FISHERY ASSESSMENT REPORT

TASMANIAN GIANT CRAB FISHERY 2004/05

David Mills, Malcolm Haddon and Caleb Gardner

June 2006

tafi
Tasmanian Aquaculture and Fisheries Institute

This assessment of the Tasmanian giant crab resource is produced by the Tasmanian Aquaculture and Fisheries Institute (TAFI). These reports provide summaries of our current understanding of the state of the stocks rather than management recommendations.

Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Private Bag 49, Hobart, Tasmania 7001. E-mail: caleb.gardner@utas.edu.au

Ph. (03) 6227 7277 Fax (03) 6227 8035

Executive summary

This report outlines giant crab fishery statistics for the 2004/2005 quota year and assesses performance against indictors defined in the Giant Crab Management Plan.

This is the first assessment since the total allowable catch (TAC) was reduced from 103.5 tonnes to 62.1 tonnes for the 2004/2005 quota season.

One of the assessable trigger points as defined in the Tasmanian Giant Crab Management Plan was breached in the 2004/2005 year. Total yearly catch was 49.3 tonnes, representing only 79% of the 62.1 tonne TAC, well down on the 90% trigger point. This low catch can be attributed to both a reduction in catch per unit effort (CPUE) when compared with the previous assessment period, plus reduced overall effort for the fishery.

Effort in the 2004/2005 quota year was only marginally higher than the 2003/04 season, which was the lowest since the introduction of quota. Fishers have reported that this low effort was due to low beach prices making fishing un-economical.

None of the trigger points relating to declines in CPUE were activated in the current assessment period. This compares favourably with the last assessment period where the trigger point relating to declines of greater than 20% over 2 years was activated in 3 of the 6 most active assessment areas. CPUE levels are now lower but stable.

Bycatch of crabs retained by lobster fishers was not of concern for the giant crab fishery in the 2004/2005 season, with a reported catch of only 140 kg – well below the trigger point of five tonnes. The potential impact of trawlers remains a concern for operators in the crab fishery although limited information is available on removals and other mortality by trawling. Anecdotal reports from crab fishers indicate that trawling effort is much reduced from previous years.

Trigger points relating to the size structure of the catch as landed at processors were not assessed, as processor splits are not available. Changes in catch size structure is now being obtained in greater resolution through on-board sampling by fishers with electronic loggers.

This is the first giant crab assessment report to include stock assessment modelling, and employs a size-based model developed within a recently completed project funded by the Fisheries Research and Development Corporation (FRDC 2001/049).

The model output suggests that without significant external impacts (*e.g.* an increase in trawl interactions) the current TAC of 62.1 t should lead to gradual stock rebuilding over the next 5 to 10 years. Conversely, under a TAC of 100 t, there is only a 50% chance of any stock rebuilding over the next 10 years. With a TAC of 100 t, there is also a 50% chance that the stock will decline over the next 10 years.

Updates about ongoing and new research into crab habitat and trawl interactions, ghost fishing and reassessing the optimum size limits for the giant crab fishery are provided.

Performance indicator	Trigger point	Status in 2004/05	
Statewide commercial catch rates	Declines in successive years	✔	Increased in 03/04 season
Regional commercial catch rates	Declines by 20% in 2 years	✔	East -5%, West +39%
Total yearly catch	Yearly catch < 90% of TAC	✕	79% of TAC taken
Bycatch by lobster fishers	Catch > 5 tonnes	✔	135 kg reported
Proportion of catch over 5 kg	Varies 30% from reference year	N/A	Data unavailable
Proportion of catch below 3 kg	Varies 30% from reference year	N/A	Data unavailable

1. Introduction

This is the fifth formal stock assessment of the Tasmanian giant crab fishery resource, and the assessment now includes the period from March 1, 2004 to February 28, 2005. The report assesses performance against indicators defined in the Giant Crab Management Plan, it provides forecasts of the likely response of the fishery to total allowable catches (TACs) set at a range of values, and summarises current research being conducted at TAFI into giant crab fishery ecology and biology.

The giant crab fishery became established in the mid 1990's when stable markets were first established, but catches have declined rapidly since a peak in 1994/95 (Figure 1). An initial response to this rapid decline was to introduce quota management, and in November 1999 a TACC of 103.5 tonnes was introduced. In response to further declines in catch per unit effort (CPUE) in much of the fishery, and poor performance against indicators in the 2002/2003 assessment (Gardner *et al.* 2004), the TACC was further reduced to 62.1 tonnes for the 2004/2005 quota season.

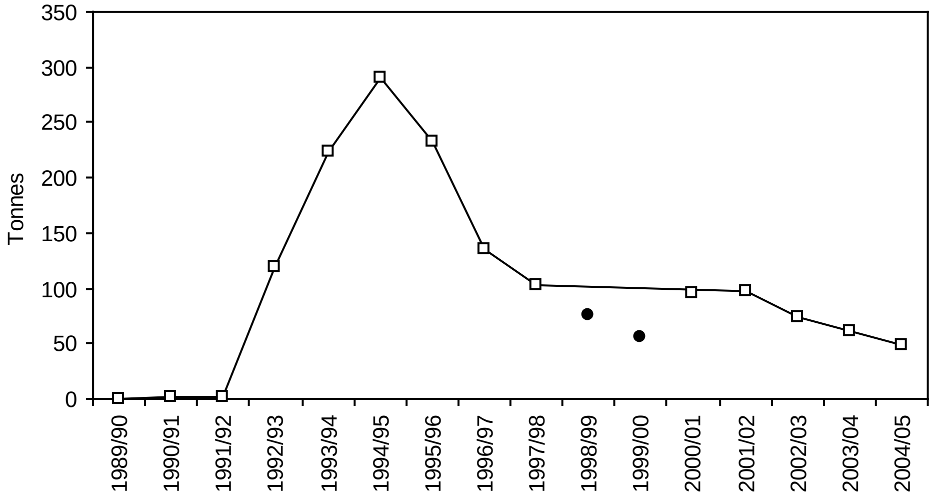


Figure 1. Historical giant crab catches in Tasmania. Catches in 1998/99 and 1999/00 (solid circles) were from partial fishing years due to an extended seasonal closure to allow revision of management arrangements.

2. Fishery assessment

Evaluation of trigger points

Commercial catch rates

Two trigger points relate to changes in commercial catch rates. The data used in this analysis is drawn from commercial logbooks. Logbook data prior to January 1995 does not include a measure of effort (as number of traps) so that data cannot be used for calculation of CPUE.

Data used for calculating catch rate has been “cleaned” for a range of factors:

1. misreporting of effort appeared to be a common problem early in the fishery and records that are less reliable have been excluded from our analyses. These exclusions were based on outliers in catch and effort data as described in the final report - FRDC2001/042.

2. Crabs are often taken incidentally to lobster fishing and catch rates under these situations are quite different to when crabs are targeted. We have restricted the analysis of catch rates to targeted effort. Fishers record if effort is targeted in the current logbooks although this was not the case prior to 2000. In earlier records, we have identified effort targeted to crabs using a set of criteria based upon depth, catch of lobsters/crabs, skipper and soak patterns (FRDC2001/042).

3. A few experienced fishers with vessels and gear more suited to crabs take most crab catch. Fishers with a smaller quota holding tend to have much lower catch rates as most of their fishing effort is directed to lobsters. The inclusion of those fishers with small catches tends to bias catch rate data. We have presented information here both for all fishers, and for data restricted to catches by fishers with an annual catch of at least two tonnes. In practice this data restriction has a negligible impact on catch rates, despite much discussion of the issue in response to previous assessments.

4. The soak time used by crab fishers varies with some leaving traps for extended periods. We have demonstrated previously that longer soak times leads to higher catch rates, although beyond 7 days there is little additional benefit. Effort in catch rate analyses presented here has been standardised to the number of 24 hour pot-days up to a maximum of 7 days.

Statewide commercial catch rates

The trigger point relating to a statewide decline in catch rate in successive years was not activated, as CPUE increased considerably in the 2003/04 quota year. While some reduction from this high occurred in the current quota year (Figure 2), statewide CPUE remains higher than at it's lowest point in 2002/03.

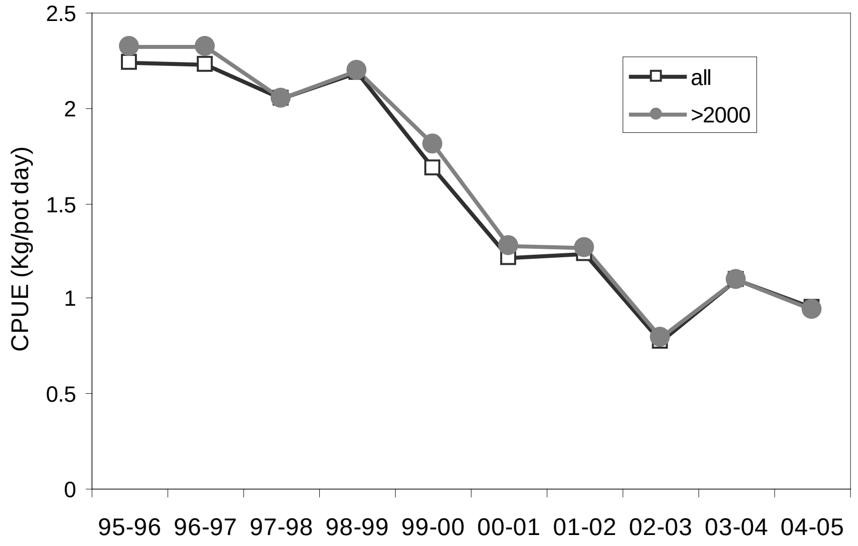


Figure 2. Trends in annual catch per unit effort statewide since 1995/96. Years are split by quota years (March –February). Effort is in standard pot days (see point 4. above). The line with open squares is with all fishers data included. The line with filled circles is with data restricted to fishers who caught over 2000kg in at least one quota year.

Seasonal patterns in CPUE (Figure 3) show catch rates in the 2004/05 quota season were generally more consistent throughout the year than in previous years. Catch rates tended to be lower than usual in summer months, but this was to a degree compensated for by higher catch rates in winter months. Higher catch rates in winter months are seen as a positive thing for the industry, as beach prices are generally higher during winter.

Effort in the 2004/05 quota season was only marginally higher than that in the previous year, which was the lowest since the introduction of quota (Figure 4). Seasonal patterns of effort (Figure 5) show that effort in the latter part of the quota year was consistently lower than in recent years. This coincided with a period of lower catch rates on the west coast, and low beach prices.

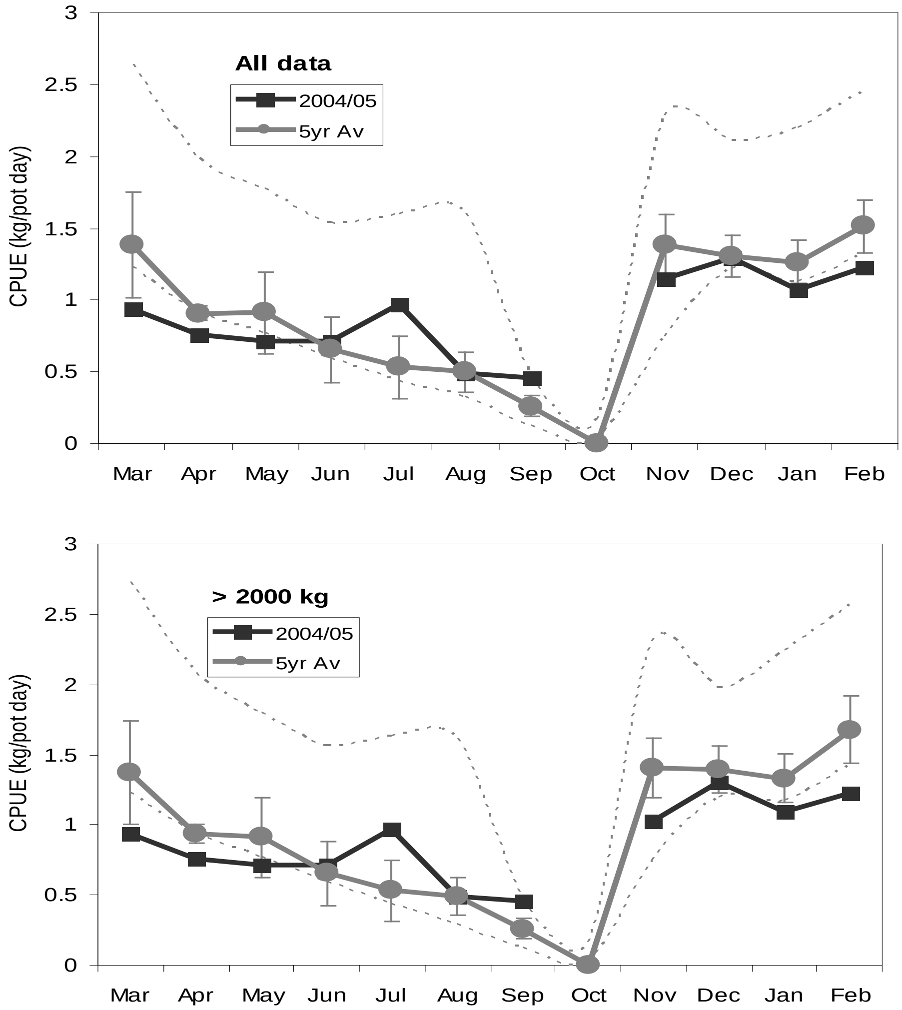


Figure 3. Statewide seasonal trends in CPUE. The upper graph includes all data, while the lower graph excludes catches from fishers who have not caught more than 2000 kg of crab in any past season. Broken grey lines represent 95% confidence intervals for all data since reliable records were available (1995).

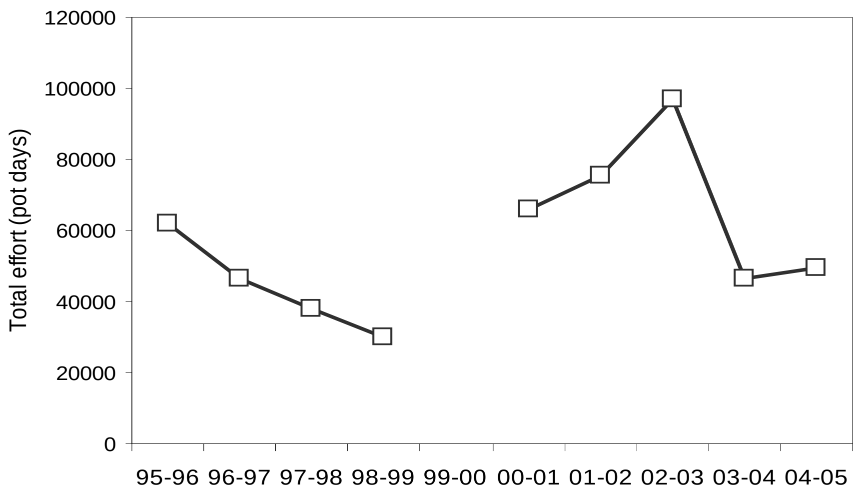


Figure 4. Total effort (pot days) for years since reliable records were available.

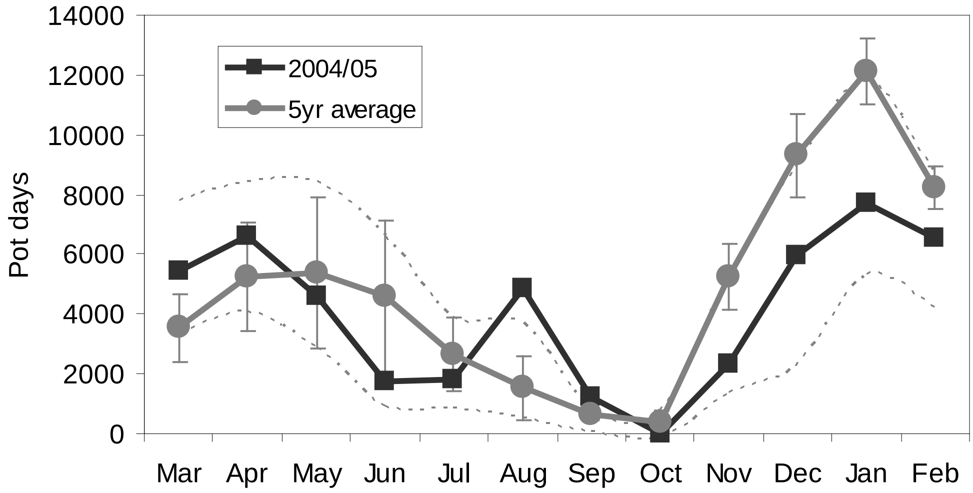


Figure 5. Seasonal trends in effort for 2004/05 (black line), average for the preceding 5 yrs (grey line) and 95% confidence limits for all data since reliable records began (broken grey lines).

Regional commercial catch rates

The second trigger relating to CPUE is activated if "CPUE for any region declines by a total of 20% in two years". As in previous years, a pattern of high inter-annual variability of catch rates within the 8 assessment areas is evident in the 2004/05 catch statistics (Figure 6). This trigger point was not activated for any of the 8 assessment areas, or for the assessment areas grouped by east and west coast (Table 1,Table 2). In the previous assessment (2003/04), this trigger point was breached in areas 2, 6, and 7.

Catch for east coast assessment areas combined show a continuing trend of stability, while catch rates on the west coast are far more volatile (Figure 7). West coast catch rates are down substantially from the previous quota year, and this was driven largely by a 49% decrease in catch rates from assessment area 5, which produced 18.4% of the total catch in 2004/05.

While reductions in catch rates over 1 year exceeded 20% for area 5 and for west coast assessment areas combined, none of the major assessment areas (areas 2-7) declined by 20% over 2 years. This must, however, be viewed in the context that catch rates 2 years ago were the lowest since reliable records are available. The greatest decline in CPUE over 2 years (18 %, Table 3) was seen in area 4 (NE) which produced 32.2% of the total catch in the 2004/05 quota year. Assessment area 2 shows consistently large increases in CPUE over one, two and four years, however only 1.9 % of the 2004/05 catch came from this area.

Previous assessments have examined changes in fisheries over 5 year periods. In this instance, 5 years previous to 2004/05 coincides with the 1999/00 quota year, in which little fishing occurred due to an extended seasonal closure while quota was introduced. Accordingly, changes for periods of 4 and 6 years are presented.

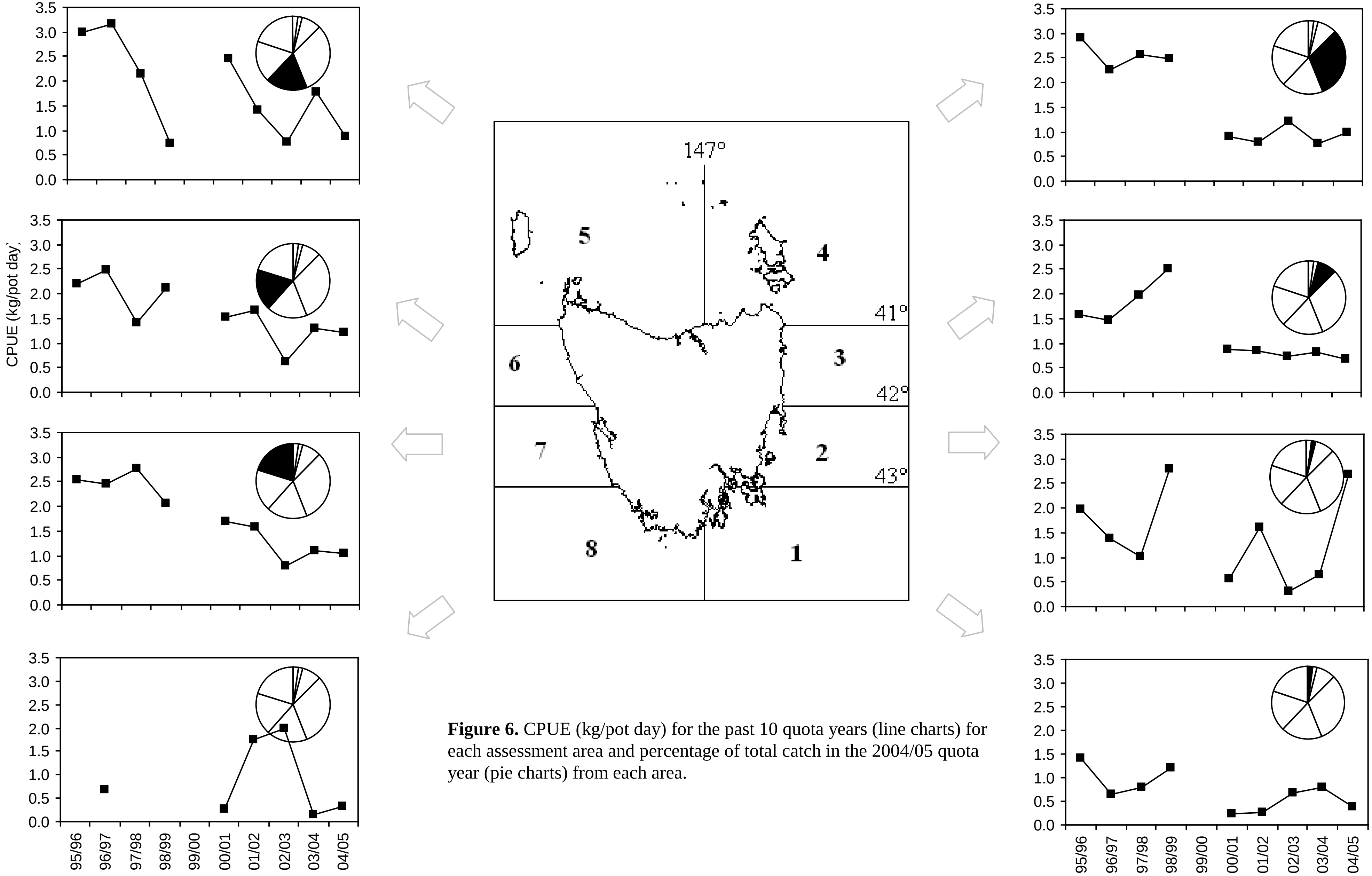
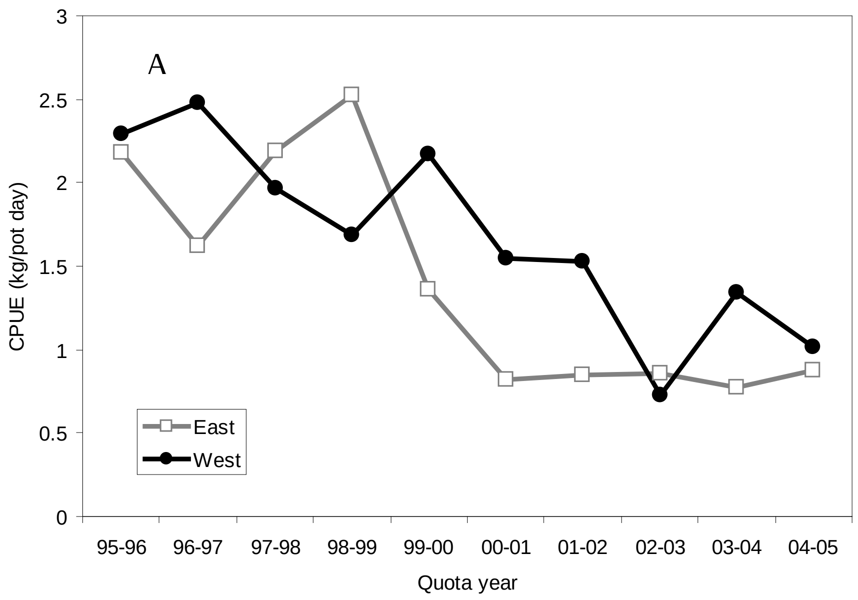


Figure 6. CPUE (kg/pot day) for the past 10 quota years (line charts) for each assessment area and percentage of total catch in the 2004/05 quota year (pie charts) from each area.



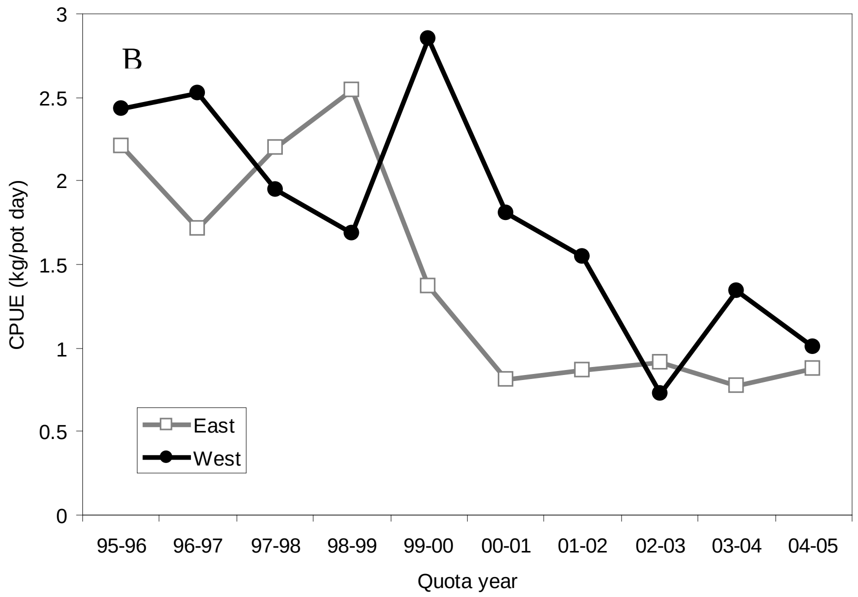


Figure 7. Trends in annual catch per unit effort for the east (Assessment Areas 1-4) and the west coasts (Assessment Areas 5-8) since 1995/96. Years are split by quota years (March –February). **A**- all fishers data included. **B** – data restricted to fishers who caught over 2000kg in at least one quota year.

Table 1. Catch per unit effort (CPUE) in each assessment area for the 2004/2005 quota year relative to CPUE 5, 2 and 1 year ago. All fisher's data included.

Area	CPUE 98/99	CPUE 00/01	CPUE 02/03	CPUE 03/04	CPUE 04/05	% Change 6 years	% Change 4 years	% Change 2 years	% Change 1 year
East	2.52	0.82	0.85	0.77	0.87	-65	+6	+2	+13
West	1.68	1.55	0.75	1.33	1.02	-39	-34	36	-23
2	2.79	0.56	0.31	0.66	2.68	-4	+379	+765	+306
3	2.5	0.87	0.72	0.83	0.69	-72	-21	-4	-17
4	2.47	0.93	1.03	0.76	0.99	-60	+6	-4	+30
5	0.75	1.71	0.75	1.72	0.88	+17	-49	+17	-49
6	2.13	1.41	0.67	1.24	1.21	-43	-14	+81	-2
7	2.05	1.69	0.8	1.11	1.06	-48	-37	+33	-5

Table 2. Catch per unit effort (CPUE) in each assessment area for the 2004/2005 quota year relative to CPUE 5, 2 and 1 year ago. Data restricted to fishers who caught over 2000kg in at least one quota year.

Area	CPUE 98/99	CPUE 00/01	CPUE 02/03	CPUE 03/04	CPUE 04/05	% Change 6 years	% Change 4 years	% Change 2 years	% Change 1 year
East	2.52	0.81	0.92	0.77	0.87	-65	+7	-5	+13
West	1.68	1.8	0.73	1.34	1.01	-40	-44	+38	-25
2	2.79	0.56	0.31	0.66	2.68	-4	+379	+765	+306
3	2.5	0.87	0.72	0.83	0.69	-72	-21	-4	-17
4	2.47	0.91	1.2	0.76	0.99	-60	+9	-18	+30
5	0.73	2.44	0.75	1.77	0.88	+21	-64	+17	-50
6	2.13	1.51	0.62	1.29	1.21	-43	-20	+95	-6
7	2.05	1.71	0.8	1.1	1.02	-50	-40	+28	-7

Seasonal variation in catch rates

While there are no management trigger points relating directly to seasonal changes in catch rates, this analysis provides additional detail concerning the mechanisms behind any observed changes in annual catch rates.

Seasonal patterns in catch rates on the east coast were fairly consistent with those seen over the past 5 years. The exception is very high catch rates in December, a month that yielded 7.8% of the catch taken on the east coast in 2004/05, yet accounted for only 3.7% of east coast effort.

West coast catch rates were down on recent years at either end of the assessment period (April – June, November- February), but were similar to previous years for winter months (July – September).

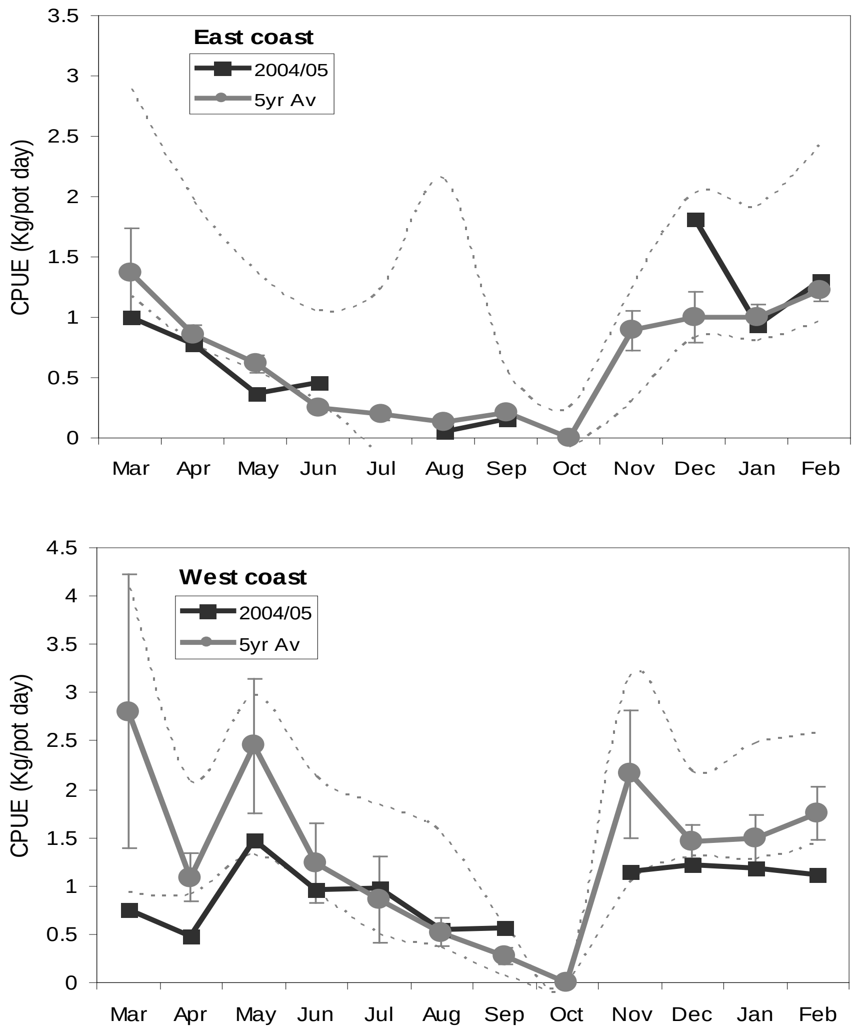
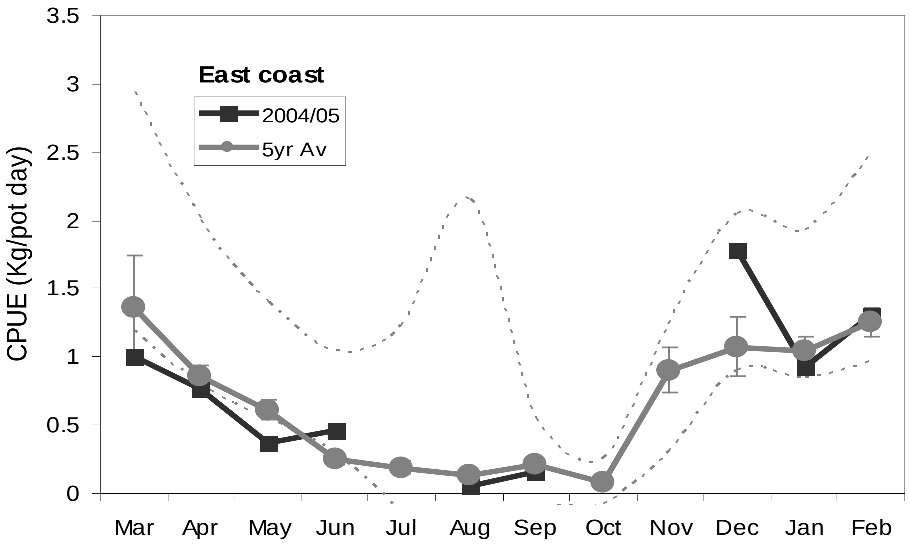


Figure 8. Seasonal variation in CPUE for the east and west coasts for the 2005/05 quota year (black lines), and average over the previous 5 quota years (grey line). **Data from all fishers are included in this graph**. Broken grey lines represent 95% confidence intervals for all data since reliable records were available (1995).



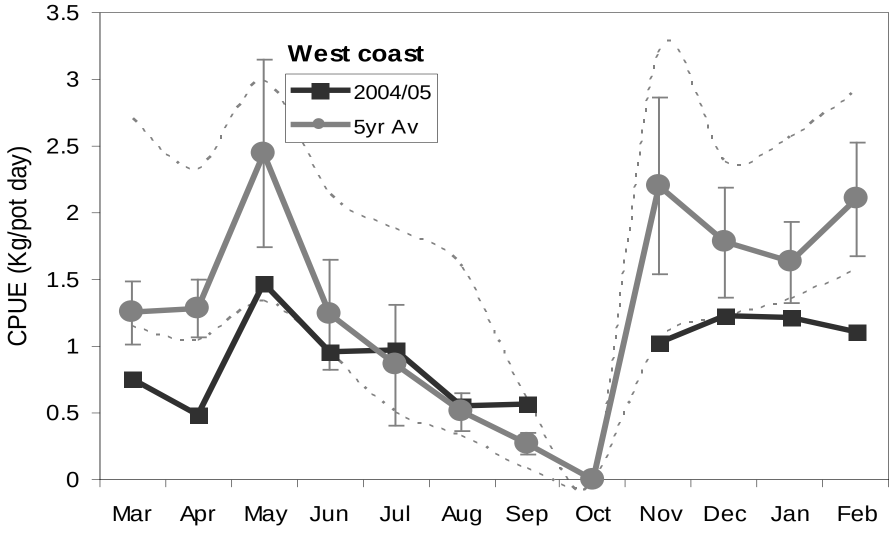


Figure 9. Seasonal variation in CPUE for the east and west coasts for the 2005/05 quota year (black lines), and average over the previous 5 quota years (grey line). **Data only from fishers who have caught more than 2000 kg of crabs in any one quota year are included in this graph**. Broken grey lines represent 95% confidence intervals for all data since reliable records were available (1995).

Total annual commercial catch

The trigger point relating to total catch is activated if the catch for a given assessment period falls below 90% of the TAC. Total catch for the current assessment period was 49.3 tonnes, representing 79% of the 62.1 tonne TAC.

This low total catch was largely driven by reduced effort in the latter part of the assessment period (Figure 11), although seasonal distribution of effort varied considerably between the east and west coasts.

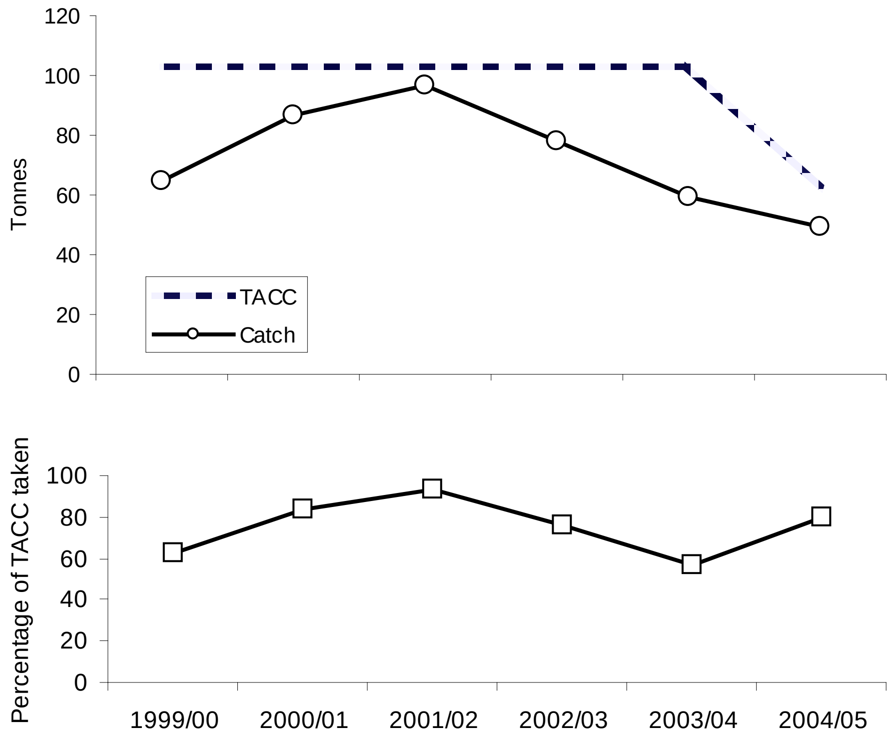


Figure 10. Total catches (from logbook records) since quota management was introduced. The top graph shows total catches and TACC, while the lower shows the percentage of the TACC caught in each year.

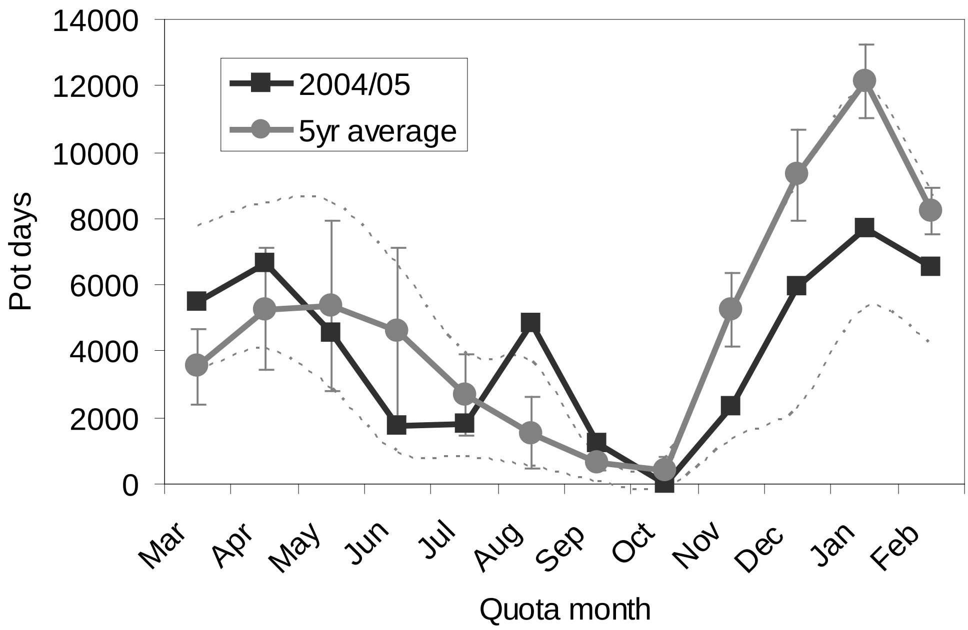


Figure 11. Statewide seasonal trends in effort for the 2004/05 quota year (black line), average for the 5 previous yeas (grey line) and 95% confidence limits for all data since reliable records were available (broken grey lines).

Effort on the west coast in the first four months of the assessment period was very low, and this was a response to low catch rates during this period (Pers. Comm from several fishers, see figures 8 and 9). Conversely, effort on the east coast over the same period was uncharacteristically high when compared with recent years (Figure 12). East coast effort tended to be lower in the latter half of the season, while over the same period on the west coast there were 2 months with relatively high effort, and 2 months with average to low effort.

Spatial distribution of the catch

The catch in the current assessment period comprised 20.7 tonnes (42%) from the east coast, and 28.6 tonnes (57%) taken from the west coast. This is the highest proportion taken from the east coast since the introduction of quota, although it is only marginally higher than in 2002/03 (Figure 13). Increases on the east coast were driven entirely by a

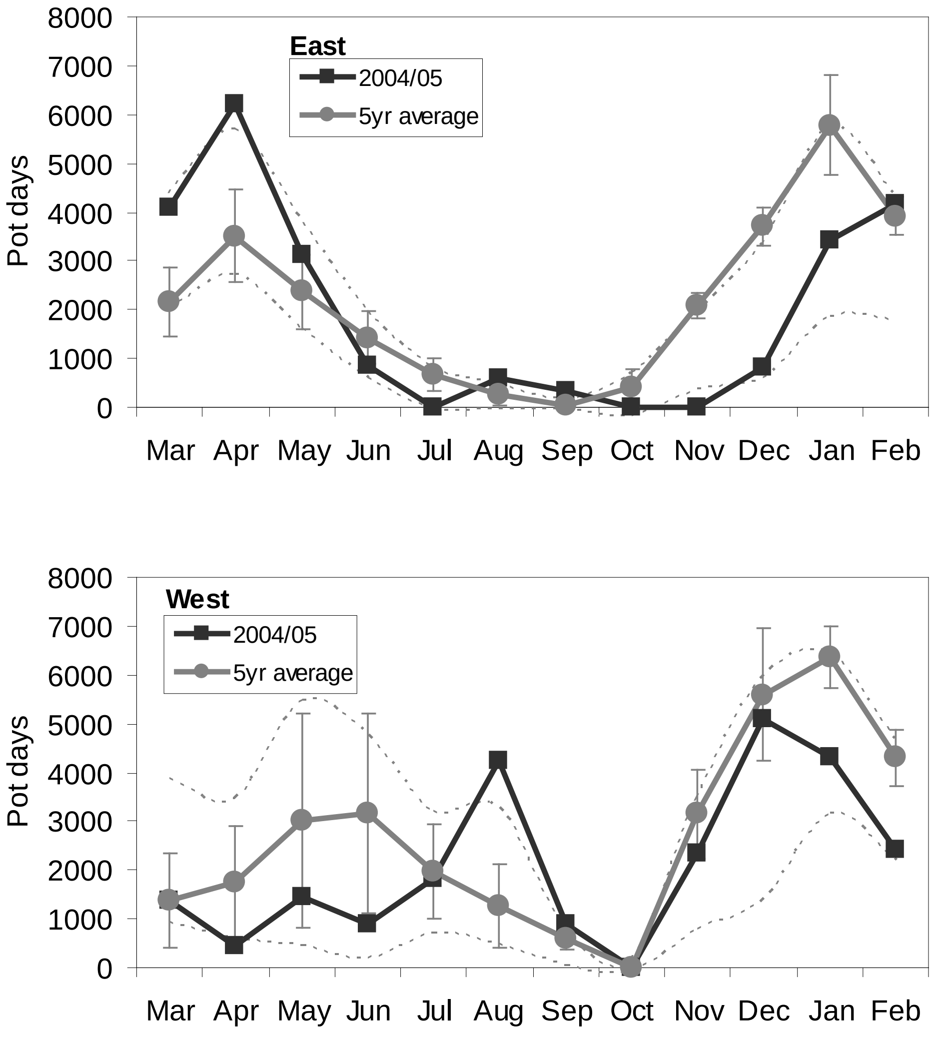


Figure 12. Seasonal trends in effort for the east and west coasts in the 2004/05 quota year (black line), average for the 5 previous yeas (grey line) and 95% confidence limits for all data since reliable records were available (broken grey lines).

continuing trend of increased catch from assessment area 4 (NE). There was a corresponding decline in the proportion of catch taken from 2 of the 3 productive assessment blocks (5 and 7) on the west coast.

Bycatch from the lobster fishery

The trigger point relating to bycatch of crabs by the lobster fishery is set at 5 t, which represents 8% of the current TAC. Each year since the introduction of quota management, bycatch from the lobster fishery has not exceeded 1.1 t (in 2000/01), and in the 2004/05 assessment period was 135 kg, or 0.3% of the landed catch (Figure 14).

Size distribution of commercial catch

There are 2 trigger points in the current management plan relating to the size distribution of the commercial catch:

- The proportion of the catch above 5kg varies by more than 30% compared to the 1996/97 distribution;
- The proportion of the catch below 3 kg varies by more than 30% compared to the 1996/97 distribution.

In the past, the only size information available for assessment purposes has been the ‘size splits’ obtained from processors. These are the size groupings by which processors determine the price of crabs, and in recent years smaller crabs have been more highly valued. Accordingly, these data must be interpreted with caution, as fishers are able to target fish of different size by varying the depth at which they fish. These size-split data have not been available for the last 2 assessment periods.

A voluntary measurement system using digital callipers and data loggers is now providing a far more accurate measure of size composition of the catch. Fishers measure all catch, not just retained animals, and data are accurate to within a few millimetres. Using this system, over 20,000 crabs have been measured in the past 3 quota years. These data have been incorporated into the stock assessment model outlined in section 2 of this report.

Limited data on size distribution of the catch can also be obtained directly from logbook returns, as fishers record the number of undersized discards. The catch of undersized crabs has been increasing on both the east and west coasts over recent years (Figure 15). Superficially, this appears to be a good sign for the fishery, and may indeed be a precursor to increased recruitment in the future. However, a note of caution is that these trends may be artefacts of behavioural interactions between crabs around traps. It is possible that larger crabs aggressively inhibit small crabs from entering traps, such that as the catch rates of large crabs decrease, smaller crabs are more likely to enter traps, masking true changes in abundance of undersized crabs. This phenomenon that has been documented in the Tasmanian lobster fishery (Frusher et al., 2003; Green et al., in review). While fluctuations in catch rates over the last few years on the east coast have been small, a degree of ‘mirroring’ between rates for undersized and legal crabs is apparent. This pattern is consistent with the operation of such a behavioural mechanism.

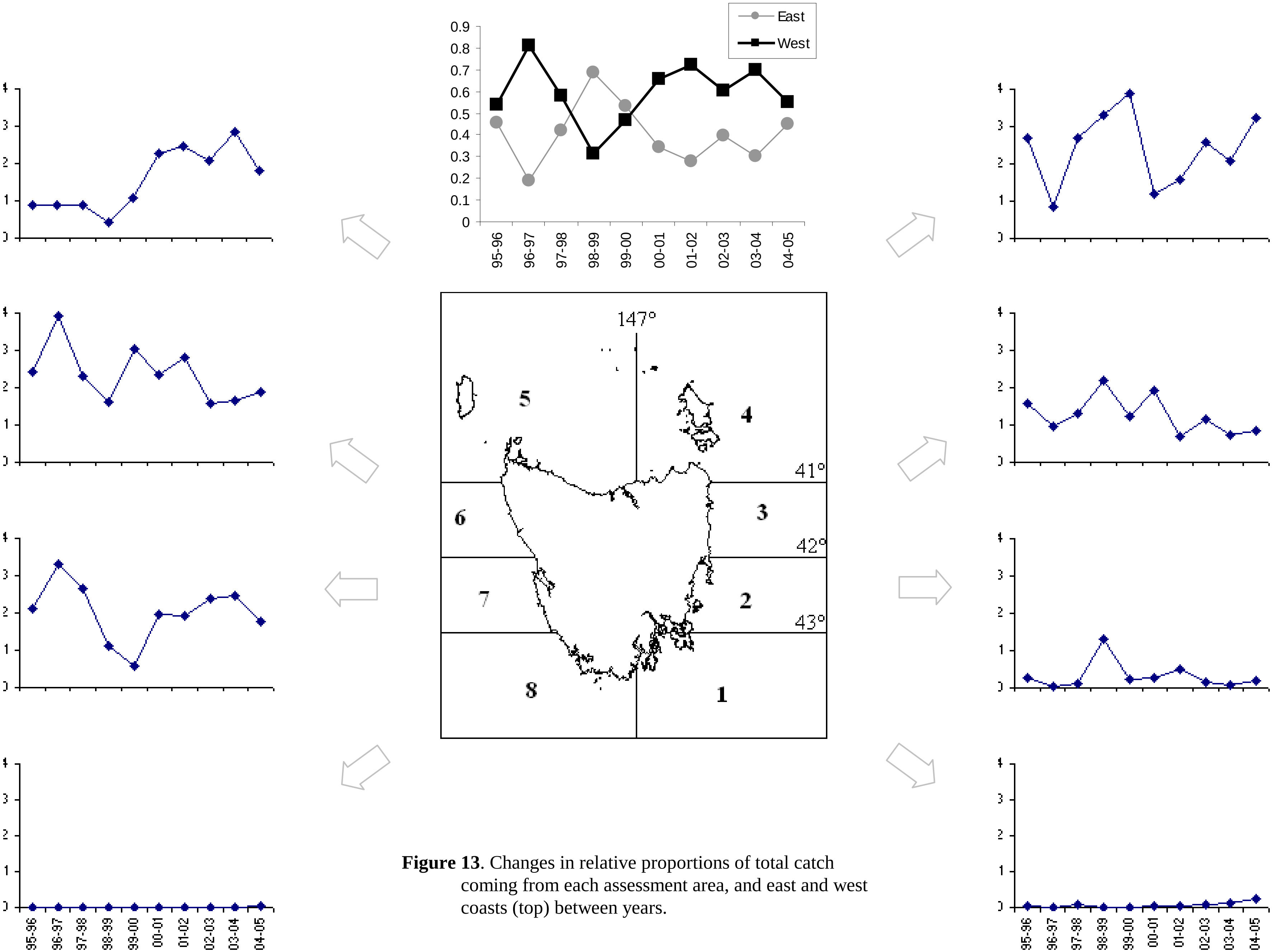


Figure 13. Changes in relative proportions of total catch coming from each assessment area, and east and west coasts (top) between years.

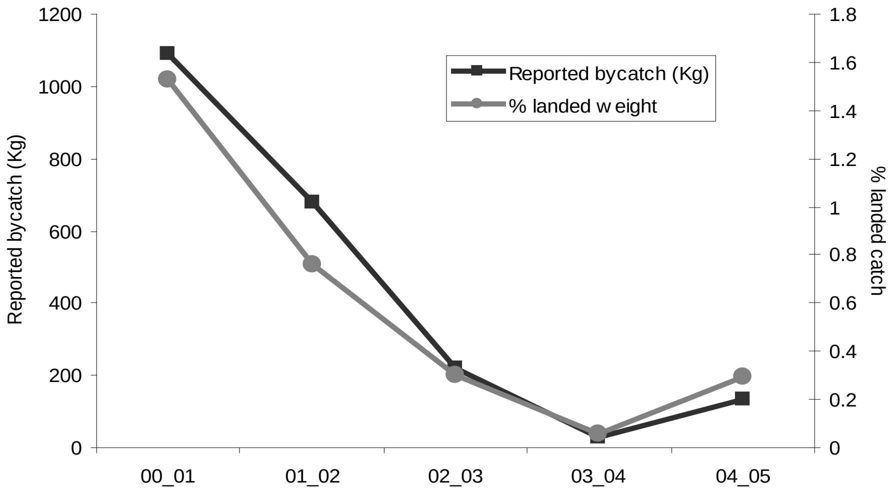


Figure 14. Total reported bycatch from the rock lobster fishery.

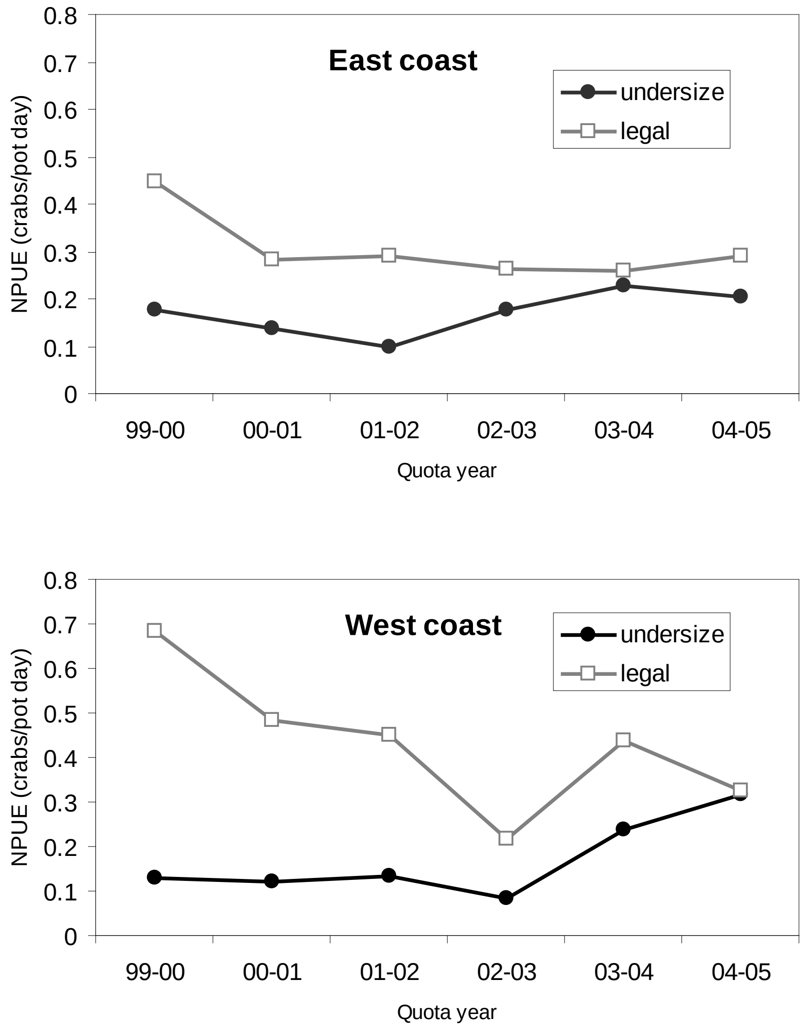


Figure 15. Number of crabs per unit effort for the east and west coast.

Other analyses

Structure of catches

Fishers record the sex of retained catch, and the number of undersized crabs discarded. Average weight can be calculated from logbooks and sales dockets. These data provide useful insights into the population structure

The productive assessment areas on the east coast (areas 3 and 4, providing 90.1% of the 2004/05 east coast catch) show relative stability in proportions of female and undersized crabs, and average weight, as does area 6 on the west coast (Figure 16). Area 5 shows a large decrease in the proportion for females in the catch, down from 52% in 2003/04 to 20% in 2004/05, contrasting with generally high proportions of females for the current assessment period (Figure 17). There is a corresponding increase in the proportion of undersized crabs in this area, up from 50% in 2003/04 to 69%. Note also that this area also suffered a 23% reduction in CPUE in the since the previous assessment period.

Figure 16. Inter-annual change in the proportion (based on numbers of individuals) of females in retained catch (solid squares), proportion of undersize in catch (hollow diamonds), and mean weight (heavy line) for each assessment area.

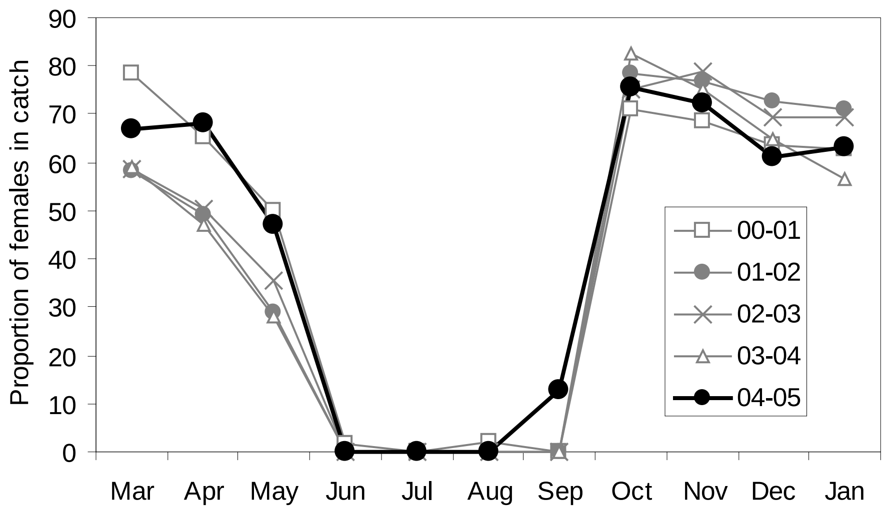


Figure 17. The proportion of retained giant crabs that were female for each month since November 1999. Note these proportions are based on number of individuals, not weight, and that a proportion of 0.75 equates to catch comprised of three females for every male.

Bycatch

Bycatch is defined as any non-target species that are caught during fishing operations. The best available information on species caught as bycatch comes from surveys conducted in 2001/02, when this information was collected as part of an FRDC project aimed at improving giant crab assessment techniques. The most common species, in order of abundance were the antlered crab *Paromola petterdi*, hermits crabs (*Strigipagurus strigimanus* and *Dardanus arrosor*) and pink ling *Genypterus blacodes*.

An improved system for bycatch reporting has been implemented to provide bycatch data on an ongoing basis. To this end, disposable cameras have been provided to fishers with instructions to photograph bycatch from every second trap. Photos are to be taken whether there is bycatch present or not.

Byproduct

Byproduct differs from bycatch in that it is retained, possibly for sale. There appears to be a problem with byproduct reporting in the fishery. In the past 3 years only 1 wrasse has been reported. The problem may be one of what fishers define as constituting byproduct. A clear definition is required so fishers know whether they are to record all fish retained from a catch for whatever purpose (private consumption, bait etc) or only fish sold to market.

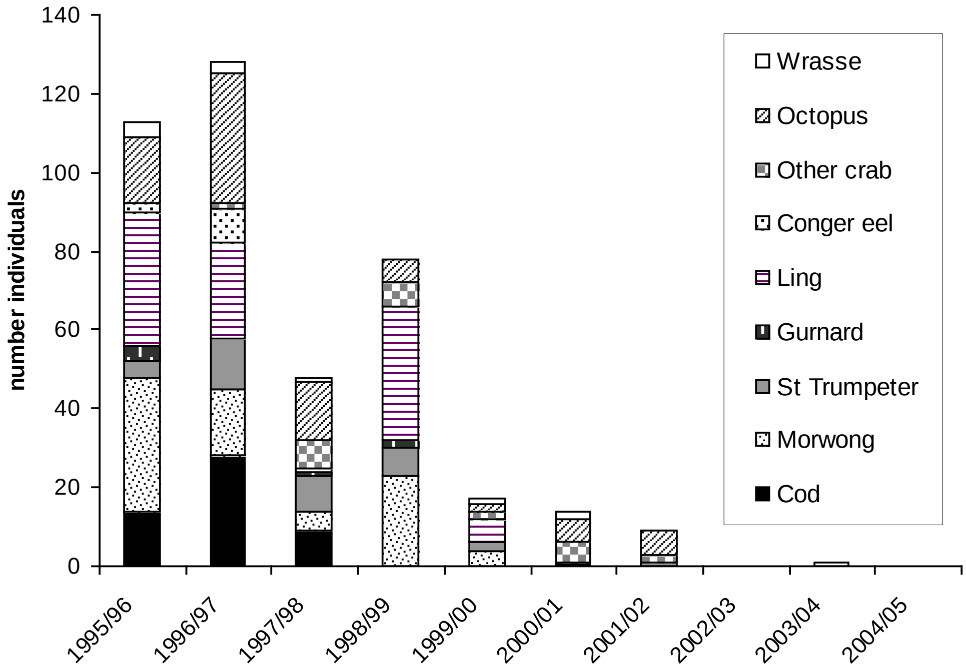


Figure 18. Reported byproduct from the fishery since the 1995/96 quota year.

Protected Species Interactions

Protected species interaction data are available for the rock lobster and crab fisheries for 2004/05. Rock lobster data have been included here as the similarlity in fishing methods is likely to give rise to similar types of interraction. As the crab fishery is further off-shore, interractions with coastal species (*e.g.* cormorants) would be limited or non-existant.

For the period 2004/05, 237 protected species interactions were reported by lobster fishers. The majority of these reports simply indicated that an interaction had occurred so the species and fate of the protected species was unknown (Figure 19). Approximately 26% of reported interactions (n=56) provided details of the species involved with all of these including seals, except a single reporting of whales swimming near the fishing vessel.

Distribution of interactions around the State was clustered with hotspots for reporting off King Island, St Helens and Tasman Peninsular (Figure 20). Reports from King Island and St Helens are relevant to the crab fishery. These areas are not known for especially higher density of seals and represent clustering of reporting effort by individual fishers rather than necessarily density of interactions. This type of human artefact would be expected as the reporting requirement for “interaction” is ambiguous: some fishers consider that a seal eating discarded bait is an interaction, while others do not. This point is clearly made by the reported whale interaction – one fisher considered that seeing a whale from their vessel constituted an interaction, yet this common event was otherwise unreported.

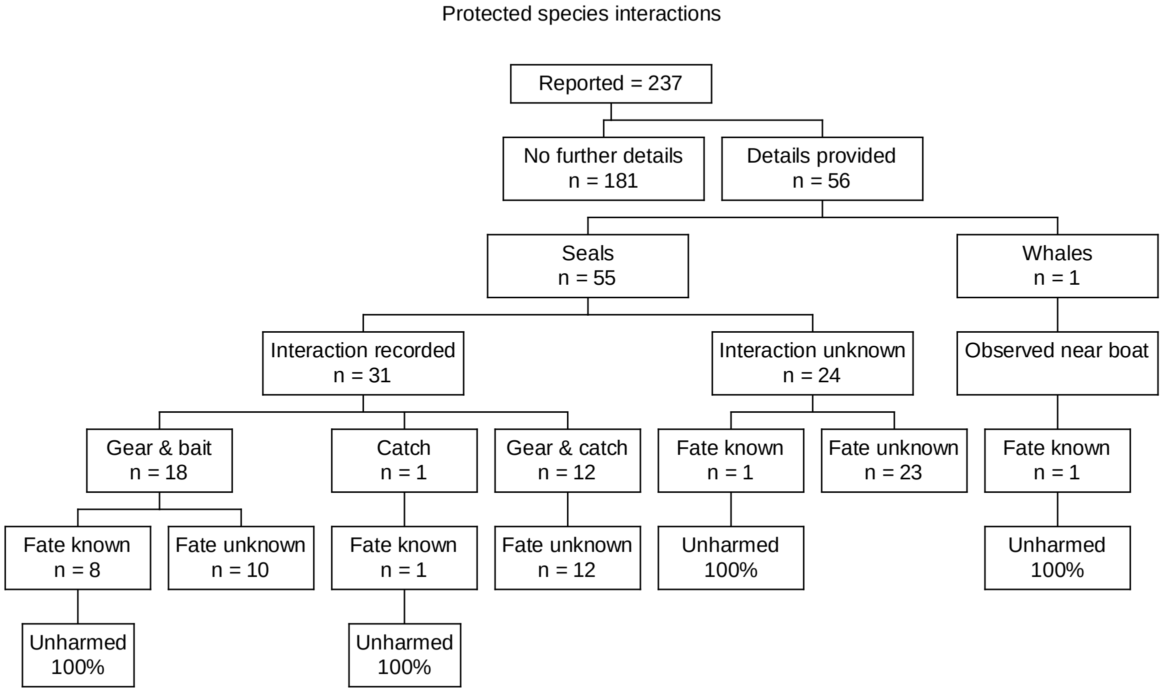


Figure 19. Schematic of reported interactions between commercial fishers and protected species.

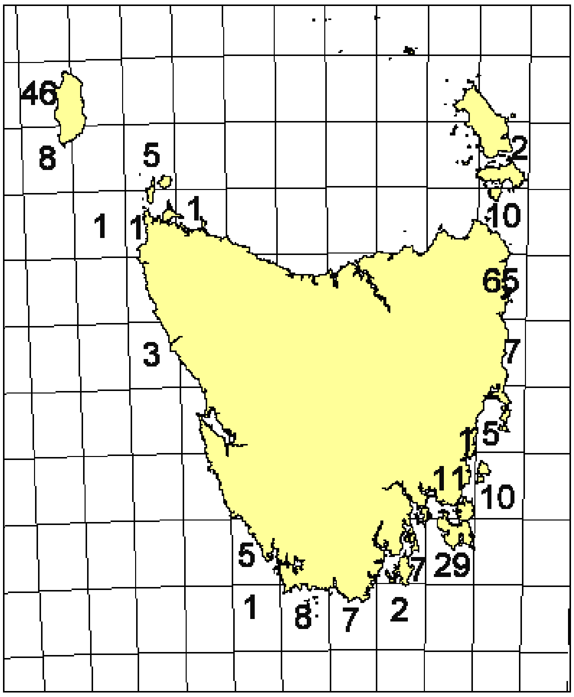


Figure 20. Distribution of reported protected species interactions with commercial fishing operations.

Stock Assessment Modelling for Tasmanian Giant Crab

Introduction

A size-based stock assessment model using an annual time-step was developed using methods similar to those described by Punt and Kennedy (1997) who developed a size-based model for the Tasmanian rock lobster. 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 document.

Uncertainties

There are many uncertainties when modelling the stock dynamics of giant crabs and these must be kept in mind when considering the management implications of the model outcomes.

In the case of the Tasmanian giant crab 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. As a stock assessment modelling problem, giant crab stocks are more complex than rock lobsters because of their exceptional growth. 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 periods between moulting are known as inter-moult periods.

The Tasmanian rock lobster model currently describes the growth of rock lobsters by summarizing the expected growth of each size class every three months. It was possible to provide such a detailed description of growth because of the extensive tagging of rock lobsters that has occurred around Tasmania. Giant crabs, on the other hand, are not so simple. They live far longer than rock lobsters and their growth includes potentially very long inter-moult periods lasting over ten years. Not only does the moulting growth increment vary with size but so does the inter-moult interval. A totally new model structure was developed to account for the extremes exhibited by giant crabs. While this model is stable, the details of the growth of the largest crabs (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.

The model is still under development, for example, it currently treats the whole of Tasmania as one population and a two population version (east and west coast fisheries treated separately) needs to be completed. At the same time, a greater range of growth possibilities will be included in the analyses in an attempt to capture more of the potential uncertainty in the assessment.

Methods

Data was available on catches from 16 years, 1989/1990 to 2004/2005, though the reported catches in the first three years were all less than one tonne. There are catch rate data, standardized to 1995/1996, available from 1995/1996 to 2004/2005; the statistical standardization is described reporting Appendix 1. In addition, data reflecting the length frequency of the commercial catch was available for the quota years between 1993/1994 to 2004/2005.

In total there are 21 parameters estimated by the model, these are the average recruitment level, four selectivity parameters, and 16 recruitment residuals defining the predicted deviation from the average recruitment that occurs each year .

The model outputs include:

- the harvest rate (the proportion of the legal sized biomass removed each year),
- the exploitable biomass (the legal sized biomass at the start of each year),
- the total biomass (biomass of all size classes),
- the catch rates (both observed and predicted),
- the egg production each year, and
- the observed and expected length frequency of the commercial catch each year.

A bootstrap procedure on the catch rate data provides an initial estimate of the uncertainty inherent in this assessment. It is likely to underestimate the uncertainty simply because there are so many processes (especially growth) that are only approximately known.

The model permits risk assessments related to altering the management arrangements with the available options for exploration including:

- varying the minimum and maximum legal lengths for either sex,
- varying the TAC,
- allowing the take of egg-bearing females,
- varying the length of the closed season for females.

In this present assessment all management options remained as they are currently except an array of different TAC values were examined for their implications for management.

The model was projected forward for ten years under each different harvest strategy. The legal lengths remained at 150 mm minimum legal length and 210 mm maximum legal length for both males and females.

The implications of four alternative TACs were examined: 50 t, 60 t, 75 t, and 100 t.

Fitting the Model

All sources of data influenced the final model fit, with acceptable fits to both length frequency data and the catch rate data (Figure 21, Figure 22). Fits to the length frequency data were poor in some years but these generally coincided with relatively small sample sizes (Figure 22). The large catches reported leading up to 1994/1995 led to a significant decline in the predicted stock size. The exploitable biomass declined from about 1,007 tonnes in 1989/1990 to about 155 tonnes in 2004/2005; this is a decline to about 15.4% of the original exploitable biomass. The bootstrap procedure permitted the generation of 90% percentile confidence intervals around the estimates of Harvest Rate and Exploitable biomass providing an indication of the precision with which the model operates (Figure 23).

Future Model Development

The model currently treats the whole of Tasmania as a unit whereas the fishery operates quite distinctly on the east and west coasts. It would be a valuable improvement to extend the model to deal with the two coasts independently (though the amount of data available for the east is less than in the west. As many different sources of data as possible should be included when fitting the model.

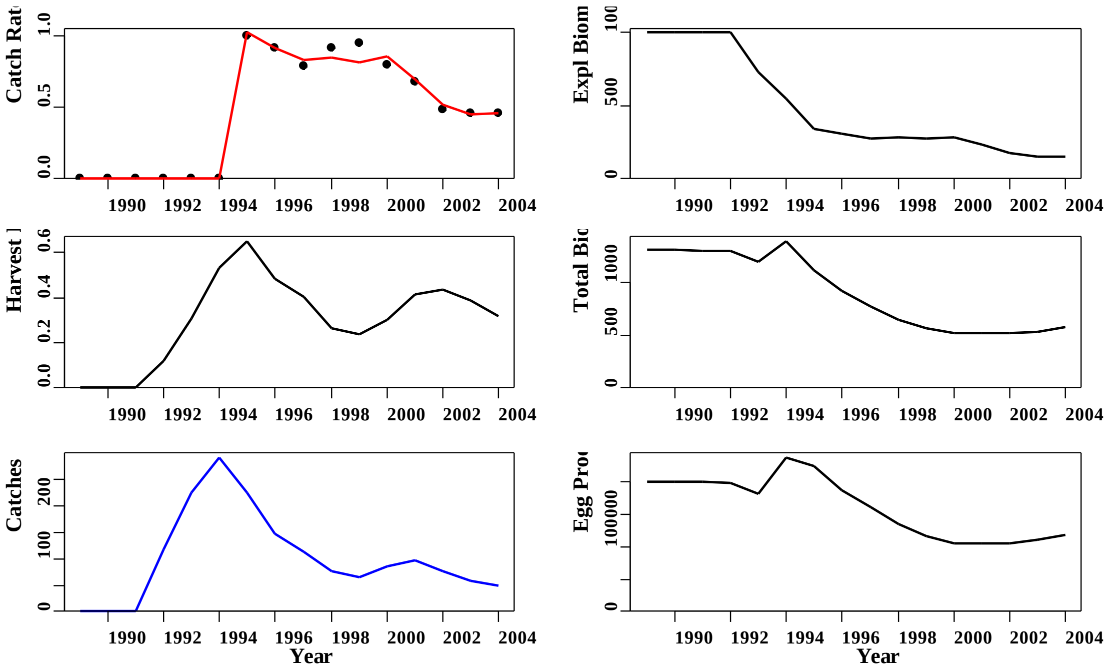


Figure 21. The fit of the model to the standardized catch rates plus the predicted harvest rates, the catch history, the exploitable and total biomass levels and the egg production. In the catch rate diagram the points are the observed standardized catch rates while the line is the fitted predicted catch rates.

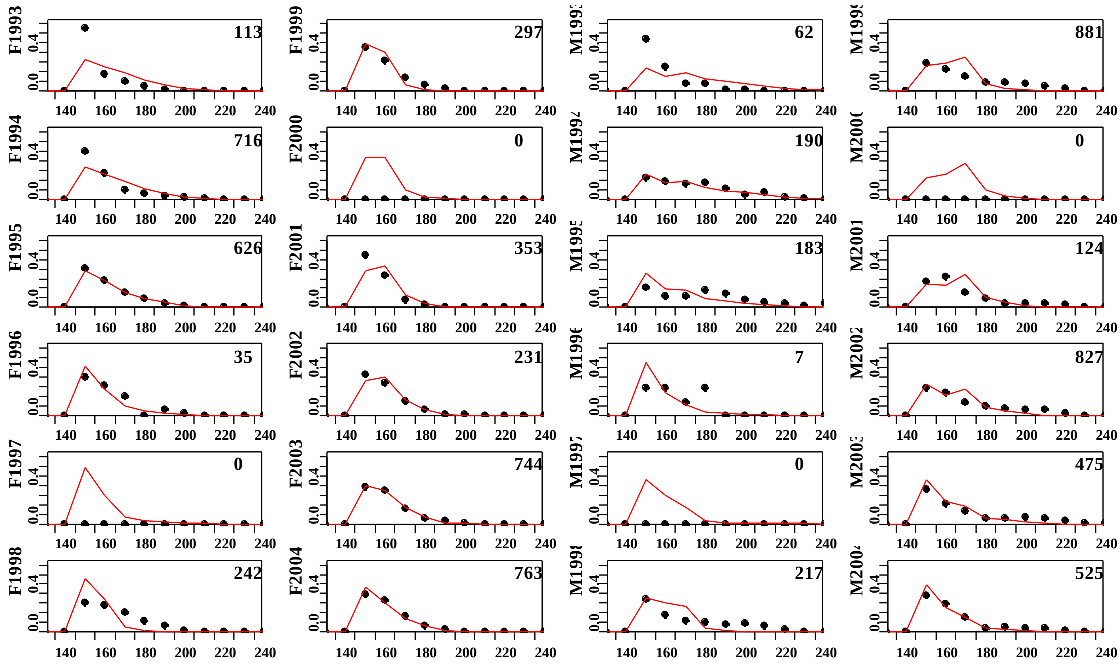


Figure 22. The observed (points, and predicted (lines) length frequencies of the commercial catches. In each case the number in each panel relates to the number of observations of sizes used in the analysis. Only the numbers of animals greater than or equal to the legal minimum length are illustrated.

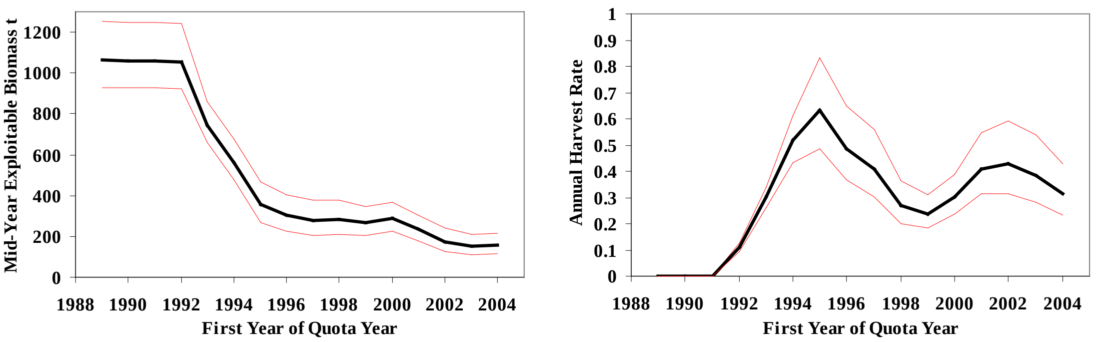


Figure 23. The predicted exploitable biomass and annual harvest rate for each of the quota years of the fishery. The thicker central lines are the median values predicted by the model while the finer outer lines are the 90% bootstrap percentile confidence intervals around each variable.

Model Projections

In all cases the projections had very wide percentile confidence intervals around the predicted future values. As with this year's rock lobster model, recruitment variation cannot be fitted to the last few years of the commercial catch rate data. This is because it takes a significant number of years for newly recruited crabs entering the smallest size classes to grow into the fishery. Until they have grown into the fishery there is no information on recruitment variation. Hence the recruitment variation required for the projections begins in 1999 rather than 2005. This means that by the first year of the projection the confidence intervals around the model outputs are already quite wide and reflect the uncertainty of the modelling of the stock dynamics (Figure 24).

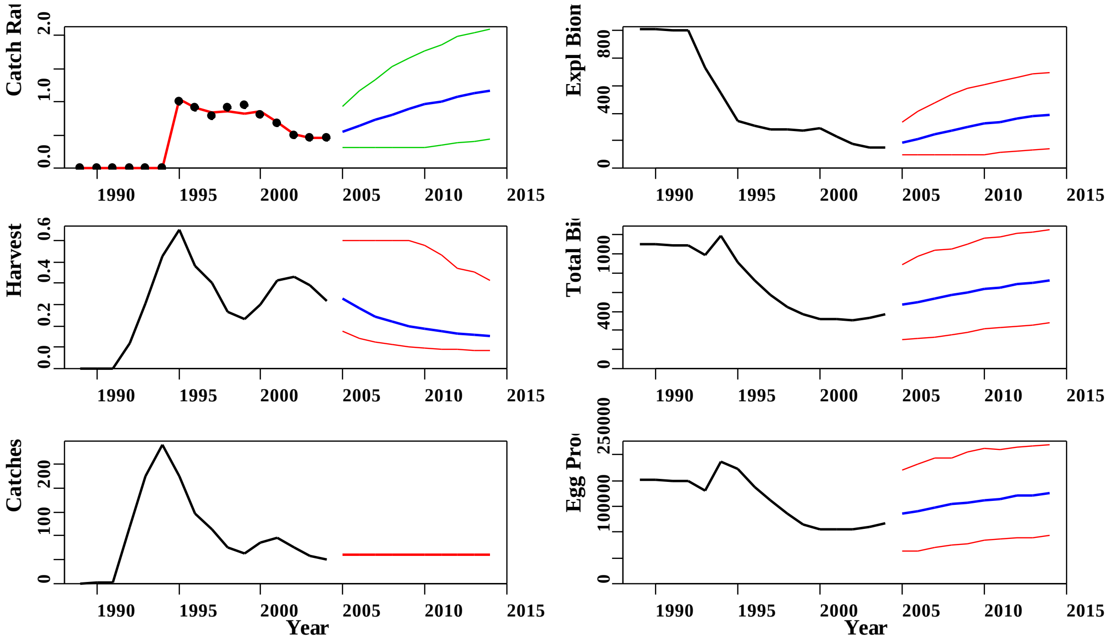


Figure 24. An example of the model outputs for 1000 simulation projections into the future under a scenario of recruitment variability of the same order as that observed over the past 16 years. The projected TAC in this projection was 60 tonnes, the current TAC.

It should be noted that the broad bounds on the uncertainty illustrate that this assessment is highly uncertain. For example, in the graph of predicted harvest rate (Figure 24,Figure 25), between 2005 and 2008 the upper limit on the confidence bound is being determined by a limit imposed by the model to avoid unrealistic answers (*e.g.* greater than 100% of available legal biomass being taken in the fishery. It is only after the fishery has rebuilt after a few years that the confidence that harvest rates have definitely dropped increases (because the upper confidence limit moves away from the maximum.

Similarly, the exploitable biomass bottoms out at a threshold below which there would not have been enough available biomass to be consistent with the history of the fishery.

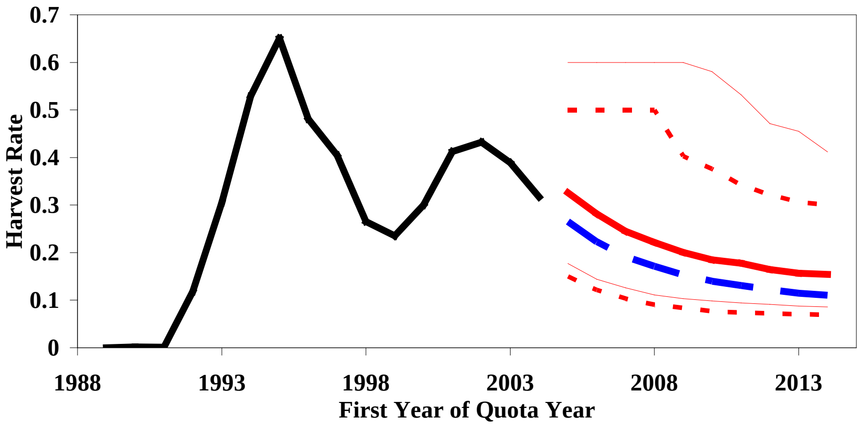


Figure 25. The projected harvest rate trajectories for TACs of 50 and 60 tonnes. The solid lines relate to the 60 t TAC while the dashed lines relate to the 50 t TAC. The outer fine lines are the 90% percentile confidence intervals derived from 1000 projections using random recruitments sampled from the recruitment variation estimated from the previous 16 years of the fishery.

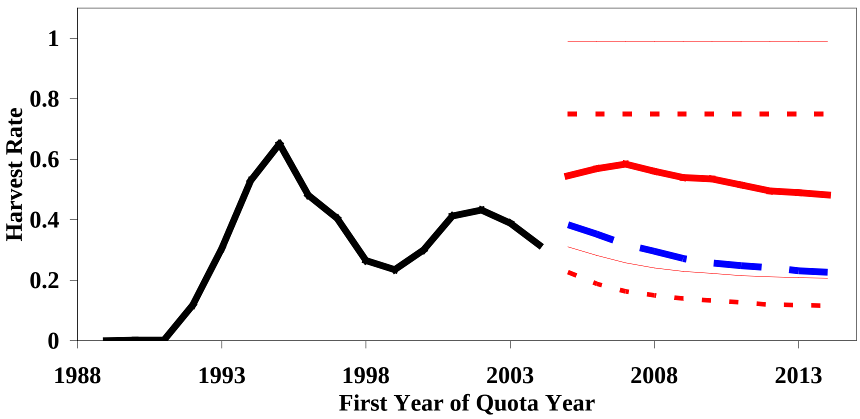


Figure 26. The projected harvest rate trajectories for TACs of 75 t and 100 tonnes. The solid lines relate to the 100 t TAC while the dashed lines relate to the 75 t TAC. The outer fine lines are the 90% percentile confidence intervals derived from 1000 projections using random recruitments sampled from the recruitment variation estimated from the previous 16 years of the fishery. The upper CI lines denote that the model has reached a limit and was prevented from predicting implausible outcomes.

When the different TAC scenarios are compared, even the 50 and 60 t scenarios exhibit periods when there is a finite likelihood that the possible harvest rates exceed the plausible (Figure 25). Thus, while the median trend is downwards for both 50 and 60 t the very broad confidence intervals indicate both the great uncertainty in this analysis as well as indicating that the next few years could still be critical for the giant crab stocks.

While these trends are clear the problems with the upper confidence intervals becomes extreme when considering the TACs of 75t and 100t (Figure 26).

With TACs of 75 t and 100 t the median harvest rate remains relatively stable through time but the upper 90% percentile confidence interval fails to reduce below the limit within the model that prevents implausible outcomes being predicted. This implies that these TACs would be a riskier option than those of 60 and 50 t.

Exploitable Biomass

The exploitable biomass is the legal sized biomass predicted by the model as being consistent with the available data (Figure 27). The lower three TAC scenarios suggest that different degrees and rates of stock rebuilding would occur should the TAC be set at anyone of these. However, with a TAC of 100 t the exploitable biomass essentially remains stable and low. While the upper confidence intervals are reasonable in this case the lower confidence intervals can reach a limit below which the exploitable biomass would reach implausible values (leading to harvest rates greater than 1).

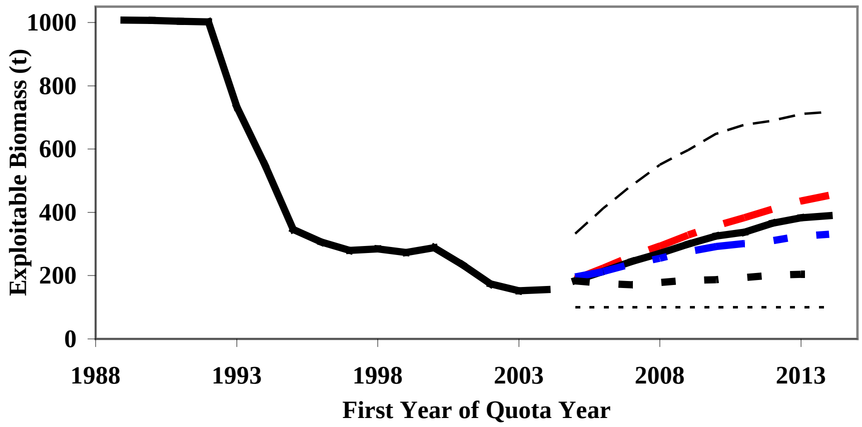


Figure 27. Exploitable biomass at the start of each quota year. The centre four lines of projection relate to the alternative TAC scenarios. The upper line is the 50 t outcome, the second line the 60 t outcomes, the third is for the 75 t TAC, and the bottom line relates to the 100 t TAC. The fine lines above and below the central four are the 90% percentile confidence intervals from the 1000 projections. The upper fine dashed line relates to the 50 t TAC with all other CIs below that one. The lower dotted line is the CI relating to the 100 t TAC.

All TAC scenarios exhibit such implausibly low exploitable biomass levels for at least three years. However, in 2008 and thereafter the 50 t TAC indicates that the minimum is avoided. The 60 t TAC rises above this minimum of 100 tonnes exploitable biomass in 2010 and beyond. Unfortunately, the 90% CIs for the 75t and 100t scenarios never rise above the 100 tonnes mark. This is consistent with the harvest rate conclusions that the level of risk of stock declines increases with the TAC, but also that a TAC of 100 t indicates only a 50:50 chance of stock rebuilding (*i.e.* the median exploitable biomass is stable and low).

Conclusions from the Modelling

- The current TAC of 62.1 t should lead to gradual stock rebuilding over the next five to 10 years unless factors not included here become involved (*e.g.* trawl interactions become significant).
- The risk of stock decline increases with TAC; with a TAC of 100 t, there is only a 50% chance that there will be any stock rebuilding over the next 10 years. Equivalently, there would be a 50% chance of a stock decline.
- The next three years continue to be critical and efforts need to continue to improve the collection of data critical to the stock assessment.

3. Related research

Shelf-break habitat assessment project

A collaborative project between CSIRO and TAFI addressing issues of habitat structure and fishery interactions in the shelf-break zone (180-400 m) is in its third and final year. The project is supported through FRDC funding (FRDC2004/066). Objectives of this project are to:

- Evaluate the vulnerability of shelf-edge habitat to damage by trawl and trap fishing gears.
- Detail the distribution of exploited shelf-edge species in relation to habitat features.
- Define and map key habitats on the shelf edge (~80-180 fm) at key locations around Tasmania where fisheries using different gear types interact.
- Evaluate ecosystem links within habitats, specifically trophic, temperature and current-flow links.
- Evaluate our ability to use video to obtain fishery independent stock assessment information such as abundance, sex ratio, condition and size of target species.

Sampling methods

Areas of interest were identified by mapping data on crab catches, trawl effort and reported areas of interaction between trawl and crab fisheries. At selected sites of interest the objectives of the study are being addressed through comprehensive surveys using acoustic (swath) mapping, video transects and biological sampling.

Swath mapping is an effective method of mapping broad areas of seafloor in detail, providing high-resolution bathymetric data as well as finer scale acoustic information (backscatter) that can provide information on habitat types present. Interpreting this fine-scale information requires ground-truthing by video transect. A towed video system (Figure 28) provided stereo video imagery and high-resolution still photos of selected areas. Using systems developed by CSIRO, the video footage can be rapidly scored for a range of habitat features including substratum properties and biotic communities present (see details below). Still photography from the camera system provides higher-resolution images than are available from video footage.

Finally, biological sampling using a benthic sled (Figure 29) allows for identification to the highest taxonomic levels of animals seen in video and still images, providing for the most complete description of biotic communities.

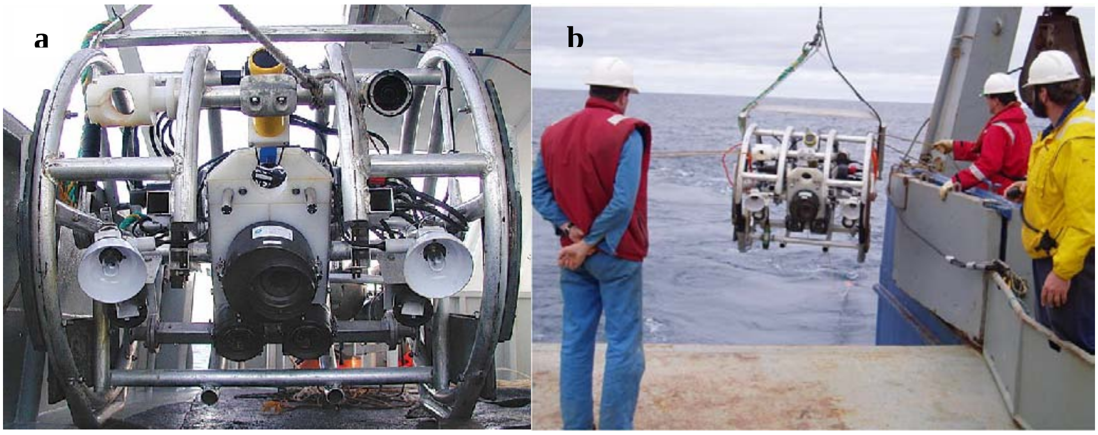


Figure 28. a) Towed camera platform with still camera (centre), paired stereo video cameras (below stills camera) and lights (white housings) clearly visible. b) Camera system being deployed.

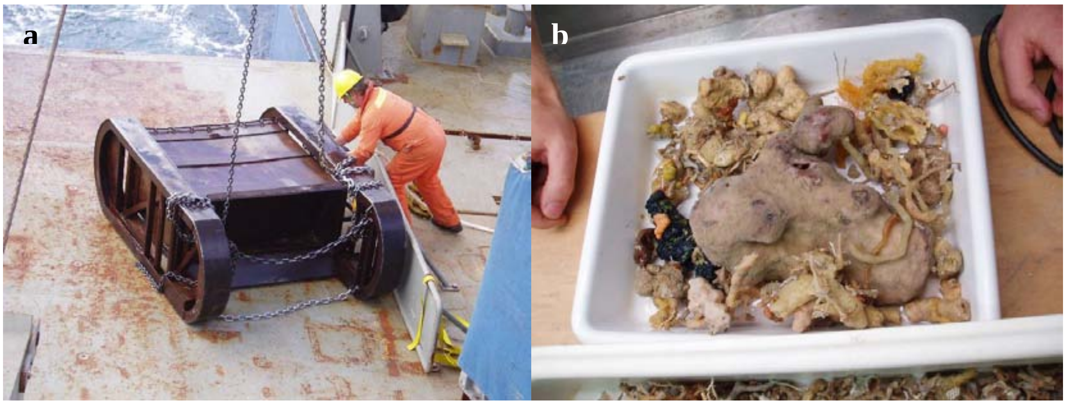


Figure 29. a) benthic sled used for sampling biotic communities b) subsample of catch from a benthic sled tow.

Analysis and results to-date

The final voyage for this project was conducted on the west coast of Tasmania from FRV Challenger in April 2005. Over the course of 4 voyages, 19 stations were sampled (Figure 30), with 90 camera tows covering depths from 125 to 500 m. These tows generated 58 hrs of video footage and 7640 still images.

Analysis of still and video images is in progress. High-resolution still images were studied in detail and a catalogue of biota developed (Figure 31). Identification of these animals was aided by reference to sled samples.

Video footage is being scored using a two-tiered approach. Firstly, four attributes – sediment (S), geomorphology (G), fauna (F) and abundance of fauna (A) - are scored for video frames sampled at 1 second intervals. A detailed set of definitions for each category has been developed to ensure consistency (

Table 3). The resulting 'SGFA' score may be used to identify broad-scale differences in habitat structure.

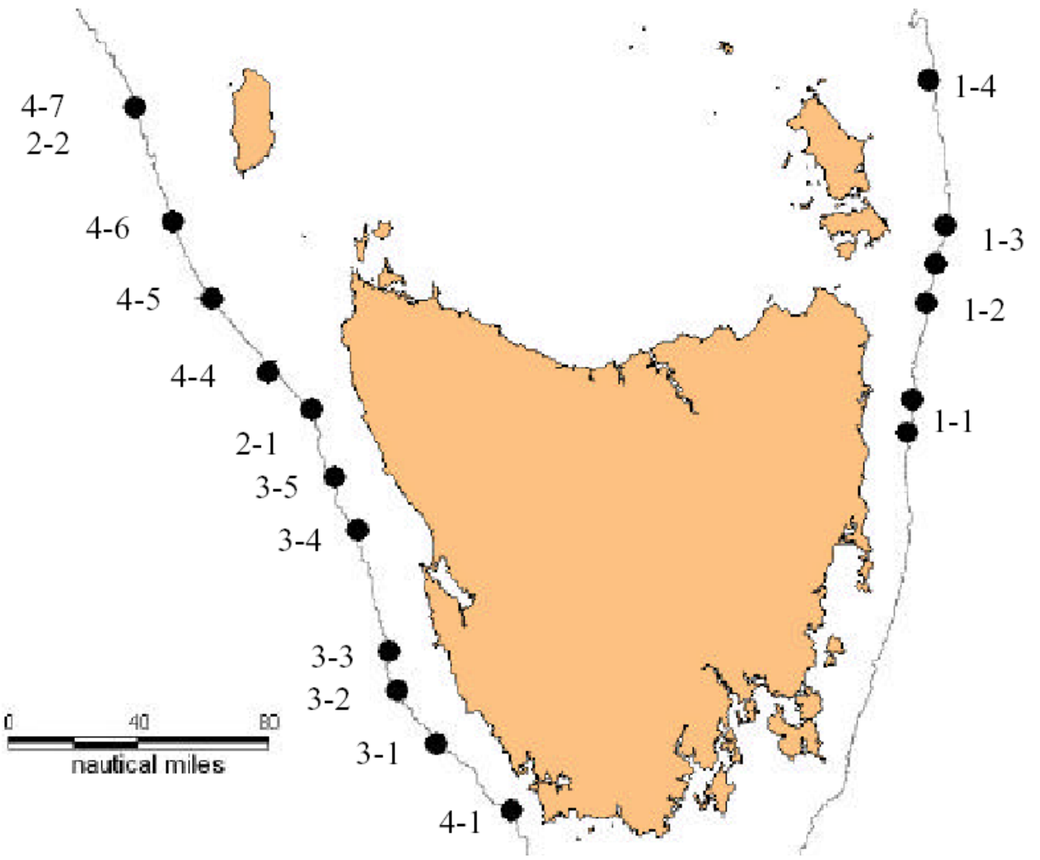


Figure 30. Distribution of sampling sites around the Tasmanian coast for surveys 1 – 4 (200 m depth contour is shown).

Secondly, the most common faunal groups (F) were re-visited in a second scoring adding more detailed definitions to these categories. While video was scored continuously with SGFA scores, ‘flags’ were also added for items of specific interest in this study. These included anthropogenic categories - gear marks, lost or discarded fishing gear, by-catch discards and rubbish – and for the presence of fauna of special interest – e.g. giant crabs, commercial finfish species etc.

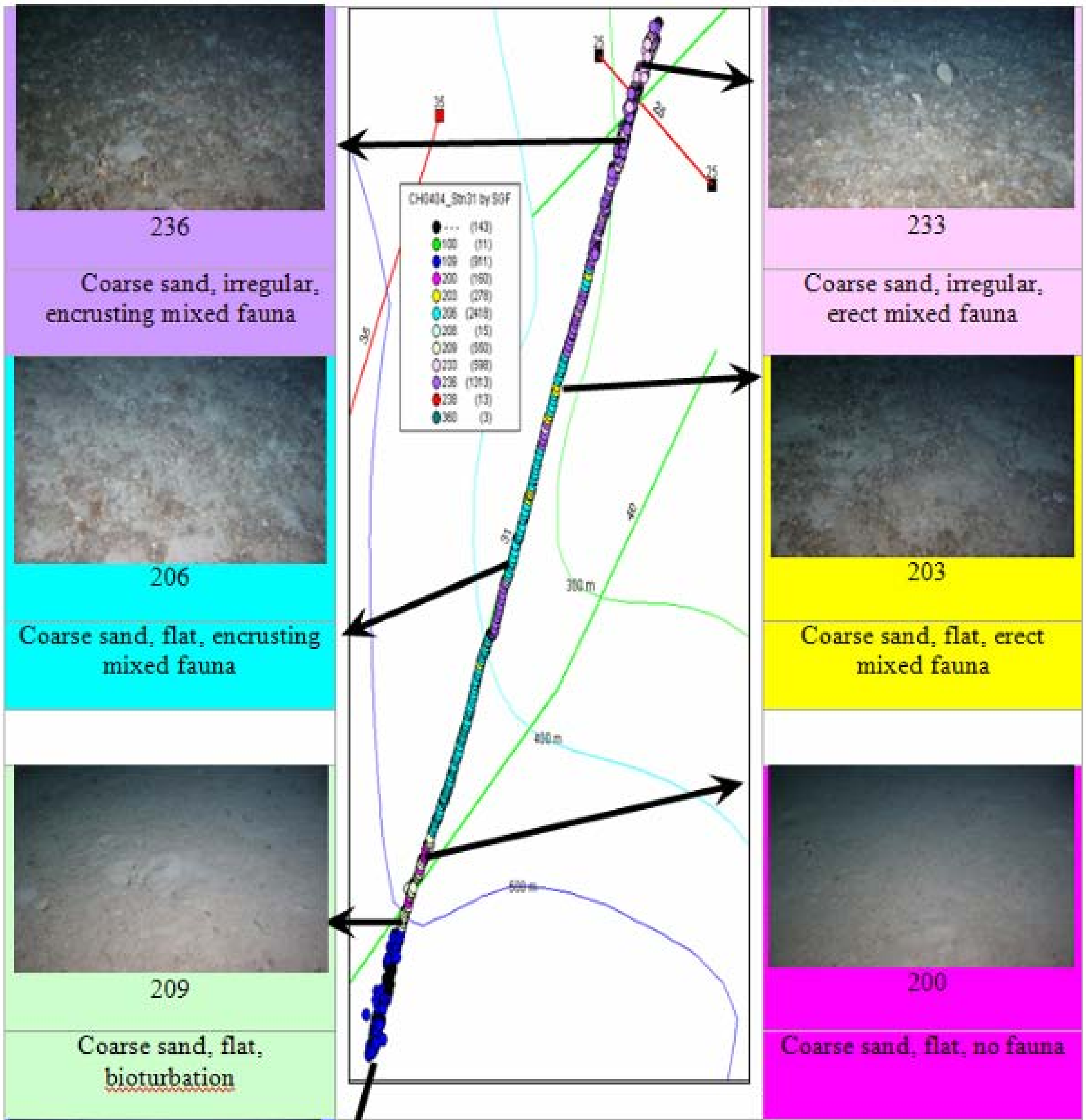
Continuous SFGA scores allow for graphic and quantitative comparisons of habitat type and faunal assemblages between sites, depth zones, areas of varying fishing pressure etc. An example from the King Island Canyons area (Figure 32) shows a clear succession in habitat types with depth. Erect and encrusting fauna on coarse bryozoan sediments are common in water to 250 m, while beyond this, encrusting fauna gradually thin out, and sediments become finer. At depths approaching 500 m fine sediment with little or no relief, and low levels of bioturbation (disturbance by animals) are fairly universal in the study area.

This project will be completed prior to the next giant crab fishery assessment, and the implications of findings from this study will be discussed in further detail the 2005-06 report.

Figure 31. Sample images from the catalogue developed through analysis of high-resolution still images.

Table 3. Details of the definitions for each category for faunal (F) scores of video frames. Scores for faunal abundance (A) are shown at the bottom of the table

FAUNA		
0	None	**No apparent epifauna or infauna**
9	Distinct infaunal bioturbators	**Infaunal bioturbators** that are discerned by the **burrows** and **tracks** over and in "soft" sediments. Somewhat of a default class used where there are "soft" sediments exhibiting a "highly irregular" morphology, indicating the presence of significant infaunal bioturbator communities. Also include burrowing ophiuroid (mattress)
3	Aggregated epifauna: Mixed large/ erect	**Mixed, attached, erect invertebrate** community. Fauna includes seawhips, erect bryozoan, large compound/colonial ascidia; gorgonians
6	Aggregated epifauna: Mixed small/ low	**Mixed, attached, low/encrusting invertebrate** community Fauna includes bryozoan turf, ascidia,
1	Aggregated epifauna: Large/erect sponges	**Large erect sponges** dominate potentially mixed fauna. Associated with hard bottom with either subcropping or outcropping consolidated sediments or substantial exposed patches of "hard" substratums. (solitary large sponges also scored 1)
2	Aggregated epifauna: Small/low sponges	**Small or low & encrusting sponges** dominate potentially mixed fauna. Associated with "hard" substratums. Also includes the small, low standing sponges sometimes seen on apparently "soft" substratum. (solitary small sponges also scored 2)
4	Aggregated epifauna: Stalked crinoids	**Stalked crinoids** dominate potentially mixed fauna The depth range is distinct and they are associated with some hard substratum for attachment. Filter feeders that inhabit areas with relatively high currents (solitary stalked crinoids also scored 4)
5	Aggregated epifauna: Octocorals	**Octocorals** dominate potentially mixed fauna A faunal group associated with "hard" substratum and generally in deeper waters. Includes gold corals (solitary octocorals also scored 5)
7	Solitary epifauna: Sessile (e.g Seapens)	**Solitary sessile individuals** Examples include seapens, gorgonians, ascidians. **NOT** sponges crinoids or octocorals (they are scored as one or two frames of 1, 2, 4 or 5 with abundance 1)
8	Mobile invertebrates	**Mobile invertebrate** fauna found on "hard" and "soft" substratum types; solitary or in aggregations. Examples include crustacea, ophiuroids (not mattress), echinoids, holothurians and asteroids
Abundance of F		
1	Low	Less than 10 % of scored area
2	Medium	Between 10 and 50 % of scored area
3	high	More than 50 % of scored area



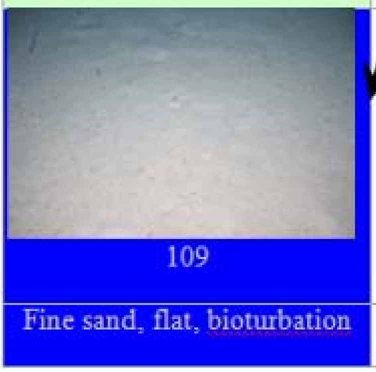


Figure 32. Graphic video analysis from site 2-2 (see Figure 30) off the west coast of King Island, showing change in characteristic habitat types as depth increases. SFG scores (abundance scores not shown) are shown below each sample image, together with an interpretation of the score. Contour lines at 300, 400 and 500 m depth as shown on the map.

Ghost fishing

The potential for crab traps to ghost fish is being assessed by TAFI in three ways; each is directed to evaluating the ability of crabs to escape from a trap after entering it. Catch and effort data is being evaluated for trends in catch rate in relation to soak time. The concept here is that as soak time increases, catch rates should decline if crabs are able to escape. Preliminary results indicate that catch rates do decline with increasing soak time.

Crabs are being placed in traps within large tanks and observed daily to determine the proportion escaping and effects of crab size. A camera has been purchased and is to be attached to a trap to collect still images of a crab trap in-situ (Figure 33). Images are collected every half hour for a period of over 20 days, or for longer periods with greater intervals between frames. This will enable us to examine crab entry and exit behaviour over an extended period of time. It is anticipated that this may also assist in examining bycatch interaction.

Figure 33. Digital frame grabber (left), rated to 600 m. The hard drive and battery are contained within the large metal cylinder. Lighting is supplied with a 3W LED light (equivalent light output of a 20W dichroic). Image to the right shows a frame from a shallow water trial deployment. The claws of a large male can be seen in the foreground, while a female crab outside the trap is visible in the background.

Re-assessing size limits in the giant crab fishery

A one year FRDC funded project will commence in 2006 which utilises new information on crab fishery biology to develop size limits that improve yield and sustainability of the fishery

One of the management objectives for the giant crab fishery has been to protect the fertility of the population. For a species with a marked difference in the size of males (large) and females (small), market preferences for a particular size of crab can dramatically change the effect of the fishery on reproductive success of the population. For example, fished populations of similar crabs elsewhere have suffered 'sperm limitation' due to the removal of large males – that is, too many sexually mature males were removed to maintain previous fertilisation rates. Such problems can be countered with appropriate size limits in the fishery.

Current size limits for giant crab were established early in the history of the fishery based on biological data collected prior to the increase in fishing effort, and untested assumptions about fishing and market practices. Although the upper size limit was introduced to protect against sperm limitation, as the fishery developed a market preference for smaller crabs became evident. As a result the sex ratio of the catch is currently skewed towards females, and a management emphasis on protecting egg production may be of greater importance than concerns about sperm limitation.

The objectives of this new project are to:

1. Describe the reproductive status of the fished giant crab population and compare it to that of the virgin population.

2. Assess the implications of changes in current size limits, and document options that best balance the aims of optimising value while rebuilding stocks.

Outputs from the project will include improvements to the crab assessment model, which will provide economic projections of the consequences of various size limits, and a report provided to fishers and the Crustacean Fishery Advisory Committee outlining the likely biological and economic consequences of various size limit options.

4. References

Frusher, S.D., Hoenig, J.M. and Gardner, C. 2003. Have changes in selectivity masked recruitment declines in crustacean trap fisheries? Fisheries Research, 65: 467-474.

Gardner, C., Mackinnon, C., Burch, P. and Bermudes, M. 2004. Tasmanian giant crab fishery 2002/2003, pp. 36: Tasmanian Aquaculture and Fisheries Institute.

Green, N., Frusher, S.D., Gardner, C. and Mills, D.J. (in review) Evaluating lobster behavior in and around traps using remote video. ICES Journal of Marine Science.

Punt, A.E. and R.B. Kennedy. 1997. Population modelling of Tasmanian rock lobster *Jasus edwardsii*, resources. Mar. Freshwat. Res., 48: 967-980.

5. Appendix 1: Standardized Catch Rates for Tasmanian Giant Crabs

Introduction

History of the Fishery

The commercial fishery for giant crab began in Tasmania during what we would now define as the 1992/1993 quota year (March to February each year) after a live export market to Melbourne, Sydney and Asia was established (Gardner, 1998). Giant crabs had previously appeared as a small bycatch by 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 and by the 1994/1995 quota year, total reported catch in Tasmanian waters peaked at 291 tonnes. While some of this total may be attributed to misreporting of catch in anticipation of a change in management (moving to quota) it was certainly the case that a large virgin stock was being fished down. By the end of the 1997/1998 quota year the total catch had fallen to just 110 tonnes (Table 4; Figure 34) and some concern were expressed that the fishery was being over-exploited. A management plan was introduced in November 1999 and an Individual Transferable Quota system was introduced in 2000/2001.

Table 4. Reported catch totals, in tonnes, by quota year from before the beginning of the Tasmanian fishery in 1992/1993 until the present. The quota year runs from March 1st to the end of February the following year. East and west are defined as either side of longitude 147° East.

Quota Year	Total	West	East	Null
1989/1990	0.202	0.002	0.105	0.095
1990/1991	1.706	1.598	0.108	
1991/1992	1.483	1.410	0.073	
1992/1993	118.157	112.794	5.363	
1993/1994	224.233	223.413	0.819	
1994/1995	291.226	217.755	73.471	
1995/1996	224.932	147.904	77.028	
1996/1997	147.380	125.231	22.149	
1997/1998	113.283	77.431	35.852	
1998/1999	75.607	30.410	45.197	
1999/2000	64.212	33.883	30.329	
2000/2001	86.510	60.606	25.904	
2001/2002	96.593	68.640	27.953	
2002/2003	75.242	45.118	30.123	
2003/2004	59.057	39.104	19.953	
2004/2005	49.334	28.604	20.730	

All of the targeted fishing for giant crab in Tasmanian waters takes place on the edge of the continental shelf on both the east and west coast. There are modes of catches in the 180m and 280m depth categories on the west coast while on the east coast the only major modal depth was the 280m depth category (Figure 35). Although it is quite probable that there is some larval exchange between coasts, it is unlikely that there is any mixing of the adult populations.

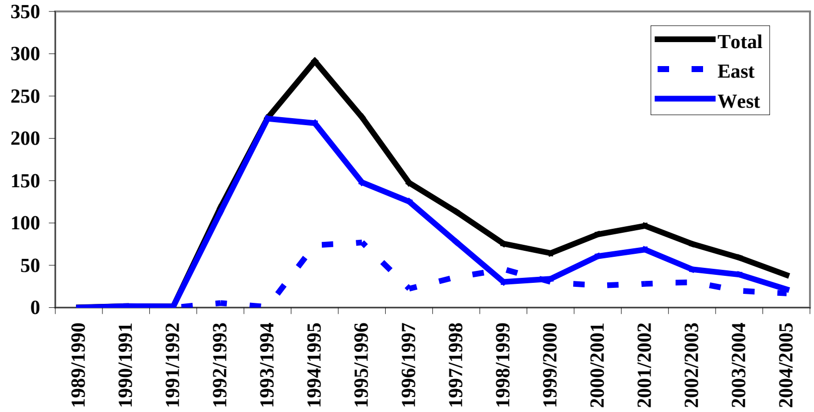


Figure 34. Total catches. And catches from the eastern and western regions, of the Tasmanian giant crab fishery (Table 1). The management plan was introduced in November 1999. The quota year is from March 1st through to February 28/29th.

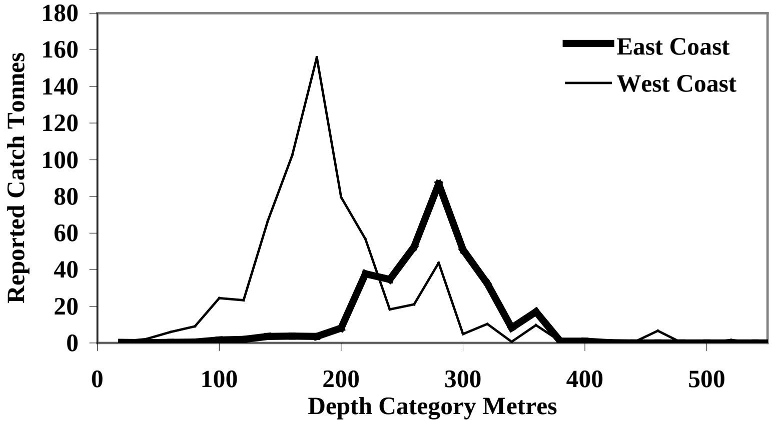


Figure 35. The distribution of total catches relative to 20m depth category for the west and east coasts separately across the history of the fishery.

The majority of the catch on each coast is taken mainly by different groups of about ten operators, however, there is also a small amount of bycatch taken by rock lobster fishers on the west coast (Gardner, 1998); this pattern continues in the latest years with 87% of the total catch being taken on the west coast in 2003/2004 by the top ten fishers, while on the east coast there have been 10 or fewer fishers since 2001/2002.

There are many factors that can influence catch rates besides the relative stock abundance. In the case of giant crabs, whether the fisher is targeting the crabs would be important, the location of fishing, the season of fishing, the depth of fishing (Figure 35), and who was doing the fishing (Figure 36), all are intuitively likely to be important factors influencing observed catch rates. Once these factors are accounted for statistically by standardization the assumption is that the relative changes in catch rates that remain are more likely related to changes in stock abundance than without the standardization. There is always the risk that not all important factors have been included but at least the standardized catch rates should provide an improvement over the raw catch rates.

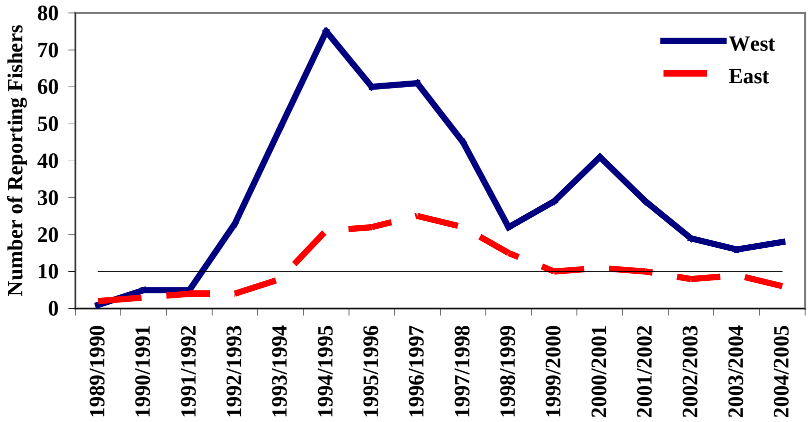


Figure 36. Number of fishers reporting any catch of giant crab in each quota year. The horizontal line is at 10 fishers.

As with most fisheries an assumption can be made that the catch rates obtained by fishers who actively target the species is more likely to represent the stock status than catches taken incidentally to, say, rock lobster fishing. Only in the most recent year has the option of identifying shots targeted at giant crabs been included on the logbook. In order to restrict the analysis to those records most likely to have been targeted at giant crabs a number of criteria were developed for data selection.

It was decided that only those vessels that had been in the fishery for a minimum of two years with a median catch of at least one tonne per annum during that period would be considered for analysis. Any remaining vessels were removed as they primarily contribute only noise to the assessment. By applying these criteria when selecting our dataset we account for around 86.6% of the total catch by weight and 75.7% by number of records (Table 5).

Methods

Catch Rates

The catch rates were measured as kilograms per port day, where a pot day was defined as the soaktime in days for each trap. This CPUE was estimated for each record in the database as:

$$\text{CPUE} = \frac{\text{Weight of Catch Kg}}{\text{Number of Traps} \times \text{SoakTime}} \qquad (1.1)$$

Soaktime is the recorded number of days the traps are in the water before being hauled. There is a belief that a soaktime greater than 7 days does not lead to any increases in catch but the reported soaktimes were used in calculating the CPUE because the normality of the log-transformed data was reduced if soaktimes were limited to 7 days.

The period under analysis included two different management arrangements with fisheries data being recorded in different logbooks. Before July 1998, fishing was restricted to fishers with commonwealth permits issued by AFMA with effort limited by gear restrictions. A total of 106 permits were issued to holders of Tasmanian rock lobster endorsements (Gardner, 1998) and catch effort data was recorded in the general fish logbook. The general fish logbook was updated in 1995 and before this time no effort was recorded, hence data from before March 1995 (the 1995/1996 quota year) cannot be included in this analysis. In the new general fish log-book, introduced in January 1995, the data recorded included the weight of the catch, the number of traps used, the time the traps were in the water, the location of fishing by 30 minute block, the average depth of fishing and the date of fishing. In November 1999 a new management plan for giant crab was introduced by the State Government that set the total allowable catch (TAC) to be 100 tonnes and the creation of a new type of fishing licence (giant crab). A new logbook for giant crab was introduced at the same time and required additional information. The new integrated catch effort or ICE logbook included the latitude and longitude of fishing and whether a fisher was targeting giant crab or not. All data fields recorded in the previous logbook were retained. Along with the introduction of a TAC, a maximum size limit of 215mm carapace length for both males and females was also introduced (the minimum legal length of 150mm for both sexes, introduced in 1993, was retained).

It is important to note that the quota allocation system and the logbook recording do not correspond completely. Quota is considered to have been used only when the animals are sold/landed whereas an entry in a fisher's logbook only records date of capture, not date of sale. It is quite common for a fisher to hold animals until the market price improves (Gardner, 1998). This is one of the reasons that it appears the quota has not been taken since it was introduced in 1999.

Data from the General fish log-book and the ICE log-book databases were extracted and combined into a single Access database for use in the following analyses.

Table 5. The number of records used in the analyses for each quota year. Data from 1994/1995 were not used in the analyses. Total All relates to all records whereas Total and East and West relate only to those records for vessels in the fishery for more than one year and catching a median catch in each year of greater than 1000 kg.

Quota Year	Total All	Total	West	East
1994/1995	288	191	114	77
1995/1996	1390	853	576	277
1996/1997	1393	765	621	144
1997/1998	1127	797	555	242
1998/1999	510	392	180	212
1999/2000	1085	909	317	592
2000/2001	1513	1231	685	546
2001/2002	1431	1254	881	373
2002/2003	539	464	335	129
2003/2004	944	879	521	358
2004/2005	900	738	482	256

Statistical Transformation

The catch rate data is not normally distributed so before statistical treatment the data was first natural log transformed, which greatly improved normality.

PROC GLM (General Linear Modelling) inside SAS 9.1 was used for the statistical analyses and the standard form of the statistical models used was:

Ln(CPUE) = Const + QYear+Skipper+DepCat+Month+Traps+Block+Month + EastWest*DepCat

With fewer or more factors used. QYear was quota year, DepCat was a series of 20m depth categories, Traps was the number of pots used, Block was the 30' statistical block. The use of Block captured all that was implicit in the East/West distinction.

A series of GLMs, sequentially adding each factor, were then fitted to the data until the optimal model, or best description of the data was identified. Optimality cannot be guaranteed simply by selecting the model that describes the maximum amount of the variation in the data. This becomes clear from considering that it would be possible to fit the data exactly if one used a model with the same number of parameters as there were data points. The definition of optimum requires some criterion that counter-balances the amount of variability accounted for with the number of parameters used to describe the data. The aim is to maximize the variation accounted for using the fewest number of parameters. Generally, the more independent parameters that are added the greater the amount of variability explained. Therefore, it is necessary to penalise a more complicated model in some way when compared to a simpler one. In this situation where we are trying to account for variability in a relatively large data set, Ripley recommends fitting by lowest AIC and retaining all models within two of the best model (unpublished manuscript). The AIC is the Akaike Information Criteria and can be defined in two ways. The first is:

$$\mathrm{AIC} = n.\mathrm{Ln}\left(\frac{\mathrm{SSE}}{n}\right) + 2p \qquad (1.2)$$

where where SSE is the sum of the squared residuals, n is the total number of observations, and p is the number of parameters. The second definition is:

$$\mathrm{AIC2} = \mathrm{Ln}\left(SSE\right) + \frac{2p}{n} \qquad (1.3)$$

In addition, the adjusted R^2, gives a better estimate of total variability described by the statistical model (Neter *et al*, 1996) than the simple R^2, with n-p degrees of freedom, and SSTO, with n-1 degrees of freedom, is the SSE plus the variation due to the statistical model:

$$R^2 = 1 - \frac{SSE}{SSTO} \quad R_A^2 = 1 - \frac{\frac{SSE}{n-p}}{\frac{SSTO}{n-1}} = 1 - \left(\frac{n-1}{n-p}\right)\left(\frac{SSE}{SSTO}\right) \tag{1.4}$$

"This adjusted coefficient of multiple determination may actually become smaller when another X variable is introduced into the model; because any increase in SSE may be more than offset by the loss of a degree of freedom in the denominator *n-p*" (Neter *et al*, 1996, p. 231).

All models were fitted using a forwards process, 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 AIC. 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.

Results

Given the factors available seven different statistical models were considered (Table 6). The geometric mean, by itself (Model 1), only accounts for about 9.2% of unadjusted variability. The skipper doing the fishing has a greater influence than quota year. The month of fishing and depth of fishing were also important. It should be noted that the interaction terms between EastWest and Depth was also influential. So location of activity in terms of longitude and depth is important.

The use of statistical block in the model meant that adding the east/west factor made no difference to the analysis (all the variation accounted for by east/west was described by Block); though the interaction terms between EastWest and depth was still significant.

Apart from two central years 1998/1999 and 1999/2000 the standardized catch rates declined steadily from 1995/1996 to 2003/2004 (Figure 37). The effect of the standardization is relatively minor with the trends described by the simple geometric mean being fairly similar to the optimum statistical model. The optimal statistical model (Table 7) was: Ln(CE) = Const + Qyear + Skipper + Month + DepCat + Block + Traps + EastWest*DepCat

The diagnostic plots related to the optimal model (Figure 38) indicate no major anomalies in the analysis.

Table 6. Descriptions of the seven statistical models compared for giant crab around the whole of Tasmania at a time step of quota years. LnCE is the natural log of catch (kg) per pot-day, Qyear is quota year (Mar 1st to Feb 28th/29th), DepCat is a series of 20m depth categories, Traps is the number of pots used, and Block is the 30' statistical reporting area. Model 1 is equivalent to the geometric mean average catch rate, and acts as a Base Case against which the other models are compared.

Model 1	Ln(CE) = Const + Qyear
Model 2	Ln(CE) = Const + Qyear + Skipper
Model 3	Ln(CE) = Const + Qyear + Skipper + Month
Model 4	Ln(CE) = Const + Qyear + Skipper + Month + DepCat
Model 5	Ln(CE) = Const + Qyear + Skipper + Month + DepCat + Block
Model 6	Ln(CE) = Const + Qyear + Skipper + Month + DepCat + Block + Traps
Model 7	Ln(CE) = Const + Qyear + Skipper + Month + DepCat + Block + Traps + EastWest*DepCat

Table 7. Statistical results from the standardization of giant crab data from Tasmania. Model definitions are in Table 6. N is the number of data records (*n*), Var% is the raw R^2 value, AdjustR^2 is the adjusted R^2 as per Eq (1.4), df Params is the degrees of freedom for the statistical model, df resids is the residual degrees of freedom (*n*-*p*), ModelSS is the variation described by the model, Resid SS is the sum of squared residual errors, #param is the number of parameters (*p*), AIC is the Akaike's Information Criterion Eq (1.2), and AIC2 is Eq (1.3). The ΔadjustedR^2 values for each model are with respect to the previous model except Model 1 which is simply the adjusted R^2.

Model	Model 1	Model 2	Model 3	Model 4	Model 6	Model 7
N	8431	8431	8431	8431	8431	8431
Var%	9.18	32.3	40.61	45.86	48.9	51.61
df Params	9	142	153	172	220	290
df Resids	8421	8288	8277	8258	8210	8140
ModelSS	987.6	3474.6	4369.2	4933.7	5260.9	5552.4
Resid SS	9771.5	7287	6389.9	5825.4	5498.2	5206.7
# Param	10	143	154	173	221	291
AdjustR2	9.082	31.127	39.512	44.728	47.528	49.883
AIC	1264	-943	-2029	-2771	-3162	-3481
AIC2	9.190	8.928	8.799	8.711	8.665	8.627
ΔAdjR2	9.08	22.04	8.38	5.22	2.80	2.35

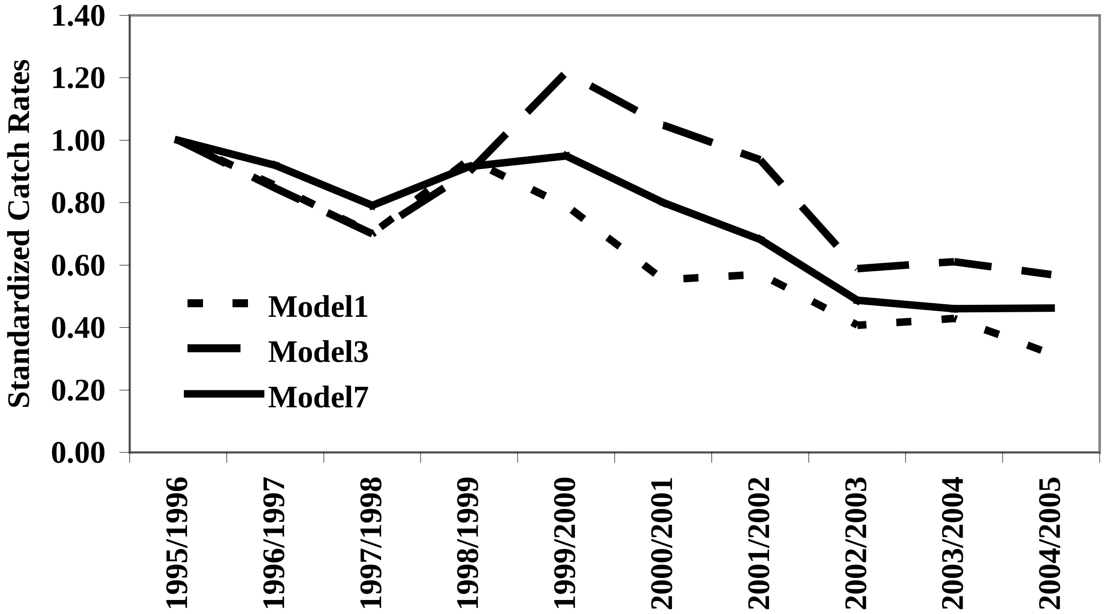


Figure 37. The standardized catch rates deriving from Models 1, 3 and 7 relative to the Quota Year to which they relate, all are relative to catch rates in 1995/1996. Data restricted to vessels in the fishery for at least two years and with a median catch greater than 1000 kg.

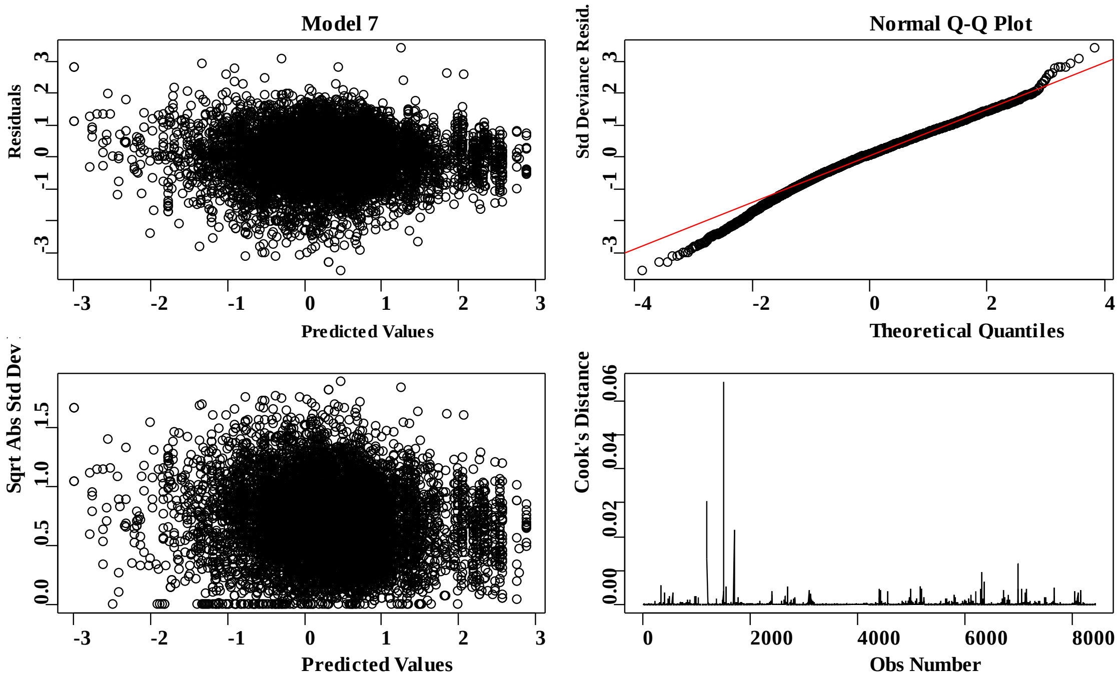


Figure 38. Diagnostic plots of the optimum statistical model : LnCPUE ~ Qyear + Skipper + Month + DepCat + Block + Traps + EastWest*DepCat. The residuals show a reasonably smooth distribution and while there is some deviation from a perfect straight line in the QQplot, the Cook's distances indicate that there are no exceptional outliers in the statistical model.

Table 8. Predicted standardized catch rates for each of the statistical models. Model 1 is the geometric mean catch rates while Model 7 was optimal; model definitions are in Table 6 and Models 1, 3, and 7 are illustrated in Figure 37. Qyear is the quota year.

Qyear	Model1	Model2	Model3	Model4	Model5	Model6	Model7
1995/1996	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1996/1997	0.8544	0.8234	0.8462	0.9181	0.8767	0.9185	0.9194
1997/1998	0.7008	0.6861	0.6998	0.7692	0.7900	0.7772	0.7914
1998/1999	0.9381	0.9695	0.8975	0.9277	0.9557	0.9330	0.9155
1999/2000	0.7896	1.2926	1.2165	0.9855	0.9961	0.9414	0.9496
2000/2001	0.5522	0.8881	1.0477	0.8930	0.8621	0.7948	0.8003
2001/2002	0.5709	0.8046	0.9365	0.7748	0.7244	0.6763	0.6817
2002/2003	0.4076	0.6006	0.5885	0.5099	0.4714	0.4901	0.4870
2003/2004	0.4290	0.7034	0.6106	0.5522	0.5290	0.4536	0.4602
2004/2005	0.3156	0.4823	0.5693	0.5006	0.4989	0.4535	0.4626

Discussion

The statistical analysis only led to minor changes to the geometric mean values.

It is recommended that Model 7 be used in any stock assessment as its factors have easily understand meanings; more complex interaction terms would have been possible but would have been complex to understand.

Difficulties with the Analysis

The fishery has two distinct areas, being the east and west coasts. By including statistical block in the analysis the influence of coast was accounted for (especially when EastWest was included in an interaction terms), however, it might be better to conduct separate assessments for the two coastlines of Tasmania as each fishery appears to have different characters. Care will needed, however, as the amount of data available from the East coast is often far less than that available for the West coast.

In addition, the annual time step of using quota years may be inappropriate because the effort permitted has varied greatly through the history of the fishery. Inclusion of Month as a factor in the standardization analysis will have alleviated this problem to some extent, but it might be advantageous to explore the outcomes by using perhaps a two-month time period as the base time step.

Bibliography

Gardner, C. (1998). *The Tasmanian Giant Crab Fishery: A Synopsis of Biological and Fisheries Information*, Internal Report No. 43, Marine Resources Division, Marine Research Laboratories, Taroona, Department of Primary Industry and Fisheries Tasmania.

Gardner, C., Mackinnon, C. (2002). *The Tasmanian Giant Crab Fishery 2000/2001: Fishery Assessment Report*, Tasmanian Aquaculture and Fisheries Institute.

Ripley, B. D. (unpublished Manuscript) Formal versus Informal Methods of Model Choice.

Neter, J., Kutner, M.H., Nachtsheim, C.J. and W. Wasserman (1996) *Applied Linear Statistical Models*. 4th Edition. Irwin. Chicago. 1408 pp.