperated into the three individual variables (dotted lines).

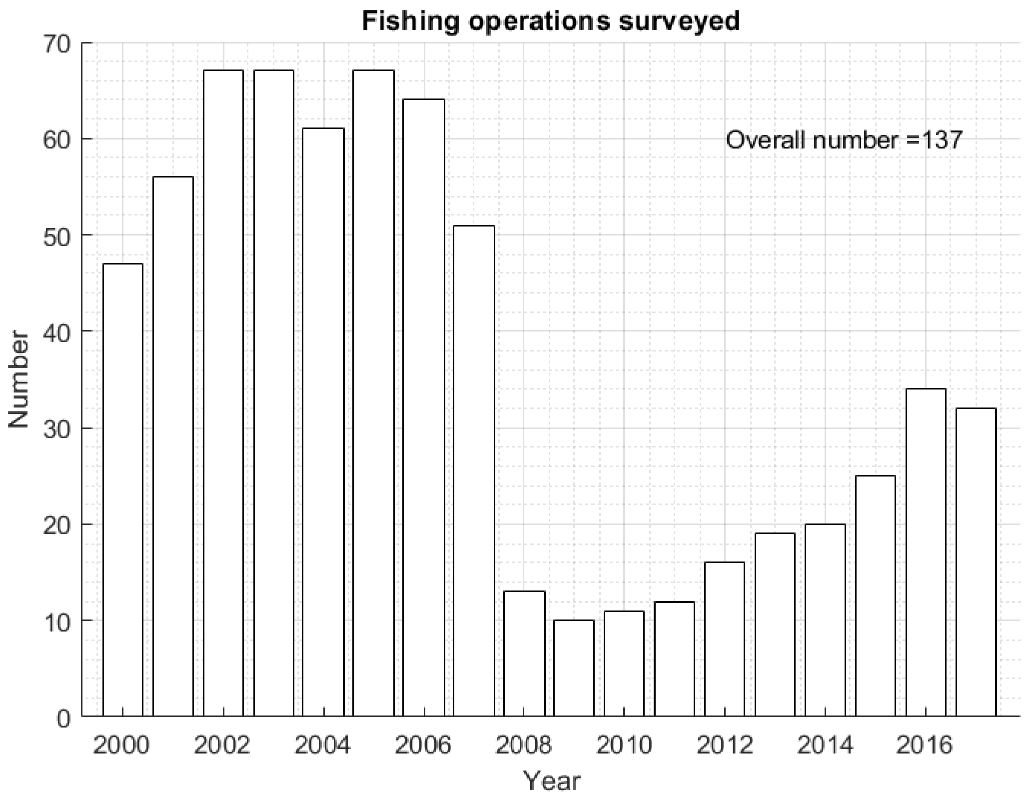

Figure E.2: The number of boats that provided fishing power data per year from two surveys conducted in 2007 and 2017.

Figure E.3: Boxplot of skipper years of fishing from two surveys conducted in 2007 and 2017.

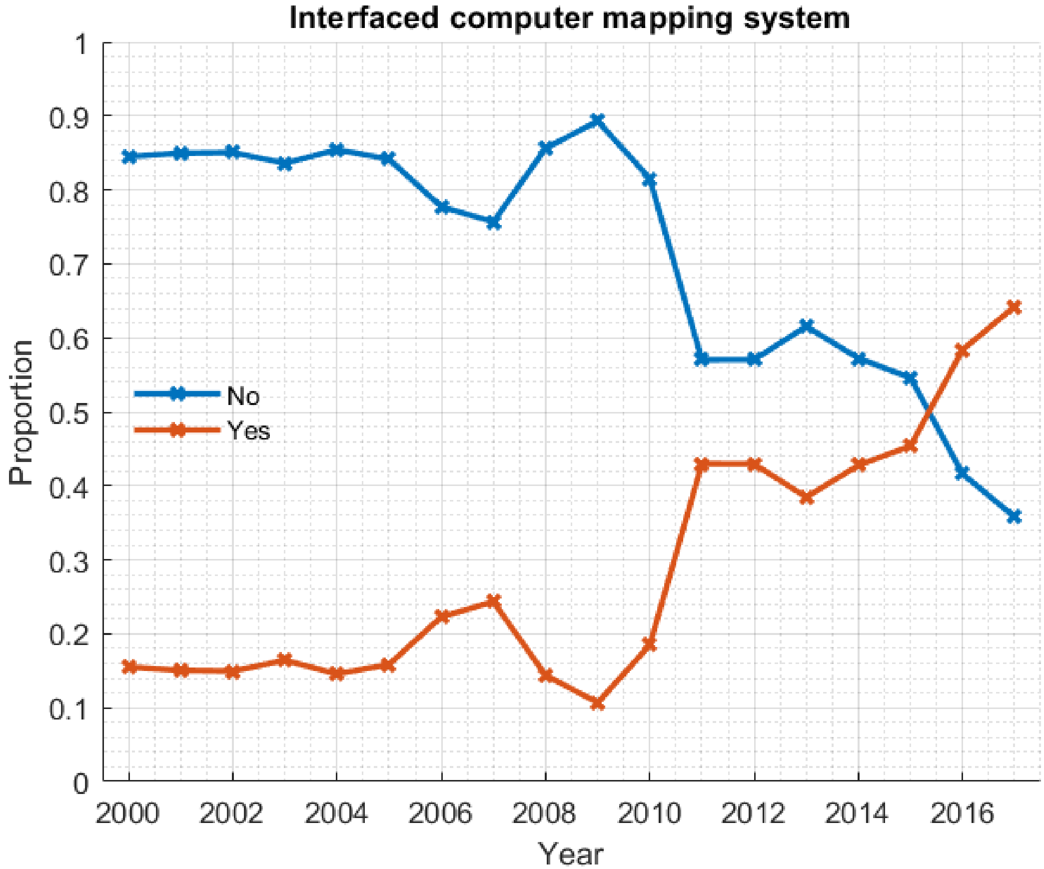

Figure E.4: Proportion of fishing effort using interfaced computer mapping systems.

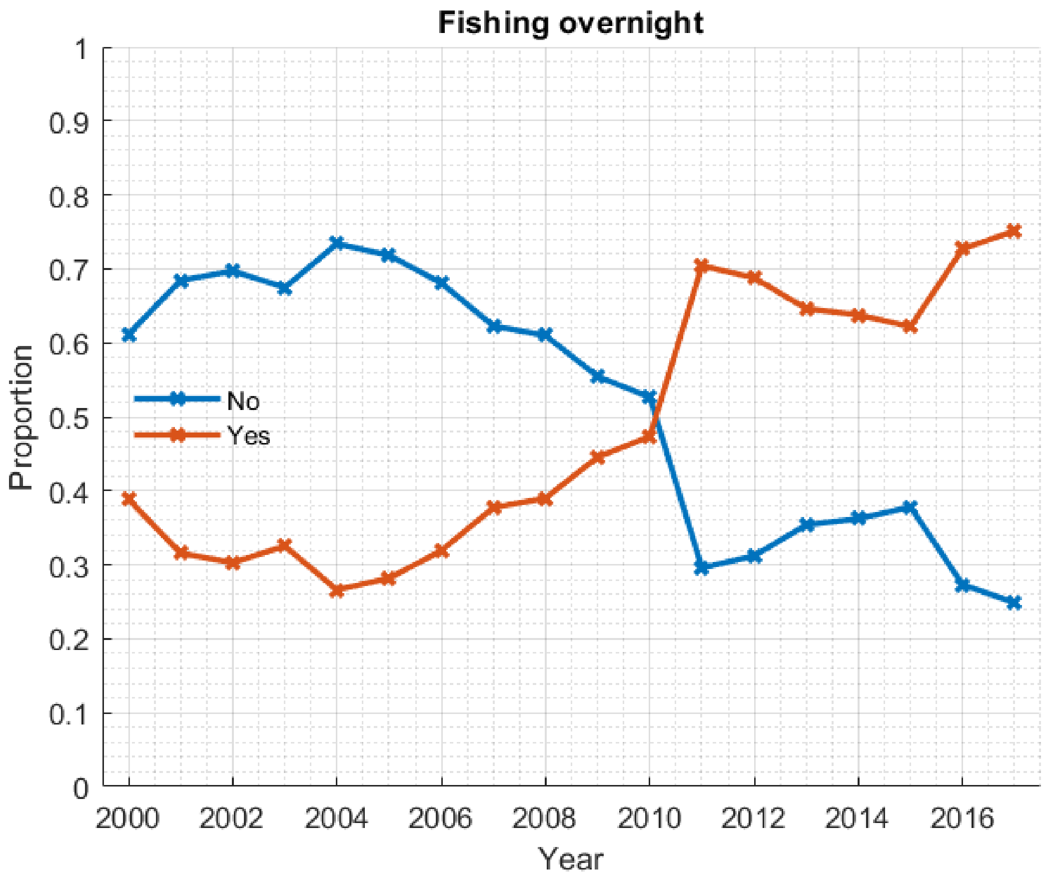

Figure E.5: Proportion of fishing effort relating to vessels staying at-sea overnight.

F Appendix - Missing sFIS in 2020

On 4 February 2022 the fishery working group reviewed two methods for estimating the missing sFIS in 2020 (Department of Agriculture and Fisheries 2022). The two options were: 1) the mean of the nearest sFIS values before and after 2020, and 2) proportional to the commercial sCPUE in 2020 (see TACC method section).

The working group noted that option 1 maintained fishery independence, but the use of the sFIS from 2021 had more influence in forming the two-year stock ratio for 2020–2021. Method option 2 was noted as fishery dependent and the sFIS from 2021 had normal influence in forming the two-year stock ratio.

A retrospective analysis was used to assess which method was better between 2000 and 2018. The analysis compared actual sFIS results against each method estimate. Years were compared that had nearest sFIS values before and after.

Option 2 was assessed as more accurate than option 1 in 9 out of the 12 retrospective years (Table F.1, column "Best 1or2"). Option 2 was endorsed by the working group for TACC calculations, but they requested investigation of filtering the commercial data in option 2 to better align with the spatial timing of the FIS.

For this, the commercial GLM analysis was restricted to the month of May and the commercial fishing grids of T30, U30, U31, V31, W31, V32, W33, W34, W37, X34, X35, W36, X37, and X38 (Figure A.3). Model terms for the commercial GLM were modified as appropriate for the reduced data:

$$kg \sim \exp(boat + year * region + gfp + gfp : \log(netlifts) + offset(\log(fishingpower))) \qquad (F.1)$$

The following results of filtering the commercial data in option 2 were noted:

- Correlation between sFIS and sCPUE improved from 0.71 to 0.75 for filtered data.
- The filtered data from May generally mimicked the annual time series of all data. However, the May signal from 2020 was below 2019 and 2020 (Figure F.1).
- Mean absolute differences from sFIS improved from 1.66 to 1.56 crab for filtered data (Table F.1).
- Both data selections for option 2 performed equally, being best in 6 out of the 12 retrospective years (Table F.1, column "Best 2or3").

If option 2 was hypothetically used in TACC calculations with the filtered data, then these results followed:

- The estimated sFIS for 2020 was lower at 5.28 crabs per ground line (Table F.2).
- Pooled indexes were less at 0.59 for 2019–2020 and 0.569 for 2020–2021.
- The same TACC was calculated at 847 t, as a result of the 50 t no-change buffer rule.

In discussion, more data filtering to weeks, fortnights or finer grids could be used to test the commercial data version of what would have been the FIS survey in 2020. However, this might not change the TACC result (as found above). In knowing that the commercial data was recorded per boat-day (not per ground-line), the number of data will thin at finer stratum levels. At the year by region level tested, the average amount of data per level was around 22–33 boat days in 2019–2021. These numbers were higher by a factor of around two in earlier years. More thinning of this data might confound attempts to standardise catch differences between boats or produce high variable results. Further investigation could use statistical resampling techniques to help estimation at finer stratum levels, and overcome the nonrandom patterns of commercial fishing.

Table F.1: Retrospective analysis for a missing sFIS. Results were for 1) Opt1: option 1 for the mean, 2) Opt2: option 2 proportional for using annual sCPUE, and 3) Opt3: option 2 proportional for using filtered May sCPUE. The ”Diff” columns show the difference between sFIS minus the option estimate. The ”best” columns highlight the closest option to sFIS. MD - mean absolute difference between sFIS and the option estimate, and SD - standard deviation of difference

Year	sFIS	Opt1	Opt2	Opt3	Diff1	Diff2	Diff3	Best 1or2	Best 2or3	Best
2001	8.01	7.19	7.54	6.56	0.82	0.47	1.45	2	2	2
2002	6.15	8.21	7.47	7.55	-2.05	-1.32	-1.39	2	2	2
2006	12.71	10.81	10.85	10.94	1.9	1.86	1.77	2	3	3
2007	10.18	13.68	13.71	14.01	-3.5	-3.53	-3.83	1	2	1
2008	14.65	8.93	9.28	10.96	5.71	5.37	3.69	2	3	3
2009	7.69	12.31	11.36	8.46	-4.63	-3.68	-0.78	2	3	3
2010	9.98	7.85	8.79	10.16	2.13	1.19	-0.18	2	3	3
2014	9.99	9.98	8.79	9.29	0.01	1.2	0.7	1	3	1
2015	10.55	8.84	10.61	12.49	1.71	-0.06	-1.94	2	2	2
2016	7.69	8.43	7.49	5.41	-0.74	0.2	2.28	2	2	2
2017	6.31	6.61	5.89	6.91	-0.31	0.41	-0.6	1	2	1
2018	5.53	6.49	6.21	5.63	-0.96	-0.68	-0.1	2	3	3
				MD	2.04	1.66	1.56			
				SD	2.64	2.31	1.96			

Table F.2: sFIS estimates for 2020. Results were for 1) Opt1: option 1 for the mean, 2) Opt2: option 2 proportional for using annual sCPUE, and 3) Opt3: option 2 proportional for using filtered May sCPUE.

Year	Opt1	Opt2	Opt3
2019	6.6736	6.6736	6.6736
2020	6.3365	7.2840	5.2820
2021	5.9994	5.9994	5.9994
Means			
2019–2020	6.5051	6.9788	5.9778
2020–2021	6.1679	6.6417	5.6407

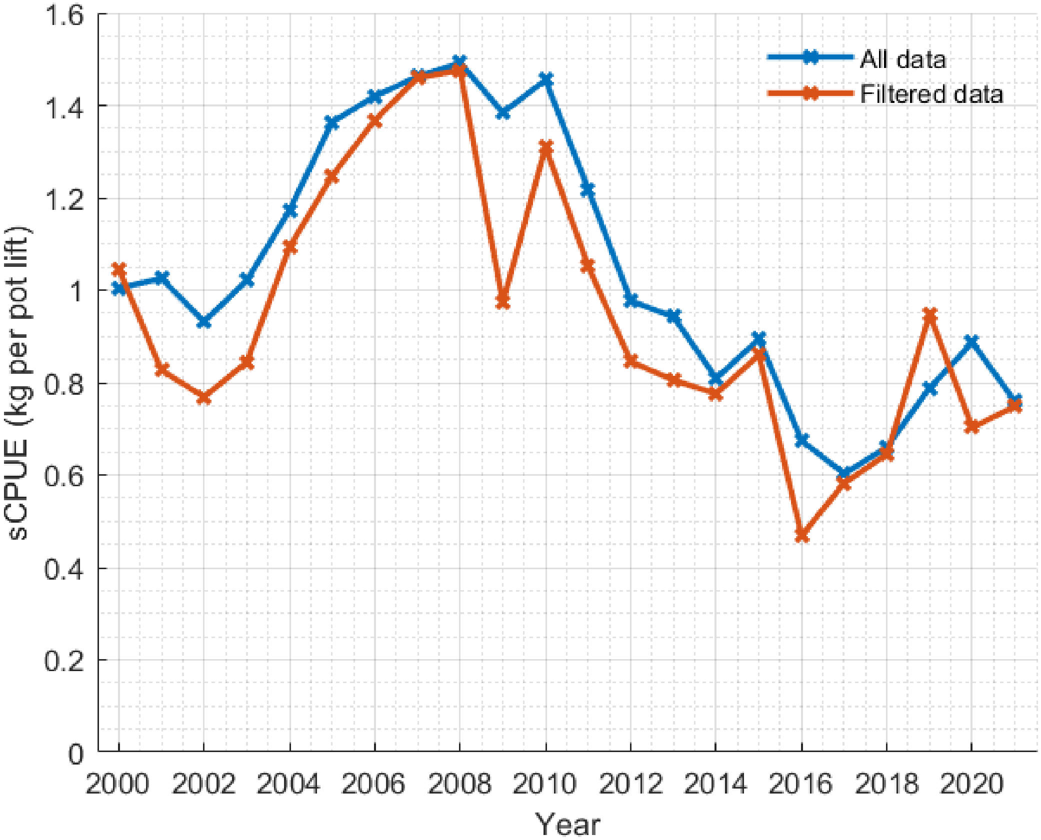

Figure F.1: Commercial catch rate sCPUE by year for all data compared to filtered May data.

G Appendix - Industry questions and responses

On 3 February 2022 Mr Peter Jones, spanner crab fisher, emailed Fisheries Queensland with a 29-page review and recommendations for the commercial catch rate standardisation. The document, with industry input, asked for a response to the conclusions and recommendations.

The response was structured against key review items (listed in *italics*). For a full copy of the review by industry, please contact Mr Peter Jones or the fishery manager via the spanner crab fishery working group.

Responses

Recommendation 1

Calculate the magnitude in percentage up or down of the impact of each influencing factor on the raw CPUE to attain the standardised CPUE.

The influence of model factors on nominal (raw) CPUE were reported in Appendix A. They were also discussed, with graphics, in past working group meetings.

A measure of the influence of an explanatory variable (type factor or variate) can be derived from the GLM coefficients associated with that variable (Ref1: Bentley, 2012). For example, the strong computer mapping coefficient estimated for the offset (Appendix E). However, for a variable to have influence on annual standardised catch rates, there must be changes in the mean values of that variable among years. Influence plots of different styles can be used to illustrate possible effects (Ref1: Bentley, 2012), and show how trends change from the raw catch rates to the final standardised ones.

Herein, influence plots were shown by sequentially adding GLM model terms, with supporting graphs illustrating the annual shifts in the key explanatory variables (e.g. annual fleet changes in fishing boats, Appendix A). The influence plots illustrated the key boat and fishing power effects on CPUE (Figure A.6). Other models terms were less influential on the annual time series of catch rates.

Spanner crab percent deviations from the nominal catch rate (kg per dilly-lift) are shown in Figure G.1, for sequentially building terms into the GLM.

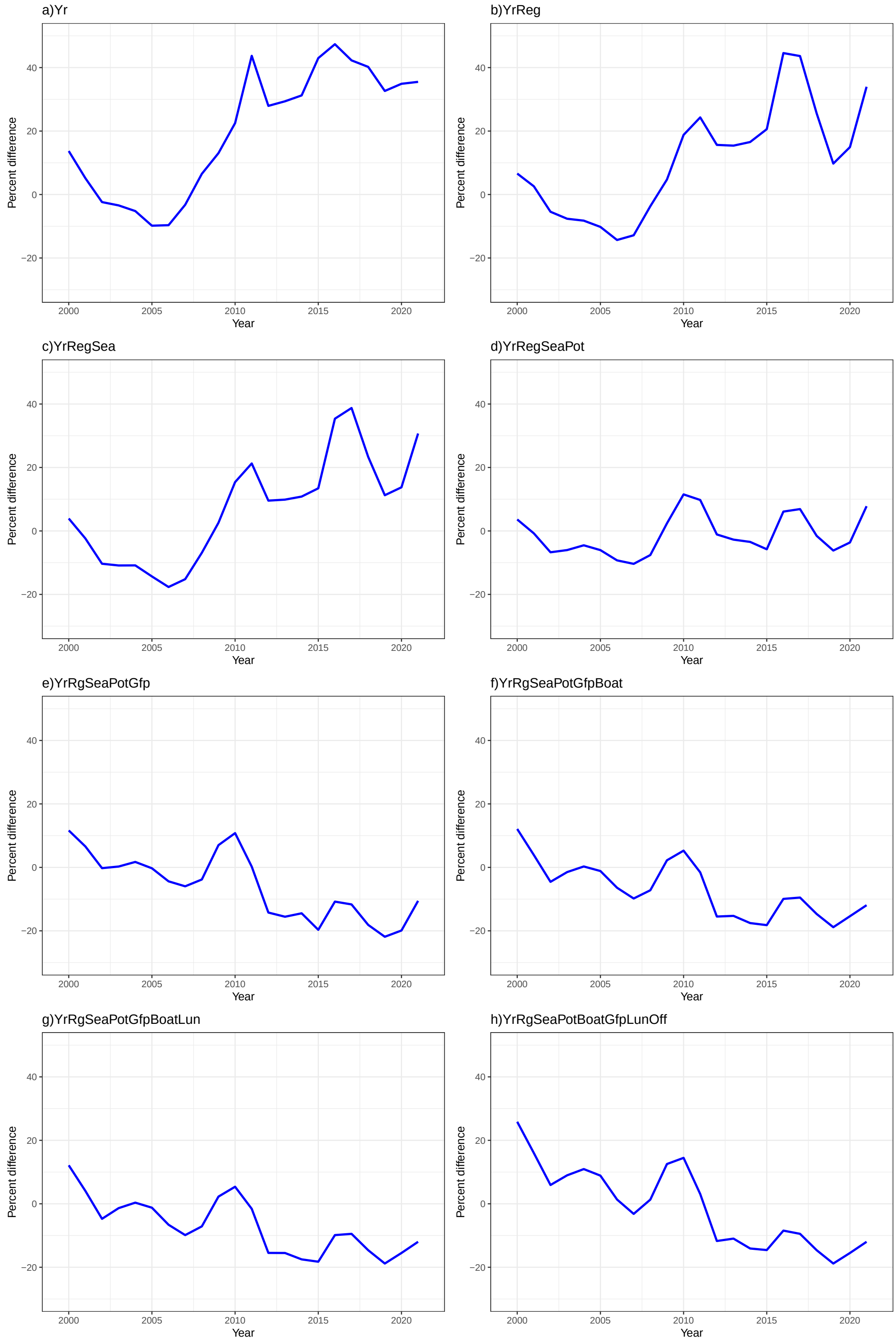

Figure G.1: Influence plot comparing the annual percent difference between standardised sCPUE for different GLMs and nominal CPUE. Model terms were year (Yr), region (Reg), seasonality (Sea), dilly lifts (Pot), GFP, boat, lunar (Lun) and the fishing power offset (Off).

Recommendation 2

Identify which influencing factors are impacting standardisation with a negative downward trend.

The influence plots illustrated the boat factor and the fishing power offset as the key negative effects on sCPUE (Figure G.1 and Figure A.6). In Figure G.1 GFP was ordered before boat in subplot e), to follow the inclusion of the pot data in subplot d). If boat was added before GFP, a similar negative effect was seen as between subplots d) to e). There was no duplication of model effects.

The estimated boat effect, from combining the GLM boat estimates (coefficients) with their fishing effort, signaled the fleet composition of boats in 2021 was about 17% better at catching crab compared to 2000 (Appendix A, Figure A.7). This was also illustrated by grouping the GLM boat estimates into their quantiles (Figure G.2). This figure showed the better half of fishing boats (boat type groups 3 and 4) from 2013–2021 completed above 80% of the fishing effort in each year, more than in the previous years.

The fishing power offset, for annual fleet changes in fishing gear and technology, was detailed in Appendix E. The main driver, for the 12% effect over 18 years, was the positive catch association with improved computer mapping. The belief stated in the industry review argued that improved vessel electronics generally do not improve catches of spanner crab. The review said such devices do not facilitate the identification of individual or aggregations of spanner crabs, but sounder technology has allowed the discrimination between hard bottom and possibly suitable soft bottom. This aspect of the fishing power offset requires discussion. It appears the review assumptions conflict with the data and results (and why the fishing gear surveys were designed and conducted in 2007 and 2017). Work on the fishing power offset was a report recommendation. The current offset implied that better vessel electronics help improve the deployment of fishing gear and catching crab.

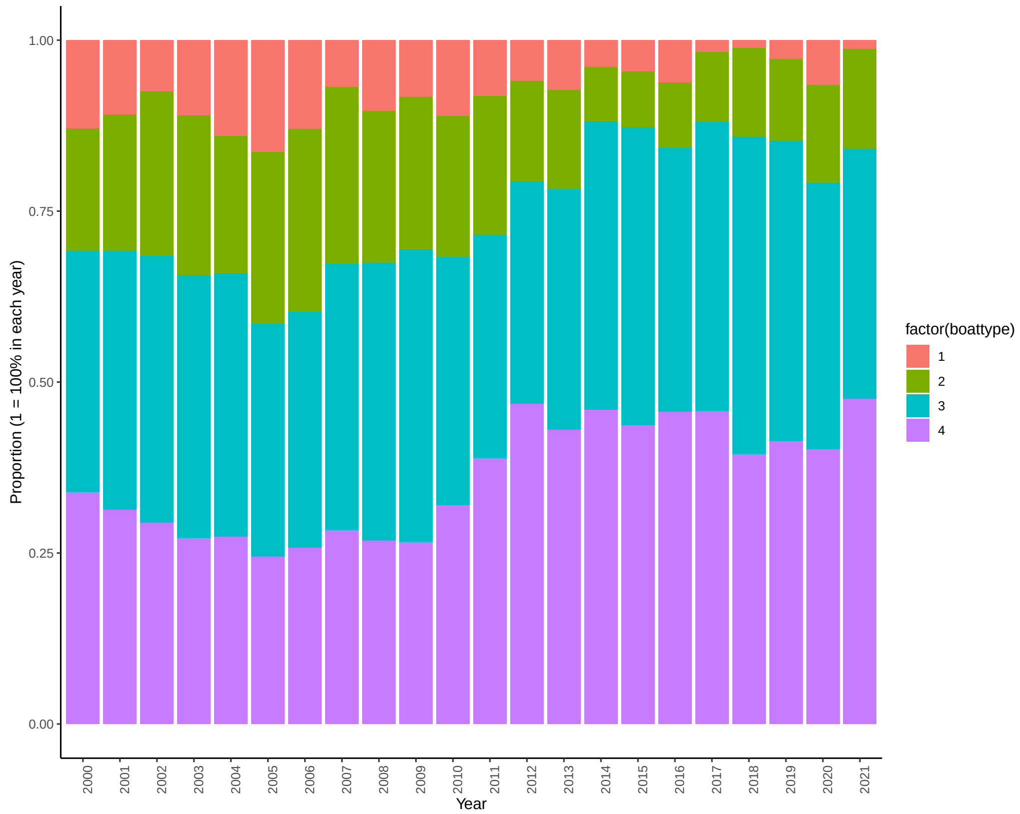

Figure G.2: Fleet composition of boat types by year. Low catching boats group 1 was the quantile less than the 25th percentile, below median group 2 was the quantile between the 25th percentile inclusive and 50th percentile, median and above group 3 was the quantile between the 50th percentile inclusive and the 75th percentile, and the high catching boats group 4 was the quantile from the 75th percentile inclusive and above.

Recommendation 3

Make any relevant changes to the standardisation process

Methods were applied to be consistent with last year since the harvest strategy. No changes were made or were obvious at this time. Any suggested changes to the commercial GLM will need to be raised, reviewed and endorsed by the working group and project team. Changes in methods and data will be investigated over the next 1–2 years, based on a continued scientific basis and working group input.

Recommendation 4

Clearly communicate to all stakeholders, what are the influencing factors and their individual magnitude in percentages for standardisation each quota year.

This report has detailed the aspects and will form the ongoing content for future reports. Feedback will be sought from the working group to better tailor the report, and to build in further information as required.

Recommendation 5

Consider a process for data collection on the size distribution and average size across the spanner crab biomass

Size information is best sampled consistently, spatially and temporally, through the FIS using constant gear. This was currently being done by using a random-stratified design for managed area A. The FIS measured and sexed all sized crab. The minimum CL sized crab caught was 2 cm and the maximum was 18 cm. More temporal replication is desirable, but requires funding.

Fishery dependent sampling would limit size measures on only legal sized crab (MLS = 10 cm CL). The scale of change in average size of legal crabs would be small to signal changes in population size; also the case for FIS sampling. Annual age-length keys would be required to support fishery dependent length samples and is not scientifically possible at this time.

Crab size information is best used to inform a stock assessment model.

The 2000–2021 FIS size data was summarised below (Figure G.3), showing generally a smaller mean length in later years (Figure G.4):

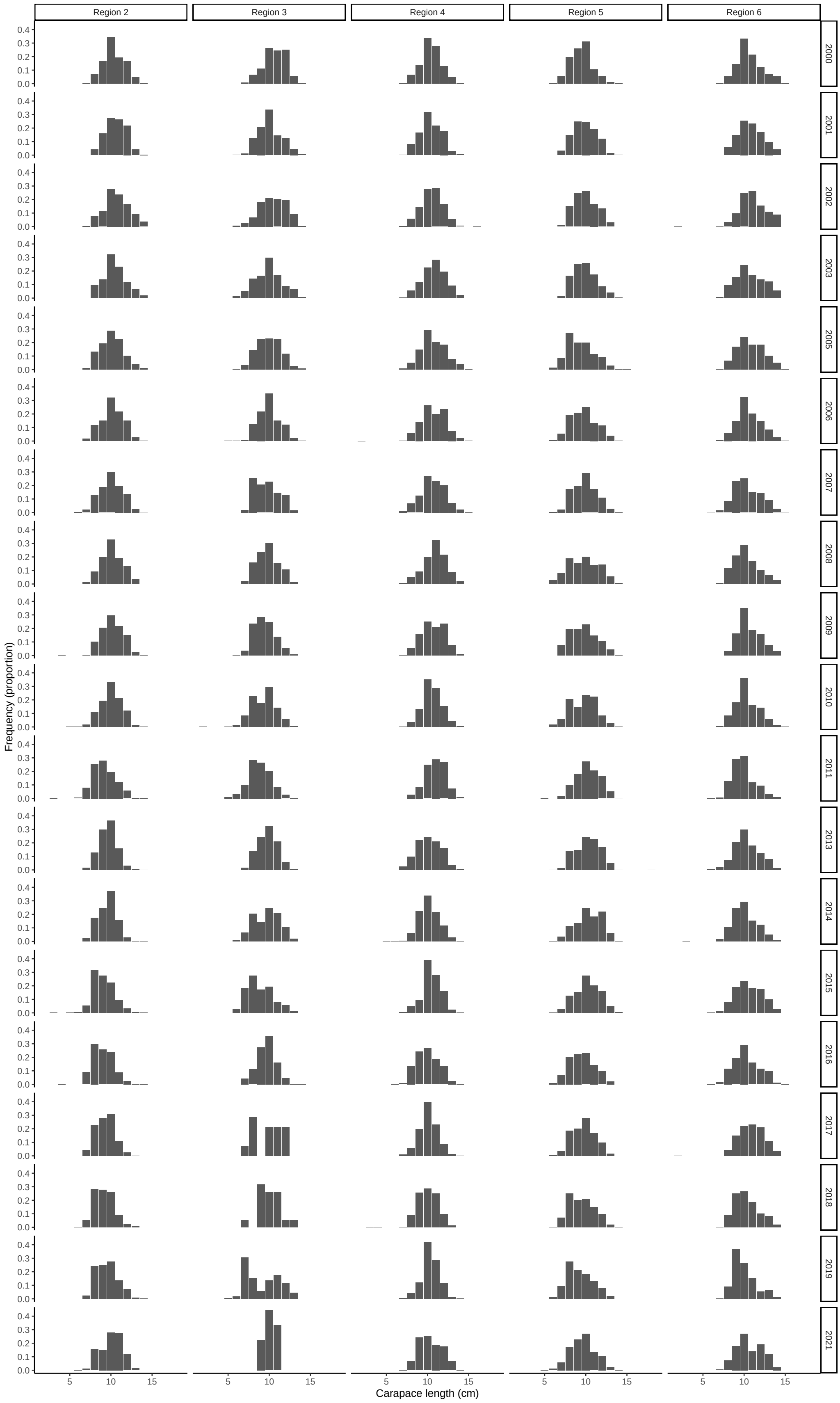

Figure G.3: Length frequencies of spanner crab by year and region.

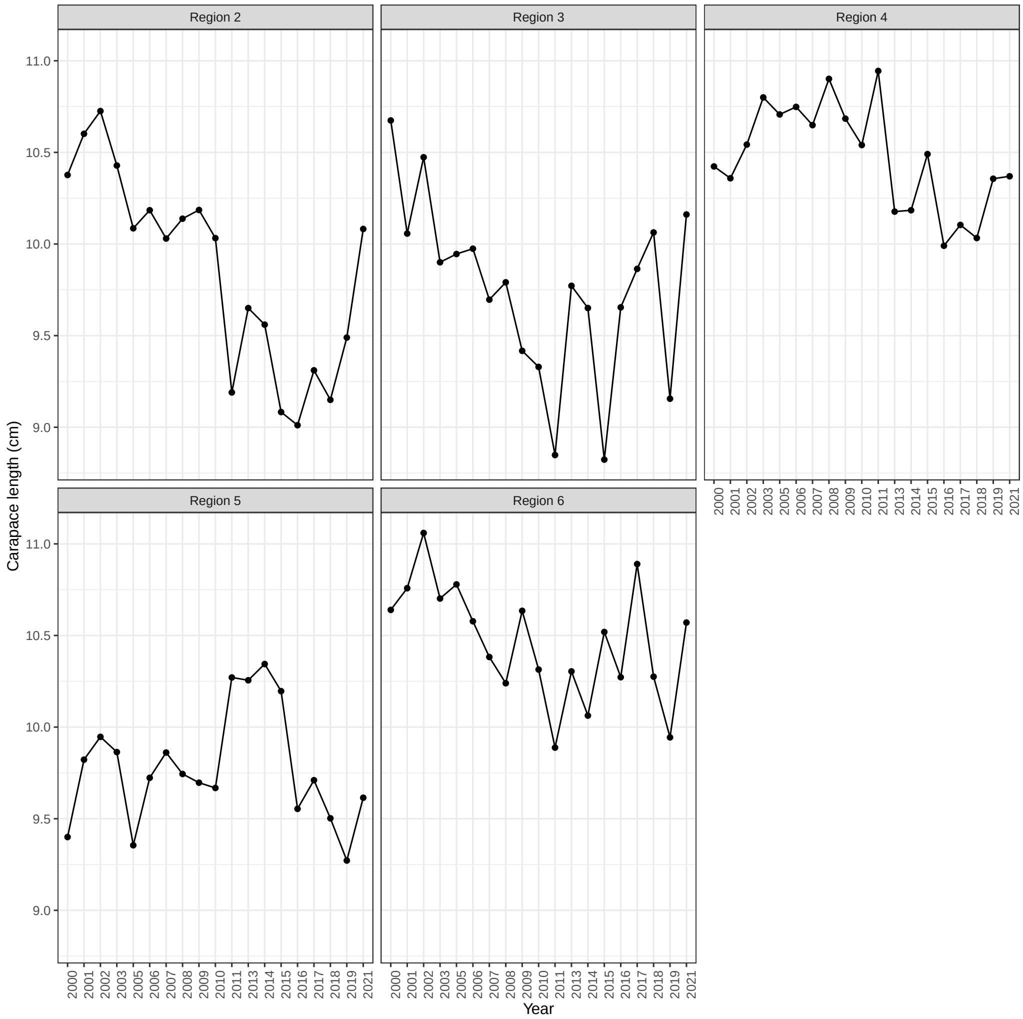

Figure G.4: Mean spanner crab lengths by year and region.

Recommendation 6

The above is critical, given that the standardised CPUE has a major input into the management procedure via harvest rules and the allocation of annual quota.

This was a general statement referring to the need for size data. The data and response was provided above.

The industry recommendation was for:

- "a sustainable biomass of product through the quota decisions, standardisation has significant impact on the economic viability/productivity of this fishery and for the industry to supply product to the market/public."; and
- "As fish/crab are removed by harvest from a population; the abundance decreases and the average size of the fish/crab of the population decreases. Currently the standardised CPUE and FIS data are used for this. Stock size distribution and average size data may be useful to affirm the biomass abundance."

Conclusion point 1

The standardistation of spanner crab CPUE has followed a general negative linear trend from the year 2000 to 2018. This linear downward trend in standardisation of -1.8% per year. When extrapolated on the graph will lead to the standardised CPUE reducing to below the limit reference point of .5 kg/pot, even if raw catch rate matches the best catch rates of the unfished biomass, at which point the fishery is to be closed

The trend in deviations between nominal and standardised catch rates can support influence plots. They cannot be used to predict a decline to the limit reference point. Standardised catch rates were estimated to increase 2018–2020 up to near 0.9 kg per pot. But declined in 2021 to 0.76. The 2021 decline was stronger in the nominal catch rate than standardised. The fishing power offset was not changed after 2017 and was not a linear pattern from year to year. The results do not support the statement.

Conclusion point 2

The standardisation downwards in this Pot Fishery is approximmately 4 times in magnitude the standardisation of a New Zealand lobster fishery and 12 times in magnitude the standardisation of the Tasmanian lobster fishery.

Review examples were selected for QLD spanner crab showing a linear decline in deviation (standardised sCPUE divided by nominal CPUE as a percentage in each year) from approximately +18% down to -16% between 2000 and 2019, Tasmanian lobster showing a flat zero trend 1947–2019 with annual deviations mostly between ± 5%, and New Zealand lobster showing a linear decline in deviation from approximately +10% down to -12% between 1980 and 2019 with a spike in annual deviation up +30%.

Drawing parallels between fisheries is difficult without extensive review, and the selected lobster fisheries and their characteristics will differ. A broader literature review would provided better context and comparison. One difference to consider was in the level of standardisation and availability of explanatory data to analyse. The following publications provide further insight into example Tasmanian (Ref 2) and New Zealand (Ref 3) lobsters:

- Ref 2 data showed a linear decline in the percent deviation between standardised and nominal CPUE from about +5% in 2000 and down to -10% in 2013, with a +5% increase again by 2019. Their standardisation only included factors for month (and therefore season), assessment area, vessel, moon phase and depth. They note important technological improvements that have occurred include GPS, weather forecasting, sophisticated sonar and 3D mapping technology used on some modern vessels. This effect is often referred to as technological creep, and unlike spanner crab, this was not accounted for in their standardisation. In addition, they note factors that are difficult to account for and most concerning are changes to the fishing behaviour of a large proportion of the fleet.
- Ref 3 data for packhorse rock lobster was an interesting example for 1992–2019. The magnitude of deviation between standardised and nominal changed linearly from -80% to +100%; Table 17 in Ref 3. Fishing year was always forced as the first explanatory variable in this analysis. Other variables analysed included: month, vessel, target species, and statistical area. No fishing power data or catchability increase was considered in this publication. There appeared to be changed fleet dynamics with more vessels being operated (reverse of spanner crab), and that would explain lower nominal lobster CPUE.

In addition to the above examples, Ref 4 concluded that technological creep has masked a continuous stock decline in European lobster. Even though spanner crab fishing was different and unchanged in the type of dilly pots used, the Ref 4 study confirmed the importance of adequate standardization, including technological development, when using fishery dependent CPUE for monitoring and management of data-limited fisheries.

The use of appropriate statistical models/ computer package to achieve effective standardisation.

This year's report was generated using the free computer software R. Results were checked against the commercially certified software GenStat. Both are recognised professional softwares. The appropriateness of statistical models and their complexity were reviewed for every past analysis. Please review the diagnostics herein.

References for Appendix G

Ref 1: Bentley, N., et al. (2012). Influence plots and metrics: Tools for better understanding fisheries catch-per-unit-effort standardizations. ICES Journal of Marine Science 69(1): 84-88.

Ref 2: University of Tasmania and Institute of Marine and Antarctic Studies. 2020-21. Rock Lobster Assessment, Catch Per Unit Effort (CPUE). url = https://tasfisheriesresearch.org/rock-lobster-assessment/catch-per-unit-effort-cpue/

Ref 3: Roberts, J., Webber, D.N. (2021). Characterisation, catch-per-unit-effort, and stock assessment of packhorse rock lobster (Sagmariasus verreauxi) in New Zealand. url = https://fs.fish.govt.nz/Doc/25015/FAR-2021-78-Packhorse-Rock-Lobster-Characterisation-CPUE-Assessment-4227.pdf.ashx

Ref 4: Kleiven, A. R., Espeland, S. H., Stiansen, S., Ono, K., Zimmermann, F. and Olsen, E. M. (2022). Technological creep masks continued decline in a lobster (Homarus gammarus) fishery over a century. Article number: 3318, Nature journal - Scientific Reports. url = https://www.nature.com/articles/s41598-022-07293-2