FISHERY ASSESSMENT REPORT

TASMANIAN GIANT CRAB FISHERY - 2006/07

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Tasmanian Aquaculture and Fisheries Institute

This assessment of the Tasmanian giant crab fishery is produced by the Tasmanian Aquaculture and Fisheries Institute (TAFI) and uses input from the Crustacean Assessment Working Group (CAWG).

CAWG met on 9 October 2007 to consider the draft assessment report and provide input into the assessment. The Working Group participants were:

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Executive summary

The assessment of the Tasmanian giant crab fishery 2006/07 updates the annual assessment for the period from 1 March 2006 to 28 February 2007, 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 2006/07 season was 57.1 tonnes, representing 92% of the 62.1 tonne TACC[1]. This is slightly lower than in the 2005/06 quota year, when 64.6 tonnes were caught.

Total State-wide fishing effort has stabilised over the last two quota years. This is a result of effort increasing on the West coast, while the East coast has seen continued reduction.

The limit reference point relating to a State-wide decline of catch rates in successive years was not exceeded, as catch rates had increased slightly in the previous quota year. However, catch rates remain at near record low levels. Regionally, the catch rate limit reference point is a reduction of 20% or more in any 2-year period. On the West coast this reference point was exceeded, with a sharp drop in the 2006/07 quota year, leading to a total decline of 23% over the 2-year period. In contrast, catch rates on the East coast remained stable at low levels after some improvement in the previous quota year.

Bycatch of crabs by lobster fishers in the 2006/07 season was not of concern for the giant crab fishery, with the reported catch of only 123 kg being well below the limit reference point of 5 tonnes.

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

In addition to the State-wide assessments, the size-based stock assessment model was used separately in the East and West coast fisheries for the first time. 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. The State-wide model estimated that the State-wide exploitable biomass declined from a maximum of about 1360 tonnes in the early 1990s to about 325 tonnes in 2006/07. This equates to about 24% of the original unfished exploitable biomass. Total biomass and egg production have remained stable at 38% and 43% respectively of their initial levels. This level of egg

[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 (Gardner 1998).

production is considered high for a crustacean fishery. Estimated harvest rates have fallen slightly in 2006/07 to 0.18.

State-wide results were similar to the combined regional results, indicating that there was sufficient information and contrast in the regional data to conduct the assessments. However, the State-wide model exhibited weaker overall depletion levels and masked regional trends in stock biomass. On the West coast, the model estimated a greater impact of fishing with harvest rates at 0.34 and a decline in exploitable biomass to 13% of the original exploitable biomass. Total biomass and egg production have remained stable at 24% and 29% respectively of their highest levels.

On the East coast, the overall smaller catches resulted in a smaller impact on the giant crab stock, although the model estimated the unfished exploitable biomass to be only about half of that on the West coast. Harvest rates on the east coast were 0.13 and exploitable biomass has declined to about 23% of the original exploitable biomass. Total biomass and egg production have remained stable at 46% and 52% respectively of their highest levels.

The risk assessment projections of the State-wide model suggested that the current TACC of 62.1 tonnes has a greater than 80% chance of resulting in rebuilding of exploitable biomass over the next 5 to 10 years, assuming no significant external impacts such as an increase in trawl interactions. However, given the currently high harvest rate and slow growth of this species, any rebuilding will occur only slowly. Assuming current catch levels, regional projections support this State-wide prediction, although the East coast model indicated that rebuilding could be minor even in the long run.

The risk of decline in exploitable biomass and thus catch rates increases with higher regional catches or higher State-wide TACC. A 25% catch increase on the West and East coasts is likely to lead to reductions in both the exploitable biomass and catch rates. If there was a return to the State-wide TACC of 103.5 tonnes (as implemented in 2000), the chance of any stock rebuilding over the next 10 years falls to less than 50% (this is equivalent to a greater than 50% chance that the stock will decline over the next 10 years). Egg production is less sensitive to change in catches (and thus harvest rate) as females mature below the size limit. Thus, even a higher TACC of 103.5 tonnes appears likely to lead to stability in reproductive output (80% probability). Management implications of alternative TACCs therefore relate mainly to the maintenance of commercially viable catch rates, with reproductive output regulated to a greater extent by the minimum legal length.

Table 1. Summary performance indicator assessment for giant crab.

Performance indicator	Reference point	Exceeded	Status in 2006/07
Total yearly catch	Yearly catch < 90% of TACC	No	92% of TACC taken
State-wide commercial catch rates	Decline in two consecutive years	No	Increased in 05/06 season, decline in 06/07 season
Regional commercial catch rates	Total decline by 20% in 2 years	Yes	East 22%, West -23%
Bycatch by lobster fishers	Catch > 5 tonnes	No	123 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

Table of Contents

1. Introduction

This assessment of the Tasmanian giant crab fishery resource covers the period between 1989/90 to 2006/07. 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 2006 to 28 February 2007. 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 (TACC).

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 that the giant crab resource was being over-exploited. 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 TACC of 103.5 tonnes in November 1999. The quota year mirrored that for rock lobsters running from 1st of March to the end of the following February (DPIWE 1999). Along with the introduction of a TACC, 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 TACC was further reduced to 62.1 tonnes for the 2004/05 quota season. The same quota remained in place for the 2006/07 quota season.

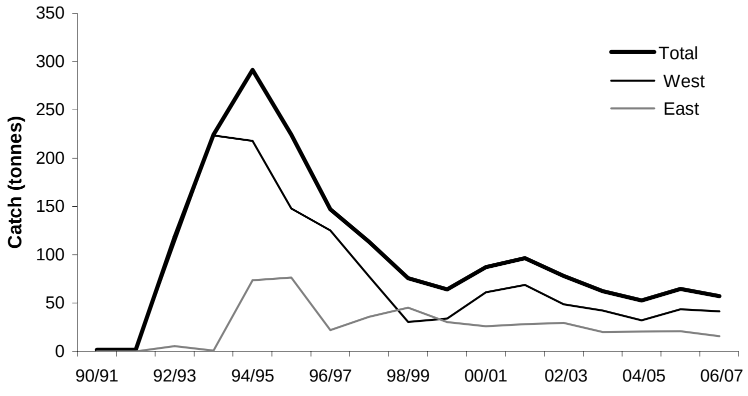


Figure 1. Historical giant crab catches in Tasmania. Catches in 1998/99 and 1999/00 were from partial fishing years due to an extended seasonal closure. East and West are divided by longitude 147ºE.

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 (TACC) and using individual transferable quotas (ITQs) to allocate proportions of the TACC;
- 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 TACC 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 57.1 tonnes, representing 92% of the 62.1 tonne total allowable commercial catch (TACC). Therefore and similarly to the previous quota year when 64.6 tonnes were caught, catches were higher than the catch limit reference point, set at 90% of the TACC (Table 2, Figure 2).

It is important to note that the quota allocation system and the logbook recordings listed in Table 2 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 (Gardner 1998).

Table 2. Catch totals in tonnes by quota year (March to February) from 1989/90 until present as reported in logbook returns. West and East are defined as either side of longitude 147ºE. TACC is the Total Allowable Commercial Catch.

Quota year	Total	West	East	TACC
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	103.5
2000/01	87.1	61.2	25.9	103.5
2001/02	96.6	68.6	28.0	103.5
2002/03	78.0	48.5	29.4	103.5
2003/04	62.3	42.3	20.0	103.5
2004/05	52.7	32.1	20.7	62.1
2005/06	64.6	43.6	21.0	62.1
2006/07	57.1	41.4	15.7	62.1

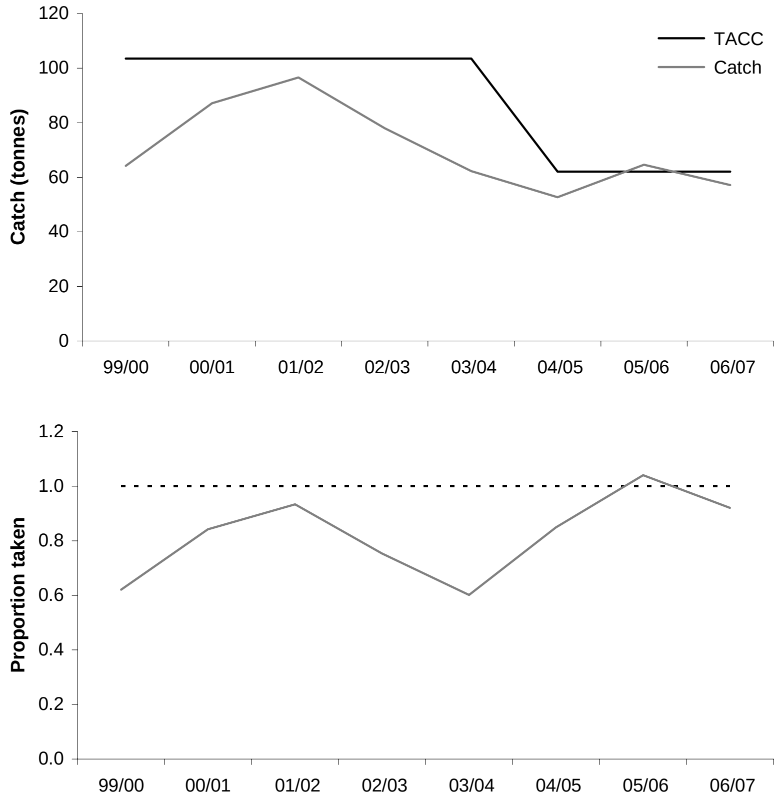


Figure 2. Total catches from logbook records and TACC since quota management was introduced (top), and the proportion of the TACC caught in each year (bottom). The dashed line marks 100%.

The catch in the current assessment period comprised 41.4 tonnes (72%) taken from the West coast and 15.7 tonnes (28%) taken from the East coast. This is within the historical range exhibited since the introduction of quota (Table 2). The ratio in catch from the two coasts appears to have stabilised over the last few years as trading of quota between crab fishing businesses has stabilised (Figure 3).

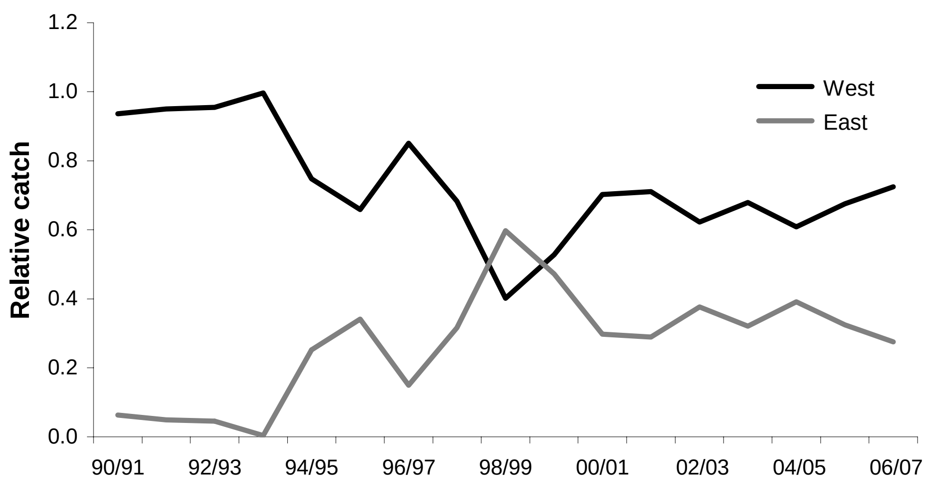


Figure 3. Relative catches coming from the East and West coast in each quota year.

3.1.2 Commercial effort

Total fishing effort has stabilised over the last two quota years. This is a result of effort increasing on the West coast, while the East coast has seen a continued reduction (Figure 4).

State-wide seasonal effort followed the pattern of previous years, although it was slightly lower in early summer (Figure 5). West coast effort was more variable in autumn and winter, but followed trends of previous years closely for the rest of the fishing season (Figure 6). On the East coast, fishing was 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.

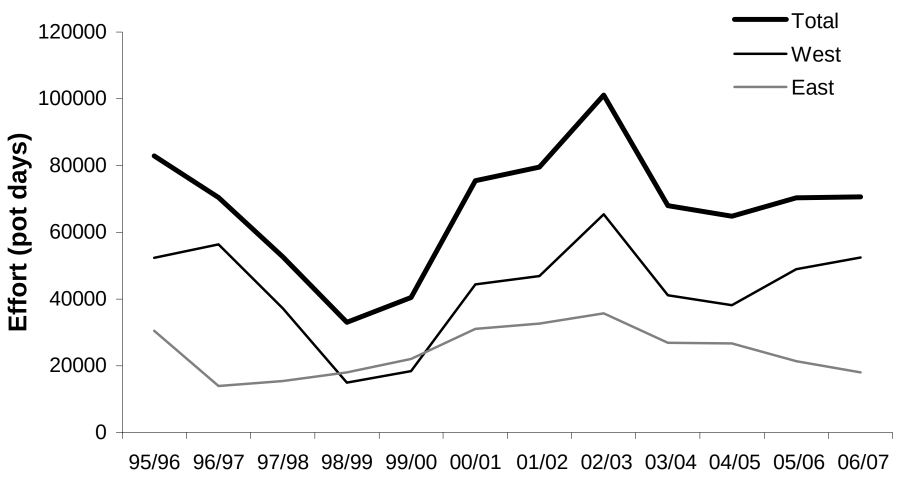


Figure 4. Total effort (pot days) and effort overall and for the West and East coast by quota year since 1995/96. 1998/99 and 1999/00 were partial fishing years.

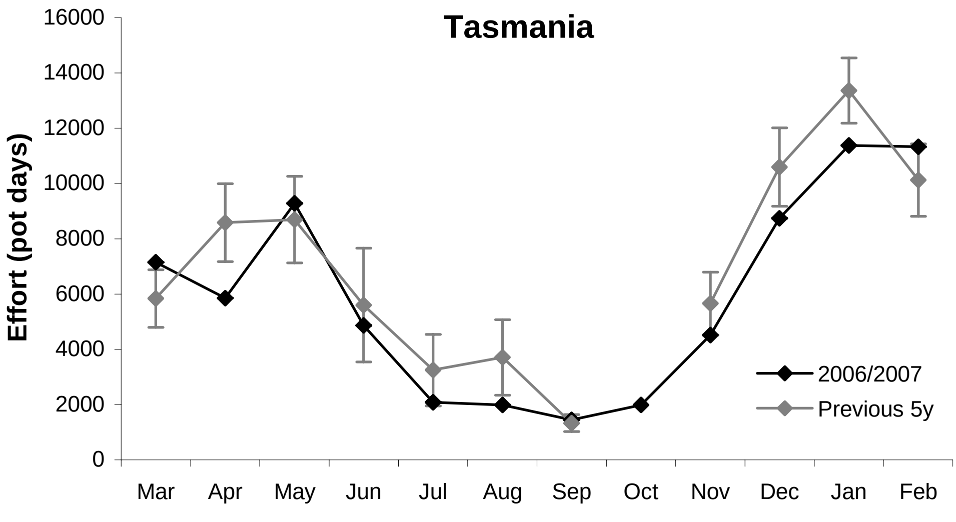


Figure 5. Seasonal trends in State-wide effort for 2006/07 quota year (black line) and annual average for the previous 5 years (grey line) including standard error bars.

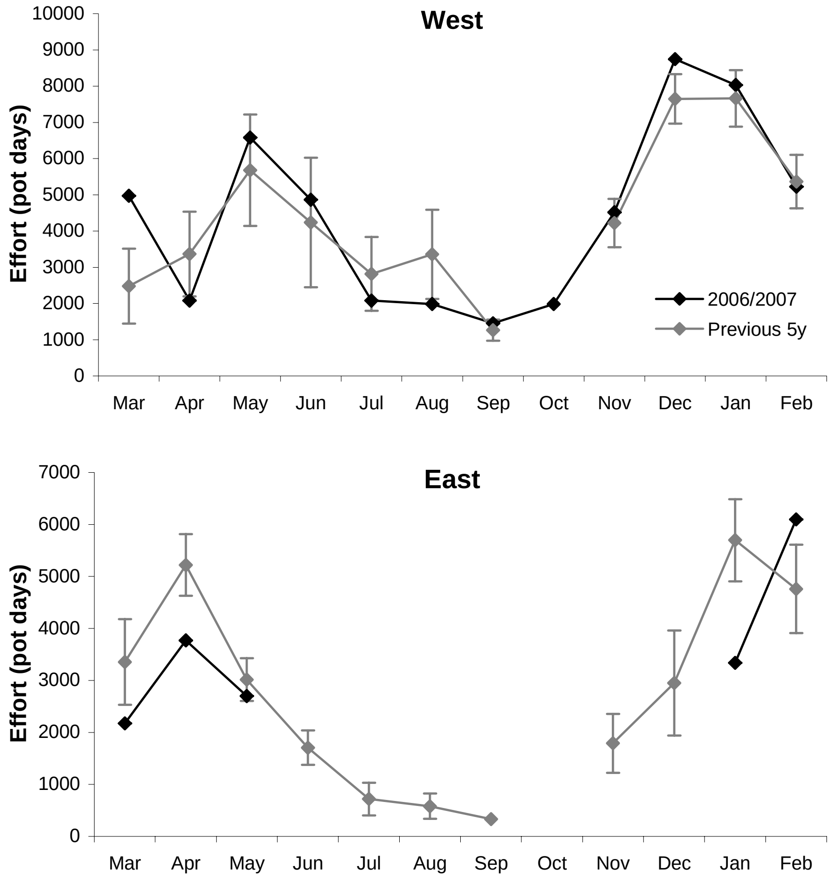


Figure 6. Seasonal trends in West and East coast effort for the 2006/07 quota year (black line) and annual average for the previous 5 yeas (grey line) including standard error bars.

3.1.3 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 rate. 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 define targeted effort and to perform an analysis for the whole of the period since 1995/96, logbook data were restricted to vessels which had been in the fishery for a minimum of 2 years and have a median catch of at least 1000 kg per year during that period. 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 6). For seasonal catch rate trends, catch rates were estimated as kilograms per pot days for each record in the database as:

$$\text{CPUE} = \frac{\text{Weight of catch (kg)}}{\text{Number of traps} \times \text{Soak time}} \qquad (3.1)$$

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). 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.

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:

$$GM_{\bar{y}} = \exp\left[\frac{1}{n}\left(\sum \ln\left(y_n\right)\right)\right] \qquad (3.2)$$

It should be noted that 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

The limit reference point relating to a State-wide decline of catch rates in two successive years was not activated (Table 3, Figure 7). However, at only about 50% of the 1995/96 catch rates, State-wide catch rates have remained low over the last few years and have shown only minor signs of recovery.

Table 3. Targeted State-wide and regional catch rates for the 2006/07 quota year relative to catch rates 5, 2 and 1 year ago. The reference point relates to the 2-year period (in bold).

	Change in catch rates (in %) compared to		
	5 years	**2 years**	Last year
State-wide	-22.1	**-5.3**	-17.3
West	-31.0	**-23.0**	-23.8
East	7.4	**22.2**	-2.2

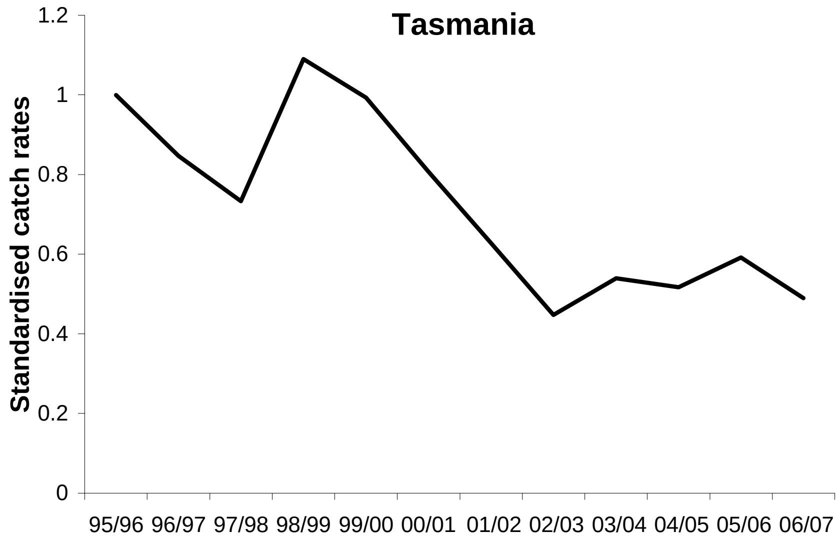


Figure 7. Trends in State-wide annual catch rates (standardised catch rates relative to 1995/96) by quota year, based on a selection of vessels that have been in the fishery for a minimum of 2 years and have a median catch of at least 1000 kg per year.

Regionally, catch rates have been low at only 30-40% of their 1995/96 levels for some years. This year, the catch rate limit reference point (a total decline by 20% over a 2-year period) was exceeded for the West coast with a decline by 23.0% (Table 3, Figure 8). The decrease occurred mainly in the 2006/07 quota year, while catch rates had been stable for the previous two years. Catch rates on the East coast remained stable at low levels.

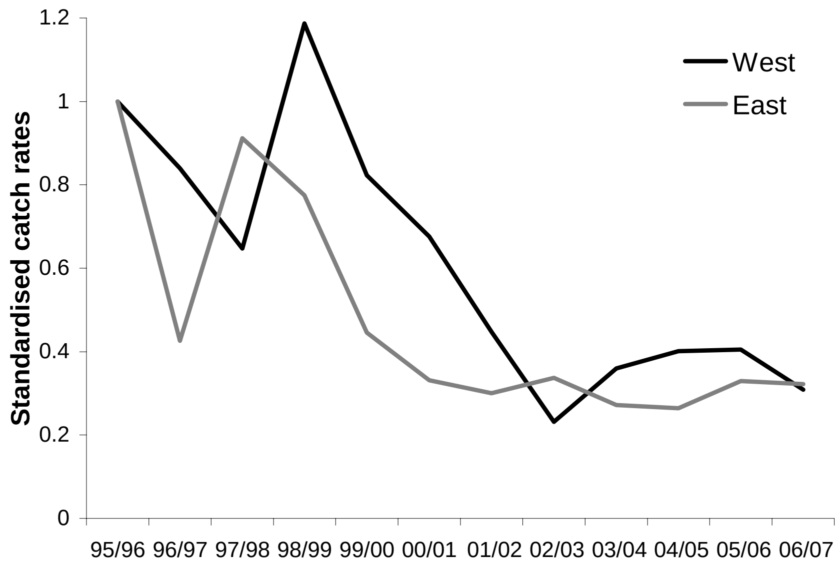


Figure 8. Trends in regional annual catch rates (standardised catch rates relative to 1995/96) for the West and East coast by quota year, based on a selection of vessels that have been in the fishery for a minimum of 2 years and have a median catch of at least 1000 kg per year.

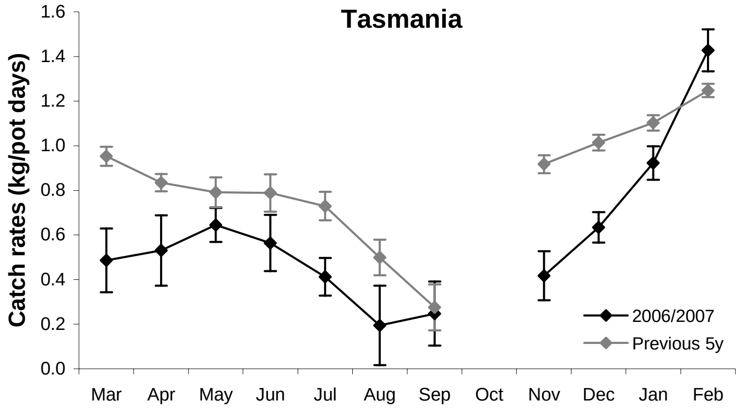


Figure 9. Trends in State-wide seasonal catch rates (geometric mean for targeted data) in the 2006/07 quota year (black line) and for the last five quota years (grey line) with standard error bars.

Seasonal catch rates

While there are no management reference points relating to seasonal changes in regional catch rates, this analysis provides additional details concerning the mechanisms behind observed changes in annual catch rates. Seasonal catch rate patterns showed that catch rates in the 2006/07 quota year were far less variable than in the previous quota year (Ziegler et al. 2007). However, they were consistently below the average of previous years with the exception of February (Figure 9).

State-wide catch rate trends were mainly a function of lower-than-average catch rates on the West coast, while catch rates on the East coast followed closely the average of previous years (Figure 10).

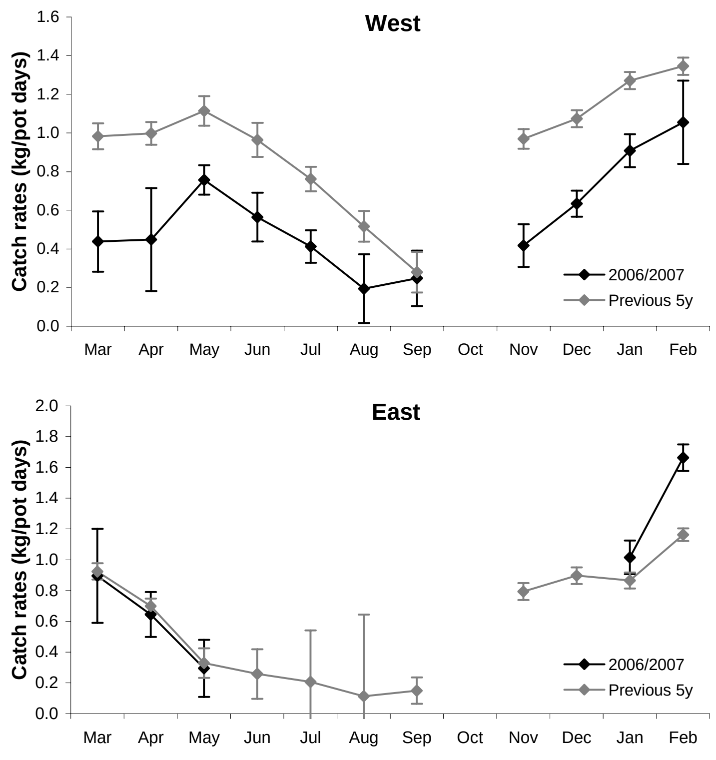


Figure 10. Seasonal trends in catch rates (geometric mean for targeted data) for the West and East coast in the 2006/07 quota year (black lines) and for the last five quota years (grey line) with standard error bars.

3.1.4 Bycatch from the lobster fishery

The reference point relating to bycatch of crabs by the lobster fishery is set at 5 tonnes, which represents about 8% of the current TACC. 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 123 kg or 0.2% of the landed giant crab catches in the 2006/07 assessment period (Figure 11). Industry members considered that the figure of 123 kg may have been an under-estimate, but whatever the true level of bycatch it was small relative to the commercial catch.

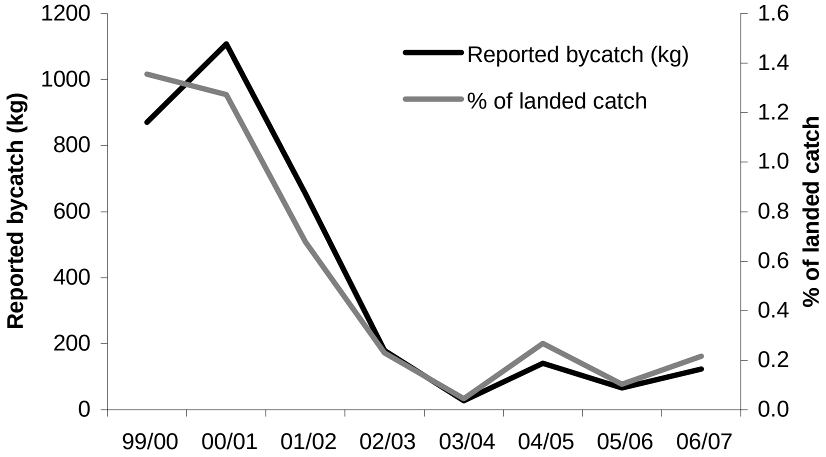


Figure 11. Total reported bycatch from the rock lobster fishery and percentage of the total giant crab catch.

3.1.5 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 is presented in Section 3.3.3 of this report (Figure 15).

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

A data collection program is underway in Tasmania and Victoria using disposable cameras and observers.The assessment of other species caught by the giant crab fishery is updated every second year, with the next assessment in 2007/08.

3.3 Stock assessment modelling

3.3.1 Introduction

A size-based stock assessment model with an annual time-step was used for the Tasmanian giant crab. It differs from the model for the Tasmanian rock lobster developed by Punt and Kennedy (1997) in a number of ways but mainly by requiring a matrix of years-to-moult accounting for the extremely long intermoult periods that characterize the growth of giant crabs.

The giant crab model was developed as part of the FRDC funded project (FRDC 2001/049) entitled ‘Developing the tools for long-term management of the giant crab resource: Data collection methodology, stock assessment and harvest strategy evaluation’. Full details of the model and the underlying description of giant crab growth are given in that report and in Chapter 5.

For the first time and in addition to the State-wide assessments, the stock assessment model was also used separately for the East and West coast fisheries.

3.3.2 Methods

Data was available for catches since 1989/90, although the reported catches in the first three years were all less than one tonne. The model was fitted to standardised catch rates since 1995/96, and data reflecting the length frequency of the commercial catch between 80-250 mm from many quota years since 1993/94.

Catch rates obtained from the logbooks of commercial fishers were used as an index of relative stock abundance through time. However, many other factors can influence catch rates besides the relative stock abundance, including whether fishers were targeting crabs, the location of effort, season, depth of fishing, and skipper. The impact of these factors have been reduced through standardisation using generalized linear models (GLM; Kimura 1981, 1988), described in Chapter 6.

A total of 23 parameters are estimated by the model. These include four selectivity parameters, the average recruitment level, and 18 recruitment residuals defining the predicted deviation from the average recruitment that occurs each year. The model assumed an equilibrium state with average recruitment levels prior to the start of the fishery in 1989/90.

The model outputs include observed and predicted catch rates, harvest rate (the proportion of the legal-sized biomass removed each year), exploitable biomass (the legal-sized biomass at the start of each quota year), total biomass (biomass of all size classes), egg production and observed and expected length frequencies between 80-250 mm of each quota year.

A bootstrap procedure of 500 replications on the catch rate data provides 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 approximately known.

Using the fitted recruitment residuals to define the expected recruitment variation in the future, the stock assessment model was projected forward to determine the likely outcomes of different management arrangements in a risk assessment. This assumes that the dynamics as described in the assessment model continue to apply and no new factors come into operation. The model allowed the following options for exploration:

- Varying the total allowable commercial catch (TACC),
- Varying the minimum and maximum legal lengths for either sex,
- Allowing the take of egg-bearing females,
- Varying the length of the closed season for females.

In this assessment all management options except for the catch level were kept constant at the present levels. The legal size limits remained at 150 mm minimum legal length and 210 mm maximum legal length for both males and females. An array of different catch values was examined for their implications for management by projecting the model forward for 10 years under each different harvest strategy. The investigated scenarios included State-wide TACCs of 51.8 tonnes, the current 62.1 tonnes, 82.8 tonnes, and 103.5 tonnes, i.e. the existing 1035 units set at 50 kg, 60 kg, 80 kg and 100 kg.

Regional projections were also conducted based around present catches from the West and East coast. Investigated scenarios included 30 tonnes, 40 tonnes and 50 tonnes on the West coast, and 15 tonnes, 20 tonnes and 25 tonnes on the East coast.

3.3.3 Uncertainties

There are many sources of uncertainty when modelling the stock dynamics of giant crabs that must be kept in mind when considering the management implications of the model outcomes.

One of the biggest sources of uncertainty derives from the description of growth, which is a fundamental component of any size-based stock assessment model. In order to grow, crustaceans like rock lobsters and giant crabs have to go through a moulting process, whereby their old carapace is shed and the new soft exoskeleton expands and then hardens. The description of growth of giant crab is more complex than that of rock lobsters because of their prolonged periods between moulting, known as inter-moult periods. Rock lobster tend to moult at least once during a year and the stock assessment model describes their growth by summarizing the expected growth of each size class at a seasonal or annual level. Giant crabs need a much more complex description of growth because their inter-moult periods can potentially extend over ten years or longer. Not only does the moulting growth increment vary with size but so does the inter-moult interval. Therefore, a model structure was developed to account for these different growth patterns exhibited by giant crabs. While this model is stable, the details of the growth of the largest crabs, i.e. most of the legal-sized animals, had to be determined through extrapolation of the details of the growth of smaller giant crabs. Such extrapolation is inherently risky but provides options for exploring the possible growth patterns and their implied stock dynamics.

3.3.4 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 12 to Figure 17). 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.

State-wide model estimates were similar to those from last year's assessment. The large catches reported in the mid 1990s led to a significant decline in the predicted stock size. The model estimated that the State-wide exploitable biomass declined from about 1360 tonnes in at the start of the fishery to about 325 tonnes in 2006/07. This level represented an overall decline to about 24% of the originally highest exploitable biomass. Harvest rates were generally high, but have slightly fallen to 0.18 in the most recent quota year as a combination of smaller catch and increased exploitable biomass. At the same time, total biomass and egg production have remained stable at 38% and 43% respectively of their highest levels. The egg production is relatively high due to a large contribution from sub-legal sized females which are fully mature by about 120 mm body length, i.e. well below the minimum size limits.

Tasmania

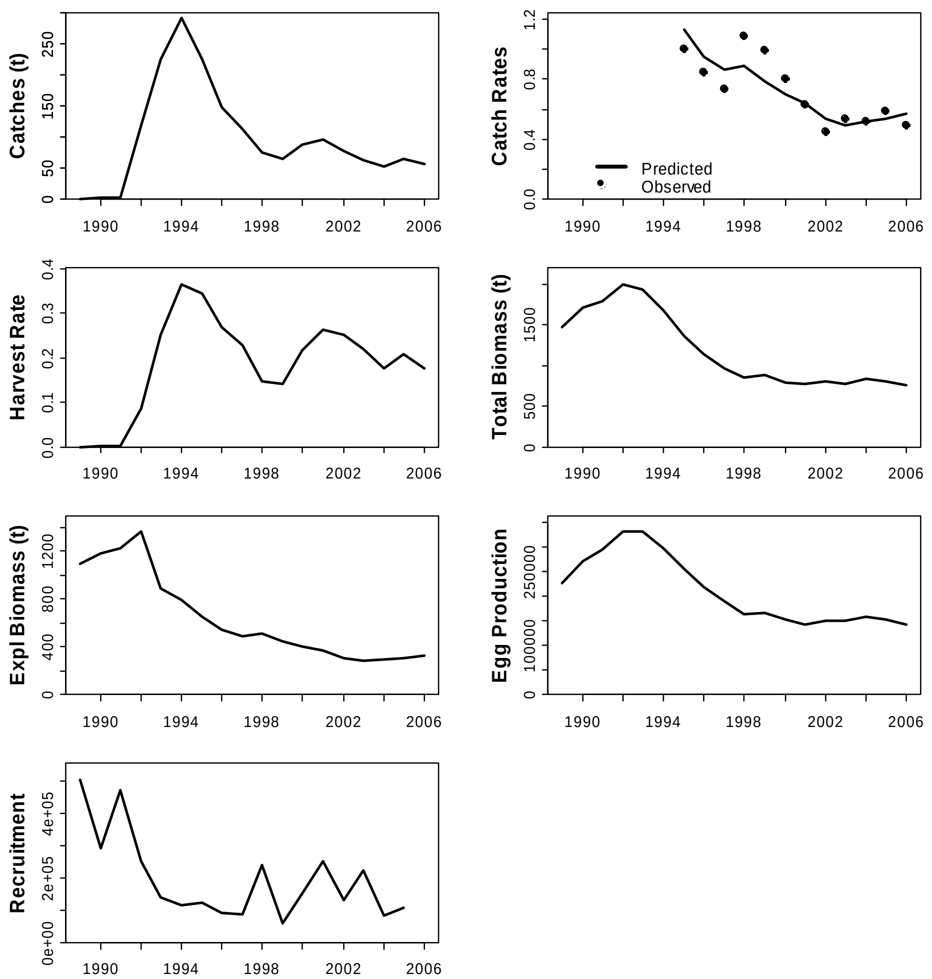


Figure 12. State-wide results of the model fitted to the observed data since 1989/90 (first year of quota year given). Observed catch, observed standardised (black dots) and fitted predicted catch rates (line), estimated annual harvest rates, total biomass and exploitable biomass at the start of each quota year, egg production and recruitment. The last year of recruitment cannot be fitted by the model and is not shown.

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 13). However, the State-wide model showed less depletion and masked regional trends in stock biomass. On the West coast, the model estimated a greater impact of fishing with harvest rates at 0.34 and a decline in exploitable biomass to only 13% of the original exploitable biomass (Figure 14). Total biomass and egg production have remained stable at 24% and 29% respectively of their initial levels.

On the East coast, the overall smaller catches resulted in a smaller impact on the giant crab stocks, although the model estimated the stock biomass to be only about half of that on the West coast (Figure 14). Harvest rates were at a 0.13 and exploitable biomass was 23% of the original exploitable biomass. Total biomass and egg production have remained stable at 46% and 52% respectively of their initial levels.

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.

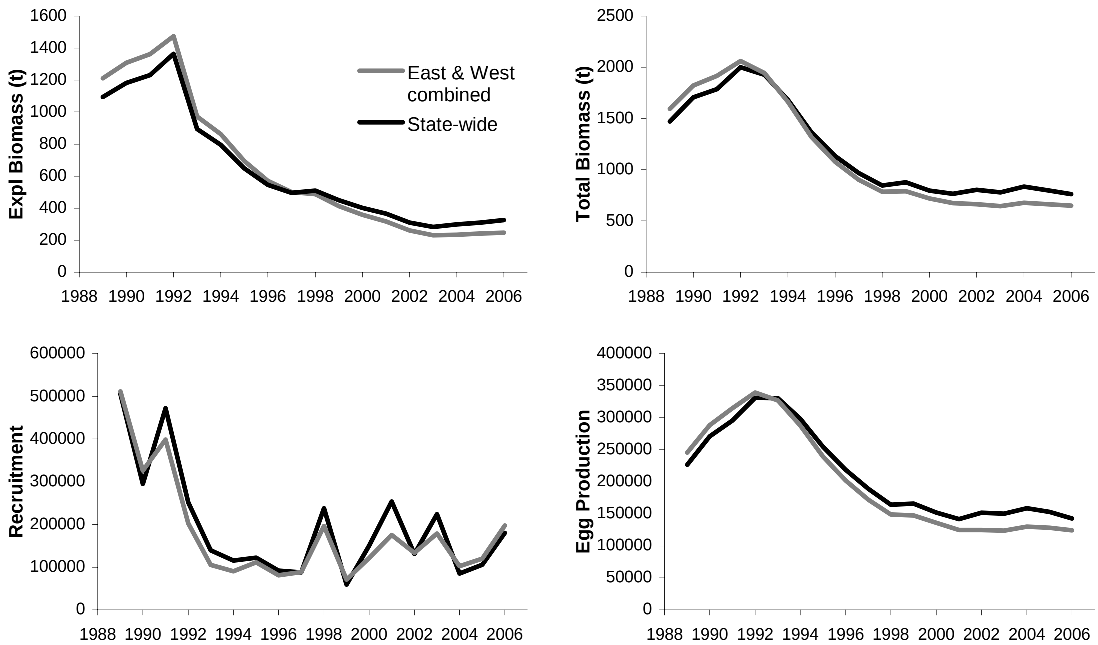
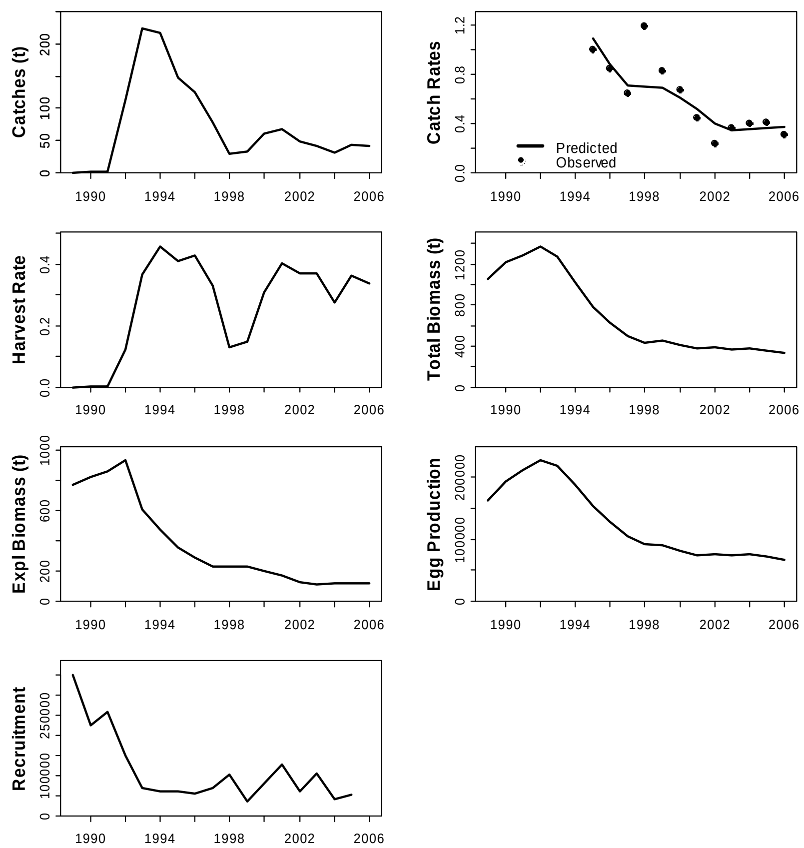


Figure 13: Comparison between the results from the State-wide model and the combined results from the East and West coast models for exploitable biomass and total biomass at the start of each quota year, egg production and recruitment since 1989/90 (first year of quota year given).

West



East

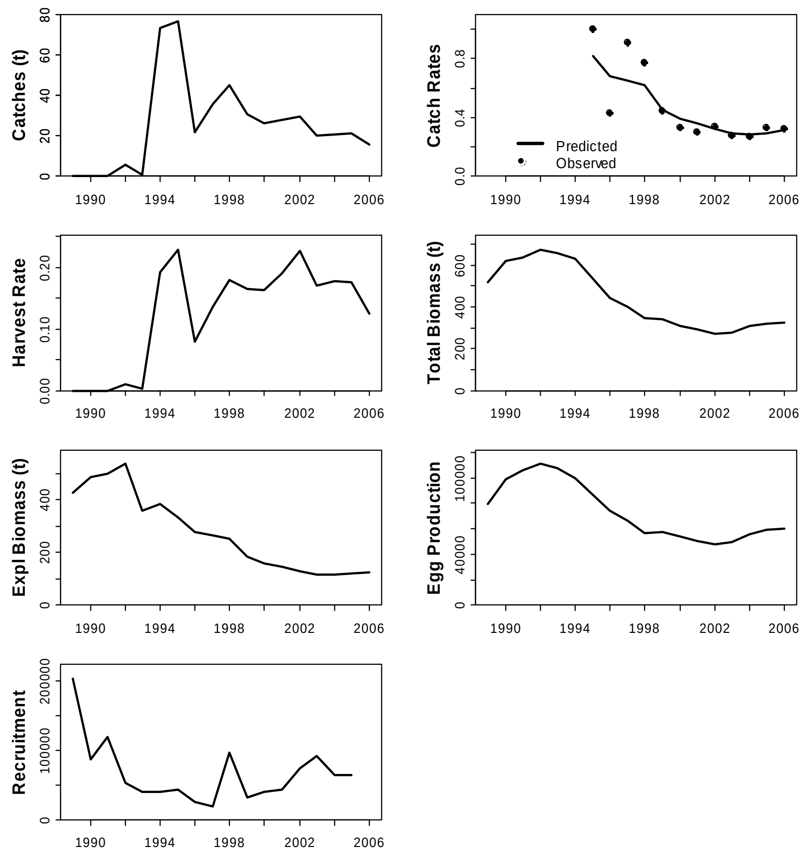


Figure 14: Regional results of the model fitted to the observed data sine 1989/90 (first year of quota year given). Observed catch, observed standardised (black dots) and fitted predicted catch rates (line), estimated annual harvest rates, total biomass and exploitable biomass at the start of each quota year, egg production and recruitment. The last year of recruitment cannot be fitted by the model and is not shown.

Tasmania

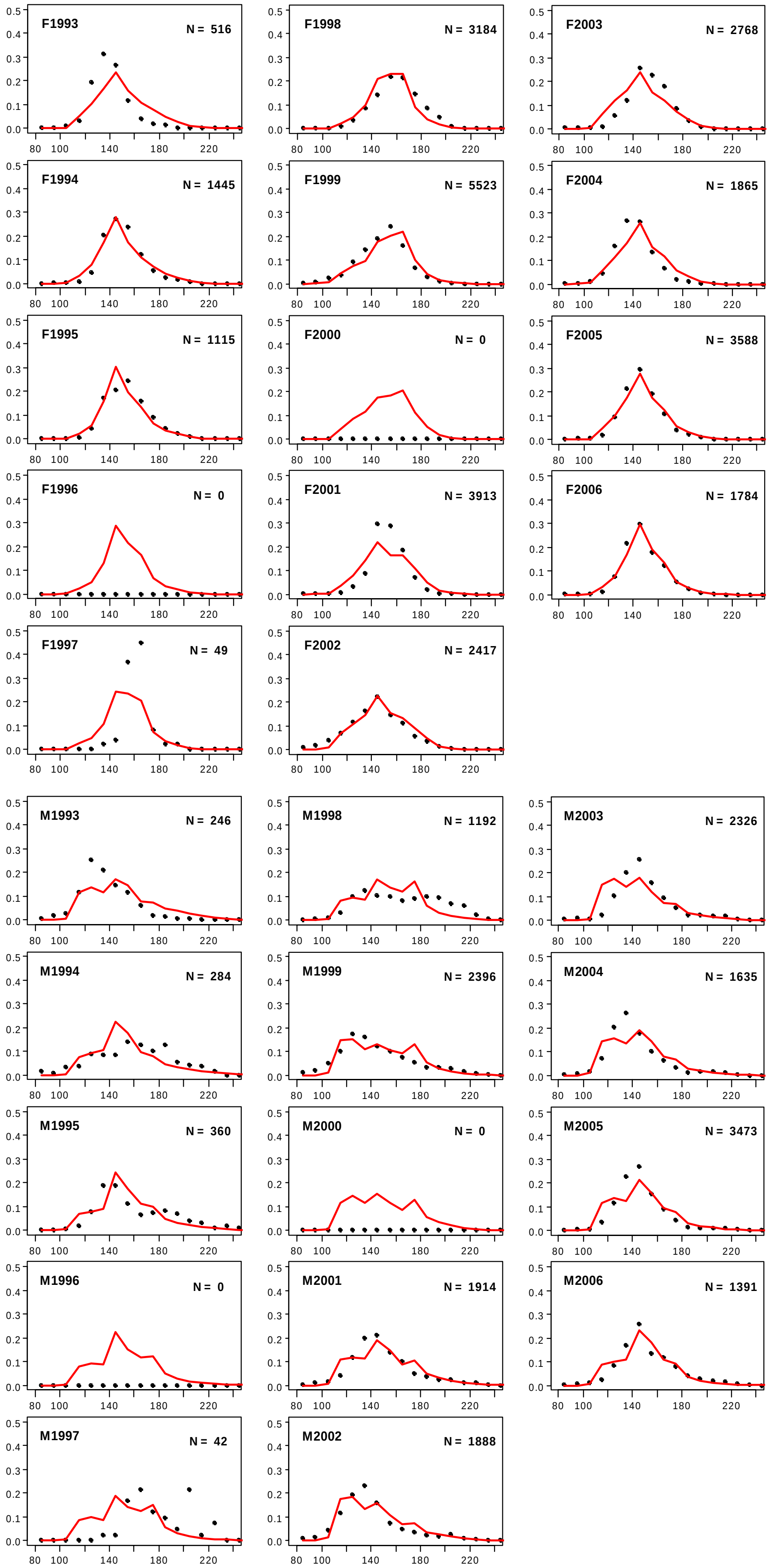


Figure 15. Observed (points) and predicted (lines) length frequencies in State-wide commercial catches since 1993/94 (F1993 and M1993) for female and male giant crab with the observed sample sizes *N*.

West

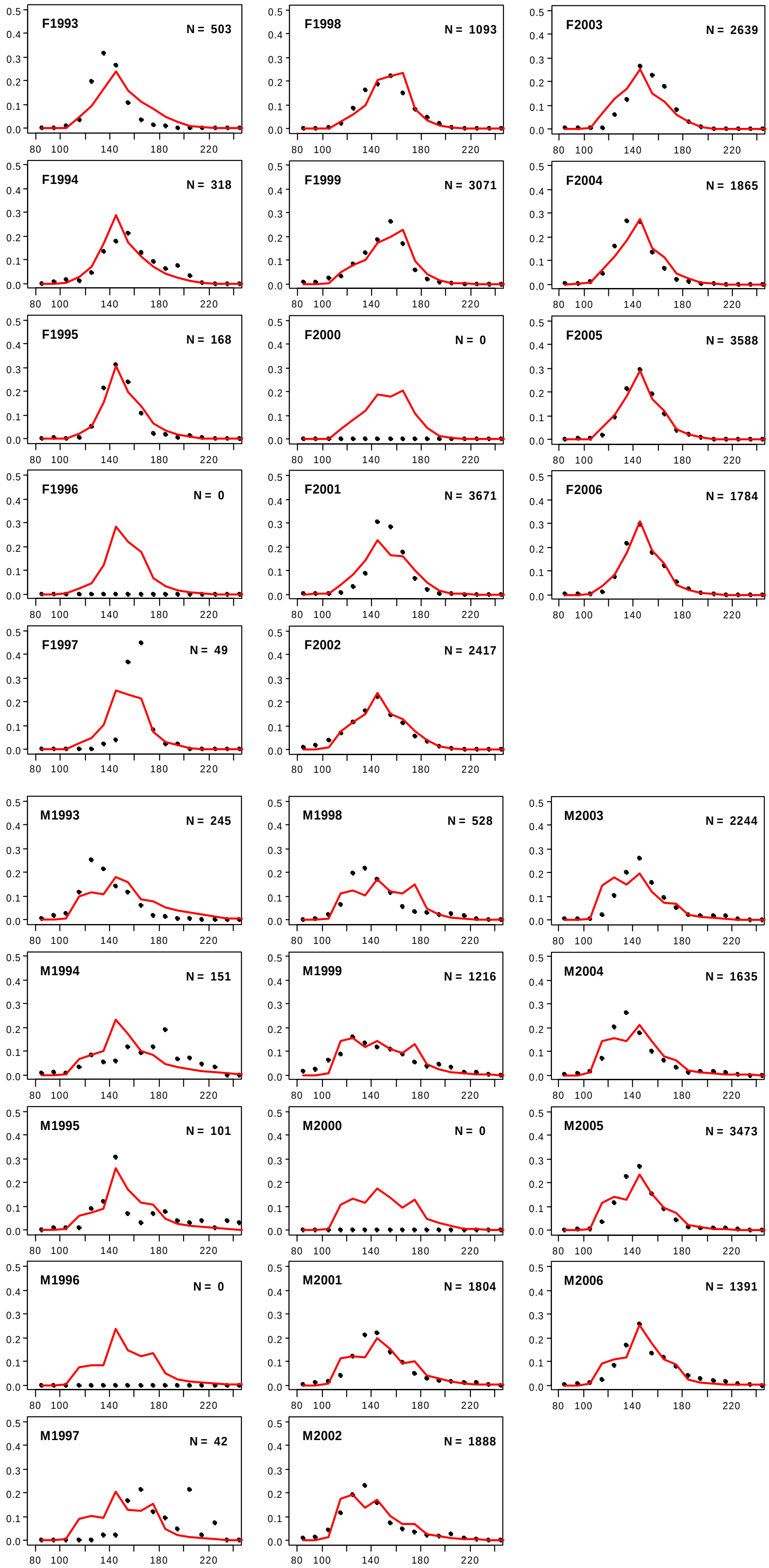


Figure 16: Observed (points) and predicted (lines) length frequencies in commercial catches from the West coast since 1993/94 (F1993 and M1993) for female and male giant crab with the observed sample sizes *N*.

East

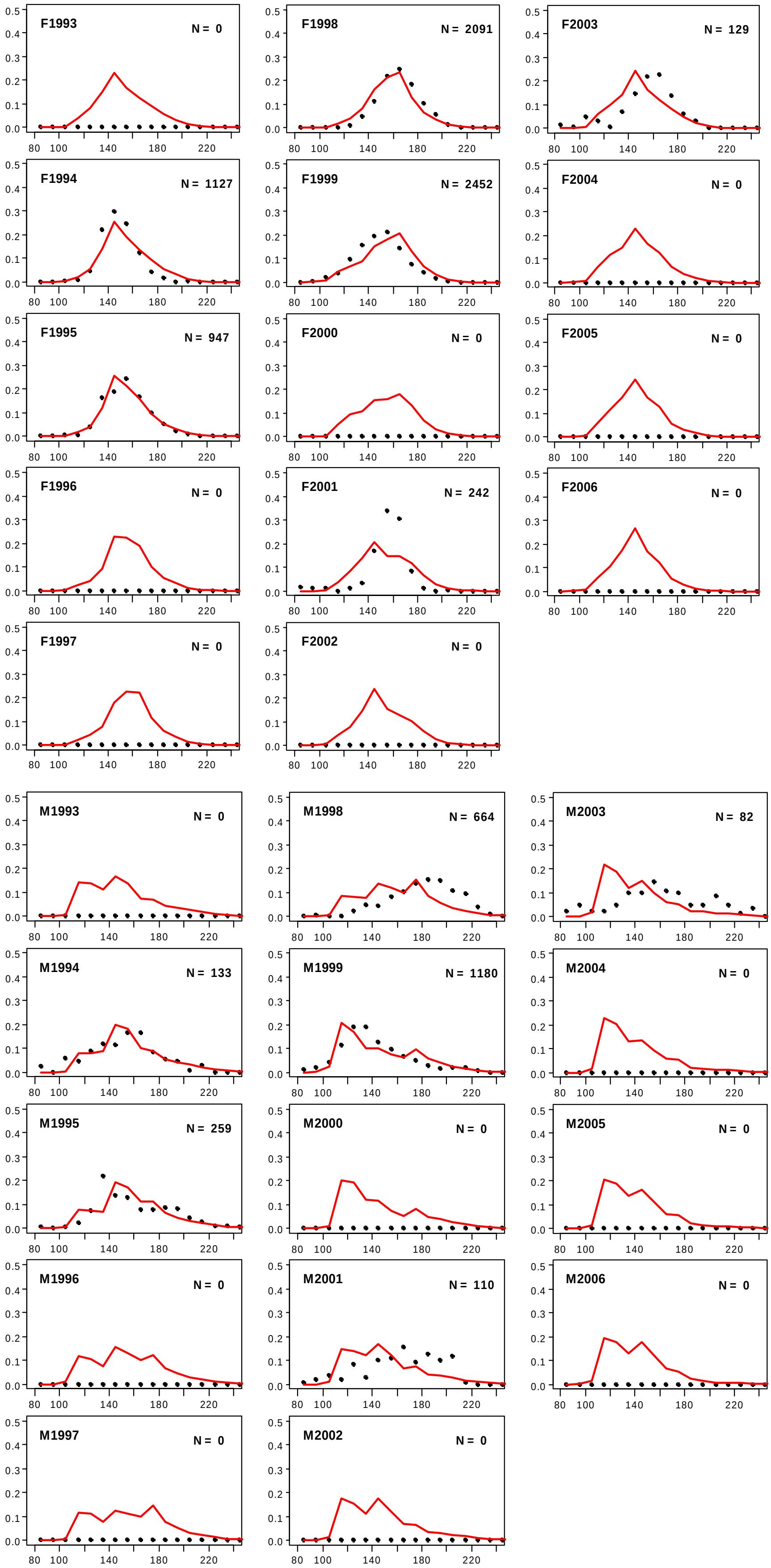


Figure 17: Observed (points) and predicted (lines) length frequencies in commercial catches from the East coast since 1993/94 (F1993 and M1993) for female and male giant crab with the observed sample sizes *N*.

The bootstrap procedure for catch rates permitted the generation of 90% confidence intervals around the estimates of harvest rate and exploitable biomass, thus providing an indication of the precision with which the model operates (Figure 18). Uncertainty in harvest rates was high in both regions, but relatively minor in the State-wide analysis. On the West coast, the high uncertainty in harvest rates was mainly a function of the low, yet relatively certain estimates of exploitable biomass, while on the East coast estimates of exploitable biomass themselves were highly uncertain.

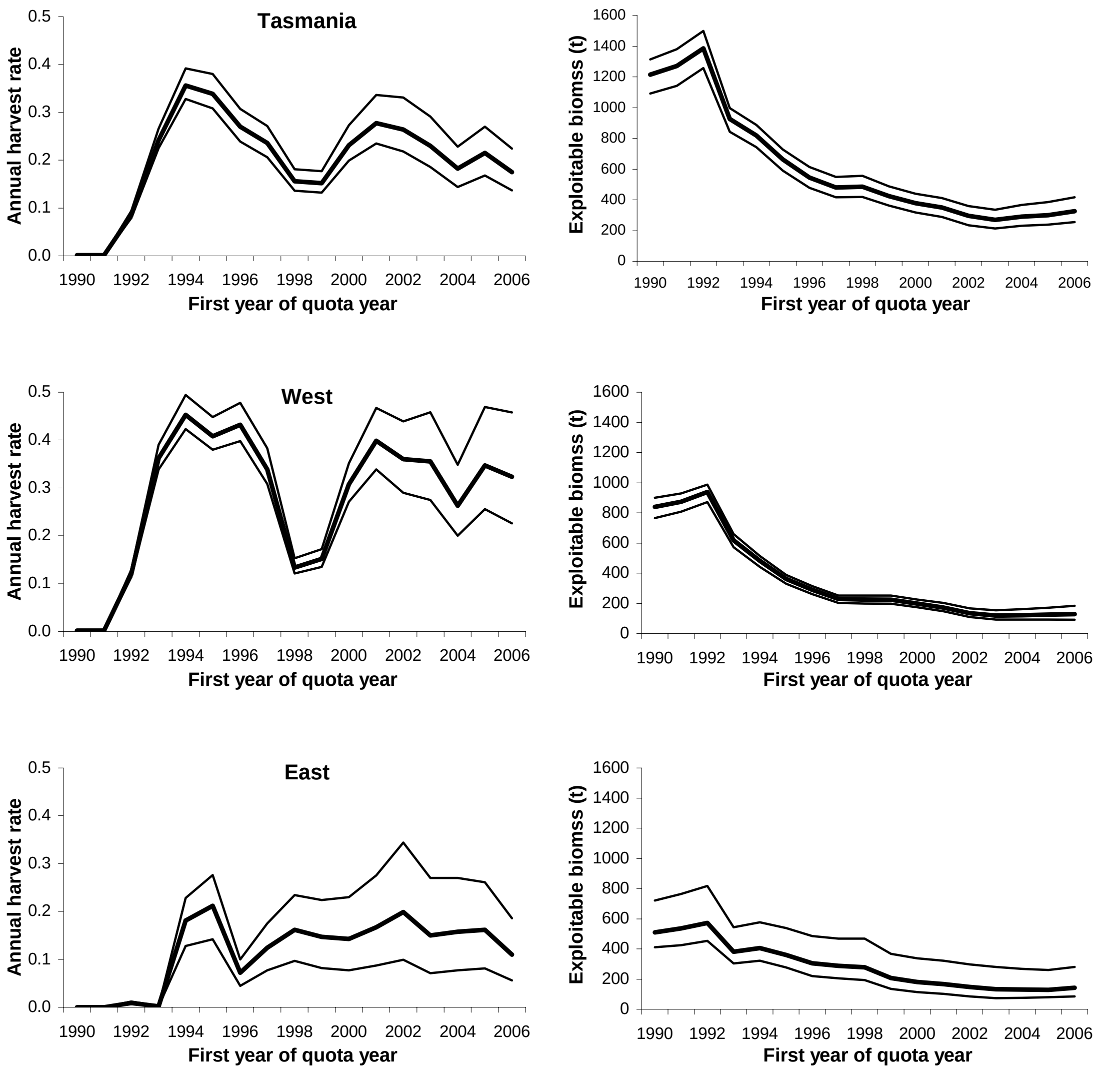


Figure 18. The predicted State-wide and regional annual harvest rate and exploitable biomass at the start of each quota year (first year of the quota year given) since 1998/90 with median values (heavy lines) and 90% confidence intervals (light lines).

3.3.5 Model Projections

In all cases, the projections had very wide confidence intervals around the predicted future values, illustrating that these projections are highly uncertain. 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 2006/07 rather than 2007/08.

The projected outcomes of the State-wide TACC scenarios with 51.8 tonnes and 62.1 tonnes were very similar (Figure 19). The higher catch level results in higher harvest rates and slightly lower yet still increasing catch rates, while total and exploitable biomass are almost identical. Both scenarios indicate an over 80% chance of stock rebuilding, however this is likely to occur only slowly.

A higher State-wide TACC of 82.8 tonnes and the old TACC of 103.5 tonnes on the other hand indicate that exploitable biomass and catch rates are more likely to drop, in the latter case with a greater than 50% chance. With the highest TACC, the upper limit on the confidence bound of the predicted harvest rate is also at times only determined by a limit imposed by the model to avoid unrealistic answers after just a few years, e.g. greater than 100% of available legal-size biomass being taken in the fishery. Similarly, the exploitable biomass reaches a lower threshold below which there would not have been enough available biomass to be consistent with the history of the fishery.

a) State-wide 51.8 tonnes

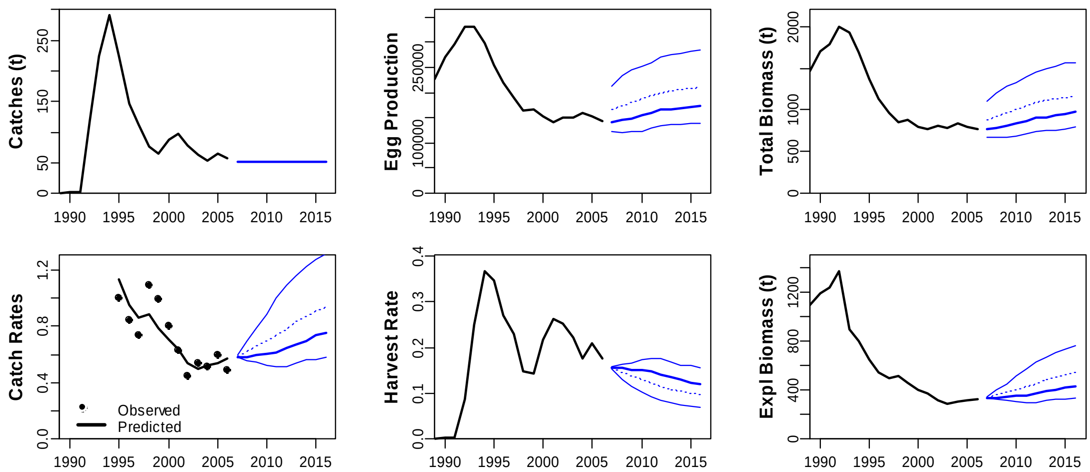
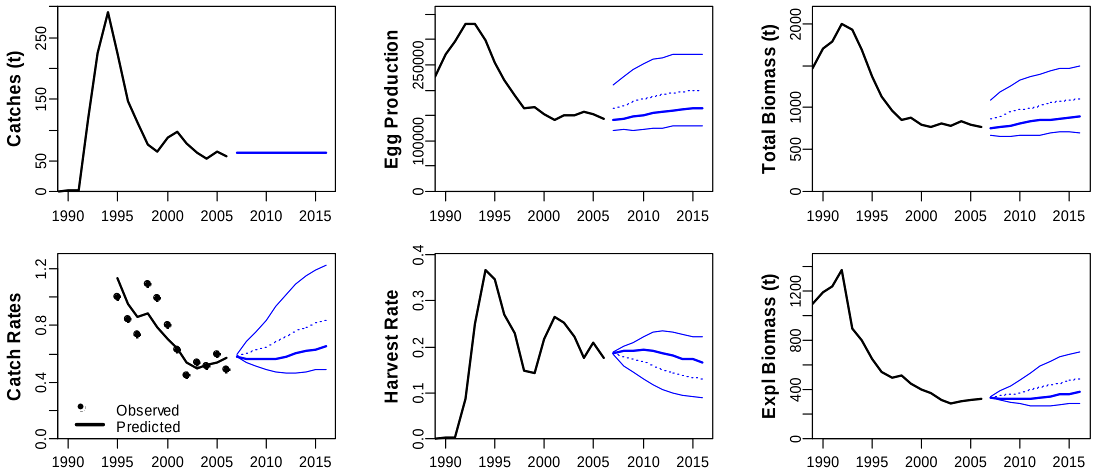
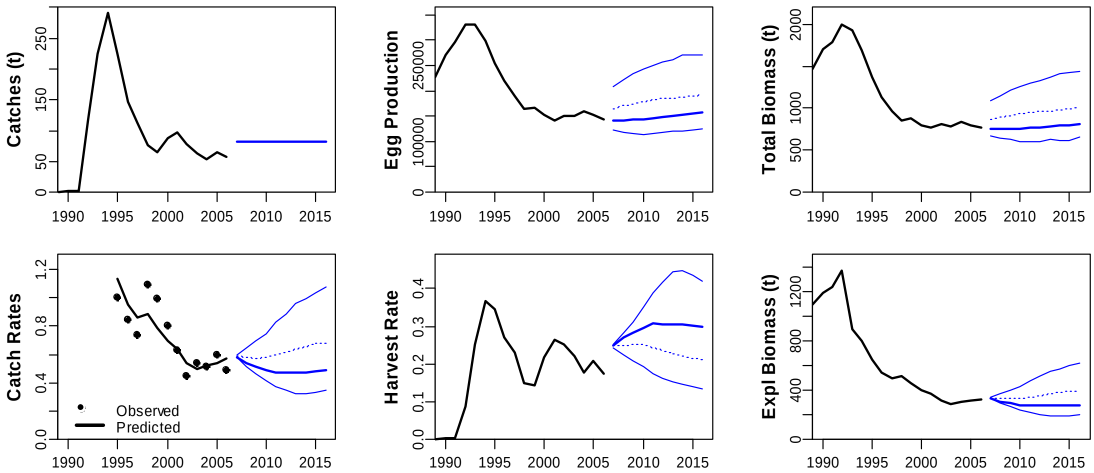


Figure 19. Model outputs for a 10-year projected State-wide TACC of (a) 51.8 tonnes derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the dotted line (median). The outer solid lines relate to the 90% percentile confidence intervals.

a) State-wide 62.1 tonnes



b) State-wide 82.8 tonnes



c) State-wide 103.5 tonnes

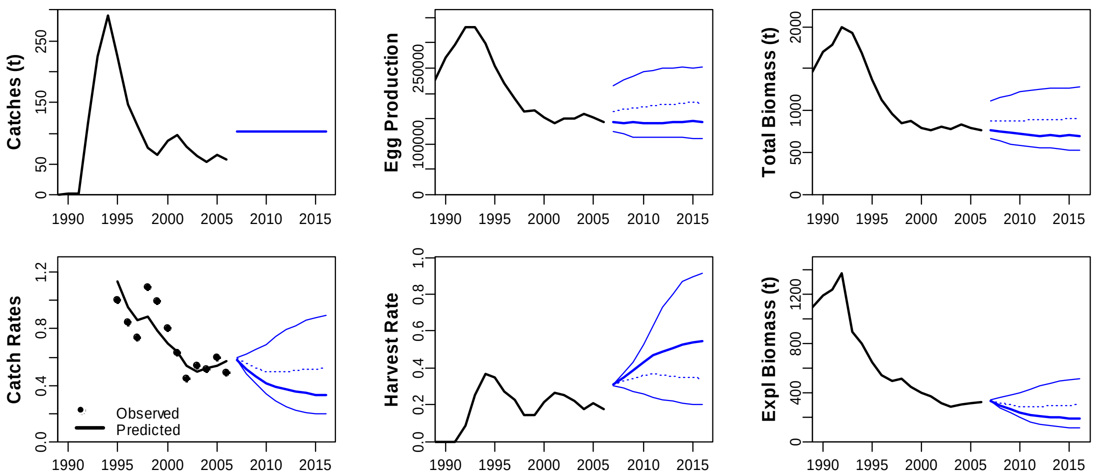


Figure 19 cont. Model outputs for a 10-year projected State-wide TACC of (b) 62.1 tonnes, the current TACC, (c) 82.8 tonnes, and (d) 103.5 tonnes, derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the dotted line (median). The outer solid lines relate to the 90% percentile confidence intervals.

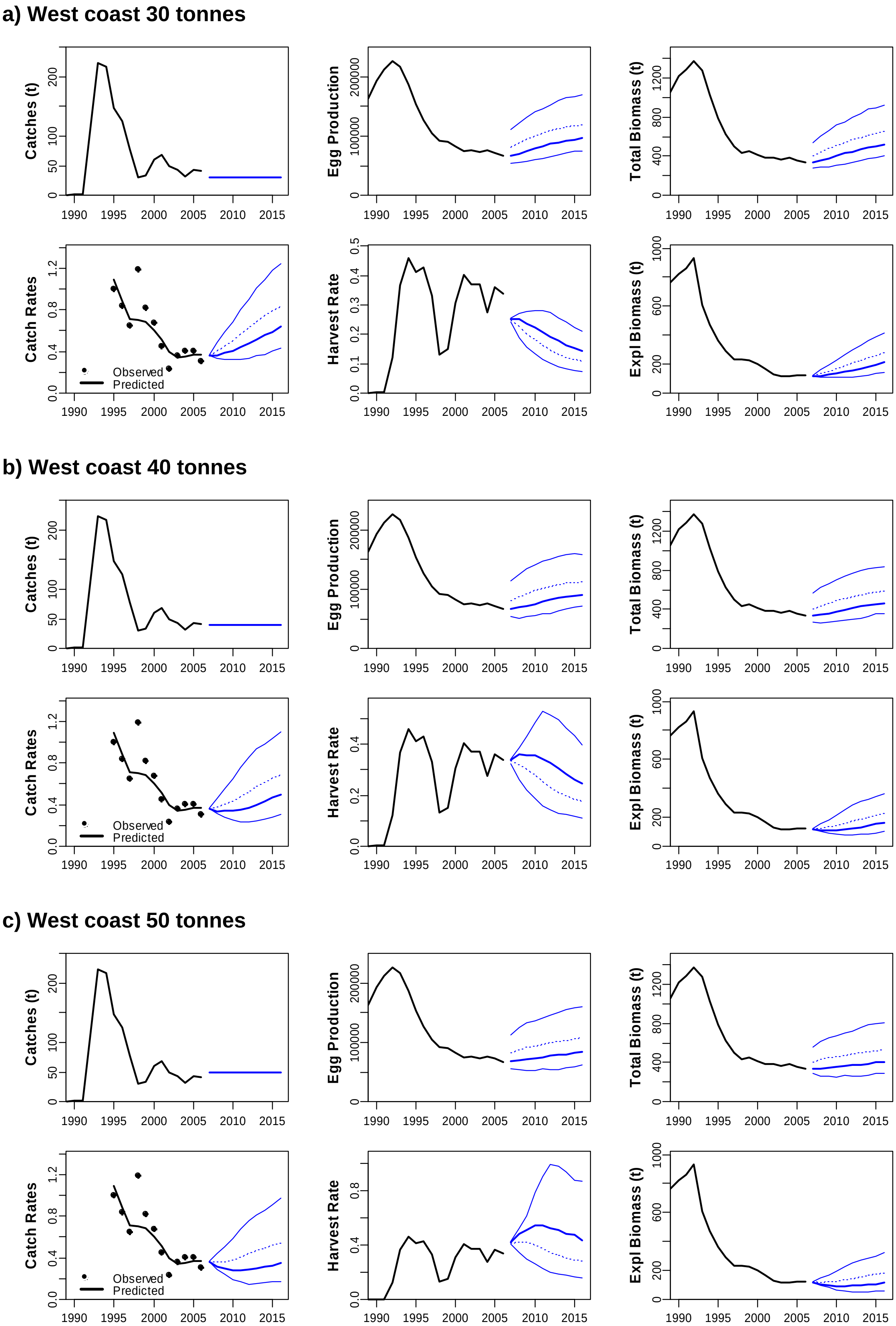
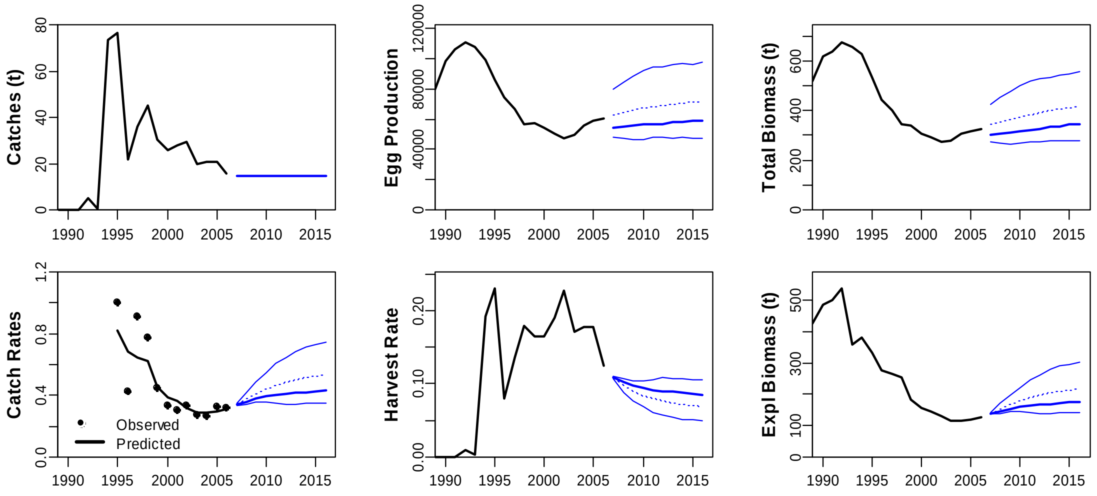
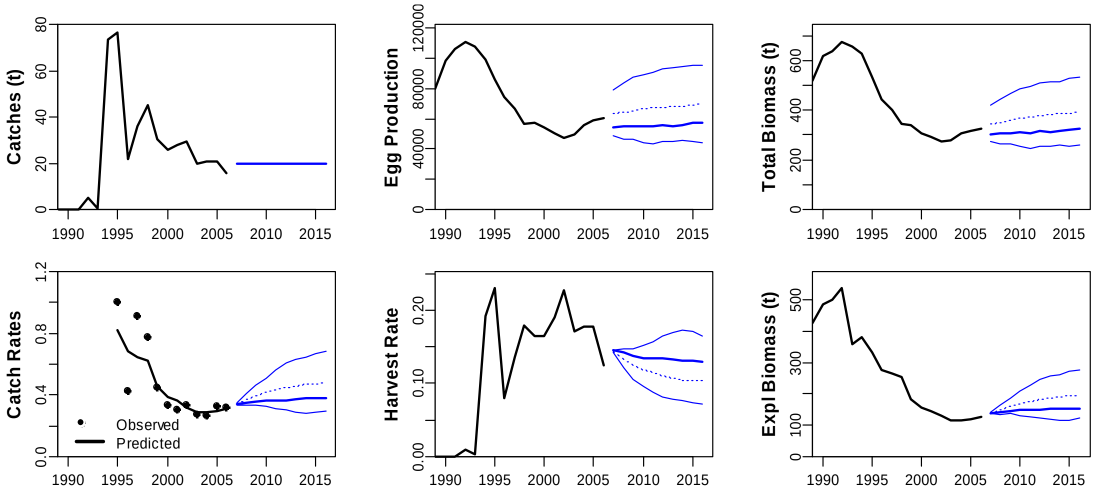


Figure 20. Model outputs for a 10-year projected West coast catch of (a) 30 tonnes, (b) 40 tonnes, and (c) 50 tonnes derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the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

a) East coast 15 tonnes



b) East coast 20 tonnes



c) East coast 25 tonnes

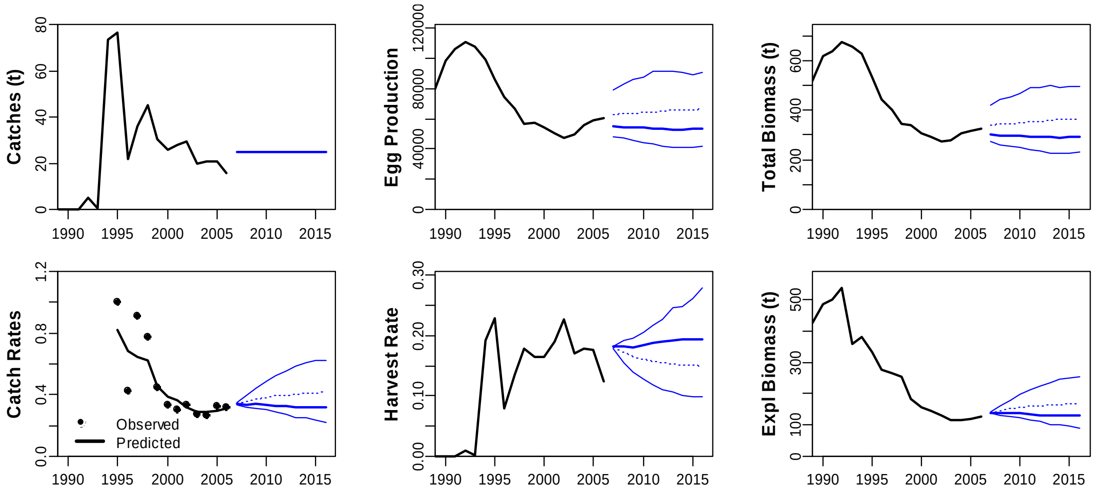


Figure 21. Model outputs for a 10-year projected East coast catch of (a) 15 tonnes, (b) 20 tonnes, and (c) 25 tonnes derived from 1000 projections. In the projections, 80% of all simulations were above (or for harvest rate below) the bold line ($P_{80\%}$), while 50% of all simulations were above the dotted line (median). The outer solid lines relate to the 90% percentile confidence intervals.

Regional projections indicated that under the status quo, i.e. around 40 tonnes on the West coast and 20 tonnes on the East coast, catch rates and legal-sized biomass remain fairly stable for some years in both regions. A 25% catch increase relative to current levels, to 50 tonnes on the West coast and 25 tonnes on the East coast, is likely to lead to lower catch rates and biomass (Figure 20 and Figure 21), while only catch reductions to 30 tonnes on the West coast and 15 tonnes on the East coast would show significant improvement of these measures. However, these improvements are likely to be small on the East coast.

3.3.6 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 20% of the virgin state. On a regional level, exploitable biomass was also estimated around 20% on the East coast, but only at around 13% on the West coast, where the majority of fishing occurs

The State-wide model predicted that the status quo with a current TACC of 62.1 tonnes should lead to a slow increase in exploitable biomass over the next 5 to 10 years. Regional projections support this prediction, although the East coast model indicated that rebuilding could be minor even in the long run. These predictions assume that no other major factor would influence the fishery, e.g. that no trawl interactions became significant again. The risk of stock decline increases with higher regional catches and State-wide TACC. A 25% catch increase on both the West and East coast is likely to lead to reduced catch rates and legal-sized biomass. When returning to the historical State-wide TACC of 103.5 tonnes, the chance of any stock rebuilding over the next 10 years falls to less than 50%. Equivalently, there would be greater than 50% chance of a stock decline.

While management implications of alternative TACCs relate mainly to the maintenance of commercially viable catch rates, reproductive output is regulated to a greater extent by the minimum legal length. Consequently, egg production appears less sensitive to alternative projected TACCs, with an estimated 80% probability of egg production remaining stable at high levels even under the highest TACC scenario of 103.5 tonnes.

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5. Appendix 1: Length-based stock assessment model

5.1 Length-Based Modelling

The FRDC report 2002/238 on the ‘Development of the tools for long-term management of the giant crab resource: Data collection methodology, stock assessment and harvest strategy evaluation’ has a detailed description of the model.

As with many other invertebrate species, giant crabs (*Pseudocarcinus gigas*) cannot be aged with any degree of ease or accuracy. An alternative way of describing the population dynamics of such a species is to use a size-based model (e.g. Punt and Kennedy 1997). The principle behind such models is that a vector of numbers at size $\mathbf{N_l}$ is projected through time by multiplying it by a square matrix representing the probabilities of growing from one size class into a subsequent set of size classes over the period of time represented by the matrix **G**. In addition, survivorship following natural and size-selective fishing mortality $\mathbf{S_l}$ occurs along with new recruitment **R** as follows:

$$\mathbf{N_{l,t+1} = S_{l,t} G N_{l,t} + R} \tag{5.1}$$

The time step and size-class selected in such models tends to be fixed at some convenient period and width over which data is available. The model here used 5 mm size-classes between 80-250 mm carapace length. Problems could arise if the maximum growth that occurs for a given size-class within a single time-step is less than the width of the size-class. If that occurs then the animals could become mathematically trapped with no hope of ever growing out of this effectively terminal size-class. In effect, this final size-class would be the equivalent of a plus group and this would only be a bad thing if this imposed excessive distortion on the description of numbers at size.

If the time-step that the growth transition matrix represents is markedly different from the biological properties of the species concerned, a proportion of animals may not moult in the available time. This lack of growth can be accommodated for small difference between the moulting interval and the time-step of the transition matrix by including the probability of not growing out of the size-class into the transition probabilities. However, this option obscures the real dynamics of the time-lags in moulting if the moulting interval was very long relative to the time-step of the transition matrix.

Such moulting intervals reach extremes in the Tasmanian giant crab, in which large animals can go many years between moults (Gardner *et al.* 2002, McGarvey *et al*. 2002). One way of attempting to capture the dynamics involved with such delays in moulting is to model the probability of moulting in a particular year in an explicit way. Then the probability of moulting depends upon both the size of the animals, the sex of the animals and the time since the animals last moulted. The moulting model is used to determine in each year how many within each size-class were expected to moult. A growth transition matrix with a time-step of one year is then applied to those animals expected to moult.

In the case of the Tasmanian giant crab, the intermoult intervals are modelled explicitly through a new matrix of the numbers of years spent in each size class before moulting. Thus, in each year instead of a single vector of numbers-at-size $\mathbf{N}_m$ for each sex representing the total population across *m* size-classes, the number-at-size for each sex are distributed within a matrix $\mathbf{N}_{m,y}$ describing the maximum number of years *y* for which the moulting dynamics are followed (Eq. (5.2)). Thus, with *m* size classes following *y* years of moulting history for each size class we end with a matrix of the following form to describe numbers-at-size:

$$
\begin{array}{ccccccccc}
\mathbf{N}_m & & & & \mathbf{N}_{m,y} & & & & \\
N_1 & & N_{1,1} & N_{1,2} & N_{1,3} & . & . & . & N_{1,y} \\
N_2 & & N_{2,1} & N_{2,2} & N_{2,3} & . & . & . & N_{2,y} \\
N_3 & & N_{3,1} & N_{3,2} & . & . & . & . & . \\
. & & . & . & . & N_{4,4} & . & . & . \\
. & \Rightarrow & . & . & . & . & . & . & . \\
. & & . & . & . & . & . & . & . \\
. & & . & . & . & . & . & . & . \\
. & & . & . & . & . & . & . & . \\
N_m & & N_{m,1} & . & . & . & . & . & N_{m,y}
\end{array}
\tag{5.2}
$$

This matrix is complemented by an equivalent order matrix describing the proportion in each size class in each year of the moulting history, that will moult in the given year $\mathbf{P}_{m,y}$. In short, this means that instead of following the fate of a vector of numbers-at-size the process follows a matrix of numbers-at-size by years-to-moult.

5.1.1 Model Structure

With size-based models, the order in which the different drivers to the dynamics occur can have a significant influence on the outcomes (Haddon 2001, p. 219), so the sequence of matrix operations is important. The sequence of operations acting on the matrix of numbers-at-size for each sex to describe the population dynamics in each year can be formally described. The numbers-at-size *i* by years-to-moult *j* matrix for sex *k* at time *t* can be represented by $N_{i,j}^{k,t}$ or in matrix notation $\mathbf{N}^{\mathbf{k,t}}$. The various stages in the algorithm will be represented by incrementing the time superscript *t* by the stage of the operation (*a to m*; stage *n* is the final step and is represented as *t*+1; stage names *i*, *j*, and *k*, are omitted to avoid confusion with subscripts in the equations). The dynamics can be represented by nine steps which follow a branching pathway (Figure 22):

a. Multiply the matrix of numbers-at-size (by years-to-moult) by the survivorship arising from applying half the background natural mortality (*M*/2):

$$N_{i,j}^{k,t+a} = N_{i,j}^{k,t} e^{-M/2} \tag{5.3}$$

b. Multiply the numbers-at-size by years-to-moult matrix by the moulting matrix for each sex k $\mathbf{P^k}$ on a cell by cell basis, to identify Γ, those fish in each size-class i and each year-to-moult j that are due to moult:

$$\Gamma_{i,j}^{k,t+b} = P_{i,j}^{k} \times N_{i,j}^{k,t+a} \qquad \text{for each } i \text{ and } j \tag{5.4}$$

c. Remove the numbers to moult from each size-class

$$N_{i,j}^{k,t+c} = N_{i,j}^{k,t+a} - \Gamma_{i,j}^{k,t+b} \tag{5.5}$$

d. Project the remainder forward one year along the years-to-moult axis. Setting the maximum number of years used to track the time till moulting as $y_{\max}$. This action empties the first column of the matrix. $Y_{\max}$ acts as a plus group:

$$\begin{aligned} N_{i,y_{\max}}^{k,t+d} &= N_{i,y_{\max}}^{k,t+c} + N_{i,y_{\max}-1}^{k,t+c} & j &= y_{\max} - 1 \\ N_{i,j+1}^{k,t+d} &= N_{i,j}^{k,t+c} & 1 \le j &\le y_{\max} - 2 \end{aligned} \tag{5.6}$$

e. Generate a vector of numbers-at-size that will moult by summing the numbers to moult from each of the years-to-moult columns of Γ:

$$n_i^k = \sum_{j=1}^{y_{\max}} \Gamma_{i,j}^{k,t+b} \qquad \text{For each } i \tag{5.7}$$

f. Fill the first column of the number-at-size matrix by multiplying the vector of crabs due to moult $\mathbf{n^k}$, by the respective growth transition matrix for each sex $\mathbf{G^k}$ which includes survivorship from moulting mortality. This action refills the first column of the numbers matrix. The effect of moulting mortality, containing in $\mathbf{G^k}$ implies that the sum of $\mathbf{n^k}$ is greater than the sum of the first column of the numbers matrix ($\sum N_{i,1}^{k,t+f}$):

$$N_{i,1}^{k,t+f} = \mathbf{G^k n^k} \tag{5.8}$$

g. Using $L_{\max}$ as the maximum size-class W_i as the vector of weight at size-class i, and V_i as the selectivity of size-class i, calculate the exploitable biomass for both sexes (k = M and F) and all size-classes:

$$T_i^k = \sum_{j=1}^{y_{\max}} N_{i,j}^{k,t+f} \qquad \text{For each } i \tag{5.9}$$

$$B_E^t = \sum_{k=M}^{F} \sum_{i=1}^{L_{\max}} T_i^k W_i^k V_i^k \tag{5.10}$$

$$N_{i,j}^{k,t}$$

$$N_{i,j}^{k,t+a} = N_{i,j}^{k,t} e^{-M/2}$$

$$N_{i,j}^{k,t+c} = N_{i,j}^{k,t+a} - \Gamma_{i,j}^{k,t+b} \longleftarrow \Gamma_{i,j}^{k,t+b} = P_{i,j}^{k} \times N_{i,j}^{k,t+a}$$

$$n_i^k = \sum_{j=1}^{y_{\max}} \Gamma_{i,j}^{k,b}$$

$$N_{i,y_{\max}}^{k,t+d} = N_{i,y_{\max}}^{k,t+c} + N_{i,y_{\max}-1}^{k,t+c}$$

$$N_{i,j+1}^{k,t+d} = N_{i,j}^{k,t+c}$$

$$N_{i,1}^{k,t+f} = \mathbf{G^k n^k}$$

$$N_{i,j}^{k,t+f}$$

$$T_i^k = \sum_{j=1}^{y_{\max}} N_{i,j}^{k,t+f}$$

$$N_{i,j}^{k,t+l} = N_{i,j}^{k,t+f}\left(1 - V_i^k H^t\right)$$

$$B_E^t = \sum_{k=M}^{F} \sum_{i=1}^{L_{\max}} T_i^k W_i^k V_i^k$$

$$N_{i,j}^{k,t+m} = N_{i,j}^{k,t+k} + R_i^t$$

$$\text{for } i = 1..6$$

$$H^t = \frac{C^t}{B_E^t} \longrightarrow \hat{C}^t = \sum_{k=M}^{F} \sum_{i=i}^{L_{\max}} T_i^k W_i^k V_i^k H^t$$

$$N_{i,j}^{k,t+1} = N_{i,j}^{k,t+l} e^{-M/2}$$

Figure 22. Schematic flow chart of the operations included in the algorithm for one time step of the Tasmanian giant crab model. All symbols are as described in Equations (5.3) to (5.15).

h. Calculate the harvest rate, H^t (conditioned on catch C^t) and then multiply H^t by the selectivity for each size-class to spread the harvest rate over all size-classes. Use this to calculate the predicted catch by numbers $X_i^{k,t}$, including weight at size to determine the predicted catch as biomass:

$$H^t = \frac{C^t}{B_E^t} \qquad \mathrm{X}_i^{k,t} = T_i^k V_i^k H^t \tag{5.11}$$

$$\hat{C}^t = \sum_{k=M}^{F} \sum_{i=i}^{L_{\max}} X_i^{k,t} W_i^k \tag{5.12}$$

l. Remove the numbers caught at size from the numbers matrix by multiplying by the survivorship modified by the selectivity curve:

$$N_{i,j}^{k,t+l} = N_{i,j}^{k,t+f} \left(1 - V_i^k H^t\right) \tag{5.13}$$

m. Distribute the recruitment across the first six size classes:

$$N_{i,j}^{k,t+m} = N_{i,j}^{k,t+k} + R_i^t \qquad \text{for i = 1..6} \tag{5.14}$$

n. Remove the final half of natural mortality:

$$N_{i,j}^{k,t+1} = N_{i,j}^{k,t+l} e^{-M/2} \tag{5.15}$$

5.1.2 Recruitment

Instead of estimating an annual recruitment for each year of the fishery, a (geometric) mean recruitment level $\bar{\mathbf{R}}$ is assumed for each region multiplied by a log-normal recruitment residuals ε_t around this mean. This mean recruitment plus a recruitment residual for each year constitute the main parameters of the model. The sex ratio of the annual recruitment is assumed to be 1:1, and recruitment is assumed to occur into the first six size-classes only:

$$R_{1..6}^{k,t} = \bar{R} e^{\varepsilon_t} / 12.0 \tag{5.16}$$

If the model were allowed to fit to the recruitment residuals in an unconstrained fashion there is the possibility of extremely good fits but unrealistically variable recruitment levels. It is usual to set a coefficient of variation for the recruitment residuals (σ_R) and develop a penalty function designed to constrain recruitment variation that is added to the total log-likelihood:

$$Penalty = \frac{\sum_{k=1}^{years} \left(\varepsilon^k\right)^2}{2\sigma_R^2} \tag{5.17}$$

5.1.3 Catches

The harvest rate H^t, the proportion of available or exploitable biomass taken, is calculated by assuming that the total commercial catch including bycatch is taken instantaneously in the middle of the season, after half the natural mortality and growth of those animals that are to moult, has occurred (Eq. (5.11)).

5.1.4 Catchability

Catchability is likely to vary across the seasons and may affect the sex ratio. However, on a yearly time scale seasonal variations should average out across years. A closed form or analytic estimation method is used to estimate the catchability. This involves comparing the observed catch rates with the exploitable biomass that gave rise to the catch rates (Haddon 2001), as described below in the section detailing with the likelihood component relating to catch rates.

5.1.5 Growth Transition Matrix

The growth transition matrix is a square matrix of length equal to the number of size classes, in which only the lower diagonal is populated. The upper diagonal is populated with zeros because negative growth is not assumed to occur. The expected mean growth increment for an animal of length L_i^s (the midpoint of size-class *i*) over a single time period was obtained from the linear regressions of moult increment versus premoult carapace length for both single moults and double moults:

$$\begin{aligned} \overline{\Delta}_i^1 &= a + bL_i^s + \varepsilon && \text{one moult} \\ \overline{\Delta}_i^2 &= 2\left(a + bL_i^s\right) + b(a + bL_i^s) + \varepsilon && \text{two moults} \end{aligned} \tag{5.18}$$

The expected mean length $\overline{L}_i^s$ of an animal of sex *s* and of size-class *i* (identified by the mid-class-length L_i^s) one moult later is:

$$\overline{L}_i^s = L_i^s + \overline{\Delta}_i \tag{5.19}$$

Equation (5.19) is used to generate the growth transition matrix. Detailed descriptions of the intermoult dynamics, and the moulting mortality is provided in the FRDC report.

5.1.6 Size at Maturity

The maturity-at-size P_i for females is described by a standard logistic curve relating the proportion of females mature to their size-class L_i:

$$P_i = \frac{1}{1+e^{-(a+bL_i)}} \tag{5.20}$$

5.1.7 Fecundity at Size

A power relationship (Gardner 1997) is assumed to hold between fecundity O_i and the size-class of female crabs:

$$O_i = cL_i^d \tag{5.21}$$

where c and d are the parameters of the power relationship. Extrusion of eggs tends to occur in May and extends through November into December. This has implications for the fishery because it is illegal to land ovigerous females and the closed season for females only extends to the end of October. All females caught are discarded between May and October, and ovigerous females are discarded at all other times (in practice in November and December). Currently it is assumed that there is no mortality associated with discarding, but this may need to be implemented to investigate the sensitivity of the dynamics to this potential issue. One way of including this discarding of ovigerous females is to alter the selectivity for females to reduce the total retained.

5.1.8 Selectivity

Selectivity of the gear is assumed to match a standard logistic curve. An alternative might be a logistic with a reducing tail for the very large size classes. While no information is available to differentiate between these, both trawl caught specimens and visual observations using benthic cameras do not indicate an abundance of very large crabs, so the second option is less likely. Selectivity is assumed to be described by a logistic curve for both sexes but with independent parameters. A simple logistic is fitted with two parameters, $L50^k$ and $L95^k$, with the k superscript denoting the separate sexes, representing the carapace lengths at which 50% and 95% are selected:

$$\begin{aligned} V_i^{k,t} &= \frac{\pi}{1+e^{-\mathrm{Ln}(19)\left(\frac{i-L50^k}{L95^s-L50^k}\right)}} && LMinL < i < LMaxL \\ V_i^{k,t} &= 0 && i < LMinL, i > LMaxL \end{aligned} \tag{5.22}$$

where $L95^k = L50^k \times Scale95^k$. To ensure that the L95 is greater than the L50 it is made up of the L50 term multiplied by a scaling parameter that is constrained to lie between 1.01 and 1.5.

Changes to selectivity following changes to the legal size limits are accounted for through the use of the *t* subscript and setting particular sizes to zero selectivity depending on the legal limits (Eq. (5.22)). The selectivity for females needs to be modified to account for the closed season for females (May 1 to October 31) and for the average proportion of ovigerous females during the open season. This is implemented by multiplying the selectivity for females by a constant π. This constant can be estimated by multiplying the proportional monthly catch by the monthly proportion of ovigerous females (or by one during the female closed season) to determine the proportion of the total catch of females that can be expected to be ovigerous. For males π is set to 1.0.

Sub-legal and super-legal sized animals are returned to the sea, and currently the model assumes zero discard mortality. A discard mortality could be implemented by increasing the portions of the selectivity curve (Eq. (5.22)) below the legal minimum length and above the legal maximum length from zero to the predicted death rate from being discarded. Thus, if there is a 10% discard mortality then the selectivity values above and below the legal lengths are multiplied by 0.1. The summation of catch would still need to exclude animals from above and below the legal limits as would the estimation of exploitable biomass. This could be implemented by having two selectivity curves for each sex, one with discards and one without, such that the removal of discards from the numbers matrix would not contribute to the landed catch.

5.1.9 Natural Mortality

Natural mortality is modelled in two ways. The first is the background natural mortality rate across all size-classes each year. This is implemented as a survivorship (e^{-M}) with which the matrix of numbers-at-size by years-to-moult is multiplied. In an effort to model some of the within season dynamics, the background natural mortality is implemented by two applications of half the natural survivorship ($e^{-M/2}$), one before fishing mortality occurs and one after.

The second form of natural mortality was implemented as a natural mortality rate associated with moulting. This was modelled as a linear relationship between the instantaneous moulting mortality and size-class. When the linear instantaneous moulting mortality rate is converted to a survivorship it becomes a non-linear descending curve. The vector of survivorships were placed into the diagonal of a square matrix and used to multiply the growth transition matrix for each sex. In this way the moulting mortality was automatically coordinated with growth when it occurs.

5.1.10 Initial Conditions

For many years before the giant crab fishery developed, rock lobster fishers caught predominantly large males as minor bycatch. Very little of this was landed and the stock was essentially unfished until the target fishery developed. Without independent information with regard the state of the stock, it was assumed that the stock was in equilibrium with its mean recruitment level at the time the fishery began.

With a simple growth description that did not require the use of tracking the years-to-moult, the equilibrium numbers-at-size was generated in an analytical fashion. However, the added complexity of the years-to-moult matrix representation meant that the equilibrium conditions needed to be determined iteratively. In practice, the population was initiated by starting with an empty numbers-at-size by years-to-moult matrix (the numbers matrix) and distributing the total recruitment across the first six size-classes. The equilibrium state within the numbers matrix was attained after 200 passages through a routine for updating the stock dynamics in the absence of fishing. The stock dynamics routine involved applying half the natural mortality, identifying those animals that would grow and subtracting them from the numbers matrix. The numbers matrix was then incremented one year forward and the first column of the numbers matrix filled with the numbers-to-moult multiplied by the respective growth transition matrix. There was no fishing mortality so the dynamics moved immediately to removing the last half of natural mortality.

5.2 Likelihood Functions for Model Fitting

5.2.1 Catch Rate Data

Assuming catch rates are log-normally distributed leads to the following likelihood:

$$L_{CE} = \prod_t \frac{1}{I_t \sqrt{2\pi}\sigma_q} \exp\left(-\frac{\left(\mathrm{Ln}I_t - \mathrm{Ln}\left(qB_t^E\right)\right)^2}{2\sigma_q^2} \right) \tag{5.23}$$

where σ_q is the standard deviation of the residual errors around the expected catch rates, I_t is the catch rate for year *t*, and B_E^t is the exploitable biomass after half of natural mortality and growth have occurred. This equation can be greatly simplified as a negative log-likelihood (minimizing this leads to the maximum likelihood estimate):

$$-LL_{CE} = -\frac{n}{2}\left(Ln(2\pi) = 2Ln(\hat{\sigma}) + 1\right) - \sum_{t=1}^{Years} Ln\left(I_t\right) \tag{5.24}$$

For further simplicity the final summation term of Ln(*I*) is a constant and can be omitted without affecting the outcome. The value of $\hat{\sigma}$ can be obtained using the maximum likelihood estimate; note the use of *n* and not *n*-1 in the denominator:

$$\hat{\sigma} = \sqrt{\frac{\sum_{t=1}^{Years}\left(Ln\left(I_t\right) - Ln\left(\hat{I}_t\right)\right)^2}{n}} \tag{5.25}$$

In addition, the maximum likelihood estimate of q, which optimises Eq. (5.24) can be determined analytically as:

$$\hat{q} = \exp\left(\frac{\sum_t Ln\left(I_t / B_t^E \right)}{n} \right) \tag{5.26}$$

where n is the number of years for which catch rates are available (Haddon 2001).

5.2.2 Length Frequency Data

It is assumed that the length-frequency data available will be fitted using a multinomial likelihood (Quinn and Deriso 1999, Haddon 2001). Thus:

$$L_{LF} = n! \prod_{i=1}^{L_{\max}} \frac{p_i^{n_i}}{n_i!} \tag{5.27}$$

where

$$n = \sum_{i=1}^{L_{\max}} n_i \tag{5.28}$$

and p_i are the expected probabilities for each size class i. When this is converted to a negative log-likelihood we obtain:

$$-LL_{LF} = -\sum_{j=1}^{n} Ln\left(j \right) - \sum_{i=1}^{L_{Max}} \left[n_i Ln\left(p_i \right) - \sum_{j=1}^{n_i} Ln\left(j \right) \right] \tag{5.29}$$

The first and last terms are merely the logarithmic form of calculating the factorial terms. For any particular problem these terms are constant and are usually ignored in the calculation of the negative log-likelihood. For added stability the number of observations in each size-class n_i can be converted to proportion by dividing by the sum of all the observations (Quinn and Deriso 1999). We are left with:

$$-LL_{LF} = -\sum_{i=1}^{L_{Max}} \frac{n_i}{n} Ln\left(p_i \right) \tag{5.30}$$

A constant second term that depends only on the observed proportions is added that causes the log-likelihood for the observation to approach zero from below as the model fit improves:

$$-LL_{LF} = -\sqrt{N} \sum_{i=1}^{L_{Max}} \left(\frac{n_i}{n} Ln\left(p_i \right) - \frac{n_i}{n} Ln\left(\frac{n_i}{n} \right) \right) \tag{5.31}$$

and the whole log-likelihood is weighted by a measure of sample size. Because samples which are usually taken in clusters can have a reduced within-cluster variance relative to samples where fish are taken individually, the square root rather than the real the sample size was used as ‘effective’ sample size. When Eq. (5.31) is minimized the match between the observed length frequencies and those predicted by the model is optimised.

5.2.3 Total Likelihood

The model is fitted by combining the various sources of likelihood and the penalty term from the recruitment residuals (Eqs. (5.17), (5.24), and (5.31)). Each of the likelihood terms was weighed with the inverse proportion to their respective variation (i.e. less weight to the more variable). These weights can also be used to explore the relative contribution of each source of likelihood to the final solution:

$$-LL = -LLCE * WtCE + -LLLF * WtLF + \text{Penalty} \tag{5.32}$$

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, almost 90% of the total catch on the West coast was taken by the top 10 fishers, while there have been 10 or fewer fishers since 2001/02 on the East coast.

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 23).

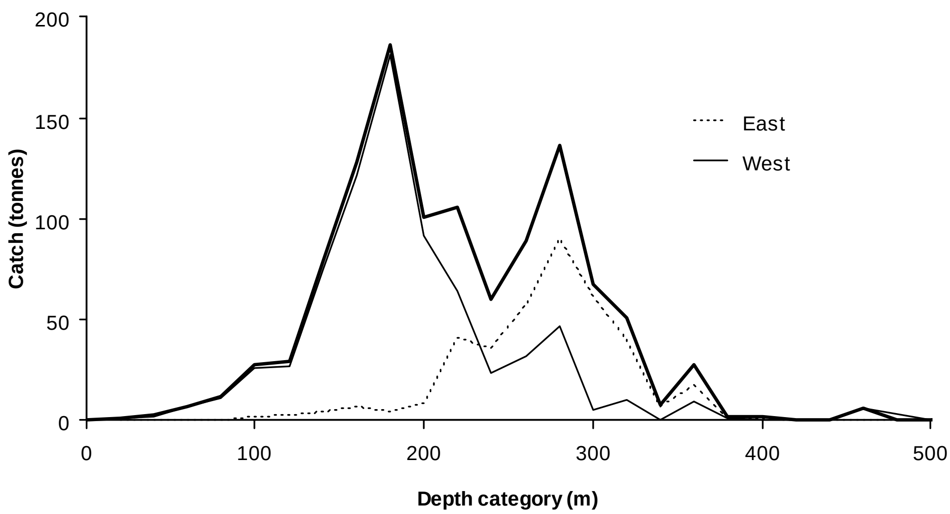

Figure 23. Distribution of total catches by 20m depth category for the West and East coast across the history of the fishery.

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:

$$\text{CPUE} = \frac{\text{Weight of catch (kg)}}{\text{Number of traps} \times \text{Soak time}} \qquad (5.33)$$

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 30º block, and average depth of fishing. With the new management plan in November 1999 setting the total allowable commercial catch (TACC) 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. The data selection was based on vessel rather than skipper because quota licences are attached to vessels. Only vessels that had been in the fishery for a minimum of 2 years with a median catch of at least 1000 kg per year during that period were considered for the analysis. Any remaining vessels 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 4).

Table 4. Overall catch and number of records (Total), and the selected catch and record numbers used in the standardisation for vessels in the fishery for at minimum of 2 years and with a median catch of at least 1000 kg per quota year (Selection) for State-wide Tasmania and each region. East and West are defined as either side of longitude 147ºE.

		Tasmania	West	East
Catch (t)	Total	1122.8	752.3	370.5
	Selection	1012.8	659.0	330.9
	Proportion	90.2%	87.6%	89.3%
Number of records	Total	14019	9599	4420
	Selection	11431	7082	3826
	Proportion	81.5%	73.8%	86.6%

Raw catch rate data were not normally distributed and thus, the data was first natural log-transformed to improved normality before the standardisation (Figure 24 and Figure 25 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, 30º 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).

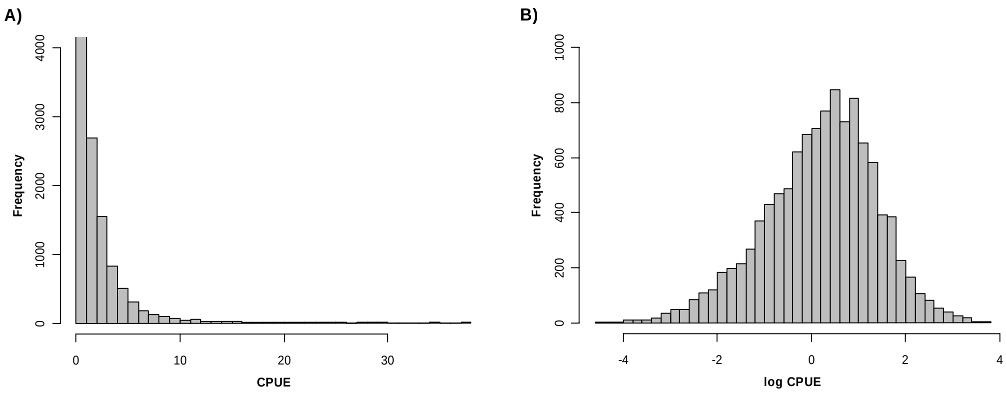

Figure 24. Distribution of (A) State-wide raw catch rate data and (B) natural log-transformed catch rate data.

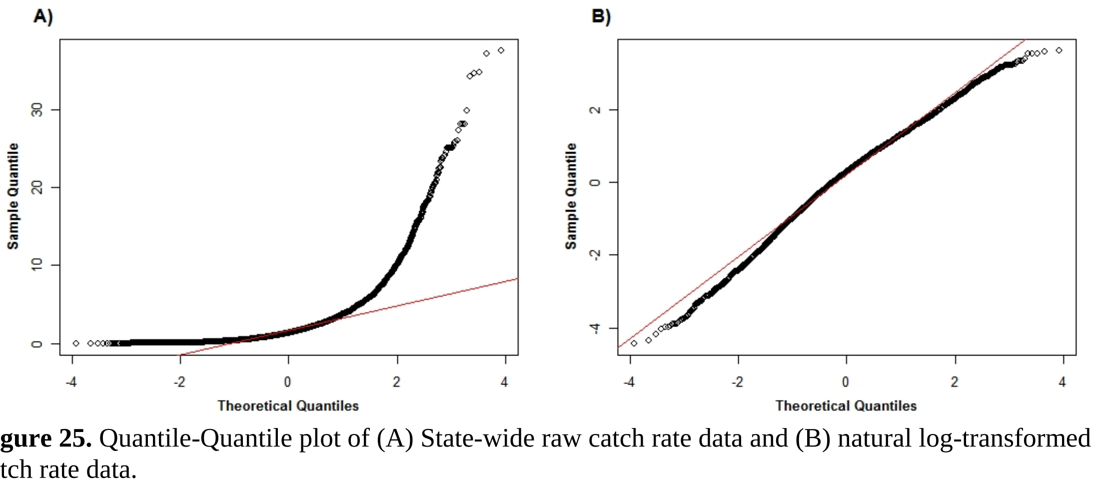

Figure 25. Quantile-Quantile plot of (A) State-wide raw catch rate data and (B) natural log-transformed catch rate data.

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):

$$\mathrm{AIC} = N * \mathrm{Ln}\left(\frac{\mathrm{SSE}}{N}\right) + 2K \tag{5.34}$$

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:

$$R^2 = 1 - \frac{SSE}{SSTO}, \quad R_A^2 = 1 - \frac{\frac{SSE}{n-K}}{\frac{SSTO}{n-1}} = 1 - \left(\frac{n-1}{n-K}\right)\left(\frac{SSE}{SSTO}\right) \tag{5.35}$$

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 an 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, eleven different statistical models were considered for each region (Table 5 to Table 10). The geometric mean by itself (Model 1) accounted for only little of the variability (Tasmania: 11%, West: 17%, East: 16%). The order of factors and their influence varied slightly between regions. The skipper conducting the fishing had greatest influences State-wide and in the West, but not in the East. The month and block of fishing were generally also important. State-wide, the depth at which the fishing occurred was far less important than last year.

Interaction terms substantially improved the fits, with Model 10 providing the optimum fit in all regions with 60% of the variation described State-wide, 64% in the West and 49% in the East. The diagnostics of Model 10 indicated that the fits to the data were reasonable. Containing a three-way interaction term, Model 10 indicated that the interactions between skipper, month and block were very influential, with variable seasonal locations between individual fishers.

Table 5. 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 30º 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	LnCE = C + Qyear
Model 2	LnCE = C + Qyear + Skipper
Model 3	LnCE = C + Qyear + Skipper + Month
Model 4	LnCE = C + Qyear + Skipper + Month + Block
Model 5	LnCE = C + Qyear + Skipper + Month + Block + Traps
Model 6	LnCE = C + Qyear + Skipper + Month + Block + Traps + Depth
Model 7	LnCE = C + Qyear + Skipper + Month + Block + Traps + Depth + Skipper*Month
Model 8	LnCE = C + Qyear + Skipper + Month + Block + Traps + Depth + Skipper*Block
Model 9	LnCE = C + Qyear + Skipper + Month + Block + Traps + Depth + Month*Block
Model 10	LnCE = C + Qyear + Skipper + Month + Block + Traps + Depth + Skipper*Month*Block
Model 11	LnCE = C + Qyear + Skipper + Month + Block + Traps + Depth + Skipper*Month + Month*Block

Table 6. Statistical results from the standardisation of giant crab catch rates for East coast. Models are defined in Table 5. *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, AdjR^2 is the adjusted R^2, and Δ AdjR^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).

Tasmania											
Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
N	10845	10845	10845	10845	10845	10845	10845	10845	10845	**10845**	10845
# Params	12	63	74	133	203	227	504	506	470	**1112**	724
Model SS	1624	3887	4856	5420	6202	6566	7715	7474	7682	**9296**	8442
Resid SS	12891	10628	9660	9096	8313	7950	6801	7042	6834	**5219**	6073
AIC	1899	-93	-1107	-1642	-2478	-2914	-4053	-3672	-4069	**-5707**	-4840
R^2	0.11	0.27	0.34	0.37	0.43	0.45	0.53	0.52	0.53	**0.64**	0.58
AdjR^2	0.11	0.26	0.33	0.37	0.42	0.44	0.51	0.49	0.51	**0.60**	0.55
Δ AdjR^2	0.11	0.15	0.07	0.04	0.05	0.02	0.07	0.05	0.07	**0.16**	0.11

Table 7. 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 30º 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	LnCE = C + Qyear
Model 2	LnCE = C + Qyear + Skipper
Model 3	LnCE = C + Qyear + Skipper + Month
Model 4	LnCE = C + Qyear + Skipper + Month + Traps
Model 5	LnCE = C + Qyear + Skipper + Month + Traps + Block
Model 6	LnCE = C + Qyear + Skipper + Month + Traps + Block + Depth
Model 7	LnCE = C + Qyear + Skipper + Month + Traps + Block + Depth + Skipper*Month
Model 8	LnCE = C + Qyear + Skipper + Month + Traps + Block + Depth + Skipper*Block
Model 9	LnCE = C + Qyear + Skipper + Month + Traps + Block + Depth + Month*Block
Model 10	LnCE = C + Qyear + Skipper + Month + Traps + Block + Depth + Skipper*Month*Block
Model 11	LnCE = C + Qyear + Skipper + Month + Traps + Block + Depth + Skipper*Month + Month*Block

Table 8. Statistical results from the standardisation of giant crab catch rates for East coast. Models are defined in Table 7. *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, AdjR^2 is the adjusted R^2, and Δ AdjR^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).

West											
Model	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
N	6617	6617	6617	6617	6617	6617	6617	6617	6617	**6617**	6617
# Params	12	48	59	116	154	174	369	353	325	**752**	507
Model SS	1726	3237	3879	4643	4891	5144	5832	5717	5596	**6695**	6180
Resid SS	8074	6562	5920	5156	4909	4655	3967	4082	4203	**3104**	3619
AIC	1340	41	-618	-1419	-1668	-1979	-2647	-2491	-2352	**-3504**	-2979
R^2	0.18	0.33	0.40	0.47	0.50	0.52	0.60	0.58	0.57	**0.68**	0.63
AdjR^2	0.17	0.33	0.40	0.46	0.49	0.51	0.57	0.56	0.55	**0.64**	0.60
Δ AdjR^2	0.17	0.15	0.07	0.06	0.02	0.02	0.06	0.05	0.04	**0.13**	0.09

Table 9. 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 30º 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	LnCE = C + Qyear
Model 2	LnCE = C + Qyear + Month
Model 3	LnCE = C + Qyear + Month + Block
Model 4	LnCE = C + Qyear + Month + Block + Skipper
Model 5	LnCE = C + Qyear + Month + Block + Skipper + Traps
Model 6	LnCE = C + Qyear + Month + Block + Skipper + Traps + Depth
Model 7	LnCE = C + Qyear + Month + Block + Skipper + Traps + Depth + Skipper*Month
Model 8	LnCE = C + Qyear + Month + Block + Skipper + Traps + Depth + Skipper*Block
Model 9	LnCE = C + Qyear + Month + Block + Skipper + Traps + Depth + Month*Block
Model 10	LnCE = C + Qyear + Month + Block + Skipper + Traps + Depth + Skipper*Month*Block
Model 11	LnCE = C + Qyear + Month + Block + Skipper + Traps + Depth + Skipper*Month + Month*Block

Table 10. Statistical results from the standardisation of giant crab catch rates for East coast. Models are defined in

Table 9. *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, AdjR^2 is the adjusted R^2, and Δ AdjR^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**
N	3729	3729	3729	3729	3729	3729	3729	3729	3729	**3729**	3729
# Params	12	23	43	62	94	114	187	169	170	**319**	236
Model SS	572	1080	1228	1297	1401	1422	1653	1506	1630	**1883**	1760
Resid SS	2971	2463	2316	2246	2142	2121	1891	2037	1914	**1661**	1783
AIC	-824	-1501	-1691	-1766	-1880	-1876	-2159	-1916	-2148	**-2378**	-2279
R^2	0.16	0.30	0.35	0.37	0.40	0.40	0.47	0.43	0.46	**0.53**	0.50
AdjR^2	0.16	0.30	0.34	0.36	0.38	0.38	0.44	0.40	0.43	**0.49**	0.46
Δ AdjR^2	0.16	0.14	0.04	0.02	0.02	0.00	0.06	0.02	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 26). 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 27). 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 a strong 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.

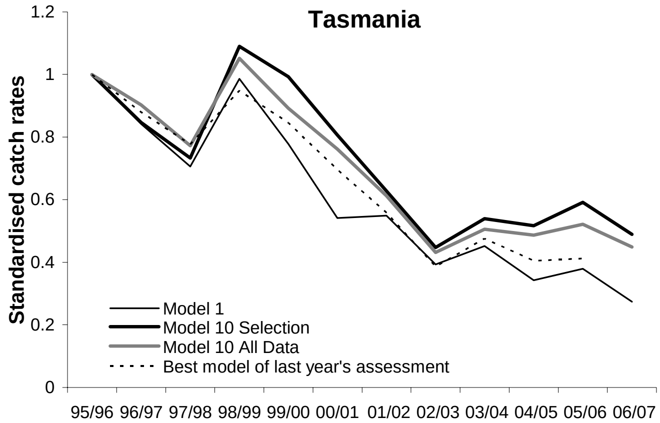

Figure 26. State-wide standardised catch rates derived from Model 1 (geometric mean, thin black line), Model 10 based on selected data when data was restricted to vessels in the fishery for a minimum of 2 years and with a median catch of at least 1000 kg per year (heavy black line), Model 10 based on all data (heavy grey line), and the best model of last year's assessment (dotted line), relative to catch rates in 1995/96.

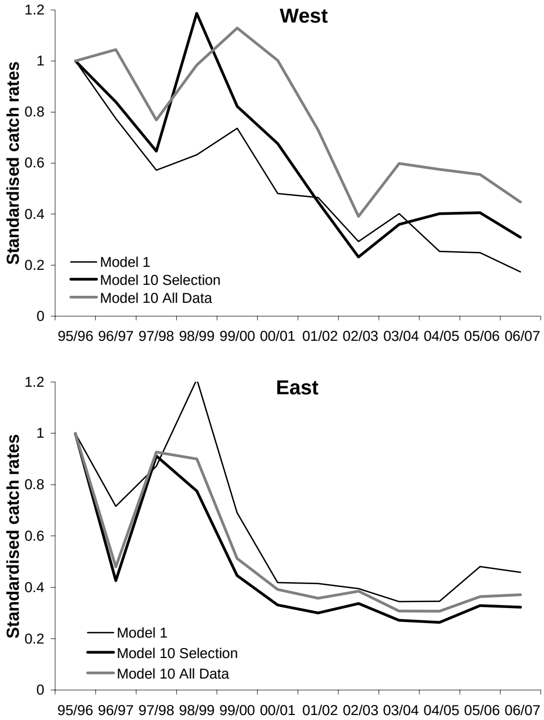

Figure 27. Standardised catch rates derived in the West and East from Model 1 (geometric mean, thin black line), Model 10 based on selected data when data was restricted to vessels in the fishery for a minimum of 2 years and with a median catch of at least 1000 kg per year (heavy black line), and Model 10 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 the East than in the West.

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.

Model 10 with a three-way interaction between skipper, month and block provided the optimum model in all regional analyses, indicating that individual skippers vary their fishing location within a year in different ways.

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.