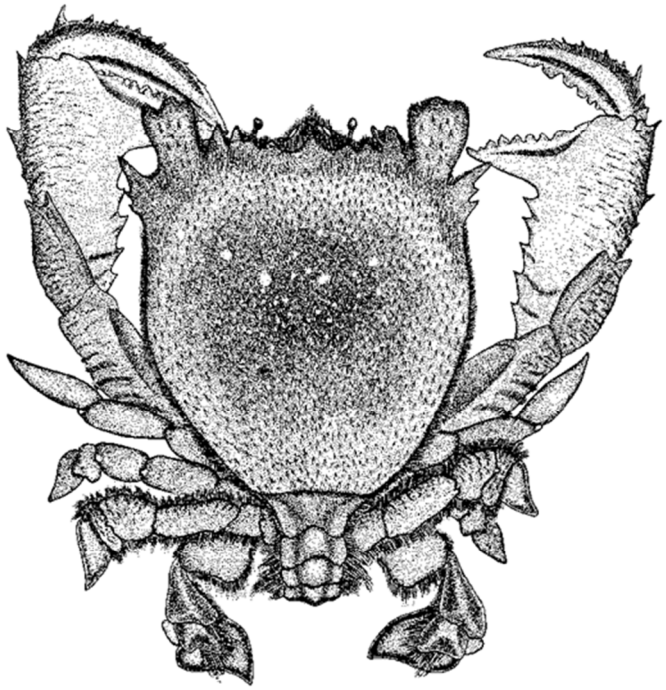
Queensland Spanner Crab Fishery

Commercial quota setting for June 2015 – May 2016



Species: *Ranina ranina*

Queensland Government

This publication has been compiled by MJ Campbell and MF O'Neill of Agri-Science Queensland and JG McGilvray of Fisheries Queensland, Department of Agriculture and Fisheries.

Summary

The Australian fishery for spanner crabs is the largest in the world, with the larger Queensland (QLD) sector's landings primarily exported live overseas and GVP valued ~A$5 million per year. Spanner crabs are unique in that they may live up to 15 years, significantly more than blue swimmer crabs (*Portunus armatus*) and mud crabs (*Scylla serrata*), the two other important crab species caught in Queensland. Spanner crabs are caught using a flat net called a dilly, on which the crabs becoming entangled via the swimming legs.

Quota setting rules are used to assess and adjust total allowable harvest (quota) around an agreed target harvest of 1631 t and capped at a maximum of 2000 t. The quota varies based on catch rate indicators from the commercial fishery and a fishery-independent survey from the previous two years, compared to target reference points. Quota management applies only to 'Managed Area A' which includes waters between Rockhampton and the New South Wales (NSW) border.

This report has been prepared to inform Fisheries Queensland (Department of Agriculture and Fisheries) and stakeholders of catch trends and the estimated quota of spanner crabs in Managed Area A for the forthcoming quota period (1 June 2015–31 May 2016). The quota calculations followed the methodology developed by the crab fishery Scientific Advisory Group (SAG) between November 2007 and March 2008.

The total reported spanner crab harvest was 917 t for the 2014 calendar year, almost all of which was taken from Managed Area A. In 2014, a total of 59 vessels were active in the QLD fishery, the lowest number since the peak in 1994 of 262 vessels. Recent spanner crab harvests from NSW waters have been about 125 t per year.

The spanner crab Managed Area A commercial standardised catch rate averaged 0.739 kg per net-lift in 2014, 24% below the target level of 1.043. Mean catch rates declined in the commercial fishery in 2014, although the magnitude of the decreases was highest in the area north of Fraser Island.

The NSW–QLD survey catch rate in 2014 was 16.849 crabs per ground-line, 22% above the target level of 13.972. This represented a decrease in survey catch rates of 0.366 crabs per ground-line, compared to the 2013 survey.

The Queensland spanner crab total allowable harvest (quota) was set at 1923 t in 2012 and 2013. In 2014, the quota was calculated at the base level of 1631 t. However, given that the 2012 fishery-independent survey was not undertaken for financial reasons, stakeholders proposed that the total allowable commercial catch (TACC) be decreased to 1777 t; a level that was halfway between the 2012/13 quota of 1923 t and the recommended base quota of 1631 t. The results from the current analysis indicate that the quota for the 2015-2016 financial year be decreased from 1777 t to the base quota of 1631 t.

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Introduction

The Australian spanner crab fishery operates across the jurisdictional waters of Queensland (QLD) and New South Wales (NSW) between ~22 and 30°S. It is the largest spanner crab fishery in the world of its kind, with annual gross landings up to ~2000 t (O'Neill et al., 2010). Spanner crabs are large, growing to about 15 cm rostral carapace length (~0.75 kg), generally mature above 7 cm, and live in oceanic waters from shallow intertidal depths to at least 100 m on sandy substrates. They are caught by entangling their legs on tightly strung 32 mm mesh over a flat square or rectangular metal frame enclosing an area of about 1 m^2 (Figure 1). Spanner crabs grow more slowly than other QLD crab species, although estimates of longevity have varied with scientific study. Maximum longevity was estimated up to ~15 years with females requiring ~6 years and males ~4 years to reach minimum legal size of 10 cm rostral carapace length (Brown et al., 1999; Kirkwood et al., 2005).

The establishment of a high-volume-live Asian market was a significant turning point in the history of the fishery. An increasing proportion of the fleet became dedicated to spanner crabbing and the fleet grew rapidly, with a trend towards larger vessels of the type used in the Western Australia (WA) rock-lobster fishery. Fishing effort increased almost exponentially between 1990 and 1994 (Appendix 4, Figure 15, page 28) as operations expanded northwards to fishing grounds north of Hervey Bay. In response to sustainability concerns, an investment warning was issued by the Queensland Fisheries Management Authority (QFMA) in January 1994. By way of the Spanner Crab Management Plan, management moved towards output controls, with a Total Allowable Catch (quota) applied on the main QLD fishing grounds (Managed Area A –

Figure 10). Management Area B was, and still is, subject to input controls, but surveys north of the Capricorn Group failed to find any evidence of significant spanner crab populations north of the existing fishery as far as Bowen.

In QLD, commercial fishing for spanner crabs is managed under licences marked with a C2 (in Managed Area A;

Figure 10, Appendix 1 page 20) or C3 (in Managed Area B; Figure 11, Appendix 1 page 21) fishery symbol (Queensland Government, 2008). Managed Area A (C2 fishery symbol) is fully developed and accounts for over 95% of the total harvest of spanner crabs in QLD. The commercial quota harvest limit (total allowable commercial catch – TACC) is reviewed every two years for Managed Area A. As of 15 March 2015, 219 C2 and 293 C3 symbols were available. Individual quota holdings can be traded between licence symbols. For the current fishing season in Managed Area A (2014–2015), there are 100 quota account holders, of which 69 own the actual quota and the other 31 lease. The remaining 119 licences holding a C2 symbol are unable to fish for spanner crabs as they do not currently hold quota.

A fixed daily in-possession limit of 16 baskets (a basket is ~66 litres capacity) of spanner crabs applies in management Area B. The number of spanner crab dilly nets per licence is limited to 45 in Managed Area A and 30 in Managed Area B. However, as of 2 March 2015, 30 general fisheries permits (GFP) were active allowing vessels to use up to 120 dilly nets depending on the number of crew aboard. Throughout QLD a closed season applies to spanner crab from midnight 20 November to midnight 20 December inclusive. This closure covers the main part of the species' spawning period in QLD waters (Brown, 1986). Also, spanner crabs are subject to minimum legal size regulation and egg carrying females must be returned to the water.

Figure 1: Entangled spanner crabs (Ranina ranina) on a flat dilly net.

The total annual commercial spanner crab quota (TACC for Managed Area A) is set using an empirical (data-based) management procedure (Dichmont and Brown, 2010; O'Neill et al., 2010). The management procedure has limited QLD tonnages to less than 2000 t since the introduction of output quota control in 2002 (Appendix 4, Figure 15, page 28). The current management procedure for spanner crab, including harvest control rules, operate around an agreed base quota of 1631 t, with a maximum quota capped at 2000 t, and catch rate abundance indicators compared against target reference points (O'Neill et al., 2010). The analysis and management details are outlined in Methods page 2 and Appendix 2 page 22.

This report has been prepared to inform Fisheries Queensland (Department of Agriculture and Fisheries) and stakeholders of the estimated quota of spanner crabs in Managed Area A for June 2015 to May 2016. The determination was made applying the methodology developed by the crab fishery Scientific Advisory Group (SAG) between November 2007 and March 2008. Application of the management decision rules (Appendix 2, page 22) indicate that the commercial quota of spanner crab should be reduced to the base TACC of 1631 t.

Methods

Data

The commercial data presented herein were extracted from the Fisheries Queensland DME database on 2 March 2015, representing spanner crab harvests from January 1988 to 31 December 2014. All current fishery-independent survey data from NSW and QLD were provided on 24 February 2015.

Definitions and constraints for the commercial data were:

- Definition of ‘annual’: In the following summaries and analyses the ‘annual’ data refer to the calendar year (1 January–31 December).

- Bulked data: For analyses resulting in the estimation of catch rates, data were restricted to records where the number of fishing days (per record) was one (i.e. the reported start date is the same as the finish date). In the data set there were 101 records (<0.05%) where catches were 'bulked' over periods of more than one day, but most of these occurred prior to1994. They were excluded from the catch rate analysis data.
- Effort criterion: Where fishing effort (number of dilly-lifts) was not reported, catch rates cannot be calculated. Thus records with no fishing effort (net-lifts) were excluded from analysis.
- Catch units: Commercial records unit of catch was kilograms.
- Pooling of 'multiple set' records: Some fishers occasionally report separate catch and effort statistics for two or more fishing sets on a given day. As the lowest level of temporal separation in our analyses is the fishing day, these records were pooled. This was done by summing the catches and efforts over all fishing operations in the day.

In line with previous assessment reports, summary tables of logbook-reported harvest and effort by region and year, as well as overall annual catch and effort statistics, are included in Appendix 4 on page 26. Management focus and quota calculations were based on modelled adjusted (standardised) mean catch rates.

Geographic details of the regions (2–6) within Managed Area A are shown in Figure 2. Note that the commercial data for Region 7 (south of the QLD/NSW border) are only for dual-licenced boats using QLD logbooks, and do not include catch data from the NSW spanner crab fishery. Figure 2 also illustrates the fishery independent survey locations.

In 2012, DAF was advised that preliminary estimates of commercial spanner crab catch rates were likely to be biased as a result of changes in export market demand. A working group of industry and DAF representatives was convened to review the matter. It became clear that the quota for 2012-14 would be biased downwards to an unacceptable degree if the logbook reported catch data were used in the usual way. A description of this data issue, as well as the methodology adopted to account for the discarding of legal-size crabs, can be found in Table 1 and Brown (2013).

As a result of this market-driven change (through which reported legal catches were not necessarily equal to landings), modifications were made to the Spanner Crab Logbook around mid-2012. The principal change in the new version (SC06) was provision for an estimate of the quantity of legal crabs discarded on days when the buyer imposed a limit on the quantity of (usually small) legal crabs that the fisher could land. For convenience, this new piece of information was entered into the logbook database in the same field as was previously used for reporting the estimated total quantity of discards (in that case almost exclusively undersize crabs). It is thus very important to remember that 'discards' in logbook versions prior to SC06 referred to undersize crabs, while those in versions SC06 *et subseq*. refer exclusively to legal size crabs. Because fishers record their catches in logbooks at different rates, the introduction of SC06 occurred over six months or so, and, as a result, there was a lengthy period during which one operator could be reporting released undersize crabs, while on the same day another could be reporting released legal crabs. To account for this, the following procedure was adopted in 2012–2013 (Brown, 2013) and applied here in 2014:

- Catch records in the 2009-10 financial year from Regions 4 and 5 were adjusted upward by a factor of 1.1543.
- Likewise, in the 2010-11 financial year, the adjustment factor was 1.3073.

- The estimated high-grading gradually declined between 1/7/11 and 30/9/12 (in Regions 4 and 5 only), and was linearly modelled (Y = *a* + *b*X) 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 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).

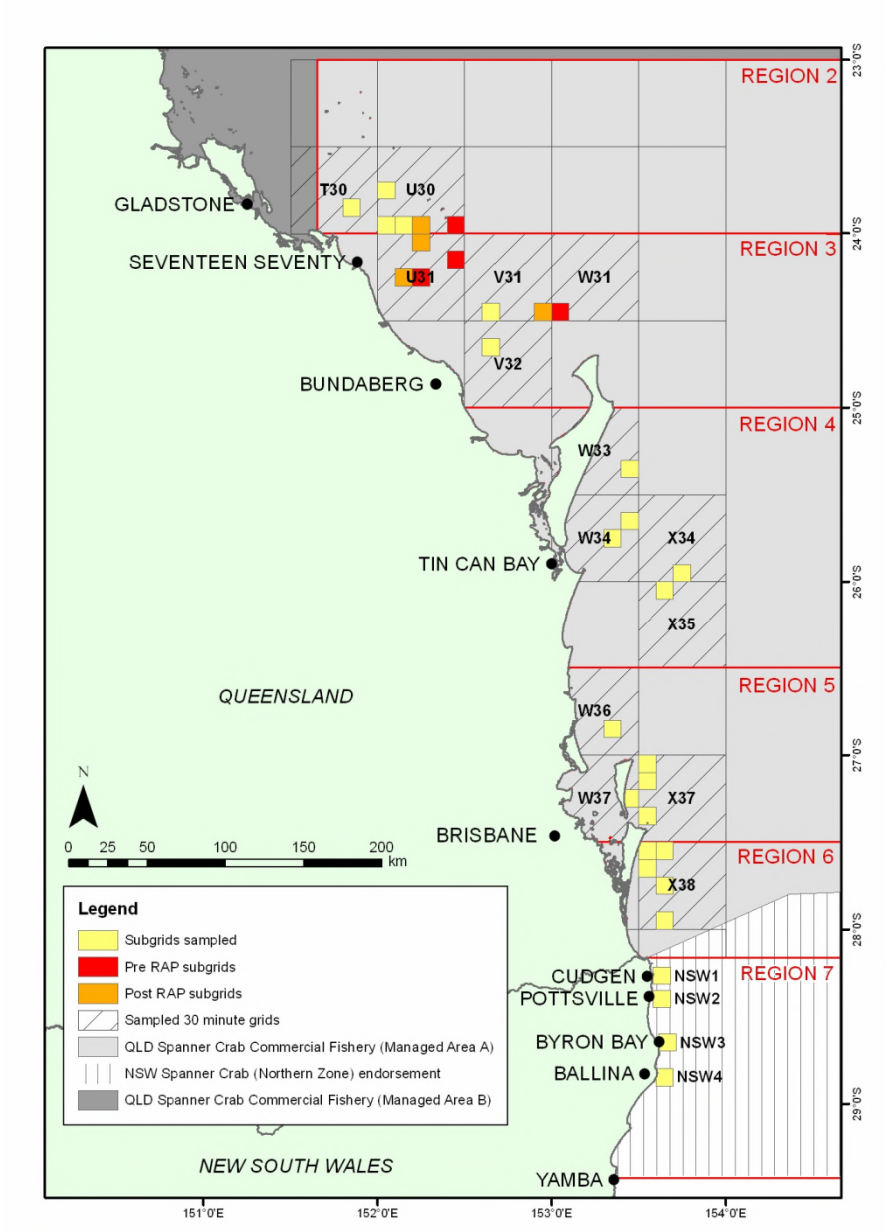

Figure 2: Chart of the NSW-QLD spanner crab fishery, showing the location of fixed 30' grids within regions and fixed 6' subgrids within grids for the extended monitoring survey. Fifteen out of a possible 100 sampling sites within each subgrid were selected randomly prior to the survey.

Table 1: MS Access code and methods pertaining to adjusting harvest weights for discarding of legal crabs (Brown, 2013).

ACCESS code for multiplier (critical month scalar), where MoNum was relative to adjustment from 1/7/2009.

```
SELECT IIf(DateDiff("m",#7/1/2009#,[StartDate])<0," -1",DateDiff("m",#7/1/2009#,[StartDate])) AS MoNum,
glm.boat, glm.StartDate, glm.year, glm.month, glm.YrFinan, glm.potlifts, glm.region, glm.glmgrid, glm.lunar,
glm.lunaradv, glm.LogVersion, glm.wt, glm.DiscardsWt,
IIf([MoNum] Between 0 And 11,1.1543,
IIf([MoNum] Between 12 And 23,1.3073,
IIf([MoNum] Between 24 And 38,1+(0.7414-0.0181*[MoNum]),
IIf([MoNum]=39,1.0491,
IIf([MoNum]=40,1.0635,
IIf(Eval([MoNum]>41 And [LogVersion]<>'06' And [Region]=4),1.085,1)))))) AS CritMoScalar,
IIf([LogVersion]="06",[wt]+[DiscardsWt],
IIf((region Between 4 And 5),wt*CritMoScalar,wt)) AS WtAdj
FROM glm;
```

Calculating the catch adjustment multiplier.

Months 0-11 (July ’09 - June ’10) based on industry data.
Months 12-23 (July -10 – June ’11) based on industry data.
Months 24-40 (July ’11 – Sept ’12) based on regression derived from (new) Logbook version 06 records.
Months 39 and 40 (Oct and Nov ’13) based on industry advice.
Month 41 (Dec ’13) – no legal discarding this month.
Months 42… (Jan ‘13 ….. Sept ’13) based on LogVersion 06 records (ratio of discards to keepers) applied to Log Version 05 (virtually no earlier versions in circulation at this point) fishing in Region 4 (little discarding evident in Version 06 records in other Regions, so ignored). Upscaling of 05 boats probably overestimates a bit, but this is balanced by not upscaling some 05s outside Region 4. Note that 06 boats don’t need upscaling, as their catches are already calculated as landings + discards. It is assumed that all the ‘discards’ records in 06 logs are actually legal discards – they are supposed to be. This still needs to be verified with industry. The discards weights are estimates only.

Analyses

Spanner crab standardised catch rates were predicted from generalised linear models (GLM). The GLM statistical modelling provided a more valid estimate of mean catch rates as it adjusted for a variety of variables that bias raw data.

The GLM models were fitted using the statistical software package GenStat (VSN International, 2013). The importance of individual model terms was assessed formally using Wald (Chi-square) statistics by dropping individual terms from the full model (VSN International, 2013).

Commercial fishery catch rates (c_f)

Commercial catch rates of spanner crabs obtained from industry logbooks between 2000 and 2014 were standardised through a generalised linear model (GLM) assuming normally distributed errors on

a cube root scale (McCullagh and Nelder, 1989). The model response variable (η) consisted of the cube root of the daily catch ($kg^{1/3}$) from each vessel. Explanatory model terms included the three-way interaction between fishing years, regions and months, as well as the main effects of individual vessels, their cube root transformed fishing effort (the number of net-lifts, which was a function of the number of ground-lines used, nets per ground-line and ground-line lifts per day), the spatial resolution of catches based on 30 × 30 min latitude and longitude grids, and the lunar cycle. The regions represented five latitudinal assessment zones between 23°S and 28.17°S (Figure 2), with the 30-min square grids nested within regions. Lunar cycle was represented by two covariates: (i) a calculated luminance measure that followed a sinusoidal pattern, and (ii) the same lunar data replicated and advanced seven days (O'Neill and Leigh, 2007). Together, these patterns modelled the cyclic variation in catches corresponding to the moon phase. A new additional model term was included for GFP. This two-level factor term (yes or no) was interacted with fishing effort to allow for different fishing dynamics. The GFP factor was created from a Fisheries Queensland licence table, based on the GFP "issue date" and "valid-to-date".

The final inclusion in the model was the spanner crab fleet's evolving fishing power. An annual offset schedule was derived from a subset of vessel catches with recorded vessel/fishing characteristics (O'Neill et al., 2010). The offset schedule allowed for change in skipper experience and was made relative to the year 2000. Skipper experience was identified in the last fleet survey analysis as a small but significant component of vessel fishing power. It was estimated to make an overall contribution to undocumented effort of about 2% between 2000 and 2007 (O'Neill et al., 2010). No additional fishing power data were available since 2007, and it is conceivable it has changed (Figure 3). To be consistent with Brown (2012), the 2007 value was used for subsequent years assuming the fleet's skipper experience had approached an interim limit; as indicated by the 2000–2007 data analysed by O'Neill et al. (2010).

Catch rates were predicted from the model 'year' term using GenStat procedure 'predict', which provided the annual abundance estimates standardised to the mean number of net-$lifts^{1/3}$ (~ median). Predicted catch rates from the cube root model were adjusted using a bias-corrected back-transformation (bcbt) of $\mu^3 + 3\mu\sigma^2$. The adjusted predictions (bcbt) were rescaled in order to compare 2013–2014 catch rates to the base 2000–2007 fixed reference catch rate of 1.043 kg per net-lift. The scalar (=0.983) was calculated as 1.043 divided by the mean of annual bcbt predictions 2000–2007 (=1.061).

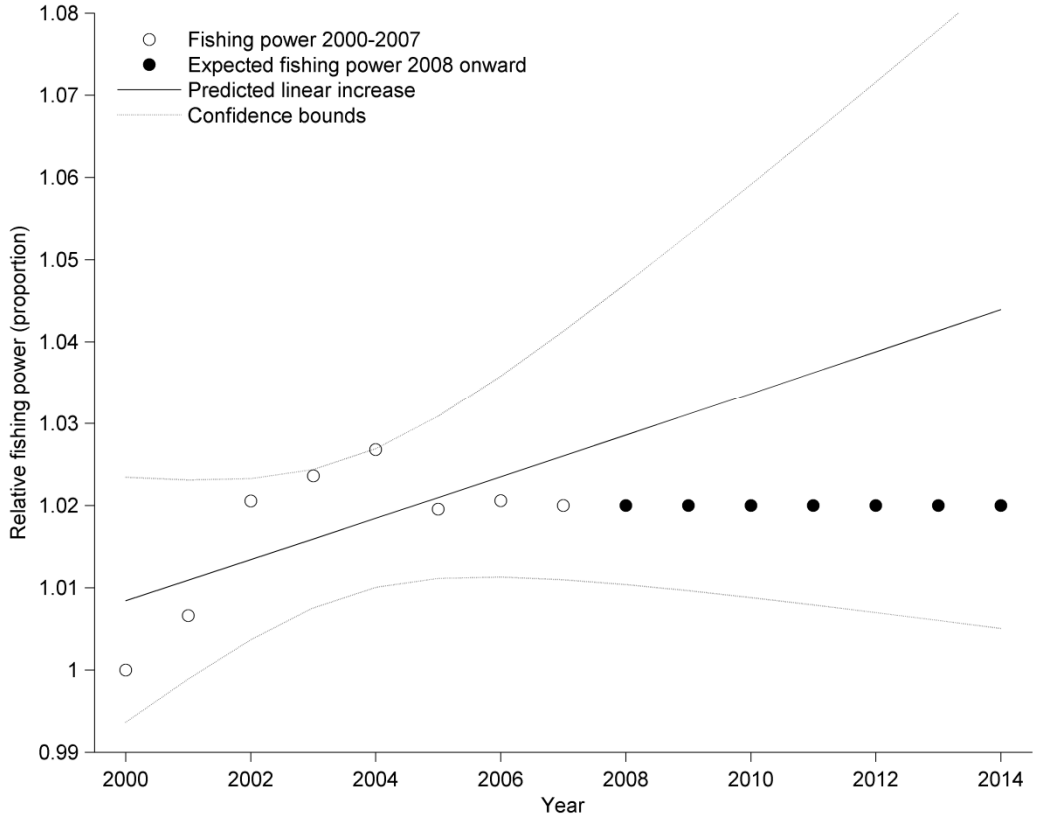

Figure 3: Linear prediction of fishing power based on 2000–2007 offset schedule; adjusted r^2=0.37, p=0.066. No fishing power data were available after 2007. The confidence bounds illustrate 2008–2014 increasing uncertainty in fishing power, with constant, increasing or nonlinear trends all possible. We used a constant level of fishing power, equal to the fishing power in 2007, for the years 2008-2014 (closed circles, above).

Survey catch rates (c_s)

Since 2000, annual fishery-independent surveys of spanner crab have been conducted in QLD waters during May, except for 2004 and 2012. Catch rate measures of abundance were collected from 25 areas (6 × 6 min grids) across the fishery (Figure 2). In all, 15 individual ground-lines (the sampling units), each consisting of 10 nets, were set in each area. The net soak times with the number of spanner crabs caught, their sex, and size (rostral carapace length) were recorded. In May 2005, the survey was extended south into northern NSW, with the placement of four new areas (Kennelly and Scandol, 2002; Brown et al., 2008). The fishery independent survey design aims to provide a more representative perspective on population distribution and size than can be obtained from compulsory commercial logbooks.

Survey catches of spanner crabs across the years exhibited a significant component of zero values (~24%). As no single statistical distribution can accommodate this inflated zero class, catches were standardised through a two-component approach, combining mean predictions from binomial regression of zero/non-zero catch and general linear regression on the conditionally distributed log-transformed non-zero catches (McCullagh and Nelder, 1989; Myers and Pepin, 1990; Mayer et

al., 2005). The first component relates to the binary response of zero or non-zero catch per ground-line, modelled using a logistic transformation with a linear function of the factor variable survey-area, log-transformation of total net hours per ground-line, and factor variable year. The second component was for just those catches where the number of crabs caught was not zero. The model response variable (η) consisted of the logarithm of number of crabs caught per ground-line. Explanatory model terms were the same as in the binary analysis.

Predicted catch rates from the log-normal model were adjusted using a common bias-corrected back-transformation of adding half the model variance i.e. $e^{\left(\mu+\frac{\sigma^2}{2}\right)}$. These catch rates were then multiplied by the binary predicted proportions for non-zero catch, to predict the overall standardised average number of spanner crabs per ground-line equivalent to the median net-hours of fishing. The predictions were standardised according to the base 2000–2007 fixed reference catch rate of 13.972 crabs per ground-line. The standardisation scalar (=0.974) was calculated as 13.972 divided by the mean of annual predictions 2000–2007 (=14.340).

Management procedure

The management procedure followed a process of a baseline quota and performance targets for standardised catch rates with range intervals. The base quota (Q_{base}) and target catch rates (fishery = $\overline{c}_{\text{f,target}}$ and survey = $\overline{c}_{\text{s,target}}$) were set by the SAG and fixed at their annual averages between 2000 and 2007. Upper and lower intervals of ±10% were set on target catch rates. The stock performance indicators are the average fishery ($\overline{c}_{\text{f}}$) and survey ($\overline{c}_{\text{s}}$) standardised catch rates in the most recent two completed calendar years. Standardised catch rates from the fishery and the survey were compared in a decision matrix (Table 2). As no prior evidence was available that either catch rate source was more accurate or reliable than the other, the two indices of spanner crab abundance were given equal weight in the assessment process. The spanner crab quota was calculated from the base quota (Q_{base} = 1631 t) and was made no larger than the maximum tonnage allowed (Q_{max} = 2000 t). New quota was compared with the tonnage set previously. If the new quota was within 5% of the previous quota, then the quota remained unchanged. Quota was calculated according to the equation

$$Q_{t+} = \min\left[\begin{cases} Q_t & \text{, if } \left(0.95Q_t \le \lambda Q_{\text{base}} \le 1.05Q_t\right) \\ \lambda Q_{\text{base}} & \text{, otherwise} \end{cases}, Q_{\max}\right] \qquad (1)$$

where Q is the quota tonnage for setting in years $t+$, and λ was from Table 2. For an extended plain English version of the decision rules see Appendix 2 page 22.

Table 2: Decision matrix for setting λ in quota calculation (1), with subscripts u and l indicating upper and lower ±10% catch-rate thresholds, and θ an average ratio of fishery and survey catch rates from the last two years divided by their target.

Mean catch rates ($\overline{c}$)	**Commercial fishery (f)**		
Survey (s)	$\overline{c}_{\text{f}} \le \overline{c}_{\text{f,target,l}}$	$\overline{c}_{\text{f,target,l}} < \overline{c}_{\text{f}} < \overline{c}_{\text{f,target,u}}$	$\overline{c}_{\text{f}} \ge \overline{c}_{\text{f,target,u}}$
$\overline{c}_{\text{s}} \ge \overline{c}_{\text{s,target,u}}$	1	1	θ_{halfup}
$\overline{c}_{\text{s,target,l}} < \overline{c}_{\text{s}} < \overline{c}_{\text{s,target,u}}$	1 or θ	1	1
$\overline{c}_{\text{s}} \le \overline{c}_{\text{s,target,l}}$	θ or 0	1 or θ	1

Matrix cell row 2, column 1: if $\overline{c}_{\mathrm{s}} < \overline{c}_{\mathrm{s,target}}$, then $\lambda = \theta$, else $\lambda = 1$.

Matrix cell row 3, column1: if $\theta \leq 0.5$, then $\lambda = 0$, else $\lambda = \theta$.

Matrix cell row 3, column 2: if $\overline{c}_{\mathrm{f}} < \overline{c}_{\mathrm{f,target}}$, then $\lambda = \theta$, else $\lambda = 1$.

Matrix cell row 1, column 3: $\lambda = \theta_{\mathrm{halfup}} = (\theta - 1)/2 + 1$,

$$\theta = \frac{\overline{c}_{\mathrm{f}}/\overline{c}_{\mathrm{f,target}} + \overline{c}_{s}/\overline{c}_{\mathrm{s,target}}}{2}$$

Results/Discussion

Commercial fishery catch rates (c_f)

Commercial catches of spanner crabs were standardised between 2000 and 2014 (Table 3). The number of net-lifts (cube root) was the most significant model term, with significantly different slopes between GFP (parameter estimate = 0.911, s.e. = 0.014) and non GFP (parameter estimate = 0.682, s.e. = 0.006) vessels (Figure 4). Figure 4 illustrates the different slopes, with greater harvest for GFP vessels pulling more net-lifts. Compared to the 2000–2005 fleets (pre-GFP), the 2013–2014 fleets average number of net-lifts per vessel day was ~25% higher, with more lifts clearly conducted by GFP vessels (

Figure 6). Catches of spanner crabs were significantly different between vessels, years, months, regions and fishing grids (Table 3). The base lunar phase variable was non-significant (*P*=0.540 for luminance).

Figure 5 shows the standardised annual average catch of kilograms per net-lift for Managed Area A (subplot a) and for Managed Area A by regions (subplot b). The 2013 and 2014 mean catch rates from Managed Area A were 0.881 kilograms per net-lift and 0.739 kilograms per net-lift, respectively. Compared to 2013, the standardised mean catches in 2014 were lower in all regions, although the decreases were of greater magnitudes in the two northernmost regions (Figure 5b).

Standardised residuals from the analysis showed some curvature from normality (Appendix 3, Figure 12, page 23), due to variation in catches and net-lifts; i.e. difficult to predict unusual high and low values in the data (

Figure 6 and Figure 7). Figure 7 also illustrates a decline in daily harvest associated with GFP vessels from 2006 to 2014. The median daily harvest by GFP vessels was 424 kg for 2010–2011 and 320 kg for 2013–2014; the 2013 and 2014 median daily harvest were similar.

The total reported harvest was 945 t and 917 t for 2013 and 2014, respectively, almost all of which was taken in Managed Area A (Appendix 4, Table 5, page 26). This harvest resulted from ~893 and 974 thousand net-lifts (Appendix 4, Table 6), by 61 and 56 vessels respectively. The 2013 and 2014 vessel numbers were at an historic low compared to the high of 262 vessels operating in 1994 (Appendix 4, Figure 16). The 2013 and 2014 vessels fished for 2820 and 2967 days respectively, a reduction from 15123 days in 1994 (Appendix 4, Figure 16).

Summary statistics show recent annual spanner crab harvests in NSW of ~125 t (Appendix 4, Figure 17, page 29). Reported statistics for the 2013/14 financial year were ~125 t harvest from 850 fishing days, with catch rates of approximately 1.5 kg per net-lift. Raw daily catch rates had declined between

1995–1996 and 2010–2011, with subsequent increases observed to 2013-14 (Appendix 4, Figure 18). The 2013–2014 raw daily catch rate was 147 kg per boat-day.

Current harvest and net-lift data variances have changed over years. Even though we have not evaluated in detail the variance in commercial logbook data,

Figure 6 and Figure 7 boxplots illustrate a number of statistical data outliers. The application of statistical GLM models and data transformations can, to a degree, overcome the influence of data outliers. However, we recommend thorough data verification before the next in-depth analyses in January 2016. Data consistency, range checking and residual plotting is required. Some work may be needed to verify logbook data with each fisher.

Table 3: Summary of GLM catch rate analyses. Model term significance p < 0.05, – indicates model term was not applicable to the analysis. For the commercial and survey non-zero analyses, F statistics can be derived by dividing the Wald (chi-square) statistics by their degrees of freedom (d.f.).

Parameter	Commercial	Survey	
	All data	Zero/non-zero	Non-zero
Summary of GLM analysis			
Number of data	74005	5478	4192
Regression mean deviance	108.06	21.955	46.489
Residual mean deviance	1.226	0.910	1.164
Regression d.f., residual d.f.	1180, 72824	47, 5430	47, 4144
Adjusted r^2	0.588	0.173	0.304
Wald statistics, d.f.			
Vessel	9875, 248	–	–
GFP.Net lifts (cube root)	15400, 2	–	–
Year.region.month	3337, 612	–	–
Fishing area (grid)	2206, 32	–	–
Luminance	0.376, 1	–	–
Luminance advance 7 days	34.23, 1	–	–
Skipper experience	Offset	–	–
Location	–	635.6, 33	1702.5, 33
Number of net hours (log)	–	10.3, 1	49.1, 1
Year	–	493.4, 13	116.3, 13

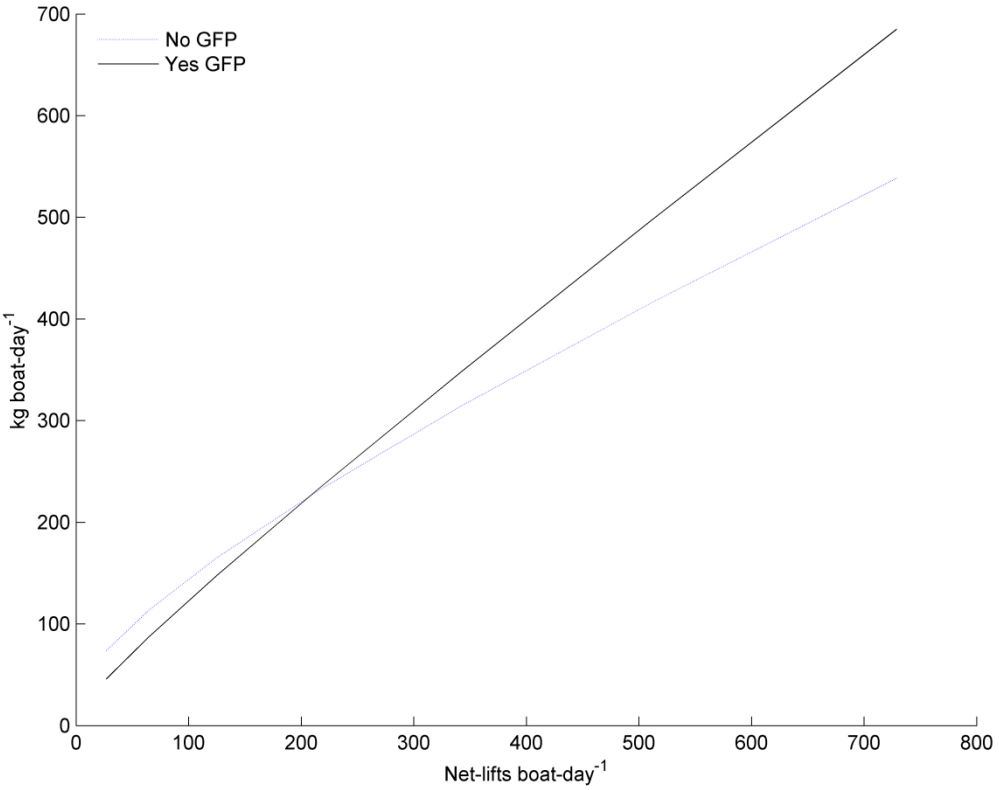

Figure 4: Plot showing the GFP vessel effect of net-lifts on daily harvest boat-day^{-1}. Note that the typical number of net-lifts boat-day^{-1} for non GFP ranged 150–350 and 250–450 for GFP, with the full range illustrated in

Figure 6.

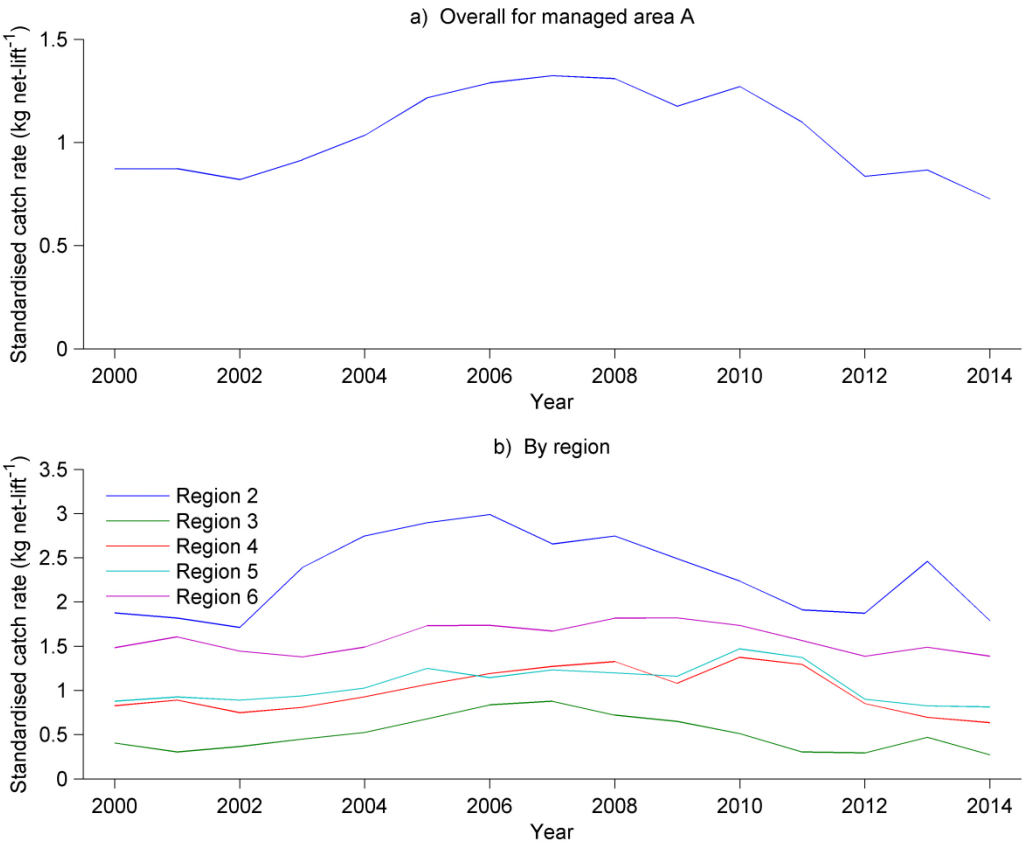

Figure 5: Standardised annual catch rates of spanner crabs for a) Managed Area A, and b) by region (Figure 2).

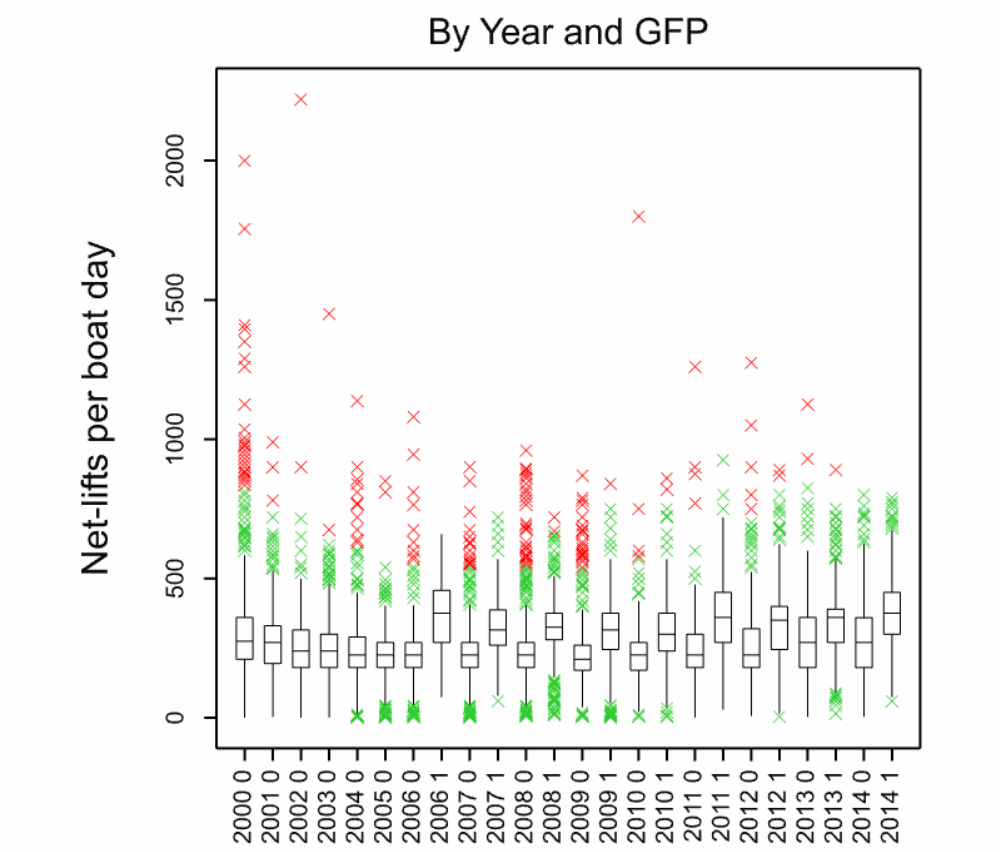

Figure 6: Boxplot of the variation in net-lifts boat-day^{-1} by year and general fisheries permit (GFP 0 = no and GFP 1 = yes). The box spans the interquartile range of the data, so that the middle 50% of the data lie within the box, with a horizontal line indicating the median. The vertical lines (whiskers) extend only to the most extreme data values which are at a distance of 1.5 times the interquartile range. Outlying data are plotted with red and green cross symbols.

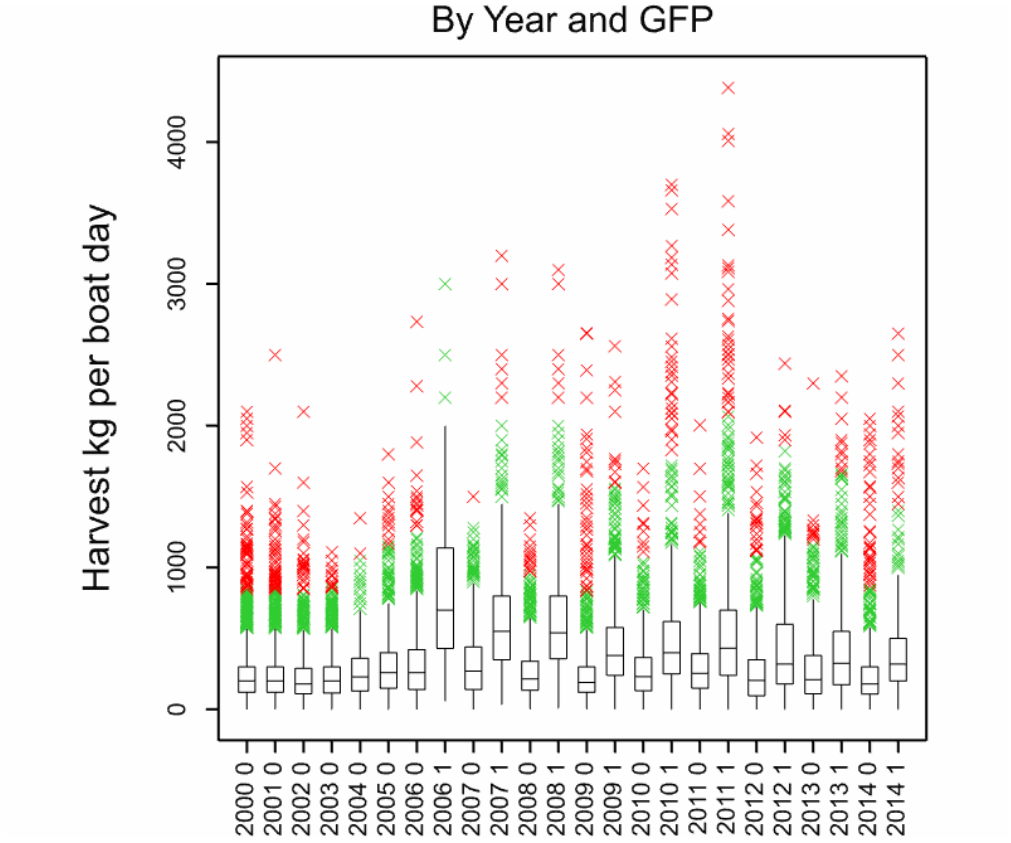

Figure 7: Boxplot of the variation in harvest kg per boat-day by year and general fisheries permit (GFP 0 = no and GFP 1 = yes). The box spans the interquartile range of the data, so that the middle 50% of the data lie within the box, with a horizontal line indicating the median. The vertical lines (whiskers) extend only to the most extreme data values which are at a distance of 1.5 times the interquartile range. Outlying data are plotted with red and green cross symbols.

Survey catch rates (c_s)

Survey catches of spanner crabs showed that 76% of ground-lines caught crab. The percentages changed significantly between years ranging 68%–83% (Table 3). Analysis of non-zero survey catches also showed significant differences between years (Table 3). The product of predicted probabilities of catching crab and average non-zero catches of crab are illustrated in

Figure 8 (model standardised catch rate = black line with diamond marker). The 2013 and 2014 values are used to calculate the 2014 two-year moving average (blue line showing a decrease from 2011;

Figure 8); this was required for quota calculation. The 2012 survey catch rate was estimated from NSW survey sites only (circled red,

Figure 8).

Nominal average spanner crab catches have increased significantly over time in survey region 2 (Figure 9), although the 2014 survey showed a slight decrease in the number of crabs caught per ground-line. Decreases in catch rate were also apparent in regions 3, 5 and 7, with the decrease observed in region 3 to 4.05 crabs per ground-line approaching the 2002 minimum of 3.36 crabs per ground-line. Increases were only apparent in regions 4 and 6, with catch rates in region 4 of 38.55 crabs per ground-line the second-highest since 2000.

Ratio indicators of male to female showed constant annual trend, with male crab dominating ~86% of the survey catch. The survey ratio of legal to undersize crab was also relatively constant in time, averaging ~54% legal.

In 2009, the catching ability of 17 of 440 ground-lines was affected by toad fish damaging bait and nets. This was model tested but found to be non-significant overall (p = 0.721 in the probability model and marginal in the non-zero model p = 0.083; therefore excluded). No toad fish interactions were recorded in this year's surveys, or any other surveys.

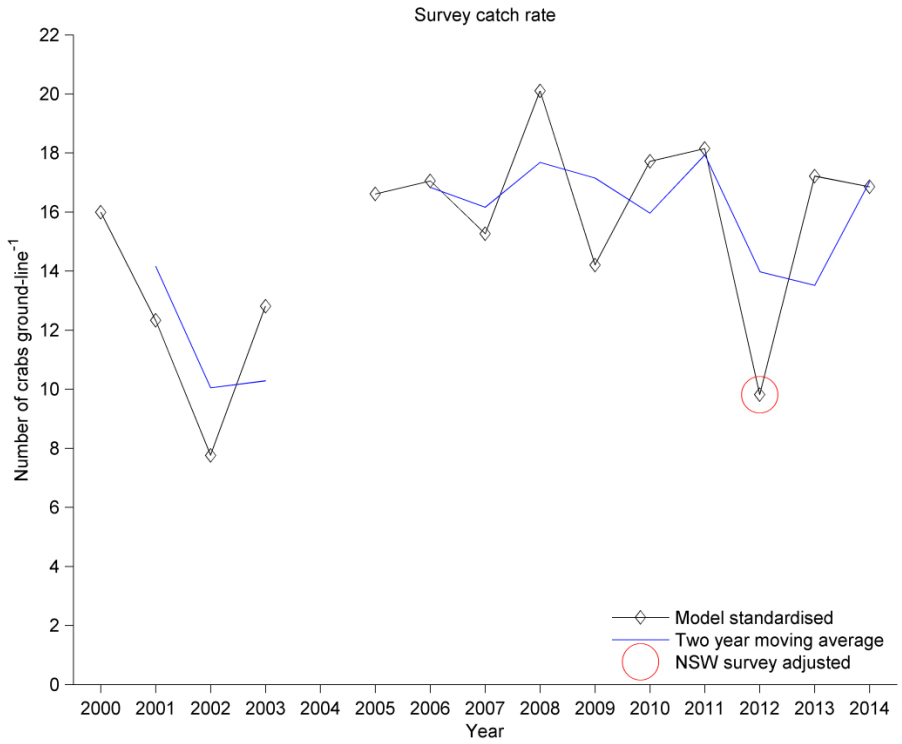

Figure 8: Standardised average catch of spanner crabs per ground-line set and average soak time ~53 minutes. The blue smoothing line is the two year moving average used in quota calculation. Note: the 2012 mean was based on NSW survey sites only (red circle). The 2012 mean was standardised upwards by the GLM adjusting for the missing 2012 QLD survey locations; up from 7.15 crabs ground-line^{-1} surveyed in NSW (Figure 9).

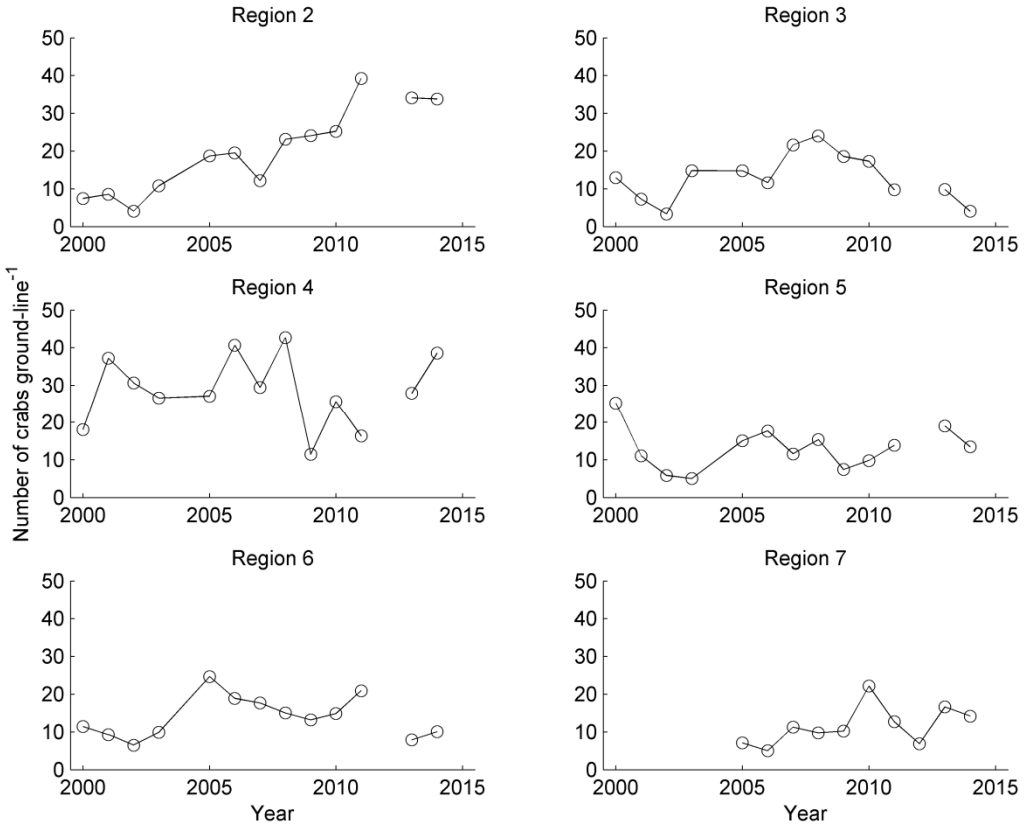

Figure 9: Nominal average catches of spanner crabs per survey ground-line by region.

Quota setting

Analysis of the commercial data indicated that the 2013–2014 average (0.796 kg per net-lift) was ~24% below the target indicator of 1.043 kg per net-lift (Table 4). Additionally, the average catch rate from the 2013 and 2014 surveys was 17.032 crabs per ground-line

Table 4: Adjusted mean (modelled) annual commercial and survey catch rates, and derived stock performance statistics for commercial quota.

Year	Commercial	Survey
2013	0.866	17.215
2014	0.726	16.849
Average 2013–2014	0.796	17.032
Base catch rates (2000-2007)	1.043	13.972
Stock Index	0.763	1.219
Pooled Index	0.991	

The Pooled Index (the arithmetic mean of the two commercial and survey indices) was 0.991. A summary of the reference points and indicators follows:

- Current quota: **1777** tonnes.
- Base quota (Q_{base}): The value of this fixed base for QLD is **1631** tonnes.
- Base Commercial Fishery Catch Rate ($\overline{c}_{\mathrm{f,target}}$): The value of this reference point is **1.043** kg per net-lift.
- Base Survey Catch Rate ($\overline{c}_{\mathrm{s,target}}$): The value of this reference point is **13.9721** crabs per ground-line.
- Commercial Index. This stock performance indicator (**0.763**) was derived as the average of the 2013 and 2014 adjusted mean catches expressed as a proportion of the base commercial fishery catch rate.
- Survey Index. This stock performance indicator (**1.219**) was expressed as a proportion of the base survey catch rate.
- Pooled Index. This overall stock performance indicator (**0.991**) was calculated as the arithmetic mean of the commercial and survey Indices.

By referencing the stock indicators against the management procedure rules (see Appendix 2 page 22) and Table 2, the following applies:

- Indicator result – Rule 5, Table 2 cell row 1 column 1, the quota is equal to the Base TACC of 1631 t.

The indicator result, Table 2 cell row 1 column 1, corresponded to inconsistent indices: the commercial data indicated a further decline below target and the survey data was still above target. In this case the management procedure defaulted to the base harvest 1631 t.

The longer survey time series has revealed the 13.972 reference target catch rate (averaged from the 2000–2007 years) was based on significant low point in 2002 (

Figure 8). This may incorrectly cause setting higher quota and/or inconsistency between commercial and survey indices. The 2002 year was also a low point in commercial catch rates (Figure 5a). In evaluating profitable fishing, it is important to consider a base quota of less than average harvest (~ consistent with active fleet size) and updating baseline catch rates towards targets that are higher than average (O'Neill et al., 2010). The standardised time series of catch rates including all years now averages 15.132 crabs per survey-ground-line and 1.041 crab per commercial-net-lift. If these average catch rates were considered as above, the indicator result would still recommend 1631 t TACC quota.

The previous missing survey years and locations have introduced complexity to the quota setting. The management procedure (TACC calculation) requires complete data for each year and spatial location. If future surveys are cancelled, additional rules are required to guide quota calculation. Considerations include:

1. Reweighting of the catch rate indices towards the commercial fishery.
2. Weighting of spatial regions based on approximate area of habitat.
3. Adjustment to quota baselines (↑ catch rate targets $\overline{c}_{\mathrm{f,target}}$ and $\overline{c}_{\mathrm{s,target}}$, and ↓ Q_{base}) to manage increased uncertainty surrounding the real values of sustainable harvest; also to manage against increased frequency of quota change and administration management cost that may arise.

4. Impute missing surveys from other years or use the base reference target catch rate, or only use a single survey mean. For imputation, Walters (2003) and Carruthers et al. (2011) note that averaging for any time period must necessarily make some assumptions about what catch rates would have been in spatial strata that had not been fished/sampled. Ignoring the missing spatial strata (averaging only over the areas that were fished/sampled) amounts to assuming that they behaved the same as the fished/sampled strata (Walters, 2003).

Acknowledgements

Anna Garland supplied the commercial logbook data and we thank her for her patience in answering numerous calls throughout a hectic time at Fisheries Queensland. Nadia Engstrom also provided valuable assistance during data collation. Daniel Johnson from NSW Primary Industries provided information on the NSW commercial spanner crab catch.

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Appendix 1: Maps of managed areas

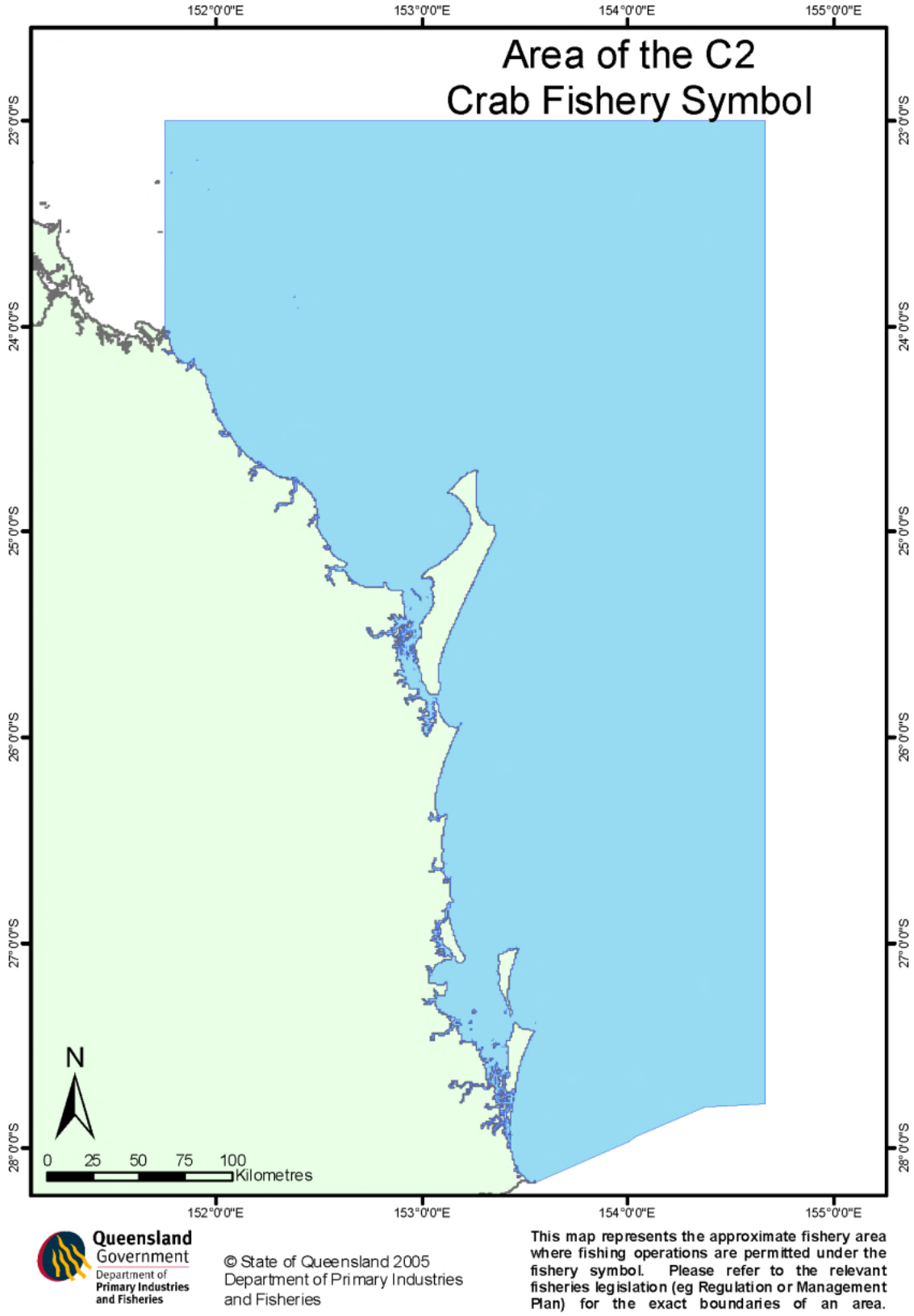

Figure 10: Map of Managed Area A for C2 licensed fishing.

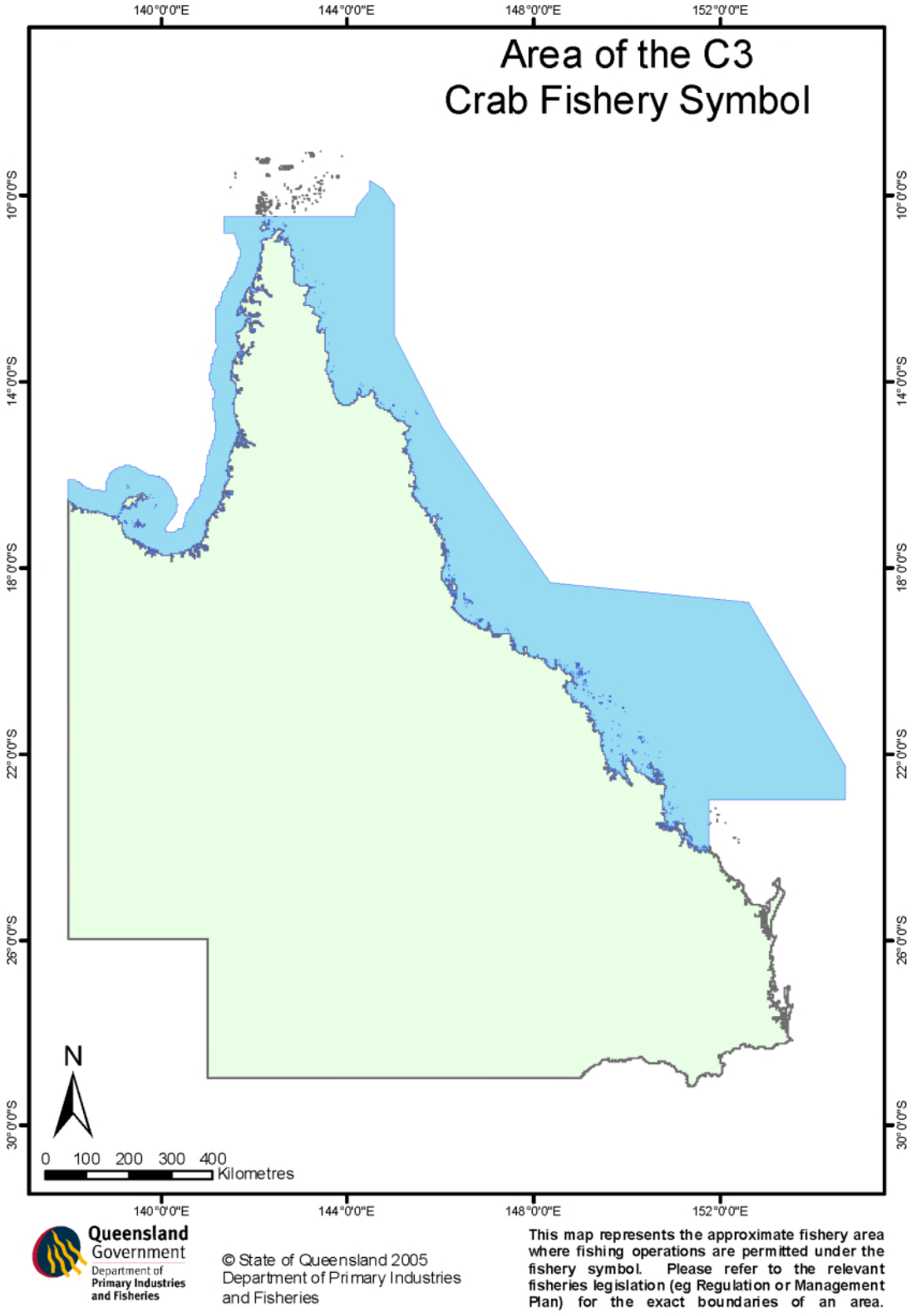

Figure 11: Map of Managed Area B for C3 licensed fishing.

Appendix 2: Management procedure

Prior to 28 February of each year in which the biennial quota cycle commences, the Chief Executive will assess the status of the spanner crab stock and re-set the Annual Quota for each of the two forthcoming years in Managed Area A (Regions 2-6).

This assessment will be based on an analysis, using procedures set out in Methods above, of changes in relative stock abundance as represented by the fishery-dependent and fishery-independent catch and effort data recorded by the Chief Executive. This set of procedures is referred to as the Scientific Method.

Notwithstanding the biennial nature of the Quota-setting cycle, the Chief Executive will each year conduct an assessment of the fishery (as above), and in the event of evidence of a sudden and catastrophic collapse of the stock will institute immediate remedial action using emergency powers provided under the Act.

In determining the Annual Quota, the Chief Executive will apply the following Decision Rules:

1. If the Pooled Index is 0.5 (–50%) or less, the Chief Executive must declare the Annual Quota to be nil; or
2. If the Commercial Index and the Survey Index are both greater than 1.1 (+10%), the Chief Executive must declare the Annual Quota to be equal to the BaseTAC increased by half the amount of the Pooled Index, with the provisos (i) that if the new value lies within ± 5% of the current Annual Quota, then the new Annual Quota will be set equal to the current Annual Quota, and (ii) that, notwithstanding any of the above, the new Annual Quota will not exceed 2,000 t; or
3. If one Index is less than 0.9 (–10%) and the other is between 1 and 0.9 (0 and –10%), the Chief Executive must declare the Annual Quota to be equal to the BaseTAC reduced by the full amount of the absolute (unsigned) Pooled Index, with the proviso that if the new value lies within ± 5% of the current Annual Quota, then the new Annual Quota will be set equal to the current Annual Quota; or
4. If the Commercial and Survey Indices are both less than 0.9 (–10%), the Chief Executive must declare the Annual Quota to be equal to the BaseTAC reduced by the full amount of the absolute (unsigned) Pooled Index, with the proviso that if the new value lies within ± 5% of the current Annual Quota, then the new Annual Quota will be set equal to the current Annual Quota; or
5. The Chief Executive must declare the Annual Quota to be equal to the BaseTAC.
6. If and when any new information becomes available indicating that the assessment and quota-setting arrangements are not consistent with the sustainable management of the fishery, the Chief Executive must review the Scientific Method and Decision Rules and, if appropriate, adjust the reference points.

Appendix 3 GLM standardised residual plots

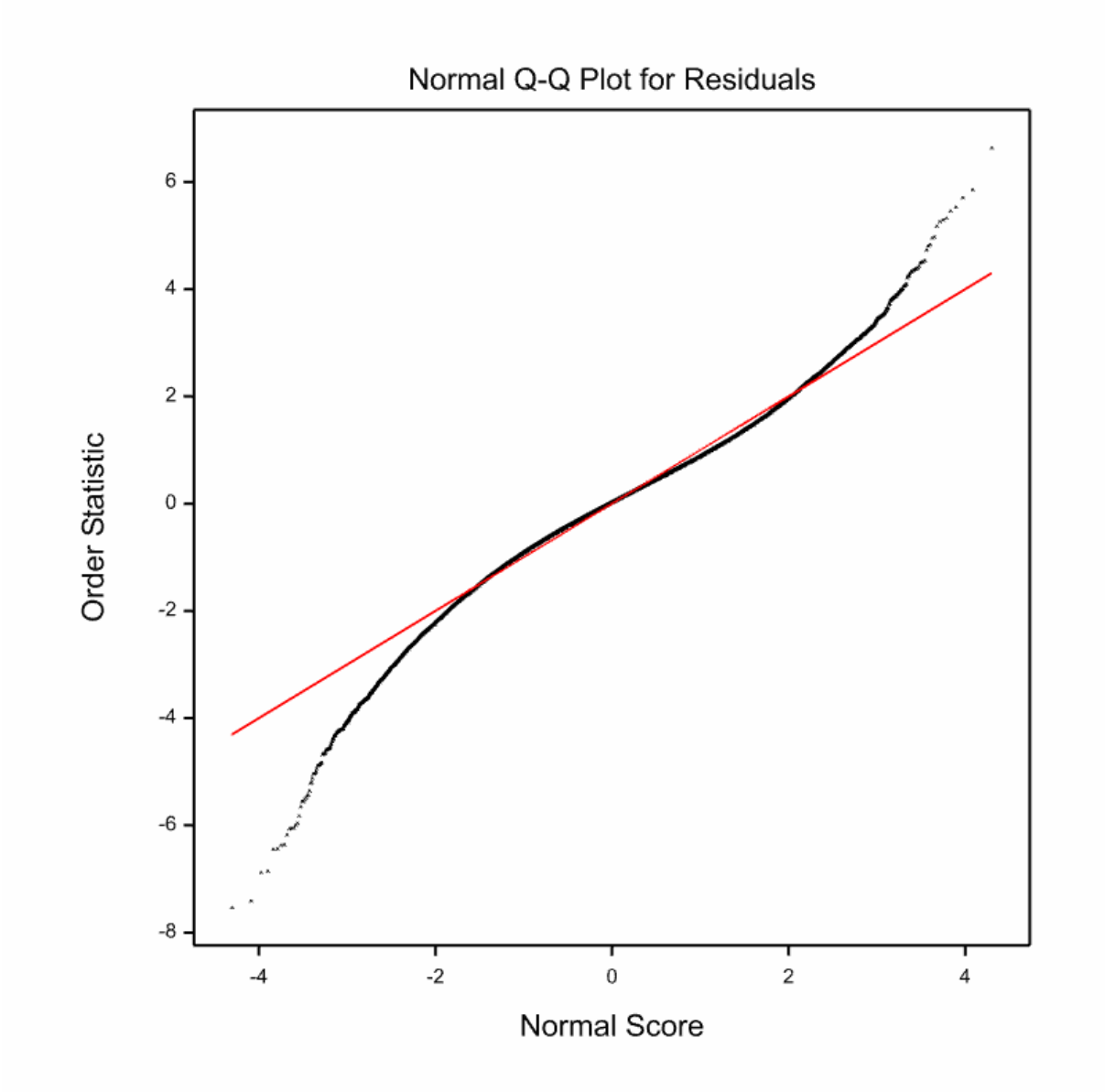

Figure 12: Normal q-q plot of standardised residuals (dots) from the GLM on commercial catches (cube root transformed; n=74005). Curvature away from straight line indicates some outlier residuals relating non-normal harvest and net-lift data.

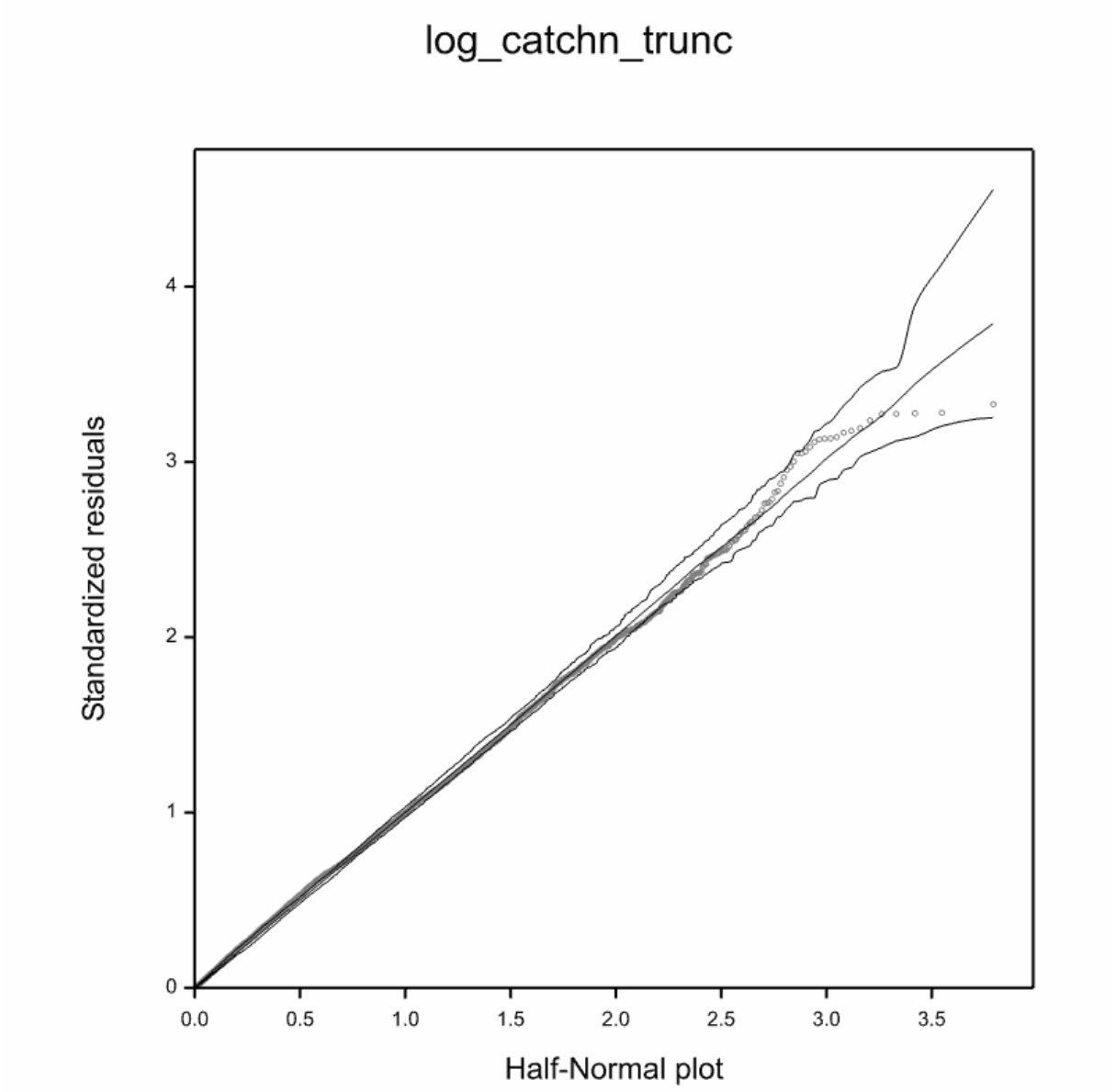

Figure 13: Half normal plot of absolute standardised residuals (circles) from the GLM on non-zero survey catches (n=4192). Comparison of circles against the straight line and 95% confidence envelopes indicate no concerning outliers or trend from normality.

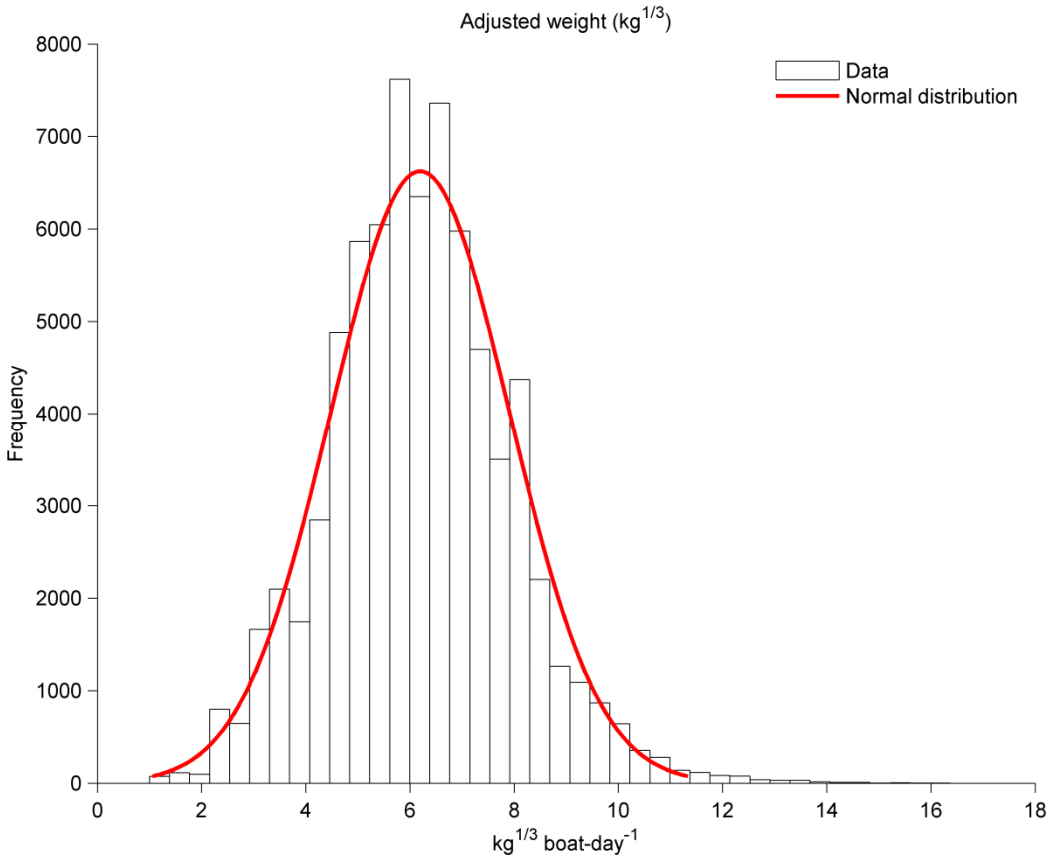

Figure 14: Distribution of cube root transformed commercial daily catches (n = 74,005) for the period 2000–2014 from Managed Area A from compulsory logbooks.

Appendix 4 Summary logbook statistics

Table 5: Annual spanner crab harvest landings (t) from Queensland waters since commencement of compulsory daily logbook reporting in 1988. Note that Managed Area A (under quota management) comprises of regions 2–6, and that the totals relate to calendar years rather than fishing years.

Year	Region							Total
	1	2	3	4	5	6	7	
1988	0.05	0.05	6.70	31.15	242.53	91.55	31.89	404
1989	0.56	0.42	131.80	44.55	112.57	70.04	82.48	442
1990	0.26	-	218.52	55.00	117.49	80.97	49.26	521
1991	-	37.93	310.41	64.19	246.63	101.86	48.28	809
1992	1.30	9.14	514.55	157.34	361.92	165.35	63.22	1273
1993	42.45	156.35	898.40	286.05	537.07	174.29	51.60	2,146
1994	196.44	499.17	1,280.83	391.05	642.27	203.19	64.81	3,278
1995	100.20	333.17	842.16	547.91	675.23	256.09	87.09	2,842
1996	139.54	432.60	1,145.39	644.42	370.94	165.33	16.03	2,914
1997	40.52	449.62	1,322.14	713.96	547.80	156.44	14.27	3,245
1998	11.26	392.86	670.65	562.48	285.31	137.62	1.04	2,061
1999	40.11	272.70	686.69	418.16	299.11	105.18	0.21	1,822
2000	78.82	312.07	934.36	402.85	313.20	139.62	0.68	2,182
2001	31.24	266.97	565.70	707.11	265.52	136.19	2.26	1,975
2002	32.38	217.75	296.76	679.06	202.85	160.63	0.97	1,590
2003	20.77	216.86	339.74	568.17	200.74	123.25	2.49	1,472
2004	26.04	223.34	283.94	654.29	222.46	130.18	1.61	1,542
2005	1.00	160.43	357.73	614.48	291.65	122.19	1.26	1,549
2006	1.49	151.54	360.33	608.77	182.09	108.89	-	1,413
2007	-	103.82	483.05	692.88	182.01	63.71	0.75	1,526
2008	-	186.76	371.12	768.13	197.78	59.30	0.27	1,583
2009	5.56	184.59	271.07	497.18	130.02	79.03	-	1,167
2010	0.30	124.02	186.56	545.47	157.05	115.56	-	1,129
2011	0.68	93.18	147.23	791.31	158.43	84.21	-	1,275
2012	-	99.21	141.12	610.54	111.45	76.47	0.63	1,039
2013	0.14	174.14	156.77	463.78	78.88	69.40	1.65	945
2014	0.20	177.11	78.16	511.93	73.10	74.93	1.45	917
Total	771	5,275	13,001	13,032	7,206	3,251	524	43,063

Table 6: Regional distribution of fishing effort (thousands of net-lifts) since 1988 in Queensland waters.

Year	Region							Total
	1	2	3	4	5	6	7	
1988	0.10	0.05	11.69	55.06	355.36	77.64	36.16	536
1989	6.16	0.33	73.62	79.54	196.03	86.42	97.76	540
1990	3.08	-	115.27	56.09	169.20	102.58	52.98	499
1991	-	16.18	205.11	84.10	278.39	88.69	49.76	722
1992	1.12	7.38	291.67	147.31	370.35	147.78	60.69	1,026
1993	30.68	86.67	562.64	229.61	606.58	199.60	48.21	1,764
1994	149.39	456.39	1281.05	406.64	1,006.56	226.12	71.43	3,598
1995	68.00	325.50	793.32	646.60	1,071.01	284.70	86.56	3,276
1996	169.03	364.61	1,028.99	595.98	590.47	186.23	22.16	2,957
1997	36.11	351.37	1,084.93	567.36	683.94	166.78	18.61	2,909
1998	9.98	333.97	619.52	417.35	380.39	152.23	1.58	1,915
1999	26.75	279.96	750.14	349.15	423.83	112.73	0.44	1,943
2000	73.57	354.97	1,171.80	414.07	538.00	154.50	0.31	2,707
2001	51.12	314.52	720.93	623.43	399.75	136.72	3.00	2,249
2002	34.50	276.16	330.82	652.65	308.34	196.16	1.48	1,800
2003	25.44	193.86	356.47	532.73	310.02	148.62	3.26	1,570
2004	19.76	147.64	262.39	518.27	368.48	134.02	2.12	1,453
2005	1.03	95.99	250.01	425.65	345.84	116.06	0.89	1,235
2006	0.99	93.16	211.43	378.63	234.48	89.59	-	1,008
2007	-	71.27	279.32	397.20	200.68	60.04	0.63	1,009
2008	-	126.63	243.42	409.39	239.76	55.45	0.18	1,075
2009	2.88	147.33	202.48	361.80	167.20	65.11	-	9,47
2010	0.24	105.41	158.65	338.35	176.01	108.94	-	888
2011	0.68	109.87	174.13	505.33	192.28	96.17	-	1,078
2012	-	93.92	158.37	430.71	167.90	86.09	0.85	938
2013	0.15	120.92	140.91	423.67	125.38	80.10	1.79	893
2014	0.44	187.43	104.77	480.63	104.28	94.35	2.45	974
Total	711	4,661	11,584	10,527	10,011	3,453	563	41,511

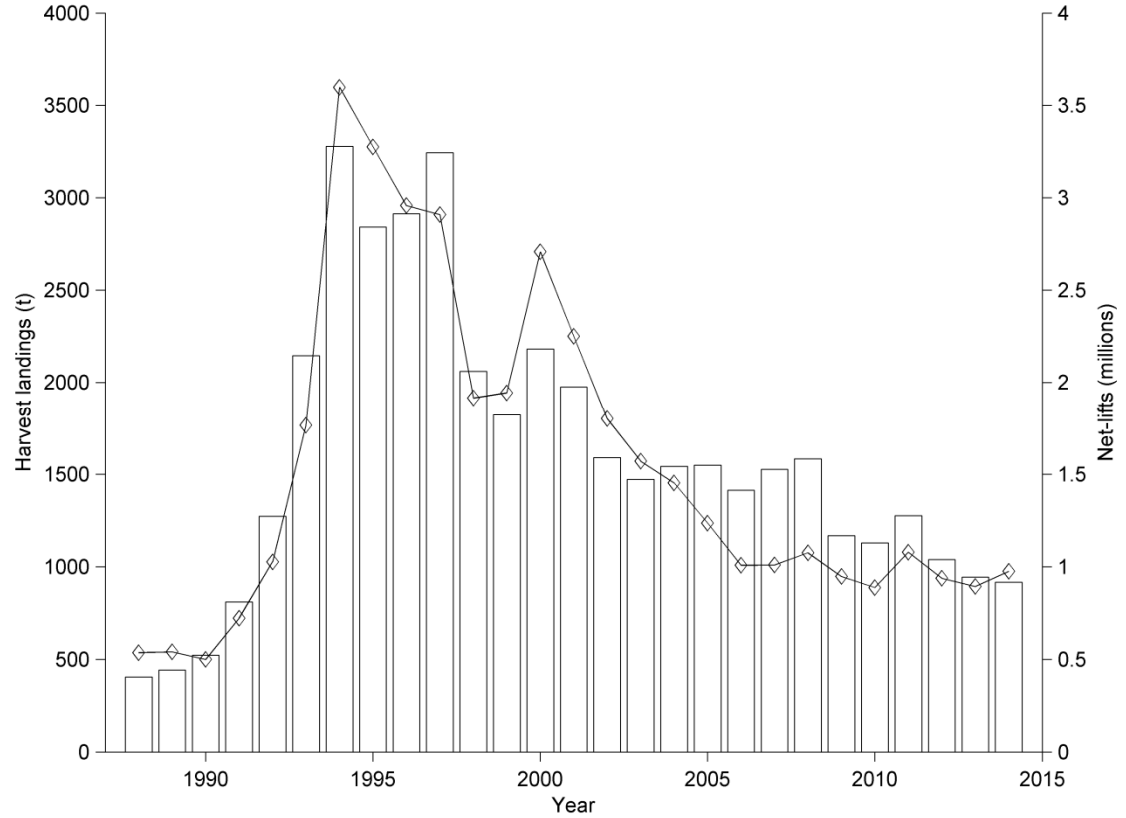

Figure 15: Annual spanner crab harvest landings (t), overlaid with annual fishing effort (million net-lifts) from all Queensland waters.

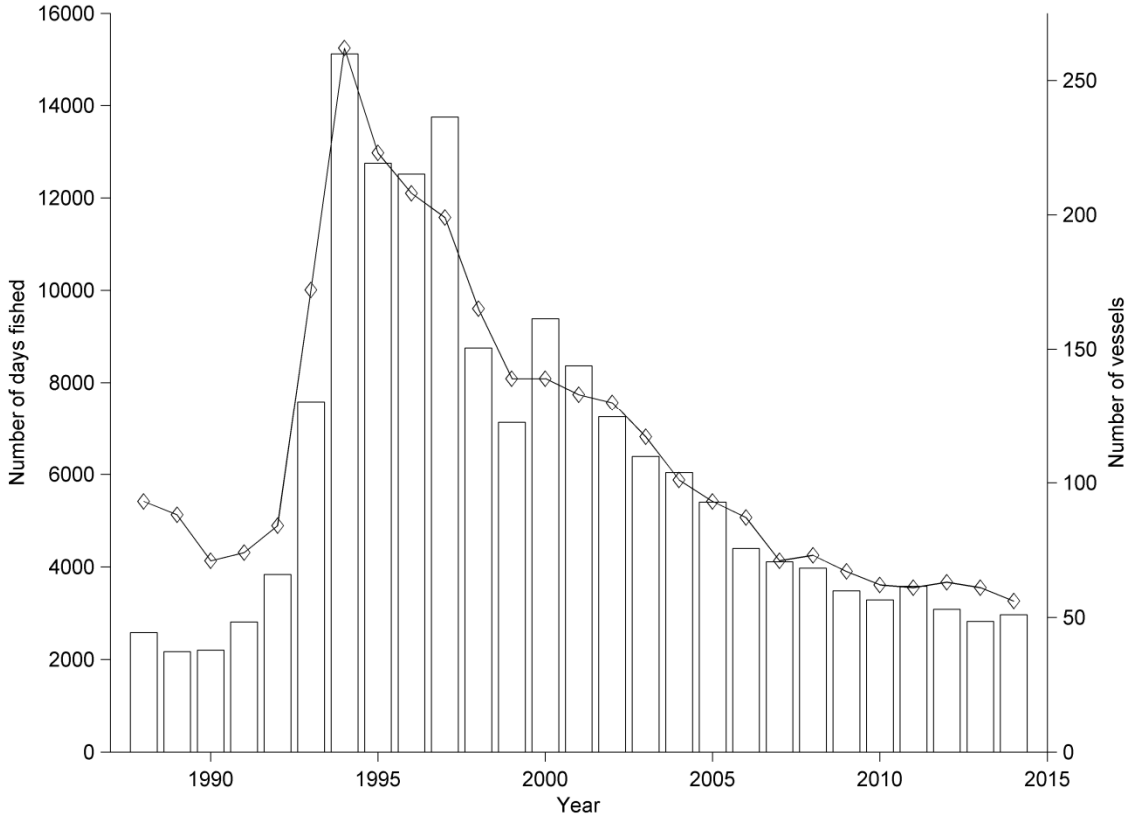

Figure 16: Annual number of commercial days fished for spanner crabs, overlaid with annual vessel numbers from all Queensland waters.

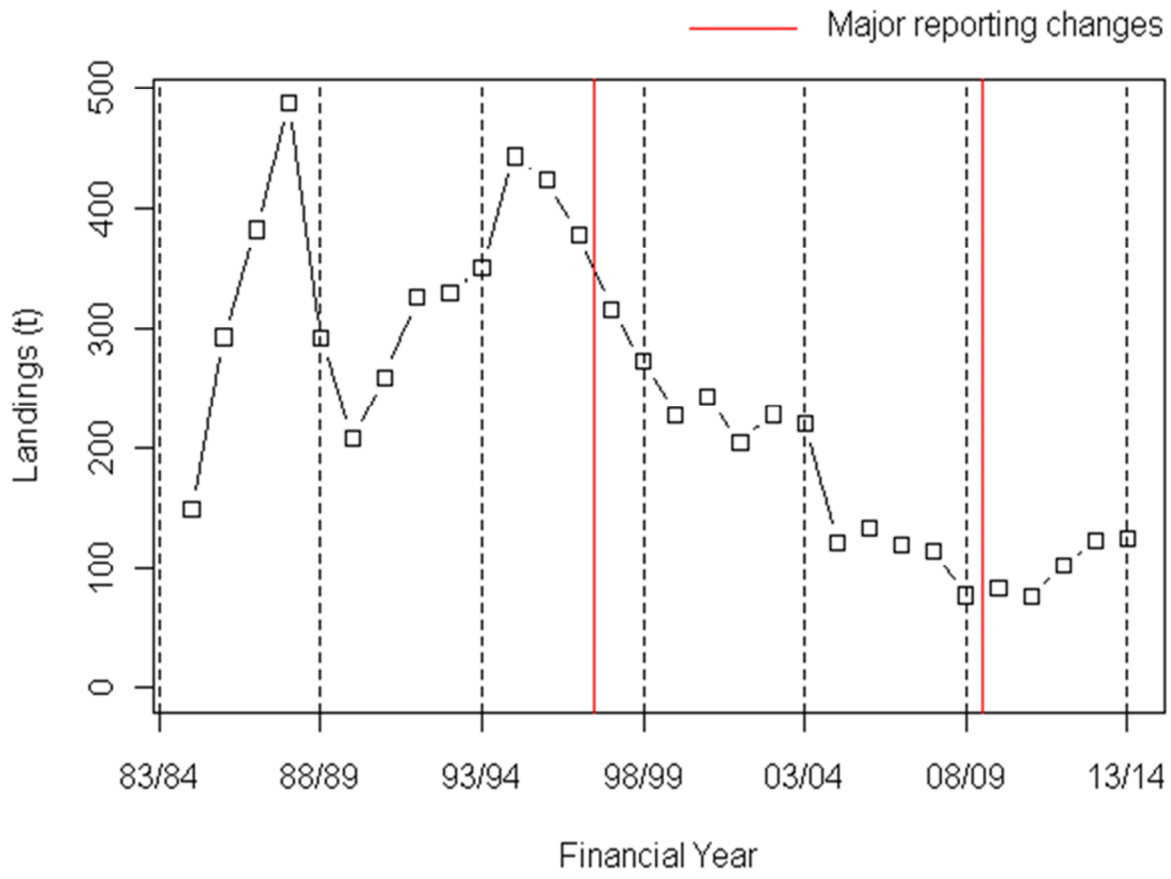

Figure 17: Spanner crab harvest landings (t) from NSW waters as a function of fiscal year.

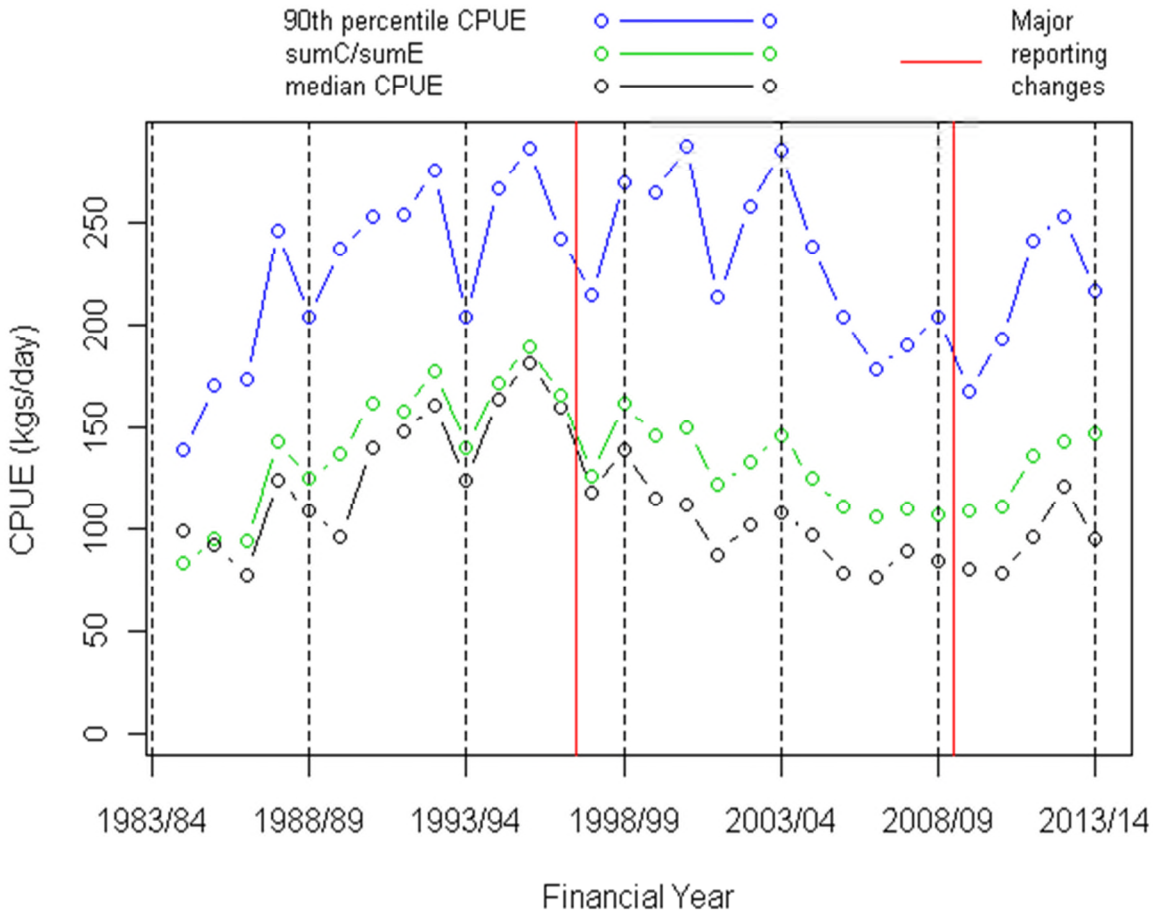

Figure 18: Spanner crab CPUE (kg boat-day^{-1}) from NSW waters as a function of fiscal year.