

FISHERY ASSESSMENT REPORT

TASMANIAN GIANT CRAB FISHERY - 2007/08

Philippe E. Ziegler, Malcolm Haddon and Caleb Gardner

February 2009



*TAFI Marine Research Laboratories, Private Bag 49, Hobart, TAS 7001, Australia.
E-mail: Philippe.Ziegler@utas.edu.au. Ph. (03) 6227 7277, Fax (03) 6227 8035*

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Executive summary

This assessment of the Tasmanian giant crab fishery covers the period from 1st March 2007 to 29th February 2008, and provides forecasts of the likely response of the fishery to the total allowable commercial catch (TACC) set at a range of values.

Total catch reported in logbooks for the 2007/08 season was 53.2 tonnes, representing only 84% of the 62.1 tonne TACC¹. This was 4.1 tonnes lower than the catch taken in the 2006/07 quota year. Industry members indicated that a factor contributing to this decline was the rapidly falling beach price after Christmas.

The limit reference point relating to a State-wide decline of catch rates in two successive years was exceeded. At only about 36% of the standardised catch rates in 1995/96, State-wide catch rates have remained low over the last few years and have shown no signs of recovery. Regionally, the catch rate limit reference point (a reduction of 20% or more in any 2-year period) was exceeded on the West coast (-30.0%) and on the East coast (-36.4%).

Bycatch of crabs by lobster fishers in the 2007/08 season was not of concern for the giant crab fishery, since the reported catch of only 61kg was well below the limit reference point of five tonnes.

Reference points relating to the weight structure of the catch landed at processors (the variation in the proportions of the catch above 5kg or below 3kg) were not assessed. Due to the availability of a stock assessment model, the length frequency data collected by fishers now provides much greater resolution than processor size-splits and is used for the biomass estimation in the stock assessment model.

In addition to the State-wide assessments, the model assessments were used separately for the East and West coast fisheries. Both the State-wide and regional size-based stock assessment models were able to generate acceptable fits to both catch rate and length frequency data, although the East coast model indicated relatively high uncertainty in estimates of biomass and harvest rates due to less length data. Compared to estimates from last year's assessment, changes in standardised catch rates and improved estimation of biological parameters resulted in higher model predictions of stock productivity in the early years of the giant crab fishery. Therefore, relative levels of estimated current biomass and egg production tended to be lower.

The State-wide model estimated that the State-wide exploitable biomass declined from a maximum of about 1601 tonnes in the early 1990s to about 291 tonnes in 2007/08. This equates to about 18% of the original unfished exploitable biomass. Total biomass and egg production have decreased to 28% and 32% respectively of their initial levels. This level of egg production is considered average for a crustacean fishery. Estimated harvest rates have fallen slightly in 2007/08 to 0.21.

¹ The quota allocation system and the logbook recording do not correspond completely. The quota is considered as taken only when animals are sold or landed, while an entry in a fisher's logbook records the date of capture, and it is quite common for a fisher to hold animals for extended periods.

State-wide results were similar to the combined regional results. On the West coast, the model also estimated harvest rates of 0.21 and a decline in exploitable biomass to only 18% of the original exploitable biomass. Total biomass and egg production have decreased to 28% and 31% of their highest historical levels, respectively. On the East coast, the smaller overall catches resulted in a smaller impact on the giant crab stock, but the limited length frequency data resulted in higher uncertainty. Harvest rates on the East coast were 0.12 and exploitable biomass was 20% of the original exploitable biomass. In this year's assessment of the East coast, both total biomass and egg production have slightly increased to 41% and 43% of their initial levels respectively.. Length frequency data from the East coast is urgently required to reduce uncertainty in the assessment.

The risk assessment projections were also less positive than in the last assessment and indicated that the current TACC is expected to lead to lower catch rates, and thus higher costs. Current catches appear likely to further decrease the already low exploitable biomass and catch rates, particularly on the West coast. Unless atypically strong recruitment occurs, any stock recovery is predicted to take a long time even under reduced catch levels due to the slow growth of giant crab.

The model estimates a 5% probability that the State-wide catch rates and exploitable biomass will rise above present levels in five years under the current TAC of 62.1. The probability of maintaining present levels increased to 20% and 48% under reduced TACs of 51.8 tonnes and 41.1 tonnes, respectively. Regional projections indicated that under the status quo with 40 tonnes on the West coast and around 15 tonnes on the East coast (i.e. less than the current TAC), catch rates and exploitable biomass would further decline on the West coast, but stabilise on the East coast. Only catch levels of around 30 tonnes on the West coast would result in a greater than 50% probability of increase in exploitable biomass and catch rates in 10 years. A catch reduction to 20 tonnes was highly likely to show further improvements of these measures, yet any improvement would be slow even under such low catches. On the East coast, future exploitable biomass had a high probability to exceed current levels under all catch scenarios, but a catch of 20 tonnes showed a declining trend over time.

Management implications of alternative TACs relate mainly to the maintenance of commercially viable catch rates, with control of reproductive output regulated to a greater extent by the minimum legal length. All catch scenarios predicted reasonably stable egg production. Given the current size limits, egg production in five years will achieve 30% of the historically highest levels (EP30%) with 67% probability State-wide, with 80% probability in the West and with 85% probability in the East. However, egg production is unlikely to achieve 40% of the historically highest levels (EP40%) State-wide or in individual regions even under reduced catches. EP40% is recommended as a target reference point for the giant crab management due to the high uncertainty in this assessment, particularly in regards to biological parameters such as growth and mortality.

Summary of performance indicators for giant crab.

Performance indicator	Reference point	Exceeded	Status in 2007/08
Total yearly catch	Yearly catch < 90% of TAC	Yes	84% of TAC taken
State-wide commercial catch rates	Decline in two consecutive years	Yes	Decline in 06/07 and 07/08 season (by total of 32.2%)
Regional commercial catch rates	Total decline by 20% in 2 years	Yes	West -30.0% East -36.4%
Bycatch by lobster fishers	Catch > 5 tonnes	No	61 kg reported as taken
Proportion of catch over 5 kg	Varies >30% from reference year	N/A	Size structure data now derived from catch sampling and used in estimation of biomass
Proportion of catch below 3 kg	Varies >30% from reference year	N/A	Size structure data now derived from catch sampling and used in estimation of biomass

Status of possible alternative performance indicators, currently under review for a revised management plan.

Alternative performance indicator	Status
Total biomass in current year above 40% of highest historical levels (<i>TotB</i> _{40%}):	State-wide West East 0% Probability 7% Probability 78% Probability
Egg production in current year above 40% of highest historical levels (<i>EP</i> _{40%}):	State-wide West East 3% Probability 21% Probability 82% Probability
Total biomass in 5 years above 40% of highest historical levels (<i>TotB</i> _{40%}):	State-wide (current TAC) West (with 40t) East (with 15t) 0% Probability 0% Probability 30% Probability
Egg production in 5 years above 40% of highest historical levels (<i>EP</i> _{40%}):	State-wide (current TAC) West (with 40t) East (with 15t) 3% Probability 6% Probability 36% Probability
Harvest rate in 5 years above current levels:	State-wide (current TAC) West (with 40t) East (with 15t) 0% Probability 1% Probability 73% Probability
Giant crab bycatch from all sectors above 5% of TAC	Less than 0.1% (61 kg reported as taken)
Protected species and byproduct	No protected species interactions reported. Four species of byproduct reported with greatest total catch being southern conger eels at 70 kg
Undersize abundance	Undersize abundance appears to be increasing on West coast with catch rates now slightly higher than on East coast for the first time

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1. Introduction

This assessment of the Tasmanian giant crab fishery resource covers the period between 1989/90 to 2007/08. It considers the performance of the fishery against the agreed set of reference points defined in the giant crab management plan (DPIWE 1999) and updates the annual assessment for the period from 1 March 2007 to 29 February 2008. Other information is provided to assist in assessing the state of the resource including results from the giant crab stock assessment model, and forecasts of the likely outcome of alternative total allowable commercial catches (TAC).

The commercial fishery for giant crab began in Tasmania in the mid 1990s after a live export market to Melbourne, Sydney and Asia was established (Gardner 1998). Giant crabs had previously been landed as byproduct of rock lobster fishers operating in deeper waters but were generally regarded more as a nuisance than a target. Once giant crab became a targeted species, catches increased dramatically. By 1994/95, total reported catch in Tasmanian waters peaked at 291 tonnes (Figure 1). While some of this catch may be attributable to over-reporting of catch in anticipation of a change in management (moving to quota), it is certain that large quantities of crabs were taken as the virgin stock was being fished down.

By the end of the 1997/98, the total catch had fallen to just 110 tonnes and some concerns were expressed about the downward trajectory of catch rates. Because quota management was introduced to the associated rock lobster fishery at this time with concerns that the crab fishery would create an effort sink, a giant crab management plan introduced an Individual Transferable Quota (ITQ) system and an initial TAC of 103.5 tonnes in November 1999. The quota year mirrored that for rock lobsters running from 1 March to the end of the following February (DPIWE 1999). Along with the introduction of a TAC, a maximum size limit was set at 215 mm carapace length for both males and females, while the minimum legal length of 150 mm for both sexes, introduced in 1993, was retained.

In response to further declines in catch per unit effort (CPUE) across much of the fishery and poor performance against indicators in the 2002/03 assessment (Gardner *et al.* 2004), the TAC was further reduced to 62.1 tonnes for the 2004/05 quota season. The same quota remained in place for the 2007/08 quota season.

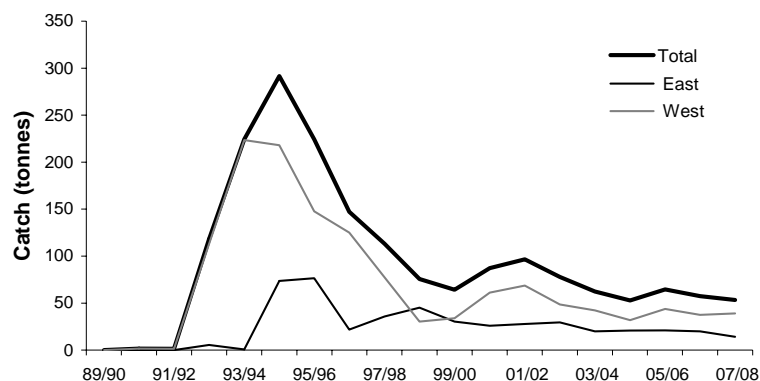


Figure 1. Historical giant crab catches in Tasmania. Catches in 1998/99 and 1999/00 were from partial fishing years due to an extended seasonal closure. East and West are divided by longitude 147°E.

2. Management objectives and strategies

The Tasmanian giant crab management plan was introduced in 1999 (DPIWE 1999) and provides the regulatory framework for the commercial fishery. The plan contains the following objectives, strategies and performance indicators.

2.1 Major objectives

- Maintain fish stocks at optimum sustainable levels by constraining the total catch and the size of individual giant crabs taken by the commercial sector;
- Sustain yield and reduce incidental fishing mortality by taking fish at a size likely to result in the optimum yield from the fishery, protecting under-size giant crabs, and minimising incidental fishing mortality as a result of fishing operations;
- Manage commercial fishing interactions by mitigating any conflict that results from competition between different fishing methods for access to shared fishing grounds;
- Provide socio-economic benefits to the community;
- Provide high quality products.

2.2 Primary strategies

- Limit the targeted commercial catch by setting a total allowable commercial catch (TAC) and using individual transferable quotas (ITQs) to allocate proportions of the TAC;
- Limit access to by-catches of giant crabs.
- Maintain minimum and maximum size limits and closures of the fishery for female giant crabs during the peak spawning period to conserve egg production, restrict fishing mortality on spawning or berried female giant crabs, and ensure a proportion of large males and females are returned to the water;
- Maintain escape gaps to reduce incidental fishing mortality;
- Restrict the number of giant crab fishing vessels in the fishery and the number of giant crab traps that can be used from individual fishing vessels.

2.3 Performance indicators and reference points

The giant crab management plan identifies (but is not limited to) a number of fishery performance indicators. Reference ranges defined for these indicators are deemed to represent the normal variation of the stocks and fishery. When the observed value of a performance indicator falls outside this range, a limit reference point or trigger point is said to have been exceeded, implying that some management action may be required. Reference points are exceeded when one or more of the following criteria are met:

- The total yearly catch does not exceed 90% of TAC in any year;
- Catch per unit effort (CPUE) for the State declines for two consecutive years;
- Catch per unit effort (CPUE) for any region declines by a total of 20% in two years;
- The bycatch of giant crabs taken by rock lobster fishers exceed 5 tonnes in any year;
- The proportion of the catch above 5 kg or below 3 kg varies by more than 30% compared to the 1996/97 distribution.²

² This performance indicator was intended to provide information on changes in the size structure of the stock. Length-based information is now collected in much greater resolution through on-board catch sampling conducted by commercial fishers, and used as an input to the assessment model to provide more informative measures on biomass and egg production.

3. Fishery assessment

3.1 Evaluation of reference points

3.1.1 Commercial catch

Total catch reported in logbooks for the current assessment period was 53.2 tonnes, representing only 84% of the 62.1 tonne total allowable commercial catch (TAC). Therefore, catches were lower than the catch limit reference point, set at 90% of the TAC (Table 1, Figure 2). Industry members indicated that a factor contributing to short-fall was because fishing became uneconomical after Christmas when beach prices fell rapidly and catch rates were too low.

It is important to note that the landed catch from the quota allocation system and the logbook recordings listed in Table 1 do not correspond completely. The quota is considered as taken only when the animals are sold or landed. In contrast, an entry in a fisher's logbook records the date of capture, not date of sale, and it is quite common for a fisher to hold animals for extended periods until the market price improves.

Table 1. Catch totals in tonnes by quota year (March to February) from 1989/90 until present as reported in logbook returns (Tasmania, West and East), landed catch from quota allocation system, and Total Allowable Commercial Catch (TAC). West and East are defined as either side of longitude 147°E.

Quota year	Tasmania	West	East	Landed catch	TAC
1989/90	0.2	0.1	0.1	-	-
1990/91	1.7	1.6	0.1	-	-
1991/92	1.5	1.4	0.1	-	-
1992/93	118.2	112.8	5.4	-	-
1993/94	224.2	223.4	0.8	-	-
1994/95	291.4	217.9	73.5	-	-
1995/96	224.3	147.8	76.6	-	-
1996/97	147.0	125.1	21.9	-	-
1997/98	113.3	77.4	35.9	-	-
1998/99	75.6	30.4	45.2	-	-
1999/00	64.2	33.9	30.3	61.3	103.5
2000/01	87.1	61.2	25.9	89.8	103.5
2001/02	96.6	68.6	28.0	94.5	103.5
2002/03	78.0	48.5	29.4	74.1	103.5
2003/04	62.3	42.3	20.0	61.6	103.5
2004/05	52.7	32.1	20.7	46.2	62.1
2005/06	64.6	43.6	21.0	59.7	62.1
2006/07	57.3	37.4	19.9	53.1	62.1
2007/08	53.2	39.0	14.2	46.8	62.1

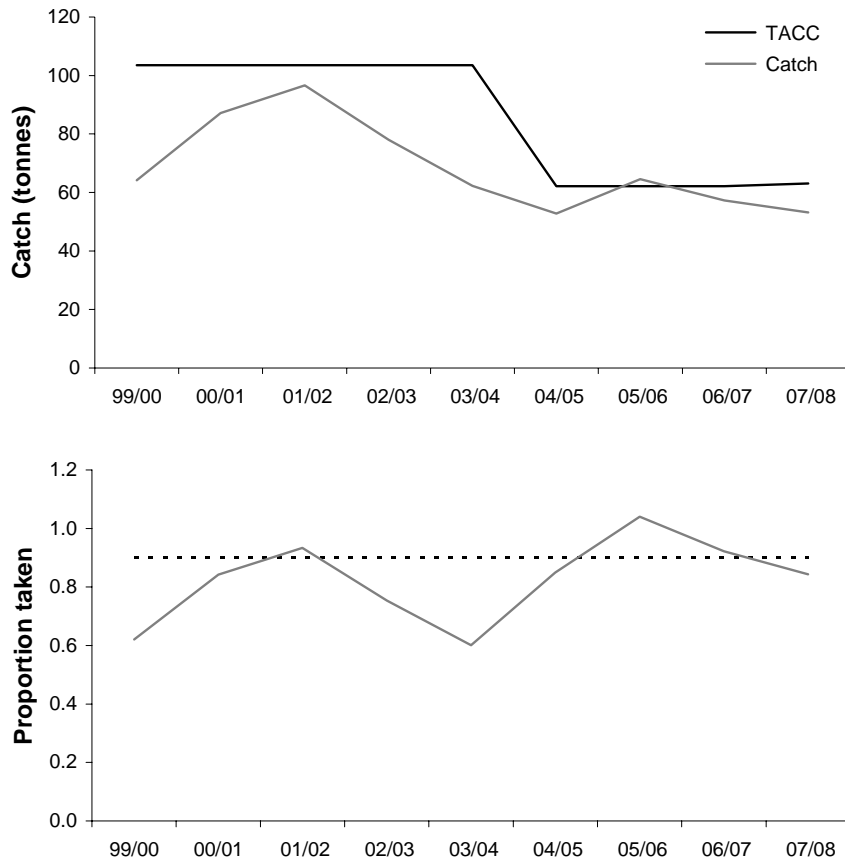


Figure 2. Total catches from logbook records and TAC since quota management was introduced (top), and the proportion of the TAC caught in each year (bottom). The dashed line marks the 90% limit reference point.

The catch in the current assessment period comprised 39.0 tonnes (73%) taken from the West coast and 14.2 tonnes (27%) taken from the East coast. This is within the historical range exhibited since the introduction of quota (Table 1). The ratio in catch from the two regions appears to have stabilised over the last few years as trading of quota between crab fishing businesses has stabilised (Figure 3).

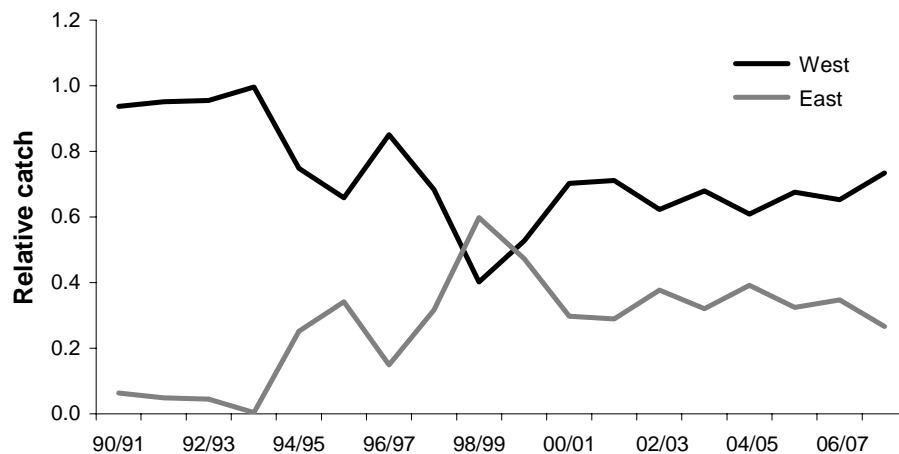


Figure 3. Relative catches coming from the East and West coasts in each quota year.

3.1.2 Commercial catch taken by other sectors

Giant crabs are also taken by SESS trawlers, but determining the catch of giant crabs from this sector is difficult. Catch records collected by AFMA identify most of the crab catches as 'crab' only and without catch locations. Information on the species composition of this 'crab' catch is potentially available through observer data and species composition of reported landings where species is identified. As of September 2008, observer data on the species composition of crab catch could not be obtained because of problems with the AFMA database. Thus the only information on crab catch by trawlers comes from landings data.

From 2002-2008 inclusive (2008 data incomplete), total landings of around 79.6 tonnes of crabs were reported from trawlers into ports in Tasmania, SA, Victoria and NSW (Table 2). Most of these landings are for unspecified crabs, while only two crab species were identified - giant crab with 20.2 tonnes and crystal crab (*Chaceon bicolour*) with 0.03 tonnes. Crystal crabs are fished commercially off Western Australia but not found around Tasmania. Additional uncertainty in the catch data derive from the lack of reported fishing location. Instead, only the landing State is recorded and include e.g. NSW with around 20% of the catch identified as giant crab where giant crabs are rarely found.

It is possible that the reported landings of unspecified crab catch are predominantly, or even entirely, giant crab and caught in Tasmanian waters. Should this be the case, giant crab catches by the trawl fishery could have been as high as 19.6 tonnes or 31% of the TAC for the trap fishery (in 2004), and accounting for the trap fishery only would therefore mean a substantial underestimation of the total catch removed from Tasmanian waters.

Table 2: Catches of crabs in the SESS trawl fishery between 2002-2008 (2008 data incomplete).

Species	Landing State	2002	2003	2004	2005	2006	2007	2008	Total
Giant crab	Tas	0.9	1.1	1.5	1.3	1.2	0.8	0.7	7.5
	Vic	1.4	1.5	1.5	1.3	1.2	0.9	0.7	8.6
	SA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	NSW	0.2	1.3	0.7	0.9	0.5	0.4	0.1	4.2
	Total	2.5	4.0	3.8	3.6	2.8	2.0	1.5	20.2
Crystal crab	Tas					0.01			
	Vic						0.01		
	Total					0.01	0.01		0.03
Unspecified crabs	Tas	1.7	1.6	0.7	0.6	0.3	0.2	0.1	5.3
	Vic	5.0	8.3	8.6	4.7	4.3	0.8	0.5	32.1
	SA	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
	NSW	2.7	5.9	3.8	3.1	3.9	1.9	0.4	21.8
	Total	9.4	15.7	13.1	8.5	8.7	2.9	1.0	59.3
Total		12.0	19.6	16.9	12.1	11.6	4.9	2.5	79.6

3.1.3 Commercial effort

Total fishing effort has stabilised over the last four quota years. However, regional effort showed differing trends with a recent drop on the West coast, and a slight increase over the last two years on the East coast (Figure 4).

State-wide seasonal effort followed the pattern of previous years, although it was slightly lower in autumn and higher in June (Figure 5). West coast effort showed a sharp peak in June, but was lower than in previous years during the remaining months (Figure 6). On the East coast, effort was similar to previous years. Fishing was again mostly restricted to the start and end of the fishing season in autumn and summer, respectively. Since crab fishers typically operate across different fisheries, these trends in seasonal effort tend to be a function of activity in other fisheries such as the scallop and rock lobster fishery.

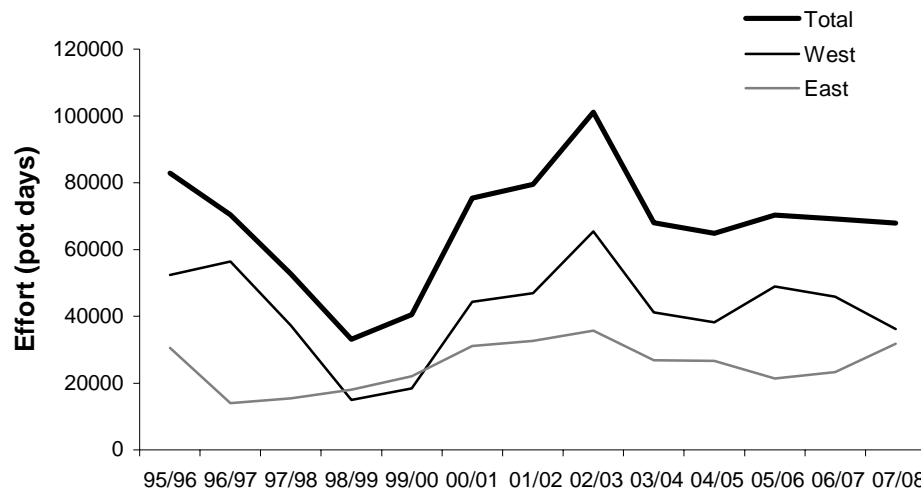


Figure 4. Total effort (pot days) and effort overall and for the West and East coast by quota year since 1995/96. Note that 1998/99 and 1999/00 were partial fishing years.

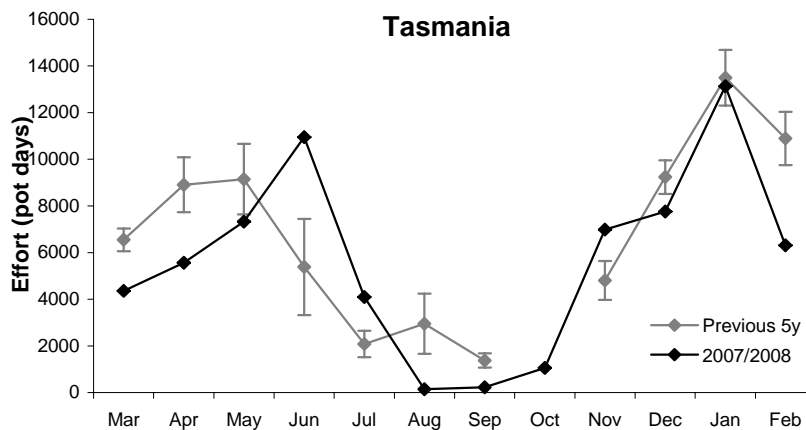


Figure 5. Seasonal trends in State-wide effort for 2007/08 quota year (black line) and annual average for the previous 5 years (grey line) including standard error bars.

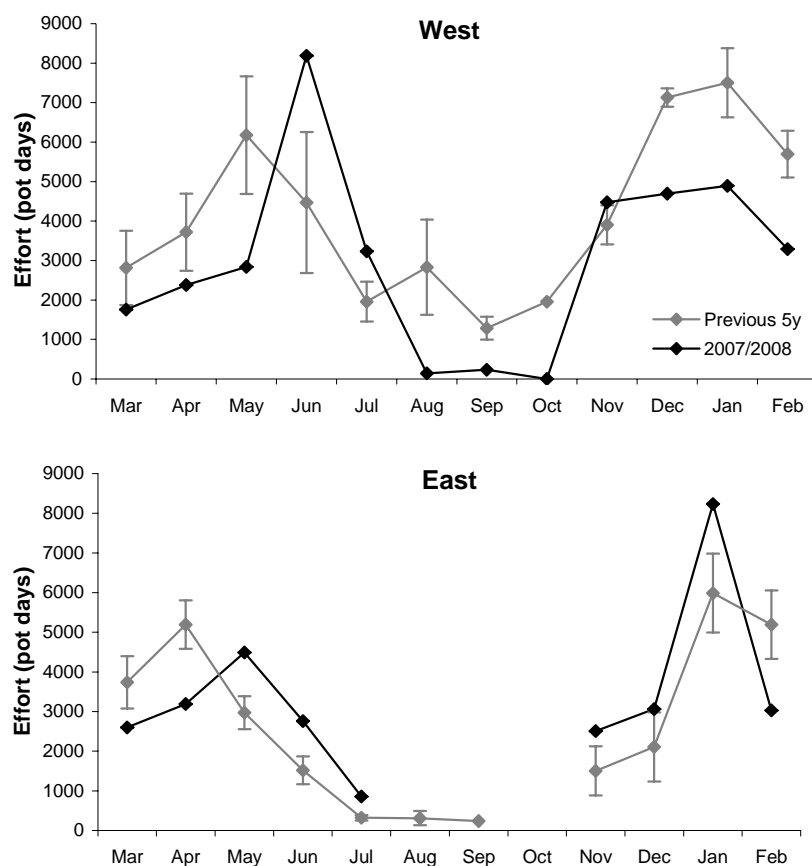


Figure 6. Seasonal trends in West and East coast effort for the 2007/08 quota year (black line) and annual average for the previous 5 years (grey line) including standard error bars.

3.1.4 Commercial catch rates

Commercial catch per unit effort (CPUE) or catch rates are drawn from commercial logbooks. Logbook data prior to January 1995 do not include a measure of effort (number of traps), so only data since the 1995/96 quota year can be used for calculating catch rates. The data have been processed for a range of factors:

- Misreporting of effort was a common problem early in the fishery. Records that were known to be false or appeared unreliable, e.g. low trap numbers or unrealistic high catch rates, have been excluded from the analyses.
- Crabs are often taken incidentally to lobster fishing and catch rates under these situations are believed to be quite different to when crabs are targeted. The analysis of catch rates here was restricted to targeted effort. Fishers note in the current logbooks whether their effort is targeted towards giant crab, but this was not the case prior to 2000. As an alternative approach to defining targeted effort and to perform an analysis for the whole of the period since 1995/96, logbook data were restricted to skippers that had reported a median catch of at least 1000 kg over a minimum of 2 years. This selected experienced fishers who use vessels and gear more suited to crabs and take most of the overall crab catch, while fishers that directed most of their fishing effort towards lobsters and tended to have lower catches and catch rates were excluded.

Catch rates have been standardised for annual State-wide and regional trends (for methods see Chapter 5). For seasonal catch rate trends, catch rates were estimated as kilograms per pot day for each record in the database as:

$$\text{CPUE} = \frac{\text{Weight of catch (kg)}}{\text{Number of traps} \times \text{Soak time}} \quad (1)$$

where pot days are defined as the number of traps multiplied with number of days the traps are in the water before being hauled (soak time). Although soak times greater than 7 days do not lead to increases in catch, capping soak times at 7 days had only minimal influence on the results and was not used.

Since catch rate data were log-normally distributed, the geometric mean rather than the arithmetic mean of all valid individual daily catch records was calculated to generate the catch rate statistics. The geometric mean is the n^{th} root of the product of the individual rates (y_i), which is equivalent to computing the arithmetic mean of the natural logarithm of each number and then taking the exponent:

$$GM_{\bar{y}} = \exp \left[\frac{1}{n} (\sum \ln(y_n)) \right] \quad (2)$$

Catch rates calculated in this manner may differ slightly from the more simplistic approach of using the arithmetic mean. The geometric mean has the advantage of being less affected by the few observations that are skewed very high, which often happens with log-normally distributed catch data.

Annual commercial catch rates

State-wide catch rates declined in two successive years and therefore activated the respective reference point (Table 3, Figure 7). At only about 36% of the 1995/96 catch rates, State-wide catch rates have shown no signs of increase over the last few years.

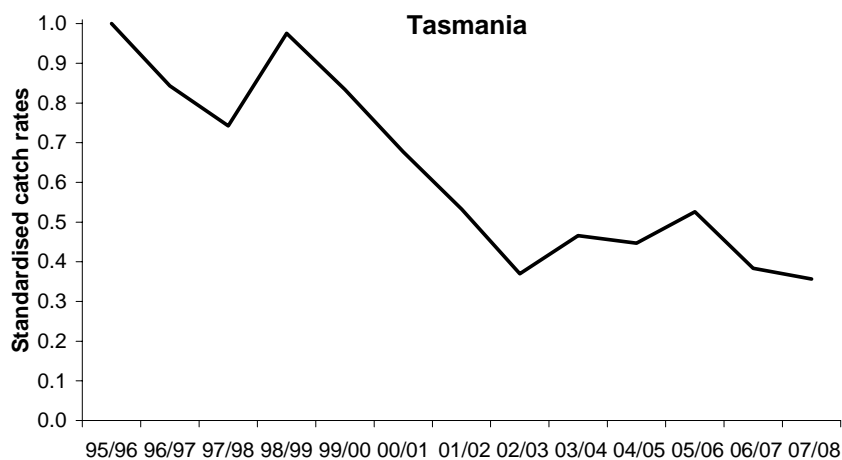


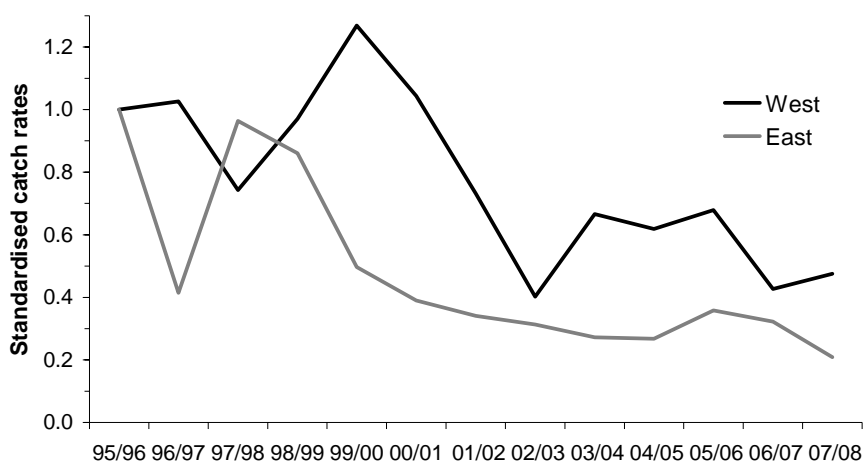
Figure 7. Trends in State-wide annual catch rates (standardised catch rates relative to 1995/96) by quota year, based on a selection of skippers that had reported a median catch of at least 1000 kg over a minimum of 2 years.

Table 3. Targeted State-wide and regional catch rates for the 2007/08 quota year relative to catch rates 5, 2 and 1 year ago. The reference point relates to the 2-year period (in bold).

Quota year	Tasmania	West	East
1995/96	1.00	1.00	1.00
1996/97	0.84	1.03	0.43
1997/98	0.74	0.74	0.98
1998/99	0.98	0.97	0.87
1999/00	0.83	1.27	0.49
2000/01	0.68	1.04	0.38
2001/02	0.53	0.73	0.33
2002/03	0.37	0.40	0.31
2003/04	0.47	0.67	0.26
2004/05	0.45	0.62	0.26
2005/06	0.53	0.68	0.34
2006/07	0.38	0.43	0.32
2007/08	0.36	0.48	0.22

Change in catch rates (in %) compared to:			
5 years	-3.5%	18.3%	-29.5%
2 years	-32.2%	-30.0%	-36.4%
Last year	-7.1%	11.4%	-32.7%

Regionally, catch rates have been slightly higher in the West than the East for some years. Compared to their 1995/96 levels, catch rates in 2007/08 have increased to 48% in the West, but fallen to 22% in the East. The catch rate limit reference point (a total decline by 20% over a 2-year period) was exceeded on the West coast with a decline by 30.0% and on East coast with a decline by 36.4% (Table 3, Figure 8). The decrease occurred mainly in the 2007/08 quota year, while catch rates had been relatively stable for the previous two years.

**Figure 8.** Trends in regional annual catch rates (standardised catch rates relative to 1995/96) for the West and East coast by quota year, based on a selection of skippers that had reported a median catch of at least 1000 kg over a minimum of 2 years.

Seasonal catch rates

While there are no management reference points relating to seasonal changes in catch rates, this analysis provides additional details into the mechanisms behind observed changes in annual catch rates. On the West coast and as a result also State-wide, low catch rates at the start of the quota year were followed by unusually high catch rates in June. This attracted high levels of effort and resulted in over 10t of crabs being caught on the West coast during this month (Figure 9). Catch rates were also higher than in the previous quota years in February. Catch rates on the East coast followed closely the average of previous years.

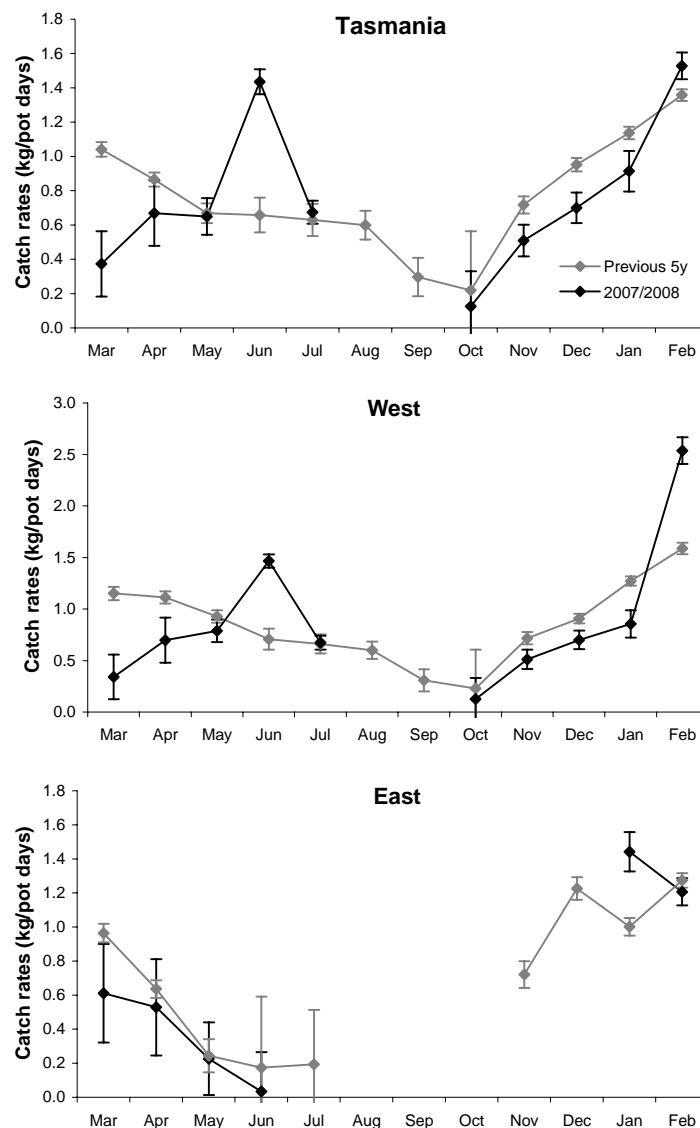


Figure 9. Trends in seasonal State-wide and regional catch rates (geometric mean based on a selection of skippers that had reported a median catch over 1000 kg over at least 2 years) in the 2007/08 quota year (black line) and for the previous five quota years (grey line) with standard error bars. Note that some months have observed effort from vessels that were not selected for these graphs (see Figure 5 and Figure 6).

3.1.5 Bycatch of crabs from the lobster fishery

The reference point relating to bycatch of crabs in the lobster fishery is set at 5 tonnes, which represents about 8% of the current TAC. Since the introduction of quota management, bycatch from the lobster fishery has not exceeded 1.1 tonnes (in 2000/01) and was reported as being just 61 kg or 0.12% of the landed giant crab catches in the 2007/08 assessment period (Figure 10). Industry members considered that any reported bycatch would probably be an under-estimate, but whatever the true level of bycatch it was likely to be small relative to the targeted crab catch.

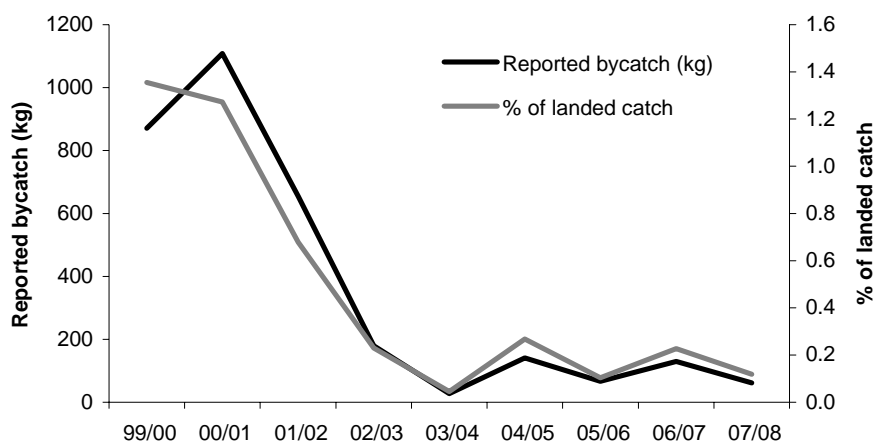


Figure 10. Total reported bycatch of crabs in the rock lobster fishery and percentage of the total giant crab catch.

3.1.6 Weight and size distribution of commercial catch

The two reference points relating to the weight distribution of the commercial catch, i.e. the variation in the proportions of the catch above 5 kg or below 3 kg, could not be assessed, because no weight information was available for this assessment.

A voluntary measurement system using digital callipers and data loggers provides measures of the size composition in the catch. Fishers measure crabs above and below the legal minimum length, not just retained animals, and data are accurate to within a few millimetres. Using this system, over 20,000 crabs have been measured across a number of quota years. These data have been incorporated into the stock assessment model and are presented in Section 3.4.2 of this report (Figure 20).

3.2 Additional information on composition of catches

Tasmanian giant crab fishers record extensive details on their catch including number of undersize released and the number of each sex in retained catch. This information illustrates different trends between the East and West coasts (Figure 11).

- Average weight of crabs on each coasts declined through time as larger crabs were removed and the fishery became more dependent on recruits. Average weights are now a little over 3 kg on each coast.
- The sex ratio of catches is very different between coasts with catches from the East strongly biased towards females while those from the West strongly biased towards males. This difference has become more pronounced over time as males have increased in the catches on the West coast.
- Catch rates of the undersize crabs that are released provide an indication of undersize abundance, and possibly the strength of future recruitment. Undersize catch rates have traditionally been lower on the West coast than on the East coast. In 2007/08, undersized catch rates became higher on the West coast after a steady and pronounced increase over the last seven years with catch rates trebling over this period. This trend may indicate future increase in the number of crabs recruiting into the exploitable biomass.

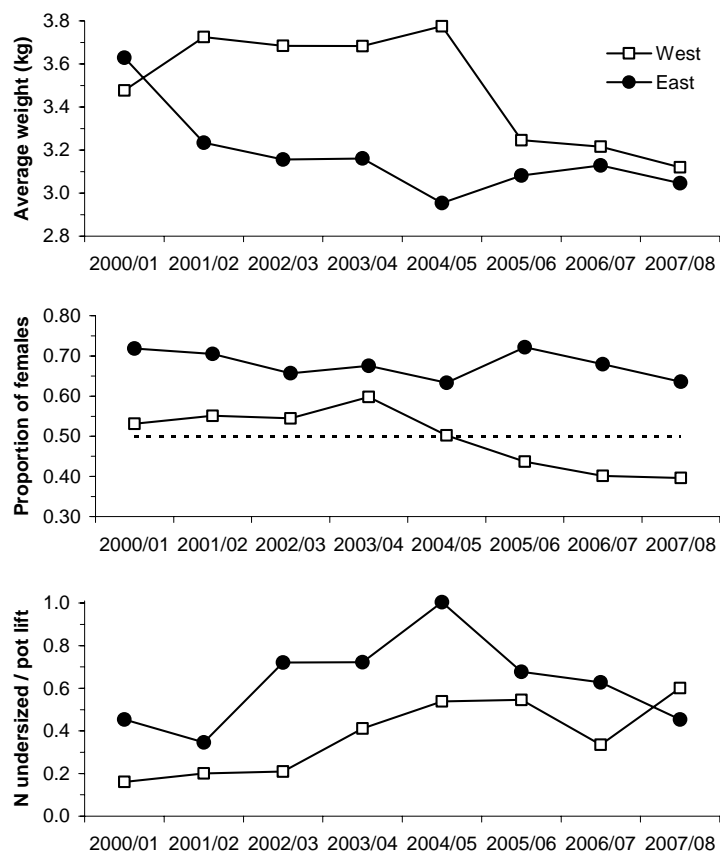


Figure 11. Top: Average weight of retained catch; Middle: the proportion of the retained catch that was female (the dotted line represents 50% or an equal split between males and females); Bottom: catch rate of released undersize crabs.

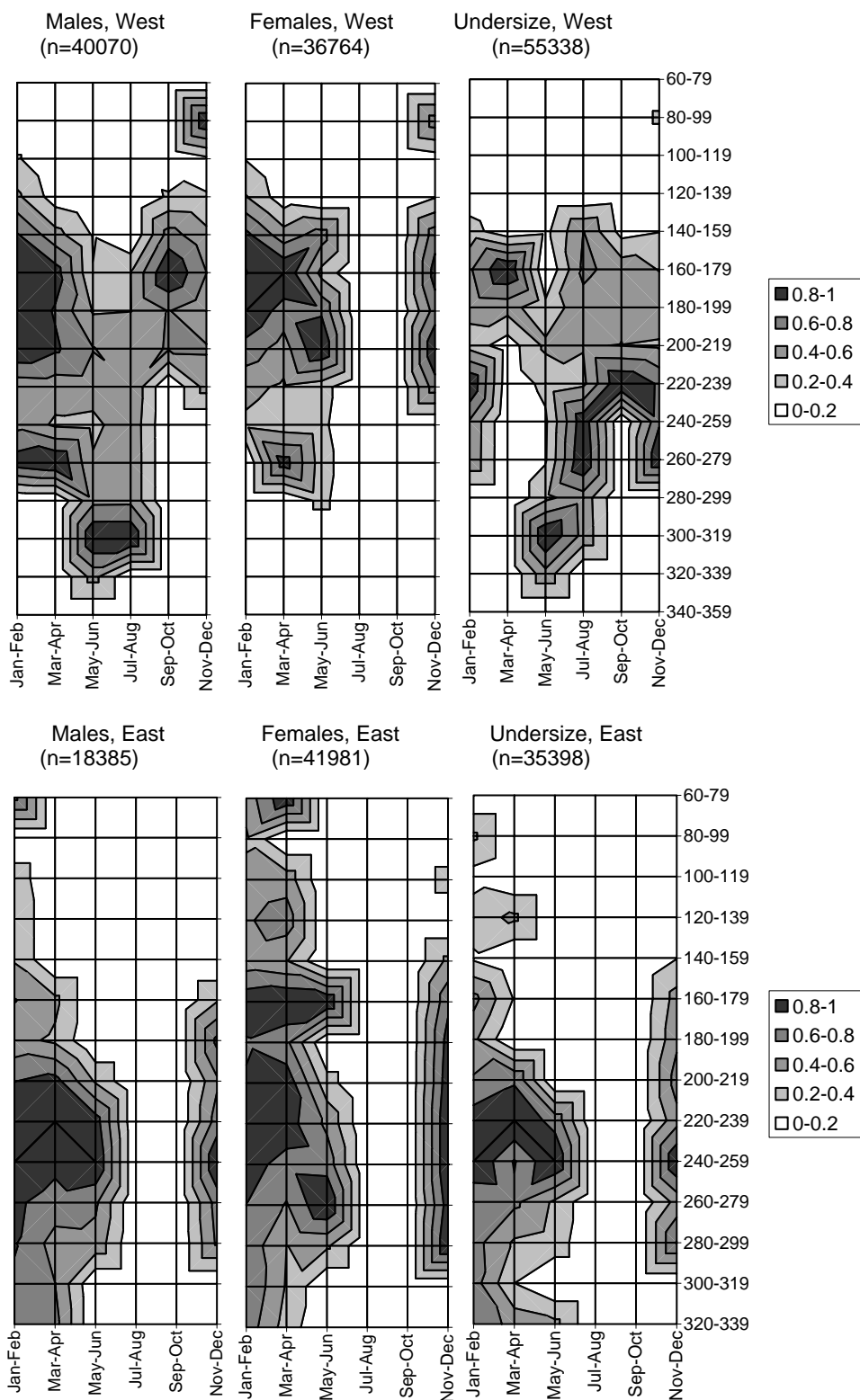


Figure 12. Seasonal patterns in catch rate of giant crab with depth (m). Data were pooled from 2000 to 2007 into 2 monthly bins with 20 m depth intervals and cells with less than 50 crabs were excluded. Catch rates were scaled to the maximum catch rate observed for any depth for that time period. While this data appear to indicate that abundance of crab at different depths varies with season, there is no support for greater abundance of undersize crabs at deeper depths.

Note that undersize crabs are not evenly distributed between regions and with depths (Figure 12, Figure 13). Consequently, change in the distribution of fishing effort may also contribute to the apparently positive trends in undersize catch rates shown in Figure 11.

Large males that are over 216 mm CL are released under current rules. The number of these animals being released was recorded for the first time in this assessment year. Only a small portion of the catch falls in this category with 1.7% of the catch (by number) being oversize males on the West coast and 2.7% on the East coast.

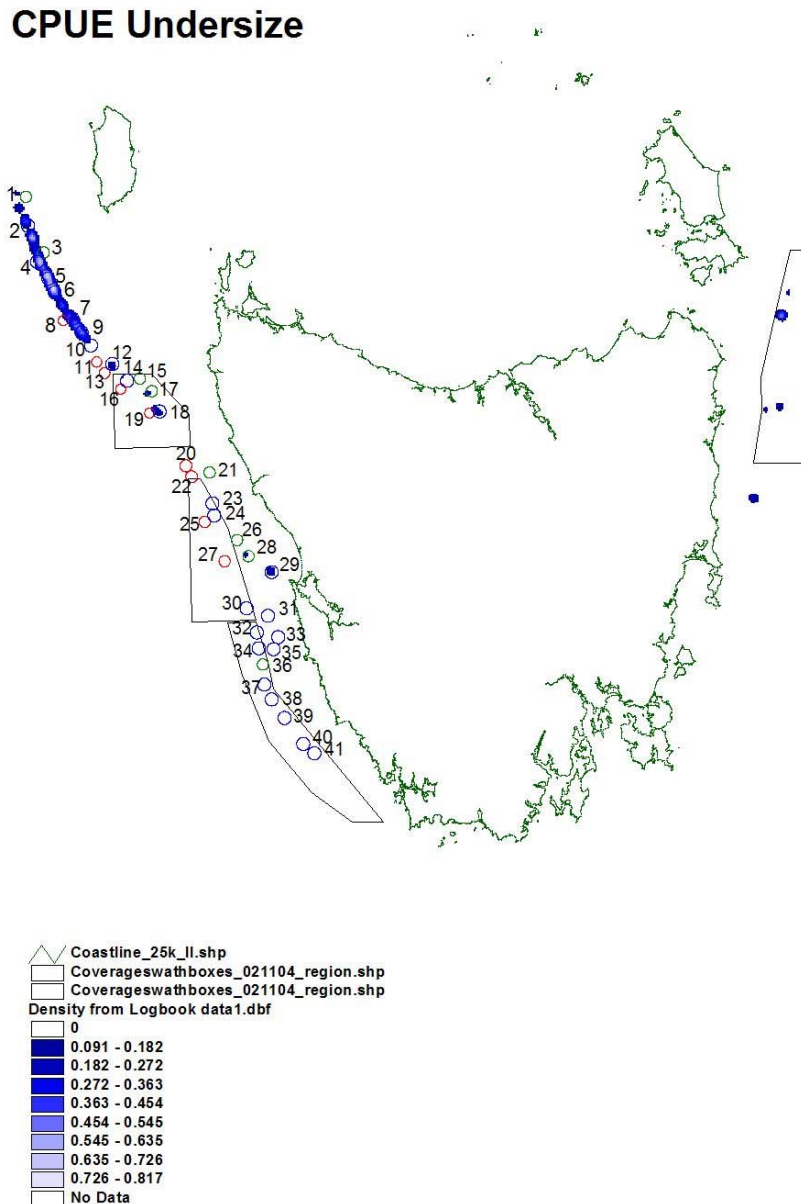


Figure 13. Density of undersize giant crabs using CPUE as a proxy shown by blue shaded regions. Boxes and circles marked are those areas targeted in swath mapping and habitat surveys. Undersize abundance appears concentrated in the NW.

3.3 Assessment of other species caught by the Tasmanian giant crab fishery

3.3.1 Byproduct

Byproduct of the giant crab fishery has been recorded in logbooks records from a small proportion of fishing trips since January 2008, i.e. for the last two months of the quota year. In 21 shots from a total of 186 conducted over this period (or around 11% of all shots), only four species were reported in crab traps, with largest catches around 70 kg of conger eel, and catches below 25 kg for ling, cod and morwong (Figure).

Considering that fishing effort is highest during those two summer months compared to the remainder of the year, annual catches of byproduct species are expected to be minor.

A data collection program is underway in Tasmania and Victoria using disposable cameras and observers. Results from this program will be reported in future stock assessment reports.

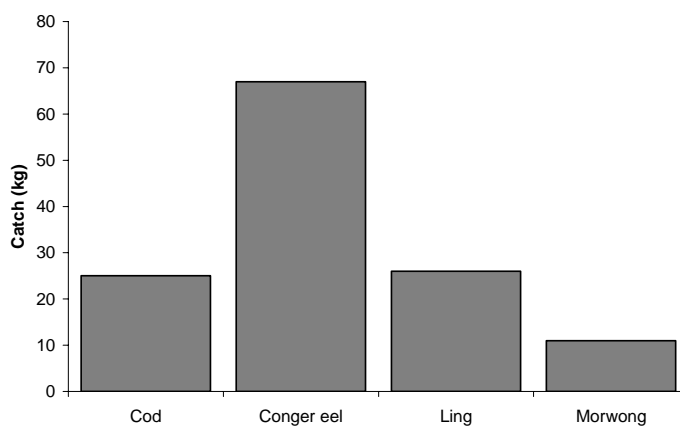


Figure 14: Reported byproduct (in kg) from the giant crab fishery in January-February 2008.

3.3.2 Protected species interactions

Protected species interactions are now recorded directly in the giant crab logbook. No protected species interactions were reported by fishers targeting crabs in 2007/08. This would be expected given that the fishery operates in deep water away from coastal areas frequented by juvenile seals and cormorants, which interact with traps in the lobster fishery.

3.4 Stock Assessment Modelling

3.4.1 Introduction

A length-based stock assessment model with an annual time-step was used for the Tasmanian giant crab. Full details of the model and the underlying description of giant crab growth are given in Chapter 5.

The model was applied to pooled data from the Western and Eastern side of the continental shelf ('Tasmania'), and to the data from the two fishing regions independently ('West' and 'East'), although management arrangements such as TAC and size limits apply to the whole Tasmanian fishery and there are currently no restrictions on the distribution of fishing effort. While separate recruitment patterns to Tasmania and the Western and Eastern regions were fitted, selectivity parameters could only be fitted in the West. The available length frequency data in the Eastern model were not sufficient to estimate reasonable selectivity functions for the two sexes, and the selectivity parameters from the Western model were used instead. Biological parameters for natural mortality, growth through moulting, length-weight relationship, female maturity and fecundity were assumed identical between the regions and assumed to be known exactly, although some were highly uncertain. The model was conditioned on commercial catch data and fitted to observed standardised catch rates and length composition data from many quota years since 1993/94 using maximum likelihood methods.

A bootstrap procedure using 500 replicate bootstrap samples of the catch rate data provided an initial estimate of the uncertainty inherent in the assessment. It is likely to underestimate the uncertainty simply because there are so many processes, particularly growth, that are only known approximately.

Using the fitted recruitment residuals to define the expected recruitment variation in the future, the stock assessment model was projected forward by 10 years to determine the likely outcomes of different management arrangements in formal risk assessment. The two regions were again treated independently assuming that the fleet dynamics remained the same for the whole period of the projection. Since the TAC applies to the whole of Tasmania, this separation of regions in the projections was somewhat artificial. But given the different recruitment patterns in the West and East, this approach provided greater contrast for the regional productivity of the giant crab stocks. A range of harvest strategies with fixed TAC levels were investigated, while all other management options, including the minimum and maximum legal length limits were kept constant at the present levels of 150 mm and 210 mm, respectively, for both males and females.

3.4.2 Fitting the Model

All sources of data influenced the final model fits, with mainly acceptable fits to both catch rate and length frequency data (Figure 15 to Figure 22). Model fits were close to observed State-wide and regional catch rates in recent years, but poor especially on the East coast during the strong fluctuations in the late 1990s. Fits to the length frequency data were poor in some years, but these generally coincided with relatively small sample sizes.

Compared to estimates from last year's assessment, changes in standardised catch rates and improved estimation of biological parameters resulted in higher model predictions of stock productivity in the early years of the giant crab fishery. Therefore, relative levels of estimated current biomass and egg production tended to be lower.

The large catches reported in the mid 1990s led to a significant reduction in the predicted stock size. The model estimated that the State-wide exploitable biomass declined from about 1601 tonnes at the start of the fishery to about 291 tonnes in 2007/08 (Table 4). This represents an overall decline to 18% (15-23% confidence interval CI) of the historically highest exploitable biomass, although the increase in lower size limits from 80 mm to 150 mm CL contributed substantially to the drop in 1992-1993. Harvest rates were generally high, but have slightly fallen to 0.18 (0.15-0.23) in the most recent quota year due to smaller catches. At the same time, total biomass and egg production have remained relatively stable at 28% (24-36%) and 32% (26-39%) respectively of their highest levels, although both show a downward trend. The relatively tight confidence intervals indicated minor uncertainty deriving from the model fit to catch rates. The model predicted 68% and 3% probability that current levels were above 30% and 40% of historically highest levels of egg production, respectively.

Tasmania

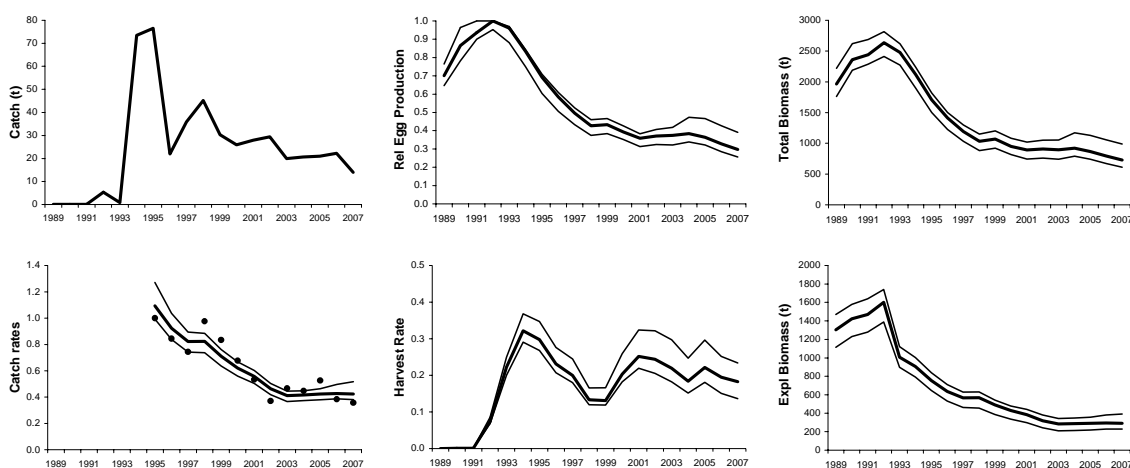


Figure 15. State-wide results of the model fitted to the observed data since 1989/90 (first year of quota year given). Observed catch, observed standardised (black dots) and fitted predicted catch rates (line), relative egg production, estimated annual harvest rates, total biomass and exploitable biomass at the start of each quota year. Median values (heavy lines) and 90% confidence intervals (light lines) from the bootstrap procedure given.

Table 4: Summary of model estimates for exploitable biomass, harvest rates and egg production. $P(EP_{40\%})$ is the probability of egg production being above 40% of its historically highest levels.

	Exploitable biomass			Harvest rates	Total biomass	Egg production	
	Virgin (t)	In 2007 (t)	% in 2007	In 2007	% in 2007	% in 2007	$P(EP_{40\%})$
Tasmania	1601 (1387-1740)	291 (227-390)	18.2 (14.8-23.4)	0.18 (0.14-0.23)	27.6 (23.9-36.2)	29.7 (25.7-39.1)	3%
West	1010 (948-1160)	184 (134-294)	18.2 (13.2-26.5)	0.21 (0.13-0.29)	28.3 (22.2-40.5)	30.9 (24.7-44.5)	21%
East	577 (512-804)	115 (82-247)	19.9 (15.4-31.3)	0.12 (0.06-0.17)	40.8 (33.3-60.7)	42.6 (33.7-63.9)	82%

The same State-wide model was run in a sensitivity analysis assuming that all crab catches from the trawl fishery that had been landed in Tasmania, South Australia, Victoria and NSW consisted entirely of giant crab and were caught in Tasmanian waters. This assumption represented an increase in annual catches of 5-19 tonnes since 2002/03. Due to the lack of alternative information, it was assumed that the trawl and the trap fishery had the same selectivity and that both fisheries targeted the same length frequencies. Including trawl catches had only a minor influence on estimates of egg production and biomass, but increased estimates of harvest rates in the years with higher catches (Figure 17).

Tasmania

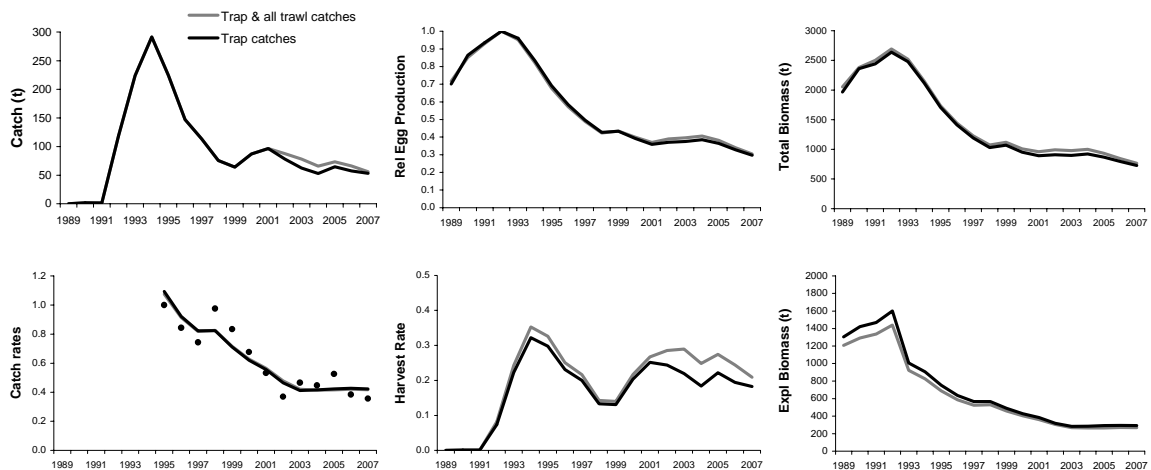


Figure 16. Comparison of State-wide results of the model fitted to the observed data since 1989/90 (first year of quota year given) with trap catches only (black lines) and trap and trawl catches combined (grey lines). Observed catch, observed standardised (black dots) and fitted predicted catch rates (lines), relative egg production, estimated annual harvest rates, total biomass and exploitable biomass at the start of each quota year.

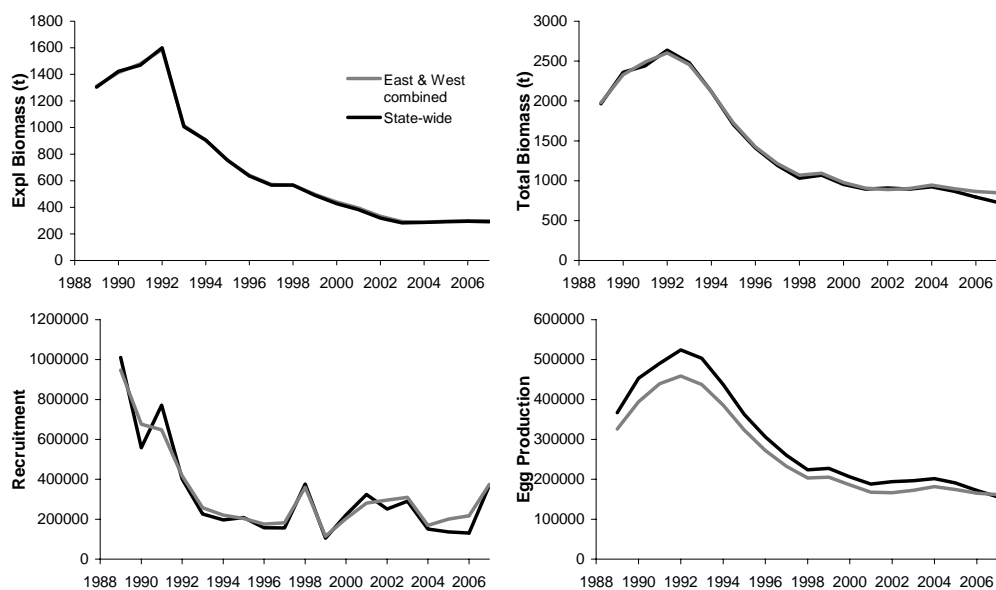


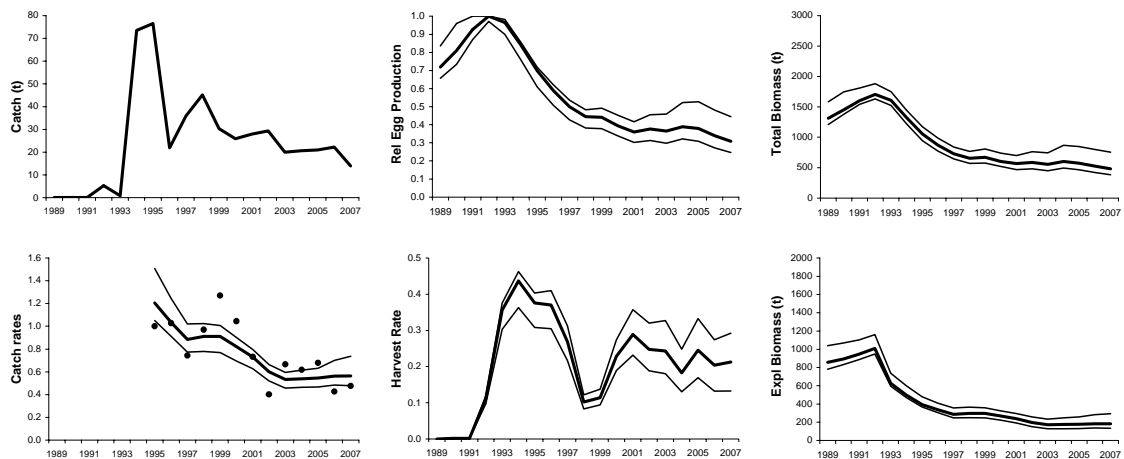
Figure 17: Comparison between the results from the State-wide model and the combined results from the East and West coast models for exploitable biomass and total biomass at the start of each quota year, egg production and recruitment since 1989/90 (first year of quota year given).

State-wide results were similar to combined regional results, indicating that there was sufficient information and contrast in the regional data to perform the separate stock assessments (Figure 17, Table 4). On the West coast, the model estimated also a harvest rates of 0.21 (0.13-0.29) and a decline in exploitable biomass to 18% (13-27%) of the original exploitable biomass (Figure 18). Total biomass and egg production have decreased to 28% (22-40%) and 31% (25-44%) respectively of their initial levels. Uncertainty was relatively minor on the West coast, although it increased in harvest rates of recent years as a function of the low, yet relatively certain estimates of exploitable biomass. The model predicted 75% and 21% probability that current levels were above 30% and 40% of historically highest levels of egg production, respectively.

On the East coast, the smaller catches have resulted in a smaller impact on the giant crab stocks, but the limited length frequency data resulted in higher uncertainty (Figure 18, Table 4). Harvest rates dropped to 0.12 (0.06-0.17) and exploitable biomass was 20% (15-31%) of the original exploitable biomass. Both total biomass and egg production have slightly increased to 41% (33-61%) and 43% (34-64%), respectively, of their initial levels. On the East coast, estimates of harvest rates and exploitable biomass were highly uncertain, probably as a result of a series of large catch rate residuals in the mid 1990s. The model predicted 98% and 82% probability that current levels were above 30% and 40% of historically highest levels of egg production, respectively.

Estimated recruitment showed some similarities between East and West with a relative recruitment peak on both coasts in 1998. Recruitment on the East coast showed no distinctive pattern in subsequent years due to stable catch rates and the lack of length frequency information.

West



East

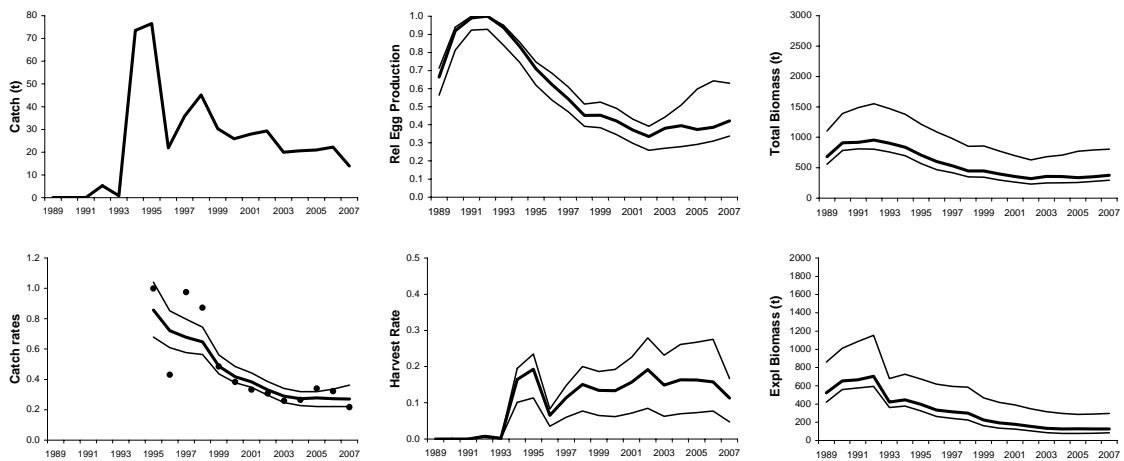
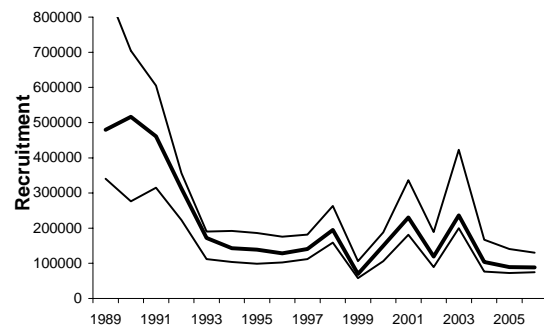


Figure 18: Regional results of the model fitted to the observed data since 1989/90 (first year of quota year given). Observed catch, observed standardised (black dots) and fitted predicted catch rates (line), egg production estimated annual harvest rates, total biomass and exploitable biomass at the start of each quota year. Median values (heavy lines) and 90% confidence intervals (light lines) from the bootstrap procedure given.

West



East

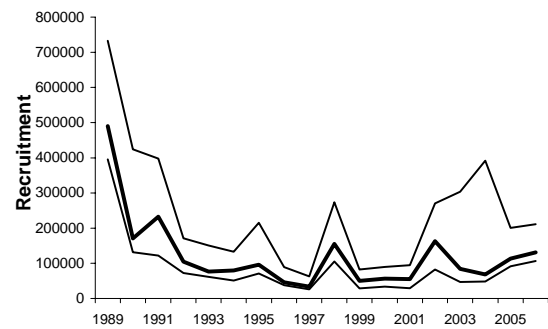


Figure 19: Regional recruitment since 1989/90 (first year of quota year given). Recruitment of the last quota year could not be fitted and is not shown.

Tasmani
a

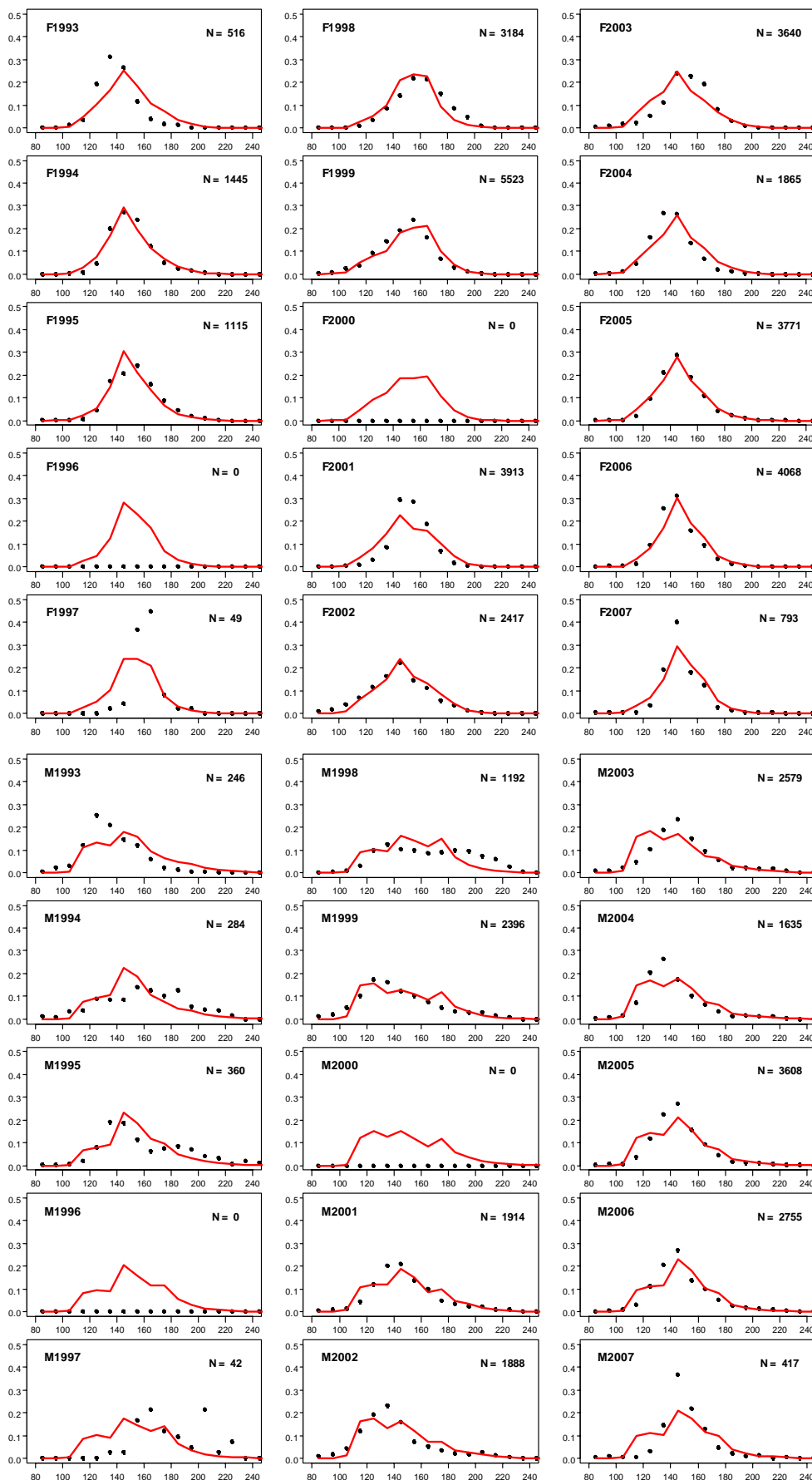


Figure 20. Observed (points) and predicted (lines) length frequencies in State-wide commercial catches since 1993/94 (F1993 and M1993) for female and male giant crab with the observed sample sizes N.

West

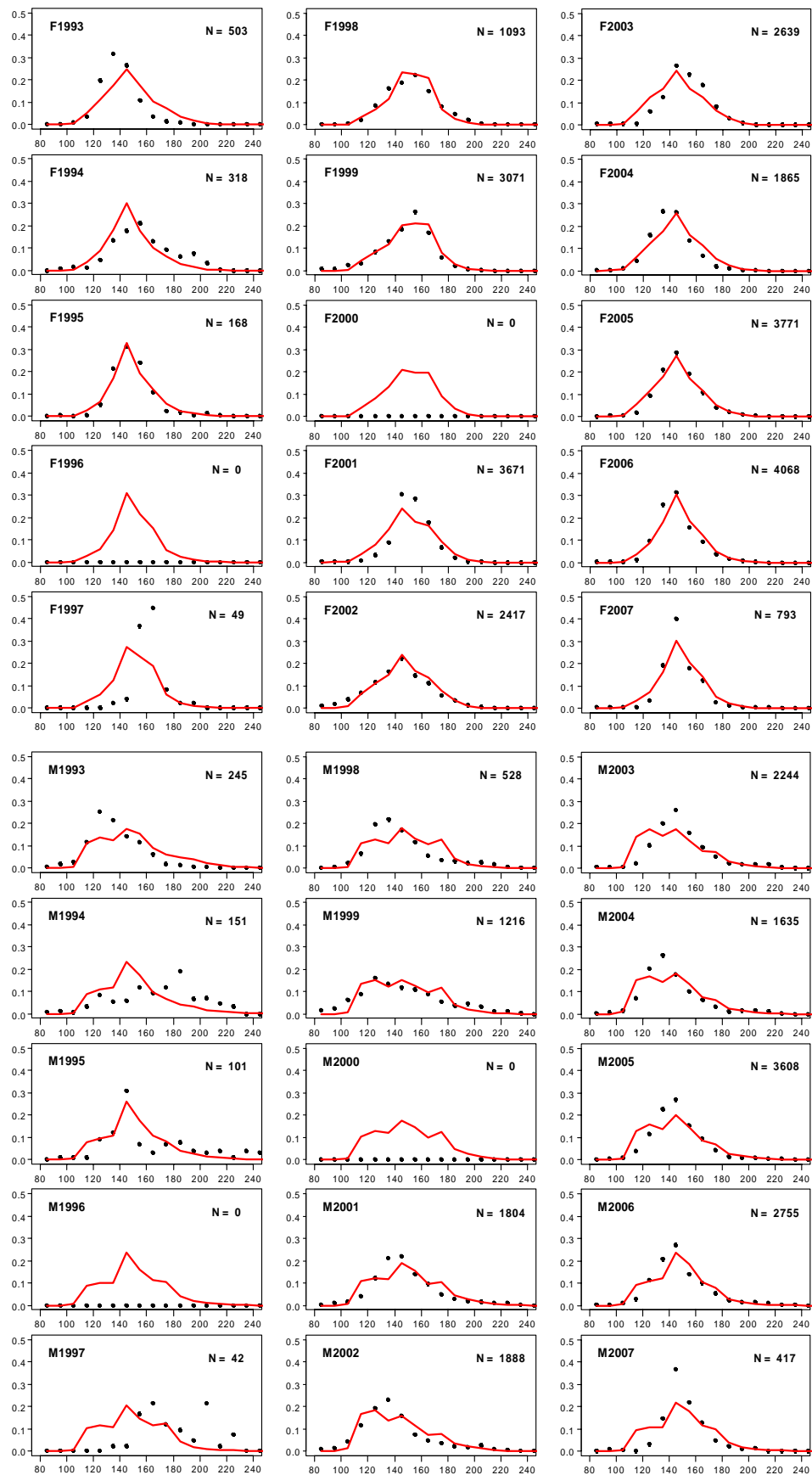


Figure 21: Observed (points) and predicted (lines) length frequencies in commercial catches from the West coast since 1993/94 (F1993 and M1993) for female and male giant crab with the observed sample sizes *N*.

East

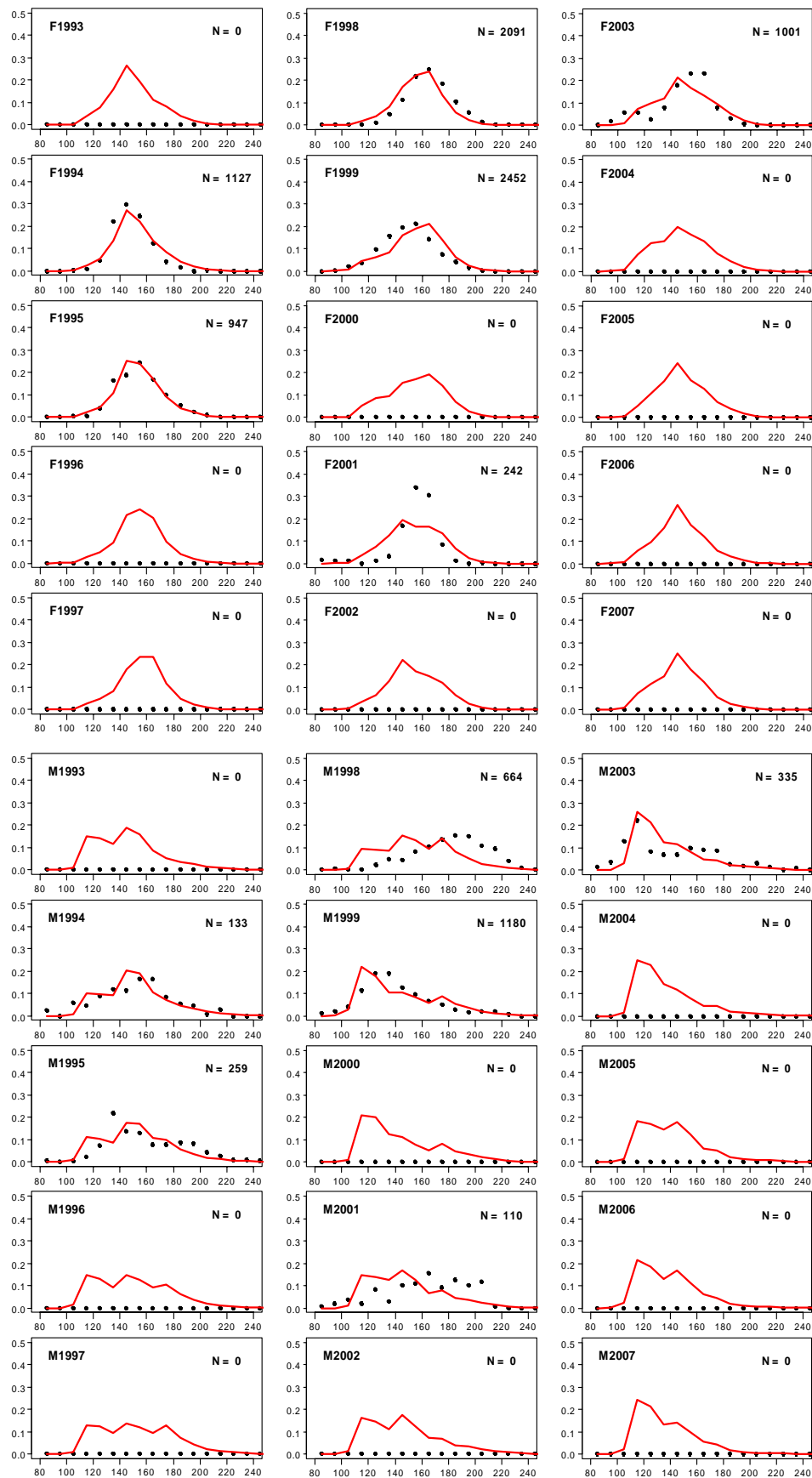


Figure 22: Observed (points) and predicted (lines) length frequencies in commercial catches from the East coast since 1993/94 (F1993 and M1993) for female and male giant crab with the observed sample sizes N .

3.4.3 Model Projections

In all cases, the projections had reasonably wide confidence intervals around the predicted future values, illustrating that these projections are highly uncertain (Figure 23 to Figure 25). Confidence intervals around the model outputs of total biomass and egg production were already quite wide by the first year of the projection. Due to the low selectivity of the traps for newly recruited crabs entering the smallest size classes (80 mm), recruitment variation could not be fitted well to the last year of the commercial catch rate data, and hence the recruitment variation required for the projections began in 2007/08 rather than 2008/09.

The projected outcomes were less optimistic than in previous years (Ziegler *et al.* 2008). State-wide, the current TAC of 62.1 tonnes had a probability of only 5% that catch rates (or exploitable biomass) would be above current levels in 5 years (Table 5, Figure 23). Harvest rates were also highly likely to increase above current levels.

Table 5. Estimated probability (%) that in 5 or 10 years catch rates will be above or harvest rate below current levels, or total biomass (TotBt) and egg production (EggProd) will be above 30% ($EP_{30\%}$) or 40% ($EP_{40\%}$) of their highest historical levels under different fixed catch scenarios.

	Catch	Catch rates		Harvest rates		TotBt		EggProd	
		Current	Current	30%	40%	30%	40%		
<i>In 5 years</i>									
Tasmania	41.1t	48%	99%	58%	1%	78%	5%		
	52.8t	20%	38%	47%	0%	71%	4%		
	62.1t	5%	0%	39%	0%	67%	3%		
	82.8t	0%	0%	18%	0%	55%	2%		
West	20t	85%	100%	82%	5%	89%	15%		
	30t	44%	97%	68%	1%	85%	10%		
	40t	8%	1%	50%	0%	80%	6%		
	50t	0%	0%	33%	0%	72%	4%		
East	10t	96%	100%	91%	41%	89%	42%		
	15t	85%	73%	86%	30%	85%	36%		
	20t	61%	1%	80%	20%	82%	28%		
<i>In 10 years</i>									
Tasmania	41.1t	68%	98%	69%	2%	81%	8%		
	52.8t	32%	50%	47%	1%	73%	5%		
	62.1t	11%	1%	34%	0%	68%	3%		
	82.8t	0%	0%	10%	0%	47%	0%		
West	20t	94%	100%	90%	12%	93%	22%		
	30t	60%	96%	73%	5%	87%	15%		
	40t	17%	13%	50%	0%	80%	9%		
	50t	1%	0%	24%	0%	67%	4%		
East	10t	92%	100%	92%	48%	89%	45%		
	15t	74%	65%	84%	28%	84%	32%		
	20t	45%	3%	74%	17%	79%	26%		

Reducing the TAC would improve catch rates and exploitable biomass, however, any stock recovery was likely to occur only slowly even under the lowest catch levels. The probabilities of maintaining current levels of catch rates or exploitable biomass in 5 years increased to 20% and 48% under TACs of 51.8 tonnes and 41.1 tonnes, respectively, and rose further to 32% and 68% after a projection period of 10 years. Increasing the State-wide TAC to 82.8 tonnes on the other hand was highly likely to result in a rapid drop of exploitable biomass and catch rates. The upper limit on the confidence bound of the predicted exploitable biomass, catch rates and harvest rate was at times only determined by a limit imposed by the model to avoid unrealistic results after just a few years, e.g. greater than 100% of available legal-size biomass being taken in the fishery (Figure 23).

Regional projections indicated that under the status quo catch, i.e. 40 tonnes on the West coast and around 15 tonnes on the East coast and therefore less than the TAC, catch rates (or exploitable biomass) would further decline on the West coast, but stabilise on the East coast (Table 5, Figure 24 and Figure 25). On the West coast, the probability of maintaining current levels of catch rates in 5 and 10 years was low at 8% and 17%, respectively. Only catch levels of 30 tonnes would result in a greater than 50% probability to increase catch rates and exploitable biomass in 10 years. A catch reduction to 20 tonnes was highly likely to show further improvements of these measures, yet any improvement would be slow even under such low catches. On the East coast, future exploitable biomass had a high probability to exceed current levels under all catch scenarios, but a catch of 20 tonnes showed a declining trend over time.

In contrast to catch rates and exploitable biomass, projected total biomass and particularly egg production levels were less sensitive to harvest levels and appear to be more regulated by other measures such as the minimum legal size limits. All catch scenarios predicted reasonably stable egg production. Given the current size limits, egg production in 5 years will achieve 30% of the historically highest levels ($EP_{30\%}$) with 67% probability State-wide, with 80% probability in the West and with 85% probability in the East. These levels remain largely unchanged even after a projection of 10 years. However, egg production is unlikely to achieve 40% of the historically highest levels ($EP_{40\%}$) State-wide or in individual regions even under reduced catches.

a) State-wide 41.1 tonnes

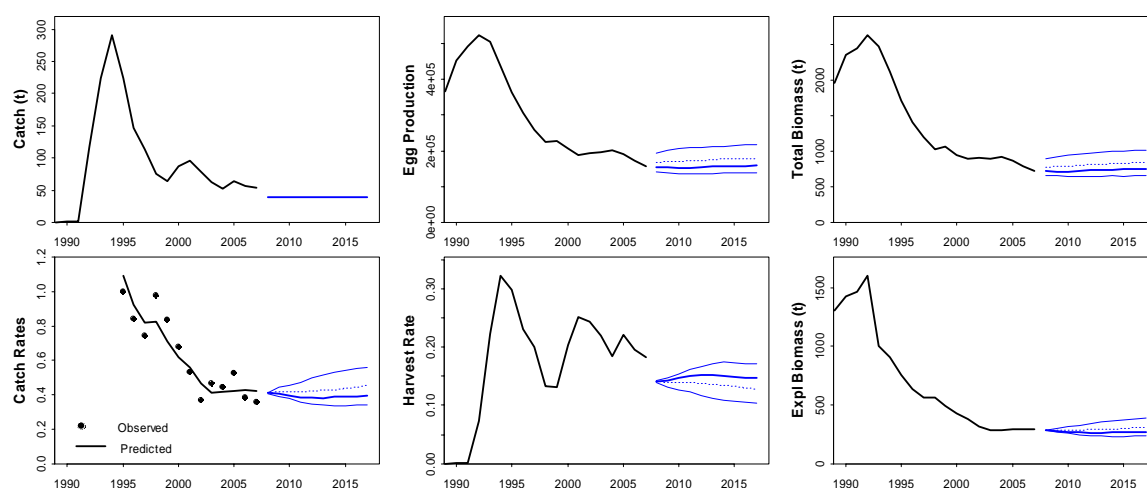
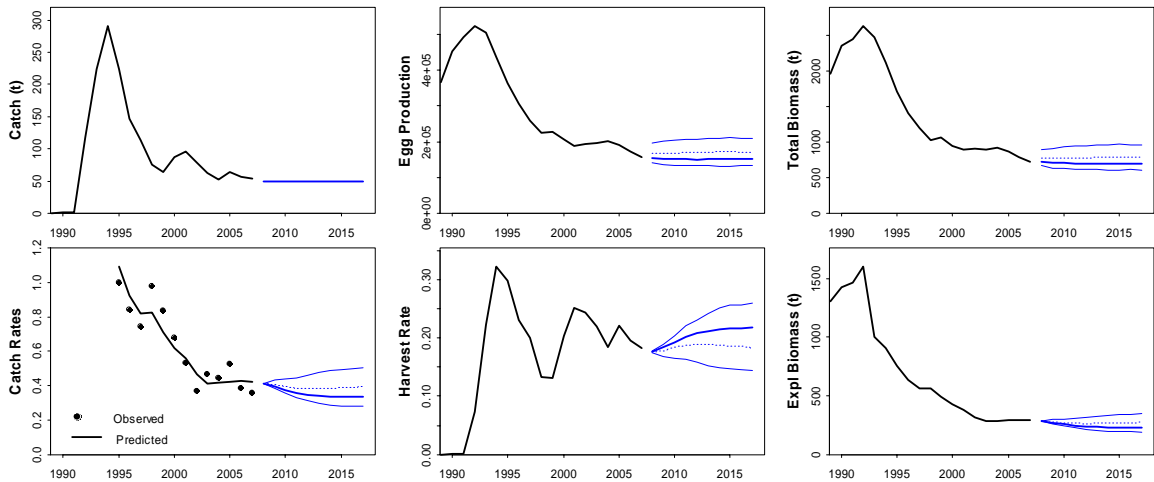
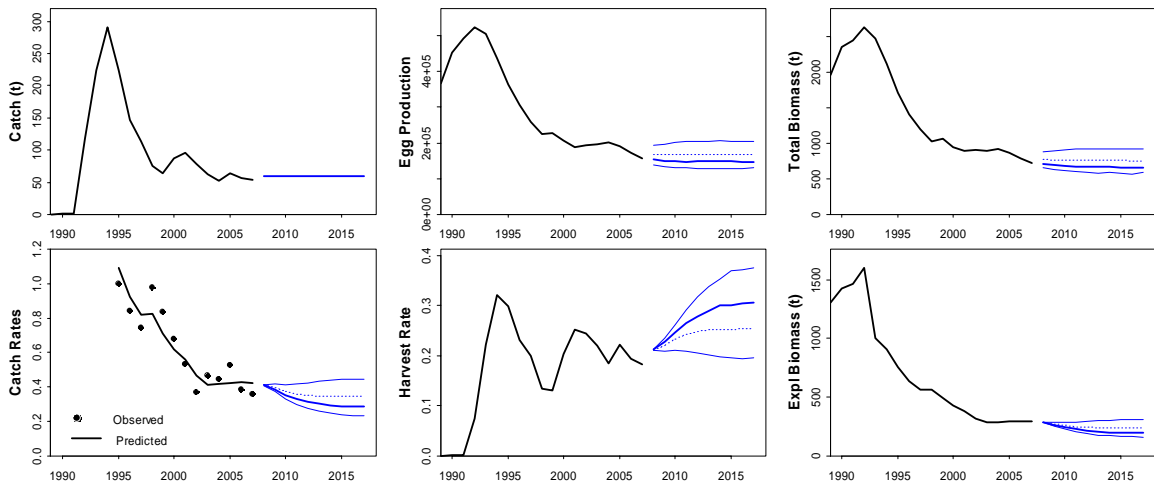


Figure 23. Model outputs for a 10-year projected State-wide TAC of (a) 41.1 tonnes derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the dotted line (median). The outer solid lines relate to the 90% percentile confidence intervals.

b) State-wide 51.8 tonnes



c) State-wide 62.1 tonnes



d) State-wide 82.8 tonnes

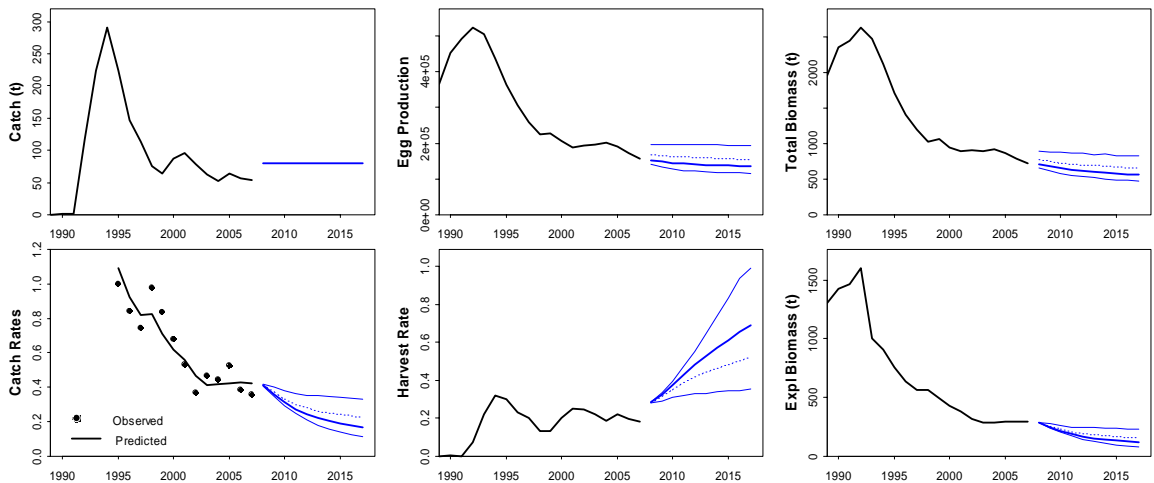
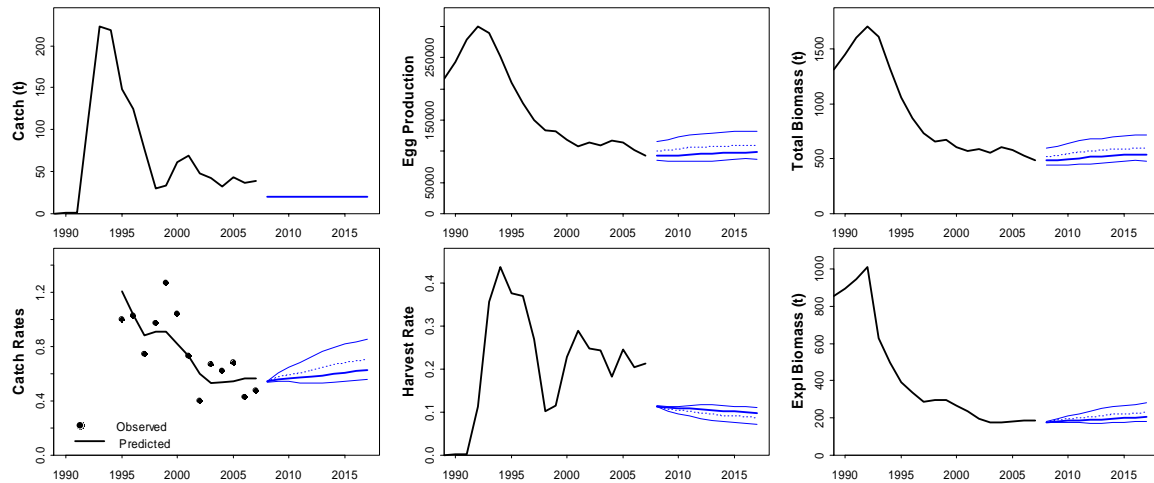
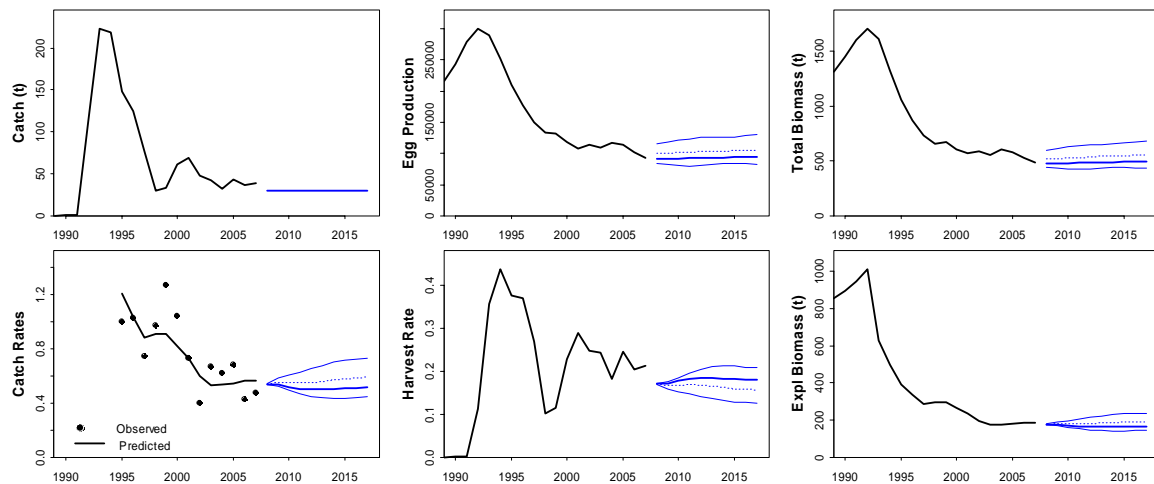


Figure 23 cont. Model outputs for a 10-year projected State-wide TAC of (b) 51.8 tonnes, the current TAC, (c) 62.1 tonnes, and (d) 82.8 tonnes, derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the dotted line (median). The outer solid lines relate to the 90% percentile confidence intervals.

a) West coast 20 tonnes



b) West coast 30 tonnes



c) West coast 40 tonnes

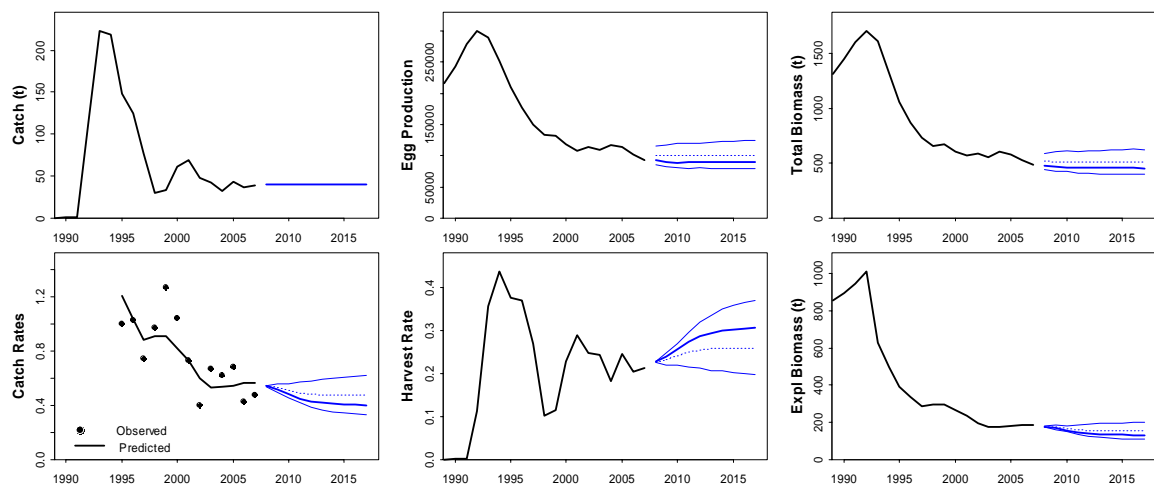
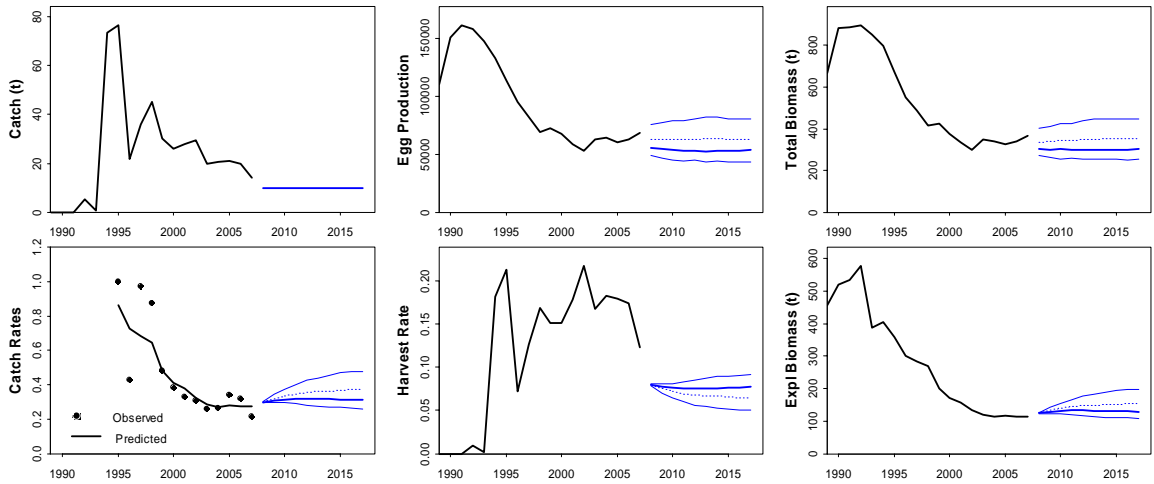
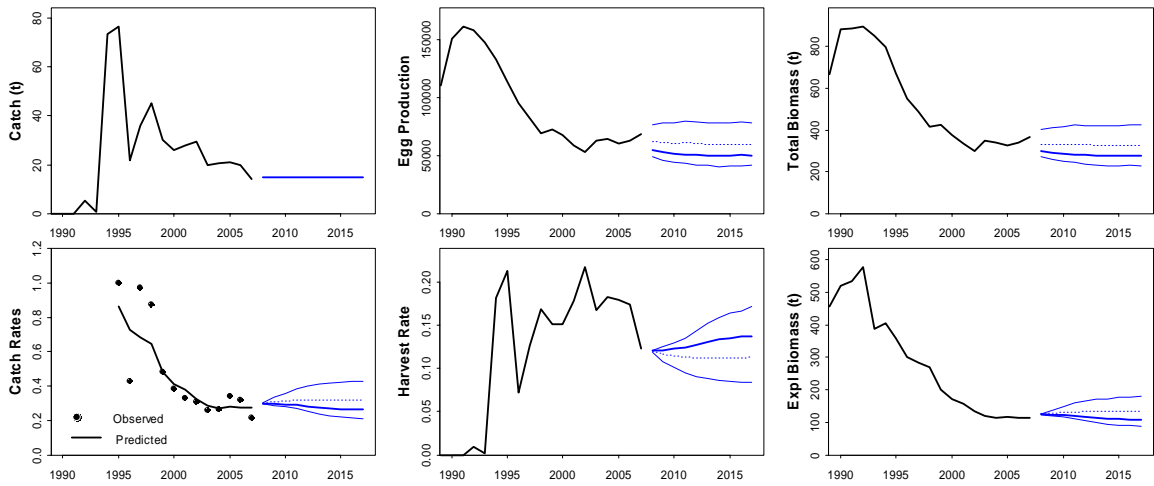


Figure 24. Model outputs for a 10-year projected West coast catch of (a) 20 tonnes, (b) 30 tonnes, and (c) 40 tonnes derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the dotted line (median). The outer solid lines relate to the 90% percentile confidence intervals.

a) East coast 10 tonnes



b) East coast 15 tonnes



c) East coast 20 tonnes

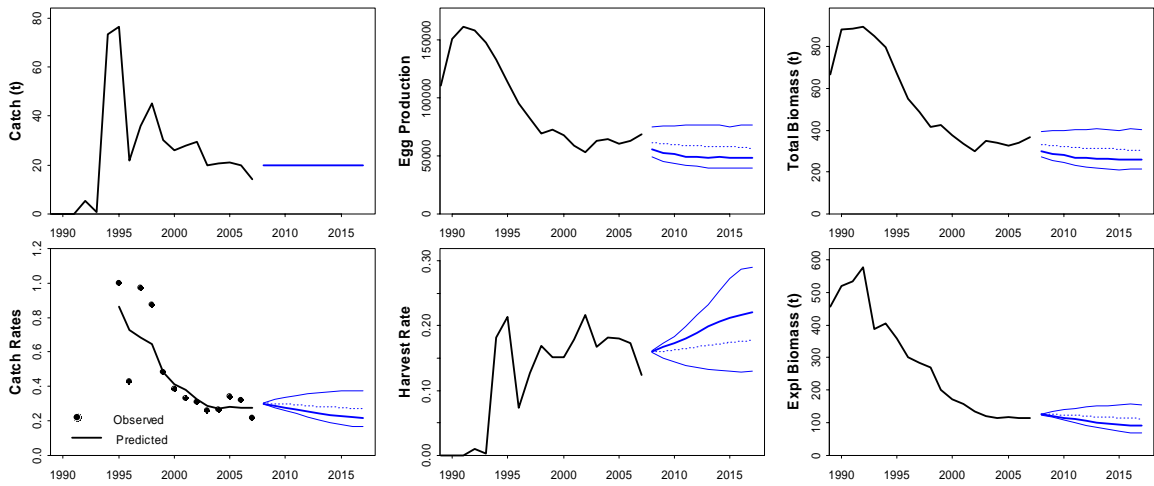


Figure 25. Model outputs for a 10-year projected East coast catch of (a) 10 tonnes, (b) 15 tonnes, and (c) 20 tonnes derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the dotted line (median). The outer solid lines relate to the 90% percentile confidence intervals.

3.4.4 Conclusions from population modelling

The process of fishing down the Tasmanian giant crab stocks appears to have stabilised the overall State-wide exploitable biomass at around 18% of the virgin state. On a regional level, exploitable biomass was estimated around 20% on the East coast and 18% on the West coast where the majority of fishing occurs.

The management implications of alternative TACs relate mainly to the maintenance of commercially viable catch rates. The State-wide model predicted that the status quo with a current TAC of 62.1 tonnes would be highly likely to further decrease catch rates and exploitable biomass over the next 5 to 10 years. Regional projections support this prediction, showing declining trends with catches of 40 tonnes on the West coast and 20 tonnes on the East coast. In the West, a catch decrease from 40 tonnes to 30 or 20 tonnes increased the probability of maintaining catch rates and exploitable biomass in 5 years from 8% to 44% and 85%, respectively. The probability of maintaining catch rates and exploitable biomass in the East was 61% for 20 tonnes and 85% for the current catch of 15 tonnes.

These predictions assume that no other major factor would influence the fishery, e.g. that impacts from another sector changed total mortality, or recruitment altered in response to climate change. Dynamic patterns in the fleet are accounted for in the assessment by standardisation of catch rates, nonetheless there remains scope for movements of the fleet to affect the assessment. For example, crab fishers reported moving gear to reduce risk of gear loss from interaction with trawlers.

While the current management of the fishery through harvest levels is mainly determining economic viability, biological sustainability is more influenced by other measures such as size limits. Egg production was relatively stable due to the contribution from sub-legal sized females which are fully mature by about 120 mm body length, i.e. well below the minimum size limit. While only a State-wide TAC of less than 51.8 tonnes had a greater than 70% probability of achieving $EP_{30\%}$ in 5 years, regionally these probabilities were above 80%. However, all tested scenarios predicted a low probability of achieving $EP_{40\%}$. Such a relatively high level of egg production is recommended as a target reference point for the giant crab management due to the high uncertainty in this assessment, particularly in regards to biological parameters such as growth and mortality.

This assessment assumes that current regulations on size limits remain in place. It may be possible to achieve a better outcome for the fishery in terms of financial profit and for the crab stocks in terms of egg production by simultaneously investigating alternative harvest rates and size limit regimes. This strategy is being explored through the project: "FRDC2006/022 Re-assessing giant crab (*Pseudocarcinus gigas*) size limits to optimise value and sustainability of the fishery".

The similarity between the estimates from the State-wide and combined regions indicated that there was sufficient information and contrast in the regional data to perform the separate stock assessments. However, the length frequency data in the East was insufficient to estimate the parameters of the selectivity function, and the model failed to estimate the recruitment pattern in recent years because no length frequency data had been available for the last four years altogether. Failure to collect future length frequency data will further increase uncertainty of the East coast model.

3.5 Habitat research summary

A large, FRDC funded project that investigated giant crab habitat was completed over the last year: FRDC2004/066 “Understanding shelf-break habitat for sustainable management of fisheries with spatial overlap” (Williams et al., 2008). Details on this project are available from the project final report, while the reports summary is reproduced here.

The shelf-edge is the region of the seafloor where the flat continental shelf drops away rapidly to form the continental slope - the steep edge of the continental margin that continues to the abyssal plains. The depth of the shelf edge is roughly between 150 and 400m. It's an important area for fisheries and is targeted by trawl and trap fisheries around Tasmania. The habitat project was developed to address a need for improved understanding of the benthic habitats in these areas. Prior to the project there was little information on habitats in these areas because sampling at these depths is challenging and requires specialised gear. Management of fisheries operating in the area had no habitat information to inform decision making - and this was especially needed for discussion of interaction of different sectors operating in the region (i.e. bottom trawl and giant crab fisheries).

Objective 1. Define and map key habitats on the shelf edge (~80-180 fm) at locations around Tasmania where fisheries using different gear types interact.

A range of methods were used to examine habitat along the shelf break including towed video, digital stills, swath mapping, sled tows and current and temperature profiling. Video transect data was emphasised in analyses for the project and provided qualitative information on faunal assemblages plus quantitative information on faunal categories, substratum type and geomorphology.

Key habitats on the shelf break were defined and mapped. Four categories of sessile fauna predominated: (1) ‘thicket or turf’ dominated by emergent bryozoans plus small erect sponges and ascidians; (2) low and/ or encrusting bryozoans and sponges; (3) low microfauna in association with detritus; and (4) absence of epifauna (often with bioturbation). Latitudinal variation in habitat was slight with differences between samples driven by depth and whether the samples were from within canyons.

Observations of microhabitat use by exploited species were made with video and digital stills data. Although finfish tended to avoid the gear, giant crabs were less responsive and 75 were observed. They were often observed excavating sediment, sometimes partially buried, while many were using small-scale habitat features including ledges and larger sponge for shelter.

Objective 2. Evaluate the resistance and resilience of habitats to impact from fishing gears using the semi-quantitative 'Ecological Risk Assessment' framework

The ecological risk assessment process applied here uses the same approach as applied for the Ecological risk assessment of the effects of fishing (ERAEF). This is a scoring process for potential risk or vulnerability (low, medium or high) against a series of attributes related to 'availability', 'encounterability', 'selectivity' (when multiplied together = susceptibility) and 'productivity'. Ranks are sub-fishery (gear) specific, with the rank score for each attribute derived via a series of tables and decision rules. A final risk rating is calculated from a 2-dimensional plot of susceptibility and productivity.

Summarising the risk scores for each sub-biome showed that the shelf-break (200-300 m) is the area of highest risk in respect of both trap and trawl fisheries: > 50% of all frames on the shelf-break rated as potentially high risk for trawl, and as medium risk for trap. The outer shelf habitats were mostly not vulnerable to either fishing method. Vulnerability of habitats to gear type was mapped along the coast, which provides guidance for spatial management.

This project offered a unique opportunity to examine the physical impact of a heavy towed epibenthic sled on shelf edge seabed habitat over a 1-year time period between two surveys. Photographic observation detected no obvious signs of habitat recovery in this period.

Clearly defined gear marks were clearly identified in 8671 video-frames, or around 3.2% of the total scored. Of these 20% were observed on the outer shelf (< 200 m), 7% on the shelf-break and 73% on the upper slope (54% in the 350-450 m depth range). Thus, the shelf-break, which was identified as potentially at high risk to impacts from trawl gear and moderately vulnerable to traps, showed the least amount of gear marks. Gear marks observed on the seabed appeared to come mainly from demersal trawls. The distribution of observed gear marks showed a good overall correspondence with areas recorded by logbooks as having trawl effort,

Our ERA analysis showed there is one conspicuous vulnerable habitat type, the bryozoan turf /thicket, potentially at high risk from trawling. The primary factors resulting in this outcome were: (i) its entire Tasmanian distribution was available to the trawl fishery (based on the management boundary); (ii) there was a very high overlap of trawl effort with its distribution (high encounters), and (iii) relative to other gears including crab traps, a trawl has a high degree of impact because it is heavy and has a large footprint. In addition, the habitat occupies a relatively small area, it has low physical resistance to this gear, and its fauna is fragile and completely removable. It occurs in deep water meaning it has relatively low resilience, having evolved in an environment with low natural disturbance and having a slow recovery following impact. Although the intrinsic vulnerability of bryozoan turf/thicket makes it potentially at risk to impact from any gear, it did not score at high risk from crab trapping. This was mainly because there is a lower impact from a lighter, static gear with a smaller footprint.

Objective 3. Detail the distribution of exploited shelf-edge species in relation to habitat features

The information collected on habitat distribution enabled comparison between habitat types and the distribution of commercial species including microhabitat utilisation for several commercial finfish and giant crab. The distribution of species was mainly inferred from catch rates derived from commercial logbook data, although some information was also obtained through the video data collected for this study. Of particular interest was the distribution of catches relative to (1) the bryozoan habitat and (2) the shelf/shelf break sediment terrace, for morwong, flathead, ocean perch, ling and giant crab.

Giant crabs mainly occupy the bryozoan turf habitat. This distribution overlaps with several commercial finfish including flathead (mainly taken between 150 and 170 m) and morwong (especially 160 and 180 m), while ling catch tended to be further offshore (>350 m).

The figures show clearly an increase in catches of flathead and morwong in more recent years (2001-2004 time period), which corresponds to the trawl fishery exploring shallower fishing grounds in that time. Note that change in the grenadier catch also occurred through this period, with the majority of that catch taken by midwater trawl where there are fewer interactions with the seabed.

Objective 4. Evaluate ecosystem links within habitats based on trophic, temperature and current-flow data.

Potential and known prey items of giant crabs were compared across habitat types. The collective distributions of prey (and inferred prey) groups of the giant crab, did not show a strong association with the structured and vulnerable bryozoan habitat occurring in the interaction area. Thus, there was no evidence that degradation of bryozoan habitat is directly detrimental to giant crabs based on loss of habitat for their prey. Conversely, occasional observations carried on the seabed suggests the discarded component of trawl catches may provide an additional food source.

Patterns in CPUE of undersize and male crabs from western Tasmania were consistent with movement to deeper water in winter and shallower water in summer. This pattern may be driven by the seasonal patterns in water temperature with crabs moving to deeper water in response to warmer water in winter (i.e. the reverse of surface waters).

Undersize crabs appeared to occupy the same depth range as legal sized catch although a distinctive spatial pattern was observed with a concentration of undersize crabs along the NW region of Tasmania. We explored whether this hot-spot of undersize abundance was a function of habitat / environmental traits of the region or of larval supply. Observations on habitat in this NW region did not identify any traits that would explain the greater abundance of juvenile crabs in this region. In contrast, simulation of larval advection suggests that this region may be larval sink, thus explaining the abundance of undersize in this region. The observation highlights the potential importance of the NW for any discussions of spatial management of the bryozoan turf habitats.

Objective 5. Evaluate the use of video to obtain stock assessment information such as abundance, sex ratio, condition and size of target species, primarily the giant crab.

A variety of target species were observed in videos, including pink ling, morwong, gemfish and giant crab. Fish species typically fled from the towed camera platform, and thus the value of fish observations was limited. In contrast, giant crabs typically showed little sign of avoidance. We observed 75 giant crabs that could be positively identified in the 77 hours of video collected throughout the surveys. This clearly indicated that abundance and density estimation by video to contribute to regular assessments would not be feasible due to cost. However, the data collected pointed to potential value from video data for point estimates of some assessment input data.

Two potential and valuable applications of video data for the crab fishery are: (i) quantification of gear selectivity, as a portion of the crabs observed could be measured by stereoscopy; (ii) validation of model based estimates of crab abundance of a smaller subset of the fishery using swept area methods.

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5. Appendix 1: Length-based stock assessment model

5.1 Model description

5.1.1 Basic population model

A length-based stock assessment model with an annual time-step was used for the Tasmanian giant crab. The model was applied to pooled data from the Western and Eastern side of the continental shelf ('Tasmania'), and to the data from the two fishing regions independently ('West' and 'East'), although management arrangements such as TAC and size limits apply to the whole Tasmanian fishery and there are currently no restrictions to the distribution of fishing effort. Most fishers have consistently concentrated their effort in one region without moving to the other region. The adult crab populations from these two fishing regions are also largely independent from each other. Movement rates of adult individuals are generally low and their movement tends to be confined within or along the continental shelf. Only 1 of around 1500 recaptured individuals appeared to have moved through Bass Strait, the large and shallow zone between the two fishing regions (PE Ziegler, unpubl. data). Although alternative management arrangements could initiate the transfer of catch across the regions, constant fishery dynamics was also assumed for the projections, with proportions of the TAC in each region essentially being equal to those in the last year of the assessment.

While separate selectivity and recruitment patterns to Tasmania and the Western and Eastern regions were fitted, biological parameters for natural mortality, growth through moulting, length-weight relationship, female maturity and fecundity were assumed identical. Biological parameters were assumed to be known without errors.

The model considered length classes from 80-250 mm for males and females. The basic length class width was 5 mm, although some calculations e.g. for growth were conducted by 10 mm length classes. Due to limitation in the data, the model operated with an annual time step that was in line with the quota year from 1 March to the end of the following February. Within each year, the chronology of events followed the sequence of applying half the natural mortality, allowing for individuals to grow, applying fishing mortality, adding new recruitment and finally applying the second half of natural mortality.

The model was conditioned on commercial catch data and fitted to standardised catch rates and length frequency composition data from many quota years since 1993/94 using maximum likelihood methods. The model estimated sex-specific selectivity parameters, the average recruitment level, and recruitment residuals defining the predicted deviation from the average recruitment that occurred each year. Instead of a pre-defined stock-recruitment relationship such as the Beverton-Holt relationship, average recruitment and recruitment residuals were fitted and constrained by a penalty term contributing to the overall log-likelihood. This penalty term was related to the recruitment variability and assumed relatively high ($\sigma = 0.75$). Prior to the start of the fishery in 1989/90, the crab populations were assumed to be at equilibrium with average recruitment levels.

5.1.2 Commercial catch and catch rate data

Catch and effort data for the models were provided by compulsory commercial logbook returns to the Tasmanian Department of Primary Industry and Water (DPIW). Prior to 1995, catch returns were based on monthly landings by skipper and one-degree or 60nm fishing blocks. Subsequent catch returns provided daily summaries of fishing operations, including number of traps used, soak time, location based on 30nm fishing blocks, average fishing depth and catch weights. In 1999, the logbook was extended by inclusion of data on the latitude and longitude of fishing and whether a fisher was targeting giant crab.

Catches were mainly taken by two small groups of operators, and there is a very small amount of bycatch by rock lobster fishers on the West coast. While discard mortality and some upgrading of catches through selectively retaining higher-valuable small crabs would undoubtedly occur, it was assumed to be minor and ignored in the model. Catch rates were standardised (see Chapter 6) and were assumed to constitute an index of relative stock abundance through time.

5.1.3 Biological data

All length frequency data were collected by fishers on board of their vessels. Fishery-independent sampling was not a viable option due to the usually small numbers of giant crabs caught on a single fishing trip. Length frequency data were more abundant in the West than East and samples were unavailable or below 100 individuals by sex in 1996/97, 1997/98 and 2000/01 in both regions. Relatively large samples were collected in the West since 2001/02, mainly by one fisher who consistently recorded and measures all crabs caught. While his fishing locations were reasonably consistent between years, his effort is concentrated in the northern half of the western fishing region along the continental shelf. In the East, sampling by a range of fishers has occurred more sporadically, and virtually no sampling has been conducted since 2001/02.

Growth was modelled by the combination of a growth transition matrix and explicit moulting probabilities in each year. The sex and length-specific growth transition matrix represented the probability of an animal growing from one length class into another during a moult. Growth increments were estimated from tagging data by Gardner et al. (2007) based on an extension of the methods described in McGarvey et al. (2002). Data were available for 641 recaptured female and 229 male crabs that had been tagged at lengths primarily below the legal minimum length of 150 mm carapace length. Comparing normal, log-normal and gamma distributions, the normal distribution was found to provide the best description for the expected distribution of growth increments in a predictive linear relationship with premoult length. The continuous probability distribution for a length increment during moulting was then integrated for each length class in the growth transition matrix, with the premoult carapace length being equal to the midpoint of a length class.

Due to long intermoult periods characterizing the growth of giant crabs, an explicit years-since-moult matrix was specified in the model in addition to the commonly-used growth transition matrix. Tag-recapture data indicated that only 50% of small males and females of around 140 mm had moulted after just over 2 years ad liberty (Gardner et al. 2007). With only limited data being available to estimate intermoult periods, logistic functions fitted to existing data were used to extrapolate to functions for a large range of crab lengths in three steps. Firstly, logistic functions with the parameters a and b were fitted to a number of length classes for which sufficient data was available, i.e. for males 100-130 mm and 131-150 mm, and for females 100-130 mm, 131-139 mm, 140-145 mm and 146-162 mm. These logistic functions fitted to broad length classes were then used to interpolate logistic functions for 10 mm length classes within the same range (100-160 mm). The interpolation was based on the observed linear relationship between length class mean and the parameter a , and the observed power relationship between a and b of their respective logistic functions. The interpolation resulted in plausible logistic functions. However, the logistic functions became flat when extrapolated to larger length classes, implying that a significant proportion of animals would moult already in the first year. Therefore as an alternative, the power relationship between length class and the time to 100% moulting was used to predict the expected maximum time for moulting in larger length classes, assuming there was no terminal moult. A logistic function was then searched for in each length class that would have a small proportion of animals moulting in the first year. The resulting logistic functions predicted that 50% males of 200 mm carapace length would have moulted after 6.0 years and 50% females of the same length after 5.5 years (Table 6).

Natural mortality was represented in two ways. Firstly, a low level of instantaneous natural mortality rate was assumed to be constant across all size-classes each year (Table 6). This natural mortality was implemented by two applications of half the natural survivorship ($e^{-M/2}$) before and after fishing mortality occurred. However, natural mortality is unlikely to be constant during the life of a crab. Individuals are particularly vulnerable to predators when their shell is soft during the moulting period (Ryer et al. 1997), while during the intermoult period natural mortality is likely to be much lower. In addition, mortality in giant crab could be associated with the actual moulting process. Because intermoult periods are very long relative to most crustaceans and they increase with crab size, there is also a size-dependent increase in risk that fouling organisms establish themselves on the carapace and prevent the suture lines from opening during the moult. Therefore, moulting mortality (MM_l) was implemented at every moult (representing the risk of predation) and increased with crab length (representing the risk from fouling) as:

$$MM_l = \alpha + \beta L_l \quad (3)$$

where α and β are the parameter of the linear relationship, and L_l is the length class. The linear instantaneous moulting mortality rate is converted to a non-linear descending curve for moulting-associated survivorship, and when combined with the average probability of moulting each year, survivorship increases with length class (Figure 26a). The optimal values for moulting mortality were determined by iteratively matching predicted and observed length distributions in the equilibrium state in the absence of fishing mortality using the earliest observed length frequency distribution in 1993/94 (Figure 27b). Males larger than 130 mm and females larger than 140 mm were assumed to be fully selected with peak or near-peak numbers observed at those lengths

in the length frequency samples. Setting the instantaneous natural mortality to a constant 0.05, the least squared comparison was relative insensitive to the intercept of the linear regression, and an average value was chosen for the model (Table 6).

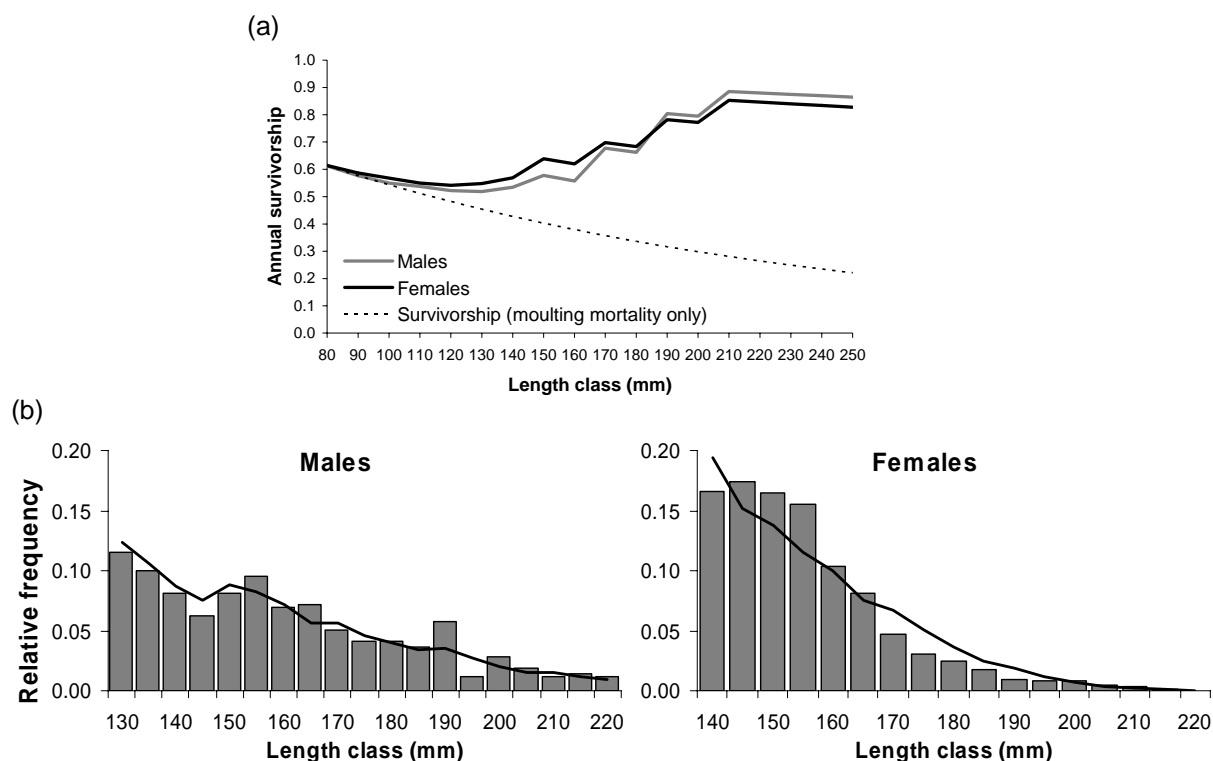


Figure 28: (a) The survivorship associated only with moulting mortality (dashed line), and actual annual survivorship when moulting mortality is combined with average annual probability of moulting for males (grey line) and females (black line); and (b) observed length frequencies for 1993/94 (grey bars) and fitted length frequencies (black line) for male and female giant crab in equilibrium state assuming moulting mortality $0.01 + 0.006 \times \text{length class}$.

Fecundity, or egg production, can substantially decline for successive broods produced between moults (Gardner 1997). This decline has been linked to carapace condition, possibly as a response to damaged pleopods (deteriorating carapace condition), reduced ovarian development due to depletion of spermatophore reserves from previous extrusions (mating appears to occur immediately after ecdysis; Levings et al. 1996), or senescence of older females. For the model, an average relationship for fecundity at length was chosen that did not account for carapace condition.

In addition, not all female crabs are reproductively active each year. Advanced gonad development indicating active spawning in the following spawning season was observed only in 85- 89% of mature females, respectively, outside the main spawning months between June and August (Gardner 1998, Gardner et al. 2002). Because reproductively-active females tend to avoid traps (Howard 1982), these proportions of reproductively-active females each year are much higher than the 40-60% active females captured by commercial fishers during the spawning period (Levings et al. 1996).

5.1.4 Quantifying uncertainty

Model parameters were estimated externally from commercial and biological data, or alternatively based on 'guestimates'. Their values represented the best understanding of population parameters based on available information. To estimate the initial uncertainty inherent in the assessment, a bootstrap procedure of 500 replications on the catch rate data was conducted. For each scenario, confidence intervals for the parameter estimates were assessed by a bootstrap procedure. New sets of catch rate data were generated by randomly selecting residuals from the original model (with replacement) and adding them to the estimated catch rates. The model was then re-fitted.

5.1.5 Risk Assessment

For the risk assessment, the stock assessment model was projected forward by 10 years. A range of fixed TAC levels were investigated with the assumption that the future TAC will be taken exactly. Fixed TAC levels were a realistic management option since the fishing industry prefers stability in management arrangements. All other management options, including the minimum and maximum legal length limits were kept constant at the present levels of 150 mm and 210 mm, respectively, for both males and females.

The two regions were again treated independently assuming that the fleet dynamics remained the same for the whole period of the projection. Since the TAC applies to the whole of Tasmania, this separation of regions in the projections was somewhat artificial. But given the different recruitment patterns in the West and East, this approach provided greater contrast for the regional productivity of the giant crab stocks. Expected recruitment variation in the future was based on the fitted average recruitment and recruitment variation from the last 12 years in each region.

Table 6: Values used for biological parameters in the giant crab model.

Parameter		Females		Males		Source	
G_l^k	Parameters for the growth transition matrices	Intercept:	43.97	Intercept:	33.84	Gardner et al. 2007	
		Gradient:	-0.17	Gradient:	-0.038		
		σ (intercept):	0.17	σ (intercept):	-0.88		
		σ (gradient):	0.021	σ (gradient):	0.03		
$P_{l,j}^k$	Parameters for the probability of moulting matrices	Length (mm)	<i>a</i>	<i>b</i>	<i>a</i>	<i>b</i>	Gardner et al. 2007
		85	-7.16	10.26	-9.26	19.23	
		95	-6.72	7.72	-8.79	13.86	
		105	-6.28	5.80	-8.32	9.99	
		115	-5.84	4.37	-7.85	7.20	
		125	-5.40	3.28	-7.38	5.19	
		135	-4.96	2.47	-6.91	3.74	
		145	-4.52	1.86	-6.44	2.69	
		155	-3.86	1.21	-5.74	1.87	
		165	-3.86	1.21	-5.74	1.87	
		175	-3.80	0.90	-4.80	1.09	
		185	-3.80	0.90	-4.80	1.09	
		195	-3.50	0.63	-3.86	0.64	
		205	-3.50	0.63	-3.86	0.64	
		215	-3.20	0.46	-3.80	0.47	
		225	-3.20	0.46	-3.80	0.47	
		235	-3.20	0.46	-3.80	0.47	
		245	-3.20	0.46	-3.80	0.47	
M	Instantaneous natural mortality	0.05		0.05		Gardner et al. 2007	
MM_l	Instantaneous moulting mortality	α : 0.01 β : 0.006		a : 0.01 b : 0.006			
W_l^k	Weight at length	α : 0.000001166 p : 2.878		a : 0.0000001099 b : 3.384		Levings et al. 2001	
Q_l	Maturity at length	c : -47.37 d : 0.4352				Gardner et al. 2002	
O_l	Fecundity at length	e : 181.7 f : 1.755				Gardner 1997	
m	Proportion of mature females that produce eggs each year	m : 0.85				Gardner 1998 Gardner et al. 2002	

5.2 Model equations

5.2.1 Basic dynamics

The general equation governing the length-based dynamics of giant crab for the number of animals $N_{t+1}^{k,l}$ of sex k in length class l at the start of time step $t+1$ is:

$$N_l^{k,t+1} = (N_l^{k,t} - \Gamma_l^{k,t})e^{-(S_l^k F^t + M)} + \sum_{l'} \Gamma_{l'}^{k,t} e^{-(S_l^k F^t + M + MM_{l'})} + R_l^{k,t} \quad (4)$$

where $N_l^{k,t}$ is the number of animals of sex k in length class l and year t , $\Gamma_l^{k,t}$ is the number of animals of sex k in length class l in year t that have moulted into larger length classes, $\Gamma_{l'}^{k,t}$ is the number of animals of sex k that have moulted from length class l' to length class l in year t , S_l^k is the selectivity for sex k and length class l , F^t is the fully-selected fishing mortality in year t , M is the instantaneous fishing mortality, $MM_{l'}$ is the moulting mortality for length class l' , and $R_l^{k,t}$ is the recruitment of animals of sex k into size class l in year t .

With intermoult periods that often last many years, the probability of moulting in a particular year had to be implemented explicitly. Thus, the probability of moulting for each sex and length class $\Gamma_t^{k,l}$ depended upon the time since the animals last moulted:

$$\Gamma_l^{k,t} = \sum_j N_{l,j}^{k,t} P_{l,j}^k \quad (5)$$

where $N_{l,j}^{k,t}$ is as above the numbers of animals of sex k in year t that have been in length class l , but in addition for distributed into j years since the last moult, and $P_{l,j}^k$ is the probability of moulting for an animal of sex k in length class l after j years since the last moult. The probability of moulting was modelled by a logistic function for each length class L_l :

$$P_{l,j}^k = \frac{1}{1 + e^{-(a+bL_l)}} \quad (6)$$

Where a and b are the parameters of the logistic function. Growth was implemented by multiplying $\Gamma_l^{k,t}$ with the sex and length-specific growth transition matrix G_l^k .

5.2.2 Recruitment

Instead of a pre-defined stock-recruitment relationship such as the Beverton-Holt relationship, recruitment for each year of the fishery was estimated as geometric mean recruitment level \bar{R} multiplied by a log-normal recruitment residuals ε_t . With a moult increment of around 30 mm at the smallest length class of 80 mm, recruitment is assumed to occur into the first six 5-mm length classes with a sex ratio of 1:1, so that:

$$R_l^{k,t} = \bar{R}e^{\varepsilon_t} / 12.0 \quad \text{if } 1 \leq l \leq 6 \quad (7)$$

where $R_l^{k,t}$ is the recruitment into length class l for sex k in year t . Recruitment variability was restricted through a penalty function that is added to the total log-likelihood:

$$Penalty = \frac{\sum_{t=1}^{years} (\varepsilon^t)^2}{2\sigma_R^2} \quad (8)$$

where σ_R is the coefficient of variation for the recruitment residuals.

5.2.3 Egg production

While the model does not explicitly predict a relationship between egg production and the numbers of animals recruiting to the fishery, it estimates egg production as a measure for the reproductive potential of the giant crab population:

$$SB^t = \sum_l m Q_l O_l N_l^{fem,t} \quad (9)$$

where m is the proportion of females that produce eggs each year (Table 1), Q_l is the maturity at length that is described by a logistic function relating the proportion of females mature to their size-class L_l :

$$Q_l = \frac{1}{1 + e^{-(c+dL_l)}} \quad (10)$$

with c and d parameters of the relationship (Table 1), and fecundity O_l is a power relationship that is assumed between fecundity and the length class L_l of female crabs (Gardner 1997):

$$O_l = eL_l^f \quad (11)$$

where c and d are the parameters of the power relationship (Table 1). Extrusion of eggs occurs in May and extends through to November. The fishery is closed for females during the main spawning season (currently June 1 to November 14) and berried females must be also returned at all other times.

5.2.4 Selectivity

Selectivity is described by a logistic function with specific parameters for sex k . A logistic function is fitted with two parameters $L50^k$ and $L95^k$ representing the carapace lengths at which 50% and 95% are selected:

$$S_l^k = \frac{\pi}{1 + e^{-\text{Ln}(19)\left(\frac{l-L50^k}{L95^k-L50^k}\right)}} \quad \text{MinSL} < l < \text{MaxSL} \quad (12)$$

$$S_l^k = 0 \quad l < \text{MinSL}, l > \text{MaxSL}$$

where $L95^k = L50^k \times \text{Scale}95^k$. The scaling parameter $\text{Scale}95^k$ is constrained to values between 1.01 - 1.5 to ensure that the $L95^k$ is greater than the $L50^k$. All non-legalized animals (below the minimum size limits MinSL and above the maximum size limits MaxSL) are assumed to be returned without discard mortality and their selectivity therefore equals zero. The selectivity for females was modified by a constant π to account for females that were returned during the closed season and due to egg-bearing assuming constant sex ratios throughout the year. For males π was set to 1.0.

5.2.5 Catches

The total commercial catch \hat{C}^t in year t was assumed to be taken in the middle of the season, after half the natural mortality and growth of those animals that were to moult had occurred. The catch was calculated from the harvest rate H^t and exploitable biomass B_E^t :

$$\hat{C}^t = H^t B_E^t = H^t \sum_k \sum_{l=1}^{L_{\max}} N_l^{k,t} W_l^k S_l^k \quad (13)$$

where W_l^k is the weight of an animal of sex k and length class l :

$$W_l^k = o^k L_l^{d^k} \quad (14)$$

and c^k and d^k are the sex-specific weight-at-length relationship parameters (Table 1).

5.2.6 Likelihood functions for model fitting

The model was fitted by combining the negative of the logarithm of the likelihood functions from catch rates ($-LL_{CE}$) and length frequency data ($-LL_{LF}$) that were weighed with the inverse proportion to their respective variation (Wt_{CE} and Wt_{LF}) i.e. less weight to the more variable, and the penalty term from the recruitment residuals:

$$-LL = -LL_{CE} * Wt_{CE} + -LL_{LF} * Wt_{LF} + \text{Penalty} \quad (15)$$

The contribution of the catch rate data to the negative of the logarithm of the likelihood function was based on the assumption that catch rates were log-normally distributed:

$$-LL_{CE} = -\frac{n}{2} (\text{Ln}(2\pi) + 2\text{Ln}(\hat{\sigma}) + 1) - \sum_t \text{Ln}(I_t) \quad (16)$$

where n is the total number of years for which catch rates were available, I_t is the observed catch rate in year t , and $\hat{\sigma}$ is:

$$\hat{\sigma} = \sqrt{\frac{\sum_t (\text{Ln}(I_t) - \text{Ln}(qB_E^t))^2}{n}} \quad (17)$$

where q is the catchability coefficient, and B_E^t is the exploitable biomass in year t after half of natural mortality and growth have occurred. The summation term of $\text{Ln}(I_t)$ is a constant and can be omitted in the negative log-likelihood.

A closed form of analytic estimation was used to estimate catchability by comparing the observed catch rates with the exploitable biomass that gave rise to the catch rates (Haddon 2001). The catchability coefficient \hat{q} was assumed to be constant and each annual \hat{q}_t to be an estimate of the overall \hat{q} . The maximum likelihood estimate of \hat{q} was determined by:

$$\hat{q} = \exp\left(\frac{\sum_t \text{Ln}(I_t / B_E^t)}{n}\right) \quad (18)$$

The length frequency data was fitted using a negative of the multinomial log-likelihood (Quinn and Deriso 1999, Haddon 2001):

$$-LL_{LF} = -\sum_t \sqrt{N^{k,t}} \sum_l (p_l^{k,t} \text{Ln}(\hat{p}_l^{k,t}) - p_l^{k,t} \text{Ln}(p_l^{k,t})) \quad (19)$$

where $N^{k,t}$ is the total sample size for sex k and year t , $p_l^{k,t}$ is the observed proportion in each length class l , and $\hat{p}_l^{k,t}$ is the predicted proportion in each length class l . The second term that is constant and depends only on the observed proportions causes the log-likelihood for the observation to approach zero from below as the model fit improves. As ‘effective’ sample size the square root rather than the real the sample size was used, because samples which are usually taken in clusters can have a reduced within-cluster variance relative to samples where fish are taken individually.

5.2.7 Equilibrium state

For many years before the giant crab fishery developed, rock lobster fishers caught predominantly large males as minor bycatch. Few crabs were landed and the stock was essentially unfished until the target fishery developed in 1993. It was therefore assumed that the stock was in equilibrium with mean recruitment levels at the time the fishery began. Equilibrium conditions in the absence of fishing could not be determined analytically due to the length-specific years-since-moult matrix, but were attained iteratively after 200 passages.

6. Appendix 2: Standardisation of catch rates for Tasmanian giant crab

6.1 Introduction

As in most fisheries, catch rates obtained from catch returns by commercial fishers can be assumed to constitute an index of relative stock abundance through time. However, many other factors can influence catch rates besides the relative stock abundance. In the case of giant crabs, targeting crabs, location, season and depth of fishing, and skipper are all intuitively likely to be important influencing factors. Standardising catch rates using generalized linear models (GLM) generally reduces the impact of these obscuring effects (Kimura 1981, 1988). However, while standardisation is preferred to the geometric mean of raw catch rates, there remains no guarantee that a relation exists between the standardised catch rates and stock size, as other factors may have effects on changes in biomass that are unaccounted for by the statistical model. At least, the standardised catch rates should provide an improvement over the raw catch rates.

The giant crab fishery operates on both the East and West coast of Tasmania. Catches are mainly taken by two groups of around 10 operators, and there is a very small amount of bycatch by rock lobster fishers on the West coast. Similar to previous years, over 90% of the total catch on the West coast was taken by the top 10 fishers, while the number of fishers on the East coast has continually declined since 2001/02 and there are only a small number of fishers left.

All of the targeted fishing for giant crab in Tasmanian waters takes place on the edge of the continental shelf. On the West coast there are catch modes in the 180m and 280m depth categories, while the only major modal depth on the East coast was the 280m depth category (Figure 29).

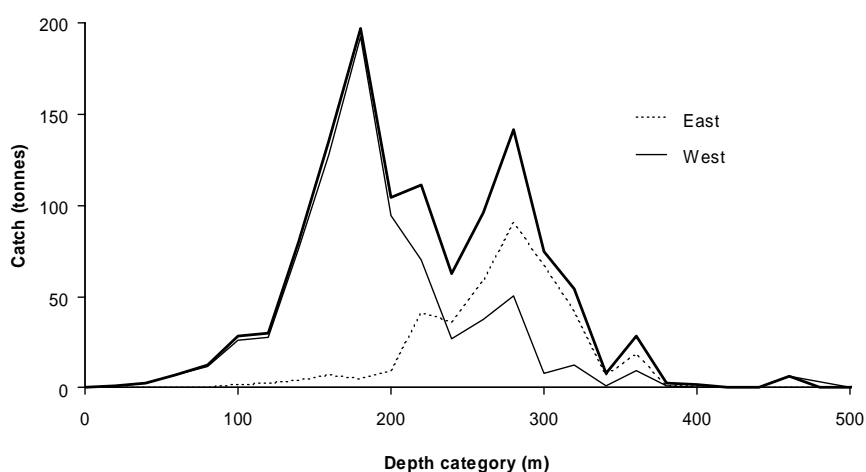


Figure 29. Distribution of total catches by 20m depth category for the West and East coast across the history of the fishery.

6.2 Methods

Catch rates or catch per unit effort (CPUE) were estimated as kilograms per pot days for each record in the database as:

$$\text{CPUE} = \frac{\text{Weight of catch (kg)}}{\text{Number of traps} \times \text{Soak time}} \quad (20)$$

where pot days are defined as the number of traps multiplied with number of days the traps are in the water before being hauled (soak time). Soak time capped at 7 days, based on the belief that soak times greater than 7 days do not lead to increases in catch, had only minimal influence on the results and was not used.

The period under analysis included two different management arrangements with fisheries data being recorded in different logbooks. Prior to 1995, catch effort data was recorded in the general fish logbook which did not contain records of effort, and hence data prior to the 1995/96 quota year cannot be included in this analysis. The new general fishing logbook introduced in January 1995 included the date of fishing and data on catch weight, number of traps used, soak time, location by 30° block, and average depth of fishing. With the new management plan in November 1999 setting the total allowable commercial catch (TAC) to 103.5 tonnes and creating a new type of giant crab fishing licence, a new Integrated Catch Effort (ICE) logbook was introduced. This new logbook extended the old logbook by data on the latitude and longitude of fishing and whether a fisher was targeting giant crab. Data from the general fishing logbook and the ICE logbook databases were checked and extracted into a single Access database for use in the following analyses.

Since information on targeting giant crab tends to be unreliable and has been included in the logbook returns only in the most recent years, a number of criteria were developed for data selection in order to restrict the analysis to those records most likely to have been targeted at giant crabs. Only skippers that had reported a median catch of at least 1000 kg over a minimum of 2 years were considered for the analysis. Any remaining skippers were removed as they were believed to contribute primarily statistical noise to the assessment rather than useful information. By applying these criteria, a large proportion of the total catch by weight by number of records are accounted for in the analysis (Table 7).

Table 7. Overall catch and number of records (Total), and the selected catch and record numbers used in the standardisation for skippers that had reported a median catch of at least 1000 kg over a minimum of 2 years (Selection) for State-wide Tasmania and each region. East and West are defined as either side of longitude 147°E.

		Tasmania	West	East
Catch (t)	Total	1135.9	760.4	375.5
	Selection	1005.3	655.8	340.8
	Proportion	88.5%	86.2%	90.8%
Number of records	Total	14255	9693	4562
	Selection	11242	7137	3966
	Proportion	78.9%	73.6%	86.9%

Raw catch rate data were not normally distributed and thus, the data was first natural log-transformed to improved normality before the standardisation (Figure 30 and

Figure 31 for State-wide data). Generalised linear models using a normal distribution family with an identity link were used for the statistical analyses of State-wide and regional catch rates. The models were fitted to different combinations of various factors for which information were available, *viz.* skipper, 20m-depth category, month fished, 30° fishing block, and number of traps. The use of fishing block captured all information that was implicit in the East/West distinction for the State-wide analysis.

All models were fitted using a forward approach by stepwise addition of each factor starting with the annual time-step. The initial factor that fitted the data the best would be added to the model first, then the next best factor would be added and so on until additional factors or interactions no longer improved the model fits. Only a limited combination of interaction terms between various factors, for which sensible interpretations could be ascribed, was considered.

The optimal model was chosen based on minimization of Akaike's Information Criterion (AIC; Burnham and Anderson 2002). Generally, the more independent parameters that are added the greater the amount of variability is explained. The AIC can be viewed as an attempt to balance the maximum amount of variability in the data accounted for with the least number of parameters used to describe the data (although this heuristic interpretation does not fully do justice to the underlying theory of the AIC).

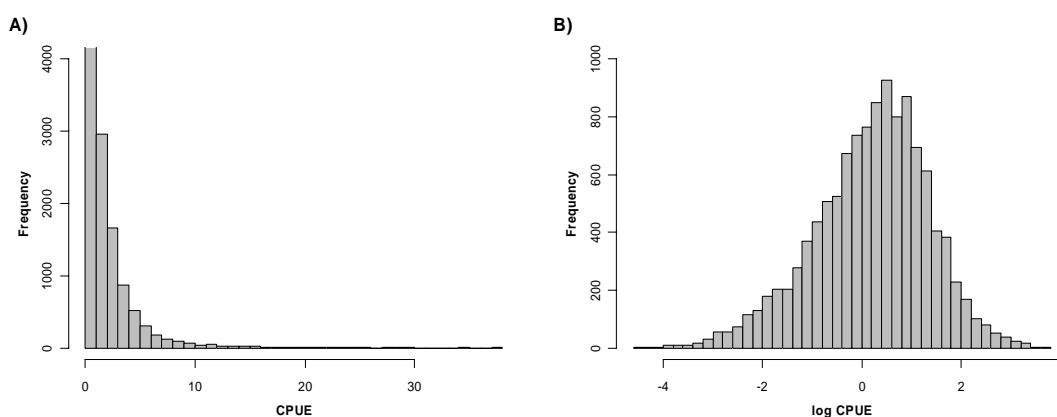


Figure 30. Distribution of (A) State-wide raw catch rate data and (B) natural log-transformed catch rate data.

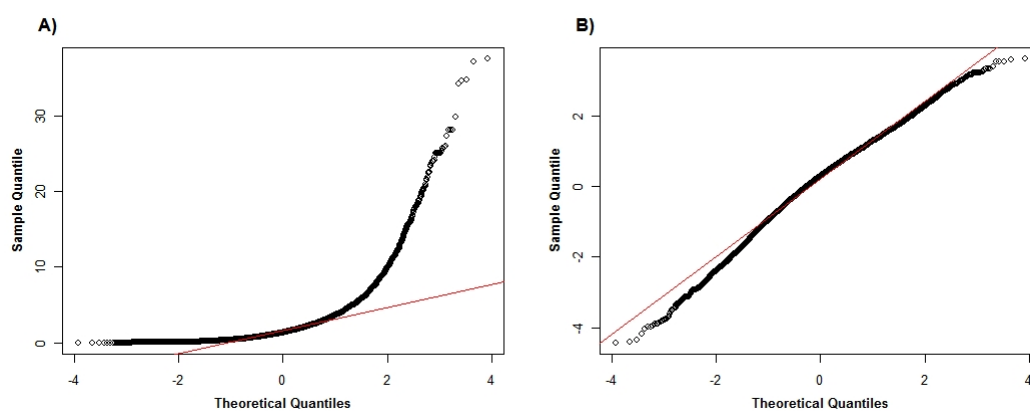


Figure 31. Quantile-Quantile plot of (A) State-wide raw catch rate data and (B) natural log-transformed catch rate data.

For large data sets and models with normally distributed errors and constant variance, the AIC can be computed from least-squares regression as (Burnham and Anderson 2002, p. 63):

$$AIC = N * \text{Ln} \left(\frac{SSE}{N} \right) + 2K \quad (21)$$

where SSE is the sum of the squared residuals, N is the total number of observations, and K is the number of parameters. The models with the lowest AIC or within 2 of the lowest AIC provide the optimum fit of all tested models.

In addition, the adjusted R_A^2 gives a better estimate of total variability described by the statistical model than the simple R^2 (Neter *et al.* 1996) with $n-K$ degrees of freedom:

$$R^2 = 1 - \frac{SSE}{SSTO}, \quad R_A^2 = 1 - \frac{\frac{SSE}{n-K}}{\frac{SSTO}{n-1}} = 1 - \left(\frac{n-1}{n-K} \right) \left(\frac{SSE}{SSTO} \right) \quad (22)$$

where SSTO is the total sum of squares calculated as the SSE plus the variation due to the statistical model with $n-1$ degrees of freedom. The adjusted R_A^2 balances a potential increase in SSE with the loss of a degree of freedom in the denominator $n-K$ when another variable is added into the model.

When the optimal model had been identified, residual plots and QQ-plots were examined to confirm that the data still conformed to the statistical assumptions under the model.

6.3 Results

Given the factors available, a number of different statistical models were considered for each region (Table 8 to Table 13). The geometric mean by itself (Model 1) accounted for only little of the variability (Tasmania: 10%, West: 12%, East: 16%). The order of factors and their influence varied slightly between regions. The skipper conducting the fishing had greatest influences State-wide. The depth at which the fishing occurred was again more important than last year, and also proved to be the most important factor in the West. In the East, the block and month of fishing were most important.

Interaction terms substantially improved the fits. The model containing a three-way interaction term provided the optimum fit in all regions indicating varied substantially with season depending on the fishing locations of individual skippers. The optimum model described 58% of the variation State-wide, 62% in the West and 48% in the East. The diagnostics indicated that the fits to the data were reasonable.

Table 8. Statistical models compared in the standardisation of giant crab catch rates for Tasmania at a time step of quota years. LnCE is the natural log of catch rates (catch per pot days), C is a constant, Qyear is quota year, Depth is the 20m-depth category, Month is the reporting month, Block is the 30° statistical reporting area, and Traps is the number of pots used. Model 1 is equivalent to the geometric mean of catch rates and acts as a Base Case against which the other models are compared.

Tasmania	
Model 1	$\text{LnCE} = C + \text{Qyear}$
Model 2	$\text{LnCE} = C + \text{Qyear} + \text{Skipper}$
Model 3	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth}$
Model 4	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month}$
Model 5	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block}$
Model 6	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps}$
Model 7	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Depth}$
Model 8	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Month}$
Model 9	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Block}$
Model 10	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Depth} * \text{Month}$
Model 11	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Depth} * \text{Block}$
Model 12	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Month} * \text{Block}$
Model 13	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Month} * \text{Block}$
Model 14	$\text{LnCE} = C + \text{Qyear} + \text{Skipper} + \text{Depth} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Month} + \text{Month} * \text{Block}$

Table 9. Statistical results from the standardisation of giant crab catch rates for East coast. Models are defined in Table 8. *N* is the number of data records, # Params is the number of parameters (*K*), Model SS is the variation described by the model, Resid SS is the sum of squared residual errors, AIC is Akaike's Information Criterion, R^2 is the raw R^2 value, Adj R^2 is the adjusted R^2 , and Δ Adj R^2 are the improvements of each model's adjusted R^2 compared to the previous model (the values for Models 7 to 14 are relative to Model 6). Model 13 provided the optimum fit (in bold). The vertical line separates simple models (Models 1-6) from those that include interaction terms (Models 7-14).

Tasmania														
Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14
N	11242	11242	11242	11242	11242	11242	11242	11242	11242	11242	11242	11242	11242	11242
# Params	13	47	71	82	140	141	450	379	378	316	454	374	962	596
Model SS	1516	3845	5136	5941	6363	6434	7337	7459	7242	6929	7042	7541	9067	8180
Resid SS	13146	10816	9525	8721	8299	8228	7324	7202	7420	7733	7619	7120	5595	6482
AIC	1785	-340	-1721	-2691	-3132	-3227	-3917	-4248	-3915	-3575	-3465	-4386	-5921	-4999
R2	0.10	0.26	0.35	0.41	0.43	0.44	0.50	0.51	0.49	0.47	0.48	0.51	0.62	0.56
AdjR2	0.10	0.26	0.35	0.40	0.43	0.43	0.48	0.49	0.48	0.46	0.46	0.50	0.58	0.53
Δ AdjR2	0.10	0.16	0.09	0.05	0.03	0.00	0.05	0.06	0.04	0.03	0.03	0.07	0.15	0.10

Table 10. Statistical models compared in the standardisation of giant crab catch rates for West coast at a time step of quota years. LnCE is the natural log of rates (catch per pot days), C is a constant, Qyear is quota year, Depth is the 20m-depth category, Month is the reporting month, Block is the 30° statistical reporting area, and Traps is the number of pots used. Model 1 is equivalent to the geometric mean of catch rates and acts as a Base Case against which the other models are compared.

West	
Model 1	$\text{LnCE} = C + \text{Qyear}$
Model 2	$\text{LnCE} = C + \text{Qyear} + \text{Depth}$
Model 3	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper}$
Model 4	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month}$
Model 5	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block}$
Model 6	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps}$
Model 7	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Depth}$
Model 8	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Month}$
Model 9	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Block}$
Model 10	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Depth} * \text{Month}$
Model 11	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Depth} * \text{Block}$
Model 12	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Month} * \text{Block}$
Model 13	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Month} * \text{Block}$
Model 14	$\text{LnCE} = C + \text{Qyear} + \text{Depth} + \text{Skipper} + \text{Month} + \text{Block} + \text{Traps} + \text{Skipper} * \text{Month} + \text{Month} * \text{Block}$

Table 11. Statistical results from the standardisation of giant crab catch rates for East coast. Models are defined in Table 10. *N* is the number of data records, # Params is the number of parameters (*K*), Model SS is the variation described by the model, Resid SS is the sum of squared residual errors, AIC is Akaike's Information Criterion, R^2 is the raw R^2 value, Adj R^2 is the adjusted R^2 , and Δ Adj R^2 are the improvements of each model's adjusted R^2 compared to the previous model (the values for Models 7 to 14 are relative to Model 6). Model 13 provided the optimum fit (in bold). The vertical line separates simple models (Models 1-6) from those that include interaction terms (Models 7-14).

West														
Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14
<i>N</i>	7137	7137	7137	7137	7137	7137	7137	7137	7137	7137	7137	7137	7137	7137
# Params	13	39	63	74	110	111	298	277	255	263	288	261	652	421
Model SS	1098	3274	4498	5019	5246	5294	5929	5881	5854	5743	5652	5835	6916	6295
Resid SS	9410	7234	6011	5489	5263	5214	4580	4627	4655	4765	4856	4674	3593	4214
AIC	1999	174	-1100	-1726	-1954	-2018	-2570	-2539	-2541	-2357	-2172	-2499	-3595	-2919
R^2	0.10	0.31	0.43	0.48	0.50	0.50	0.56	0.56	0.56	0.55	0.54	0.56	0.66	0.60
Adj R^2	0.10	0.31	0.42	0.47	0.49	0.50	0.55	0.54	0.54	0.53	0.52	0.54	0.62	0.57
Δ Adj R^2	0.10	0.20	0.12	0.05	0.02	0.00	0.05	0.05	0.04	0.03	0.02	0.04	0.13	0.08

Table 12. Statistical models compared in the standardisation of giant crab catch rates for East coast at a time step of quota years. LnCE is the natural log of catch rates (catch per pot days), C is a constant, Qyear is quota year, Depth is the 20m-depth category, Month is the reporting month, Block is the 30° statistical reporting area, and Traps is the number of pots used. Model 1 is equivalent to the geometric mean of catch rates and acts as a Base Case against which the other models are compared.

East	
Model 1	$\text{LnCE} = C + \text{Qyear}$
Model 2	$\text{LnCE} = C + \text{Qyear} + \text{Block}$
Model 3	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month}$
Model 4	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper}$
Model 5	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper} + \text{Depth}$
Model 6	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper} + \text{Depth} + \text{Traps}$
Model 7	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper} + \text{Depth} + \text{Traps} + \text{Skipper} * \text{Month}$
Model 8	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper} + \text{Depth} + \text{Traps} + \text{Skipper} * \text{Block}$
Model 9	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper} + \text{Depth} + \text{Traps} + \text{Month} * \text{Block}$
Model 10	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper} + \text{Depth} + \text{Traps} + \text{Skipper} * \text{Month} * \text{Block}$
Model 11	$\text{LnCE} = C + \text{Qyear} + \text{Block} + \text{Month} + \text{Skipper} + \text{Depth} + \text{Traps} + \text{Skipper} * \text{Month} + \text{Month} * \text{Block}$

Table 13. Statistical results from the standardisation of giant crab catch rates for East coast. Models are defined in Table 12. *N* is the number of data records, # Params is the number of parameters (*K*), Model SS is the variation described by the model, Resid SS is the sum of squared residual errors, AIC is Akaike's Information Criterion, R^2 is the raw R^2 value, $\text{Adj}R^2$ is the adjusted R^2 , and $\Delta \text{Adj}R^2$ are the improvements of each model's adjusted R^2 compared to the previous model (the values for Models 7 to 11 are relative to Model 6). Model 10 provided the optimum fit (in bold). The vertical line separates simple models (Models 1-6) from those that include interaction terms (Models 7-11).

East											
Model	1	2	3	4	5	6	7	8	9	10	11
<i>N</i>	3966	3966	3966	3966	3966	3966	3966	3966	3966	3966	3966
# Params	13	33	44	58	79	80	155	138	140	301	208
Model SS	678	804	1441	1501	1531	1542	1787	1633	1760	2037	1912
Resid SS	3222	3095	2458	2399	2368	2357	2113	2267	2139	1863	1988
AIC	-798	-917	-1809	-1878	-1887	-1903	-2188	-1942	-2168	-2396	-2324
R^2	0.17	0.21	0.37	0.38	0.39	0.40	0.46	0.42	0.45	0.52	0.49
$\text{Adj}R^2$	0.17	0.20	0.36	0.38	0.38	0.38	0.44	0.40	0.43	0.48	0.46
$\Delta \text{Adj}R^2$	0.17	0.03	0.16	0.01	0.00	0.00	0.05	0.01	0.05	0.10	0.08

With the exception of the year 1998/99, the State-wide standardised catch rates declined steadily from 1995/96 to 2002/03 and have since stabilised at around 50% of the levels in 1995/96 (Figure 32). Estimated catch rates tended to be higher compared to the simple geometric mean and those estimated by the best model of last year's assessment.

Regional standardised catch rates differed quite substantially from the geometric mean, particularly during the early years (Figure 33). In addition, data selection to those vessels in the fishery for a minimum of two years and with a median catch of at least 1000 kg per year had some impact on the estimates in the West. However, standardised catch rates were similar State-wide and in the East independent of whether selected data or all data were used.

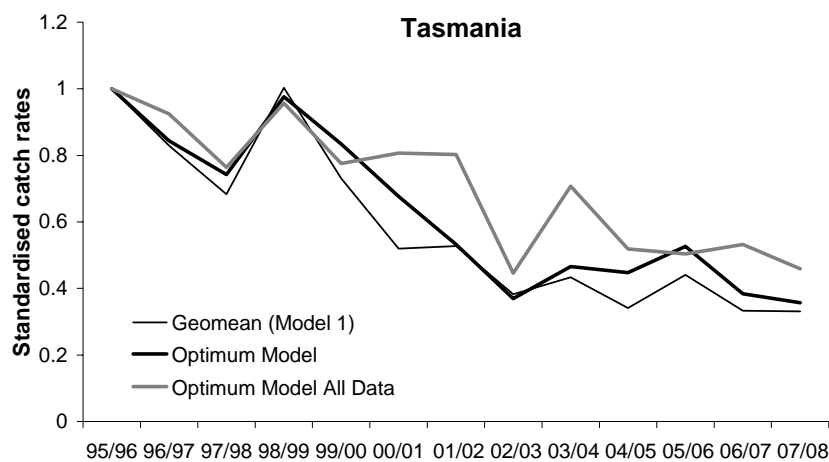


Figure 32. State-wide standardised catch rates derived from the geometric mean (Model 1, thin black line), and the optimum model when data was restricted to skippers that had reported a median catch of at least 1000 kg over a minimum of 2 years (heavy black line), and the optimum model based on all data (heavy grey line), relative to catch rates in 1995/96.

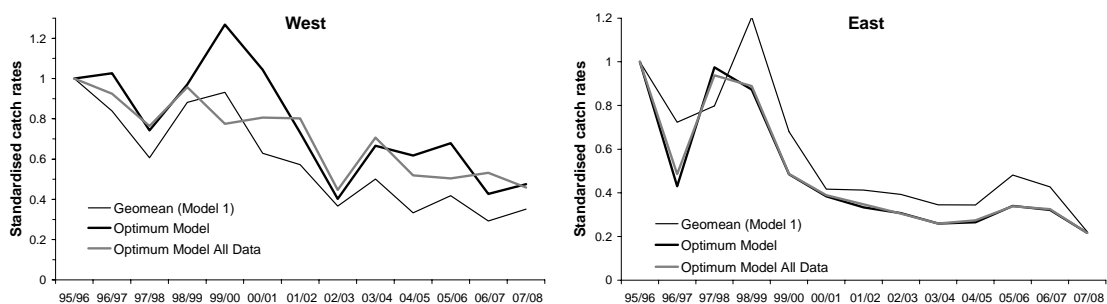


Figure 33. Standardised catch rates derived in the West and East from the geometric mean (Model 1, thin black line), and the optimum model when data was restricted to skippers that had reported a median catch of at least 1000 kg over a minimum of 2 years (heavy black line), and the optimum model based on all data (heavy grey line), relative to catch rates in 1995/96.

6.4 Discussion

The State-wide Tasmanian catch rate standardisation accounted for the regional differences to some degree by including statistical fishing blocks. When analysed separately, catch rates in the West and East showed substantial differences. Initially, catch rates in both areas strongly fluctuated and then decreased over time, but recently they have been more stable in both regions. Standardised catch rates were slightly higher in the West than in the East.

Although the amount of data available from the East is far less than that available for the West, the results for the East were surprisingly stable. The optimum model based on all data was similar to those based on data selection to vessels in the fishery for a minimum of two years and with median catches of at least 1000 kg per year. The differences of optimum statistical models based on all or selected data in the West suggests that the data selection removed some 'noise' in the data.

The optimum model with a three-way interaction between skipper, month and block provided the optimum model in all regional analyses, indicating that catch rates vary with season and depending on the fishing location of individual skippers.

As in past assessments, quota years were used as time steps. This approach may be inappropriate, because the effort permitted has greatly varied through the history of the fishery. Inclusion of Month as a factor in the analysis may have alleviated this problem, but it would be worth exploring assessment outcomes using shorter time periods (e.g. one or two months) as the base time step.