2-2018

Improving confidence in the management of the blue swimmer crab (Portunus armatus) in Shark Bay PART II: Socio-economic significance of commercial Blue Swimmer crabs in Shark Bay. FRDC project no. 2012/15

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Primary Industries and Regional Development

GOVERNMENT OF WESTERN AUSTRALIA

Fisheries Research Report No. 284

Improving confidence in the management of the blue swimmer crab (*Portunus armatus*) in Shark Bay

PART II: Socio-economic significance of commercial Blue Swimmer crabs in Shark Bay

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February 2018

HORIZON CONSULTANCY

FRDC
FISHERIES RESEARCH & DEVELOPMENT CORPORATION

Correct citation:
Daley, R. and van Putten, I. 2018.Improving confidence in the management of the blue swimmer crab (*Portunus armatus*) in Shark Bay. PART II: Socio-economic significance of commercial blue swimmer crabs in Shark Bay. FRDC Project No. 2012/015. Fisheries Research Report No. 284, Department of Primary Industries and Regional Development, 48pp.

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ISSN: 1447 – 2058 (Print) ISBN: 978-1-877098-88-8 (Print)
ISSN: 2206 – 0928 (Online) ISBN: 978-1-877098-89-5 (Online)

2123/17

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Acknowledgments

The authors of this report are grateful for the input provided by fishers from the Shark Bay trap and prawn trawl sectors and processors. Drs Arani Chandrapavan and Mervi Kangas provided crucial input in the project planning phase and ongoing support throughout the duration of the project. Errol Sporer provided fishery data that underpins the scenario analysis and economic model. We also thank the Fisheries Research and Development Corporation for their financial support to complete this project.

Glossary of terms and acronyms

ABARES: Australian Bureau of Agricultural and Resource Economics and Sciences.

Beach Price: The price received by commercial fishers at the point of first landing, excluding any price margins for marketing, transport, sales commissions, packaging or value adding.

Byproduct: species in the catch that are not targeted but are retained for sale.

DFWA: Department of Fisheries Western Australia.

Gross Value of Production (GVP): The gross value of the landed catch, based on the Beach Price multiplied by the volume of the landed catch.

Total Allowable Commercial Catch (TACC): The catch limit set annually to control commercial catch.

1 Executive Summary

The Shark Bay crab fishery is faced with substantial changes. The fishery reopened in late 2013 after a 18 month closure due to a significant stock decline from adverse environmental conditions. The stock is now recovering and The Department of Fisheries Western Australia (DFWA) has implemented substantial management changes including the introduction of catch quotas to limit the catches of individual fishing businesses and a Total Allowable Commercial Catch (TACC) for the fishery. Fishers are challenged with adapting to the changes in management and inter-annual variability in crab catch volume linked to environmental conditions.

This study was undertaken in 2014/2015 to provide a reference point for the socio-economic performance of the fishery so future improvements could be measured and to support decision making by fishers and managers as the fishery adapts to change. A set of socio-economic criteria were developed to assess current performance, and to identify risks and opportunities for the future. The criteria were: 1. Gross value of production (GVP) (total catch multiplied by price); 2. Profitability; 3. Supply chain resilience and 4. Employment and flow on benefits. These criteria were estimated using catch data obtained from DFWA and price data and other catch related information from Australian Bureau of Agricultural & Resource Economics and Sciences (ABARES) and fisher interviews. The interviews also provided information on the structure of the crab supply chain. Participation in the study was high and represented all trap vessels and seventeen of the eighteen prawn trawl vessels active during the 2013/2014 season, as well as the two major processors that handle more than 90% of market volume. There were no scallop vessels active during the study.

The daily logbook catch data are considered reliable because they are verified by landings. Catches peak during winter for both trap and prawn trawl crab sectors. Catch volume in the season following the closure (2013/2014) was 372 t. This post closure catch volume is much lower than the 838 t caught in the season 09/10 preceding the closure.

Even though catches are highest in winter (June-August), domestic prices are highest in summer (December-February). For the 2010/11 fishing season the average price was estimated at $4.25 per kilo by ABARES. The price for the 13/14 fishing season was estimated to be higher at $5.24 per kilo. GVP for the 13/14 season is estimated at $1.62 million, compared to $3.37 million prior to the closure (10/11). It was not possible to interpret long-term trends in GVP and other economic indicators due to inconsistencies in available historical price data.

Detailed profitability analysis (assuming average prices per kilo and costs per vessel) predicts neither trap nor prawn trawl sectors will make an economic profit (taking variable and fixed costs and depreciation into account) in the long term unless fishing businesses are able to achieve some combination of an increase price and/or volume and a reduction in costs. Sensitivity tests found that with 2013/2014 prices ($5.24/kg) the volume threshold for a one vessel trap business to achieve economic profit is 123 tonnes of crabs; alternatively if catch volume remained at the 2013/2014 level of 89 tonnes per vessel a price of $7.26/kg is needed.

Similarly a single vessel prawn trawl business would need to increase its catch to 19.7 tonnes of crabs per annum. The ageing prawn trawl fleet needs to improve its economic performance to make vessel replacement viable.

Optimal strategies for improving profitability are likely to differ between sectors because their fixed costs vary significantly. Prawn trawl has higher fixed costs than trap but these are offset against returns from the target species (prawns). This means any increase in crab catch has a positive effect on returns, without substantial additional costs. This provides the prawn trawl sector with resilience against fluctuations in the crab market; the trap sector lacks this resilience. Given that the opportunities for increased price are limited by competing imported crab, efficiencies through increased volume will be key to achieving economic profits for businesses fishing for crab.

Both the trap and prawn trawl fisheries have separate short supply chains. Both chains include fishers, processors, wholesalers, a number of market destinations, and domestic and international consumers. Both have only one major processor that carry 85-100% of volume. An additional processor closed permanently during the crab fishery closure. The key differences are that most of the trap crab catch is processed locally and sold as high value product internationally whereas the prawn trawl crab catch is processed mainly overseas and sold overseas or re-imported for domestic sale.

The trap sector supply chain has contributed more (than prawn trawl) to local employment in Shark Bay but this has fallen since the closure. Direct expenditure on labour fell from around $713K per annum to an estimated $327K per annum and indirect labour spending is estimated to have halved to an estimated $563K. The social cost of the associated skills that were lost is likely to have long-term impacts because experienced process workers and deck-hands have left Shark Bay.

Some type of further adjustment to change is essential for the long term economic sustainability of the fishery as a whole. The changes to management arrangements are likely to favour the crab prawn trawl sector at the expense of trap. The crab trap sector was already vulnerable after the crab closure because it did not have other species to fall back whereas prawn trawl sector did. Trap businesses are now more vulnerable to reduced crab volume under the TACC. The most likely consequence is leasing of quota from trap to the prawn trawl sector because it is more resilient to inter-annual fluctuations in crab price and volume.

2 Introduction

The Shark Bay World Heritage area lies in the Gascoyne region of northwest Western Australia, which includes the shires of Carnarvon, Exmouth and Denham. The major regional industries include tourism ($249 million per year in 2012), retail, horticulture, mining, fishing ($38.4 million per year) and pastoralism (Carnarvon Council 2017.). Tourism attracts more than 210,000 visitors per year (Carnarvon Council 2017). Despite the many natural assets, attracting capital investment remains a key challenge for this region.

Shark Bay sustains prawn, scallop and crab trawl fishing, crab trap fishing, and a range of finfish species such as pink snapper and whiting (Department of Fisheries 2011). These fisheries rely on biological production from the extensive inshore habitats and seagrass beds of Shark Bay that are nursery areas for a range of invertebrate species including prawns and crabs (Department of Fisheries 2011). Fisheries provide valuable income and employment for the small rural community of the Shire of Shark Bay of just under 1,000 people.

The blue swimmer crab (*Portunus armatus*) resource in Shark Bay is managed by DFWA and harvested commercially by the Shark Bay crab trap and Shark Bay prawn trawl fisheries (Figure 2.1), with small amounts retained by the Shark Bay scallop trawl fishery. The resource is marketed commercially as a premium quality product because it is harvested from a World Heritage Area. The crab stock also supports a small (~2.4 t) but important recreational fishery in the Shark Bay area. Seasonal fishing patterns vary between sectors where. The prawn trawl fishery generally operates from March to October and the crab trap fishery is permitted to operate year round.

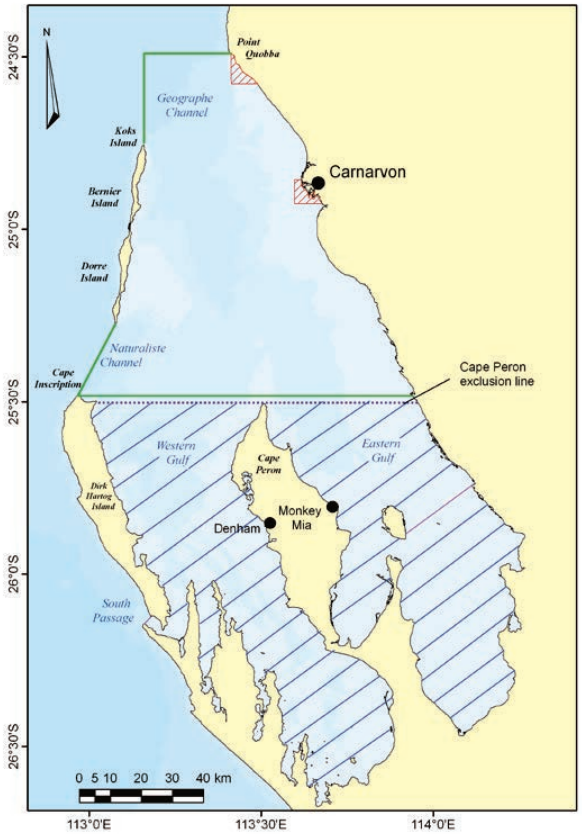

Figure 2.1. Map of the Shark Bay Swimmer Crab Fishery showing the boundaries and exclusion zones (///) (Modified after Harris et al. 2014).

Prior to 2000 the combined annual landings by all sectors was limited to catches of less than 170 t (Figure 2.2). The combined annual landings of blue swimmer crabs by all sectors increased threefold from 297 t in 2000 (238 t by trap and 58 t by prawn trawl), to its peak at 828 t in 2010 (490 t by trap and 338 t by prawn trawl) (Figure 2.2). Prior to 2011, the Shark Bay crab fishery was Australia's largest producing blue swimmer crab fishery but between July and December of that year, abundance and commercial catch rates declined rapidly across the region. The cause for the decline has been attributed to a heat wave and flooding during the summer of 2010/11 (Chandrapavan et al. 2018). Commercial fishing for blue swimmer crabs in Shark Bay ceased in April 2012 on a voluntary industry-agreed basis to facilitate stock rebuilding which had a major economic impact on these fisheries. The trap fishery was closed between April 2012 and September 2013 with the exception of a short-term commercial trial during June 2013. Since then, crab stocks in Shark Bay have partially recovered, to the extent that commercial fishing activities were allowed to resume in late 2013.

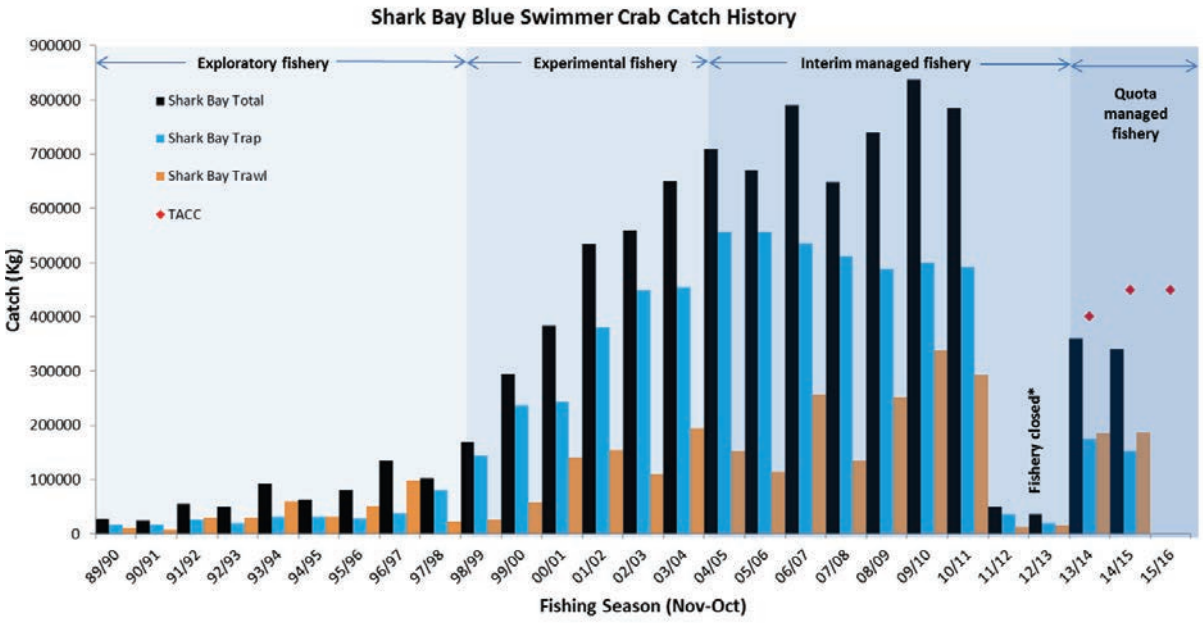

Figure 2.2. Commercial catch history for blue swimmer crabs in Shark Bay from 1989 to present. The fishing season is defined as 1 November to 31 October. The fishery closed between April 2012 and October 2013 and catches shown for 2012/13 were taken as part of an experimental fishing trial (*). Fishing resumed under a quota managed fishery in 2013 with a TACC of 400 t for the 2013/14 season and 450 t for the 2014/15 and 2015/16 seasons.

Individual fishers currently operate under a quota managed system, with regulation of licence and trap numbers or length of headrope of prawn trawl net. Supplementary controls include minimum size limits, gear specifications, and area, seasonal and daily time restrictions. Substantial changes were made to management of the fishery prior to allowing fishing to resume following the closure. A TACC was introduced and set initially at 400 t for the 2013/2014 season and 450 t set for the 2014/15 season. An expanded fisheries independent research survey program was implemented following the closure and stock indices derived from the survey data inform the TACC setting and other key management decisions. These changes are now having an impact on how the fishery operates. A new management plan with Individual Transferrable Quotas (ITQs) was fully implemented for the 2015/16 season and the TACC was allocated to the sectors: as trap 66%, prawn trawl 33.8% and scallop trawl sector 0.2%. Trap fishers were apportioned 66% based on the number of units of entitlement they hold whilst the prawn and scallop fleet allocation is a 'fleet' allocation. Quota is transferrable between sectors subject to seasonal closures and zoning restrictions. Trap fishers are also subject to spatial restrictions and only two licence owners are permitted to fish in waters south of Cape Peron where additional gear restrictions apply (< 200 traps).

Although the trap sector had the largest allocation of the TACC, it had only 5 licences during 2013/14, entitled to a maximum of 300 traps each (Chandrapavan et al. 2018). These were consolidated and fished by only two owners operating a total of five vessel licences in 2014.

The trawl sector has a greater number of licenses: 18 prawn trawl and 10 scallop trawl. There has been some reduction in the number of prawn trawl licences (down from 27) via an

industry funded buyback scheme that was formalised during 2011. Trawl sectors are authorised to take blue swimmer crabs as a retained non-target species (byproduct). Management controls include limited entry, seasonal and area closures, and gear controls including by-catch reduction devices (grids and secondary fish escape devices). Vessel monitoring systems (VMS) are required for all trawlers in these fleets (DFWA 2011).

Stakeholders are working towards economic viability of the fishery. Since reopening, both the crab trap and prawn trawl sectors have implemented improvements to utilize the crab resource more efficiently, including gear modifications, improving processing techniques and developing a range of value added products. Crab fishing businesses will need to make key decisions in the next five years relating to the transfer and leasing of quota.

Long term sustainability of Shark Bay blue swimmer crab fishery can only be achieved if environmental, economic and social effects are considered. Under the Western Australian Government, DFWA are committed to integrating these factors in management decisions (Chandrapavan et al. 2013). Harvest strategy policy instructs that ecological objectives are considered first, potentially leading to some trade-offs against economic and social objectives but overall management performance is maximised if these trade-offs are limited. The social and economic objectives of the fishery are to maximise the opportunity for economic returns from crab resources and support regional communities by providing a sustainable fishery. Gaps have previously been identified in the comprehensiveness of the social and economic information for the crab fishery (Harris et al. 2014). Further investigation of the economic and social characteristics and the interplay between them is needed to enable a transparent and quantitative investigation of the overall success of output controls.

In this report we first translate the broadly stated socio-economic objectives of the fishery into criteria that can be used to evaluate performance. Two main data sets were used: initially existing catch and price information and then industry questionnaire data collected from fishers and processers directly involved in the fishery. We also describe the supply chains to evaluate resilience to change. The central aim of this report was to provide an initial reference point for the performance of the reopened fishery under new management arrangements so future improvements can be measured. We also provide scenario evaluation tools that can be used to explore how alternative management decisions could maximise economic return for the fishery. A set of scenarios was trialled. Finally we summarised the implications for management.

3 Methods

Four main criteria were selected to measure *present* fishery performance against the economic and social objectives of the fishery. The criteria used in this research have been used to evaluate other fisheries, including crab fisheries in Australia (Paterson et al. 2013). The criteria was chosen for simplicity given the general nature of the management objectives, for ease of repeatability, and for effective analysis of the limited industry data (due to the small number of participants in this fishery). These criteria were: 1. Gross Value of Production (GVP); 2. Profitability; 3. Supply chain resilience; 4. Employment and Flow on benefits. These criteria were evaluated using interview data, commercial catch data, and price data. The price data were made available by ABARES and include a 15% adjustment to crab prices to account for an average marketing and transport cost that is contained in the processor returns for all finfish and crab. The beach price for the 2013/14 season was estimated at $5.24 per kilo of blue swimmer crab. Scenario analysis was used to explore *future* options for the fishery, particularly profitability under different price and volume assumptions and quota leasing.

3.1 Interview data

The socio-economic data was collected using a face-to-face interview method. A list of fisher names and contact details were obtained from DFWA and potential respondents were approached by telephone and email and asked to participate in an interview by the first author of this report. Fishers from both the trap and trawl sectors and crab processors were asked to participate.

Two separate questionnaires were applied to obtain data used to estimate values for the performance criteria. The first questionnaire was aimed at obtaining fishery relevant information and consisted of five sets of general questions (Appendix A). In the second questionnaire participants were asked detailed information about their fishing operation to develop cost centres used to estimate fixed and variable costs, returns, and profit (Appendix B).

Because licences are few in number and some operators are in a relatively remote area of WA, the first author of the report organised site visits and ensured that both fishers and processors located in Perth, Fremantle, and Carnarvon could be interviewed. In summary, the information necessary to estimate the performance criteria values was gathered in three stages.

In stage 1 the project was introduced to representatives of both the trap and prawn trawl sectors at a meeting in Fremantle on 3 September 2014. A trap operator and the key prawn trawl processor were interviewed during the following week.

Stage 2 of data gathering started in Fremantle in October 2014 with interviews with prawn trawler owners (2 vessels) and a follow up interview with the key prawn trawl processor. This was immediately followed by interviewing the major prawn trawler owner (10 vessels), prawn trawler skippers (5 vessels) and the crab trap processor in Carnarvon.

Stage 3 consisted of follow-up phone calls (n=6) and e-mails (n=4) in December 2014 and January 2015 aimed to obtain additional details of prices and costs to check the costing model.

3.2 Catch and price data

Monthly crab catch data compiled from daily logbooks were obtained from DFWA for 2000 to 2014 for the trap fishery and for 2002 to 2014 for the prawn trawl fisheries. Prawn trawl catch data were also obtained for major prawn species, as well as other byproduct (e.g. finfish and squid). For comparison between the trap and prawn trawl sectors, only 2002 to 2014 crab data were used.

Beach price data for Western Australia were obtained from ABARES for three seasons: 2010/11=$4.25/kg, 2011/12=$6.47/kg and 2012/13=$9.23/kg. These values have been independently checked by ABARES. Up to date crab beach prices for the 2013/14 season were made available by ABARES in May 2015. For 13/14, a beach price of $5.24/kg was used. This figure varied from the price based on interviews (n=18 vessels, average=$7.00, std. dev $0.40). The variance was because the interview prices did not account for freight and marketing costs. Sensitivity testing varied the beach price between $4.00/kg and $10.00/kg. Seasonal variation in beach price was assessed in a semi quantitative manner by asking for the highest and lowest prices and the corresponding time of year during interviews.

3.3 Data analysis

All calculations were performed in Microsoft Excel, in a spreadsheet that is available to stakeholders for developing additional scenarios.

3.3.1 Catch, price and GVP

Trap and prawn trawl catch data were first examined for seasonal and annual trends in volume that could influence demand and price. Seasonal trends were explored by pooling data between years, placing pooled data into monthly bins and calculating the average for each month. For this analysis, only the 2007–2011 data were selected to best reflect fishery practices prior to the closure.

For analysis of annual trends in crab catch, special consideration was given to the timing of the fishing seasons. Some trap vessels break for winter then recommence fishing just before Christmas, such that a trap season runs from November of one year to October of the following year. For example the 2013/2014 trap season ran from November 2013 to October 2014. Prawn trawl fishing is generally occurs from March to October, such that a fishing season corresponds with a calendar year. This makes comparisons between the prawn trawl and crab trap fisheries possible. For example, the 2013/2014 trap season is equivalent to the 2014 prawn trawl season.

GVP is a simple indicator of the value of the fishery to the community. GVP was calculated from catch volumes multiplied by beach price (for the fishing seasons where beach prices were available). As only annual and not monthly beach prices were available, they had to be

matched to fishing seasons. For example the 2013 beach price was matched to the 2012/2013 season.

3.3.2 Profitability

Profit is an important indicator of the long-term prospects of the fishery because a positive profit is essential for businesses to replace their capital equipment when due for renewals and thus survive in the long term. Baseline scenarios of profitability were developed for both trap and prawn trawl to examine current economic viability of a typical but hypothetical fishing businesses and to set the scene for scenario modelling (see Section 3.3.5). Profitability was measured by estimating turnover then subtracting costs. Turnover and costs were attributed on a per vessel basis. Key assumptions are given below (Table 1).

Turnover was estimated by multiplying crab catch per vessel and beach price. Crab catch per vessel was calculated in two ways: 1. from historical catch data, and 2. by dividing the current TACC by the number of vessels active in the trap and prawn trawl fisheries (Table 1). These values were then multiplied by the 2013/2014 beach price to obtain plausible ranges of turnover (catch data) and typical current turnover (proportion of TACC) from crabs in the two fisheries. For prawn trawl, prawns are the main target species and thus contribute the most to turnover. Turnover from prawns was calculated by multiplying the volume of prawn catch expected by prawn trawlers (taken from Industry Costing Questionnaire data, Appendix B) by current prawn prices obtained from DFWA (Appendix D).

Typical costs were estimated based on Industry Costing Questionnaire data (Appendix B, Appendix E). Costs were divided into variable costs, labour costs and fixed costs. Accounting profit (gross margin) was calculated by subtracting only variable costs from turnover (depreciation and debt and interest payment costs were excluded from gross margins). Economic profit was calculated by further subtracting all costs (including variable costs, depreciation, and debt & interest payment) from turnover. It is important to note that a positive gross margins may permit businesses to continue operating in the short-medium term (1-5 years) but positive economic profits are required in the longer term to ensure capital can be replaced over time (>10 years).

A key function of the profit base case is a tabular (Excel) model of the relationship between catch returns and costs to estimate break-even points, that is, where costs are equal to turnover. This relationship was used to estimate the catch volume needed to break even given the current price, or alternatively what price would be needed to break-even, given the current volume. Details of assumptions that underpin the model are outlined in Appendices D and E. It is important to remember that the model is flexible because these assumptions can be adjusted to represent larger and smaller vessels and fishing businesses.

This base case was later used as the basis for comparison when exploring alternative scenarios by varying the prices and catch/vessel (see Section 3.3.5).

Table 1. Key model assumptions that underpin profitability estimation.

Variable	Trap	Prawn trawl
Allocation (under current TACC)	264 t#	135.2 t#
Number of vessels (active 2013/201)	3	18
Crab catch per vessel/year	89 tonnes	7.5 tonnes
Prawn (King & Tiger) catch/vessel	n/a	100 tonnes*
Average crab price	$5.24/kg	$5.24/kg
Average prawn price	n/a	$13/kg
Lease quota price (crab)	n/a	$2.20/ kilo

based on 400 tonnes split 2/3 trap (267 tonnes between three operators/vessel although in reality not split equally) and 1/3 trawl (133 tonnes split between 18 vessels).

* based on average King and Tiger prawn catches over the past 5 years.

3.3.3 Supply chain resilience

Supply chains were studied to identify i) where and how the benefits from the fishery flow-on to the community, ii) identify vulnerabilities in the supply chain, and iii) help understand business practices. Flow charts were developed to describe nine key stages and the flow of product between them: 1. Fisher, 2. interim storage, 3. fish receiver, 4. interim transport, 5. interim storage 6. Primary wholesale, 7. Secondary wholesale, 8. Market destination, 9. Consumers (modified after Plaganyi et al. 2014).

3.3.4 Employment and flow on benefits

Employment costs and major items of local expenditure were used as a measure of investment in the community. These were compared between the 2010/2011 season and the 2013/2014 season to examine how the fishery has changed since the closure.

Direct labour costs for the trap sector were summed directly from interview data. For prawn trawl these were estimated from the costing model (Appendix E3) because not all vessels provided data. We assumed that 10% of the direct labour costs were attributable to sorting and packing crabs.

The major downstream benefits of crab fishing have been employment in crab processing in Carnarvon at two factories prior to the closure with one factory remaining operational after the closure. One of these provided labour cost data for the purpose of this study. The other (closed) factory could not be contacted.

Upstream indirect beneficiaries (those providing goods and services to vessels) in Carnarvon are associated with, fuel, ice, bait, and vessel maintenance. These full costs were considered only for the trap fishery because the prawn trawl fishery does not use ice or bait. Upstream indirect benefits were not attributed to the crab catch in the prawn trawl fishery because fuel and maintenance costs are fixed by fishing practices for prawns and apply regardless of crabs.

For the trap fishery total fuel costs for 2013/14 were summed directly from the interview data. The 2010/2011 fuel costs were estimated based on the interview data scaled for the change in number of vessels and the change in fuel price: up 16.5% over 3 years (Australian Institute of Petroleum 2015). Ice, bait and maintenance costs were similarly calculated from the costing model (Appendix E), allowing for a 10% price increase (3.3% per annum).

3.3.5 Scenario evaluation

A number of scenarios were developed to explore future opportunities for the fishery. The two leading scenarios build on the baseline profit scenario (see Section 3.3.2) to explore the potential for greater profit in trap and prawn trawl fishing operations under different conditions for prices, volumes, and costs. The third scenario explores quota-trading. The final scenario explores the economic cost and benefit ratio of investing in more independent catch and effort data to improve precision in the stock status. All scenarios assume a business operating a single vessel.

Profits are most sensitive to variation in prices (market driven), volume (management driven) and costs (driven by business structure and external factors). The two leading scenarios explore the extent to which these factors influenced economic performance by varying the price between plausible limits of $4 and $10/kg based on historical beach prices and varying the crab catch/vessel between historical high and low levels. For the prawn trawl fleet, price and volume of prawns were also varied. Historical catch per vessel was calculated from historical catch data and vessel numbers.

Under the new management arrangements there is potential to increase economic efficiency by leasing quota from the trap to the prawn trawl sector and *vice versa*. For scenario evaluation a cost of $2.20/kg was assumed based on interview data. This base case was then modified to include the additional turnover and costs.

4 Results

4.1 Participation

Participation in the study was comprehensive from crab trap and trawl sectors as well as processors (Table 2), however the scallop trawl sector collectively declined to participate. The trap sector consists of five vessel licenses owned by three operators. Of the three operators, only two operators were active in 2014 (with three vessels) and both participated in the survey. Almost all prawn trawl licences (17/18) were represented in the survey by owners and/or operators.

Processors were also interviewed. By late 2014, the trap sector only sold to one exporter/processor. One operator has sold to another buyer in Carnarvon, but that operation has now closed and the corresponding product is now being processed outside the region. Most of the prawn trawl licences (14/18) supply to an exporter/processor in Fremantle. The remaining four prawn trawl licenses supply product mainly to the east coast domestic market.

Table 2. Summary of industry engagement for vessel licences owned in 2014/15

Group	Number in fishery	Number in Study	Participation
Trap fishers	5 licenses	5	100%
Prawn trawl fishers	18 licenses	17	94%
Scallop trawlers	10 licenses	1	10%*
Exporter/processor	2	2	100%

* Collectively the scallop trawl fishery group declined to participate but one operator who is also active in the prawn trawl fleet completed a questionnaire.

4.2 General fishery practices

The following brief descriptions of fishery practices were compiled from general questionnaires to help interpret results. Some key logistical constraints and differences in cost structures of the fishing operations between the trap and prawn trawl sectors were identified.

Trap fishing is a daily operation using high speed (45 km/hr) planing hull vessels of around 15 m fitted with 750–860 hp engines (Figure 4.1). Traps are baited with imported Sardinella (*Sardinella* sp., Clupeidae) while steaming 30–50 km from Carnarvon (or Denham in previous years) to and from the fishing grounds. Each day traps are set and hauled during daylight in sets of 25 pots that are tethered to each other along the sea-floor. Traps are hauled using a hydraulic pot-hauler, then emptied and rebaited by hand before resetting. The catch is chilled using ice.

Prawn trawlers are steel vessels of 22–25 m that carry out fishing trips of 22–24 days (Figure 4.2). Trip length is geared for targeting prawns between full moons. Nets are deployed and retrieved up to 6 times per night using hydraulic winches. The catch is released from the net into hoppers that hydraulically lift the catch onto sorting tables on which the catch is then sorted. Crabs are packed into boxes and frozen using on-board freezers. At the end of each

trip, prawn trawlers return to port for unloading, re-fuelling and servicing (generally during the full-moon period).

Figure 4.1. Crab trap vessel. Photo: Cummins Diesel

Figure 4.2. Prawn trawlers tied up at Carnarvon. Photo: Horizon Consultancy.

4.3 Catch price and gross value of production

An important economic indicator of the value of Australian fisheries to the economy is the estimated GVP, calculated from total catches multiplied by beach price.

When the monthly average catch values were calculated (Figure 4.3), a clear seasonal trend was evident in the combined trap and trawl catches, peaking in late autumn with an average of 117 t caught in May. Catches then declined through winter (June-August) and then

increase in late spring and early summer (November-December). Catches in the trap fishery peaked for longer, averaging 68–69 t/month through autumn from March to May. Trap catches are much lower from September to October because most operators stop fishing. When the trap season resumes in November, catches rise sharply with renewed effort. Average prawn trawl catches were lower but showed a generally similar pattern peaking in May at 48 tonnes. The prawn trawl fishery does not operate during the months of November to February inclusive.

The annual fishing season data (Figure 4.4) show commercial crab catch volume for prawn trawl and trap combined was high prior to the closure, staying above 648 tonnes between the 2006/07 season and the 2010/11 season and rising to 838 t for the 09/10 fishing season. In the 2011/12 season only 48 t was caught from November 2011 to February 2012 before the fishery was closed. The fishery was closed between April 2012 and September 2013 with the exception of a short-term commercial trap fishing trial during June 2013.

When the fishery reopened for the 2013/14 season, the prawn trawl crab catch was 196 t. This sector was able to exceed its allocation of 135.2 t by leasing in 61 t of quota from the trap sector providing economy of scale and volume of crab catch for the prawn trawl fishery. The prawn trawl crab fishery was therefore proportionally larger than trap by taking 58% of the TACC. By contrast, the crab trap fishery took only 176 t, well below its allocation of 267 t.

Analysis of GVP shows some economic recovery in the 2013/14 fishing season (Figure 4.5). Just prior to the closure in 2010/2011 combined GVP was $3.37 million, based on a relatively low official beach price of $4.25. After the closure the GVP had returned to $1.75 million which is 55% of the pre-closure value. This recovery was largely attributable to the higher beach price of $5.24 in the 2013/14 season and does not reflect the economic and biological risks indicated by reduced volume.

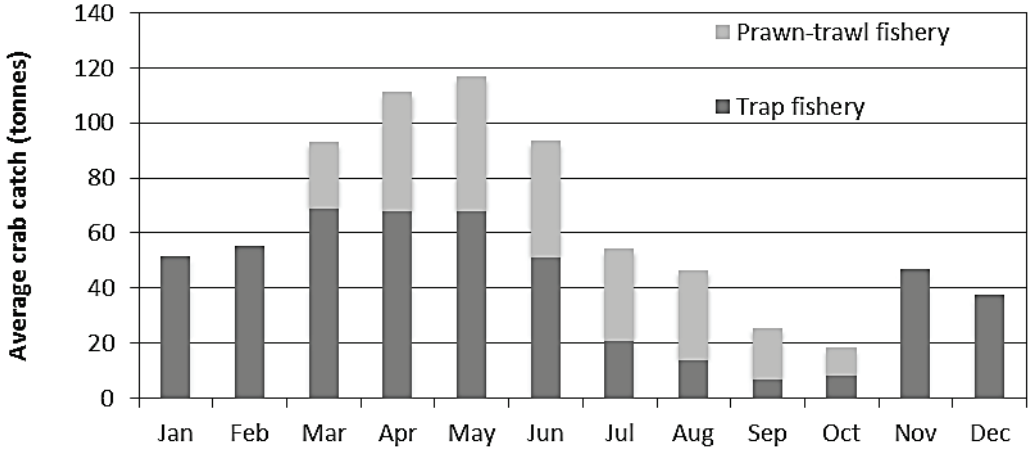

Figure 4.3. Monthly crab catches for Shark Bay crab trap and prawn trawl fisheries averaged for the years 2007 to 2011.

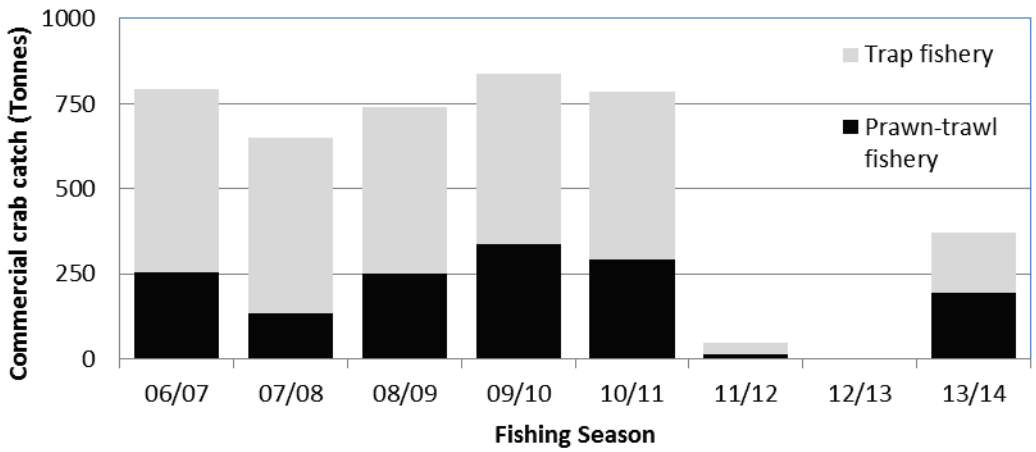

Figure 4.4. Crab catches for the fishing seasons 06/07 through to 13/14 in the Shark Bay crab trap and prawn trawl fisheries.

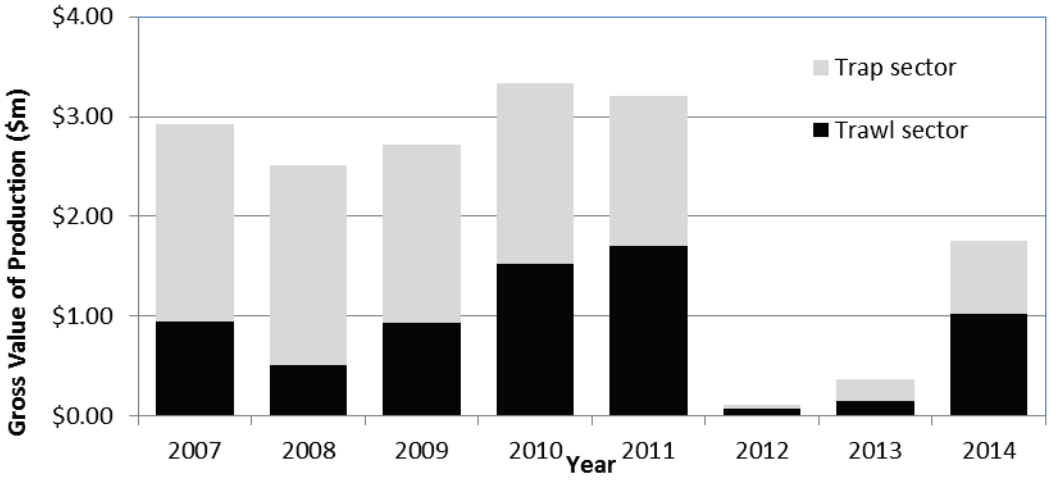

Figure 4.5. Gross value of swimmer crab production for the Shark Bay crab trap and prawn trawl fisheries before and after the closure.

Table 3. Catches and beach prices used to calculate gross value of crab production

Year	Commercial trap Catch (t)	Commercial prawn trawl Catch (t)	Beach price $/kg
(2010)/11	499	293	$4.25
(2011)/12*	36	12	$6.47
(2013)/ 14	175	196	$5.24

* Crab fishery closed from February 2012 until the end of the 12/13 fishing season.

4.4 Profitability

4.4.1 Trap

Analysis of catch data showed the average crab catch per vessel in the trap fishery was highly variable between 2000 and 2014 (Figure 4.6). During this period, the average catch increased from 2000 to peak at 211 t in 2011, and the catch per vessel did not fall below 50 tonnes per vessel except during the closure.

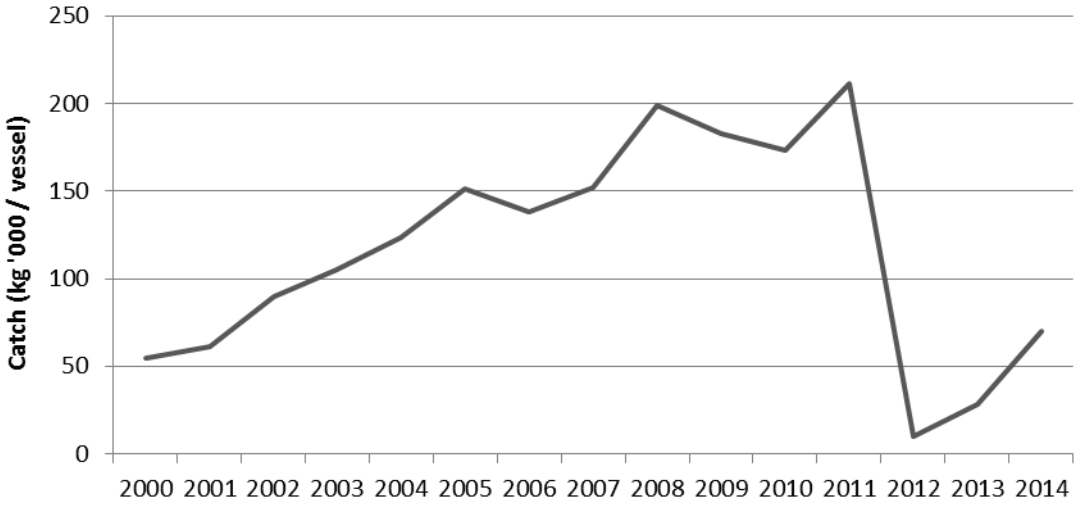

Figure 4.6. The average crab catch per Shark Bay trap vessel from 2000 to 2014.

Current turnover for a trap fisher catching 89 t based on a share of current TACC and receiving a price of $5.24 per kilo was estimated at $466K. At this catch level the fisher is estimated to have a positive gross margin of $85K. The fisher's economic profit however, will be negative at $180K. This means that the trap fishery will be able to cover variable costs and sustain fishing operations in the short to medium term at current prices and catch levels but these businesses will not be viable in the long term as they are not able to cover their depreciation on their capital. Not covering depreciation with turnover means that they are not financially able to replace their capital (e.g. vessels and gear). At a catch of 89 t for the trap sector the price of crab would need to be at least $7.26/kg to get an economic profit of $0 (breakeven) alternatively at current price of 5.24/kg the catch for the trap sector would need to be at least 123 t.

4.4.2 Prawn trawl

The crab catches per vessel in the prawn trawl sector were much lower than those for the trap sector as crabs are a byproduct (Figure 4.7). Average per vessel volume has never exceeded 20 t. In 2014, average catches in the prawn trawl sector were around 10 t per vessel (which is above the 2008 level for this sector).

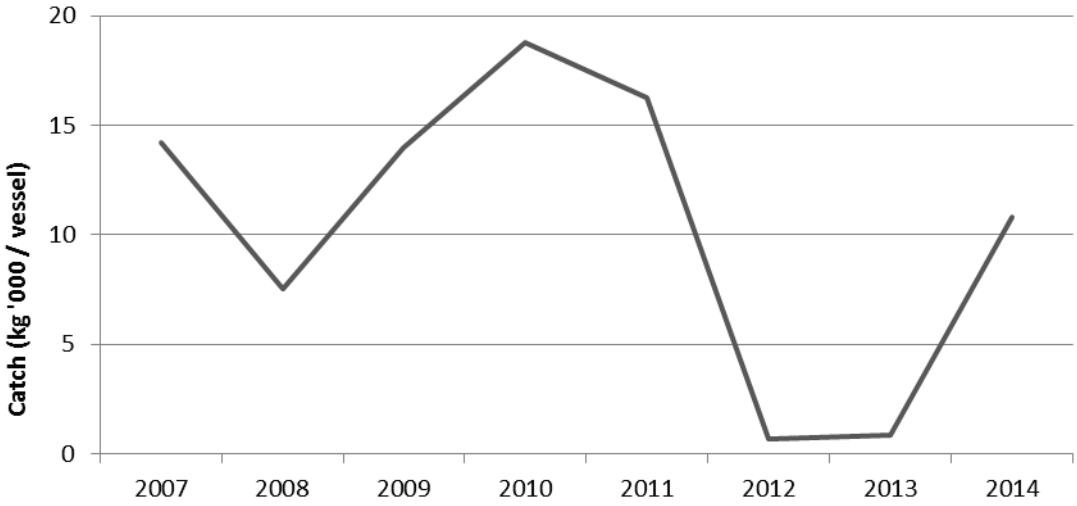

Figure 4.7. The average crab catch per Shark Bay prawn trawl vessel from 2007 to 2014

To model and analyse the profitability of the prawn trawl sector, an estimated 7.5 t of crab catch per vessel is assumed and a price of $5.24/kg . The crab catch makes up 6.2% of the total catch in weight. Turnover attributable to crabs for the prawn trawl fishery is estimated to be over $39K per vessel per year. In terms of returns, crabs make up 2.8% of total turnover per vessel per year (estimated at $1.4 million).

For a typical prawn trawl vessel, the overall gross margin (for all species caught) using a crab catch of 7.5 t is estimated at $134K. The prawn trawl sector has a negative economic profit (for which in this study debt and interest payments are excluded) at $39K. If crab prices were $13.77/kg (at a catch of 7.5 t), economic profit would be zero (assuming prawn catches and prices remain the same). At the current price of $5.24 the catch of crabs would need to be 19.7 t per annum per vessel for the sector's economic profit to break even.

4.5 Supply chain resilience

Prawn trawl and trap sectors have separate supply chains for crabs (Figure 4.8). Both are reliant on value adding to increase prices. Leasing of quota from trap to prawn trawl lead to reduced volume in the trap supply chain, and a corresponding increase for the prawn trawl sector. Questionnaire data shows international sales for both trap and prawn trawl are increasing because overseas buyers are more likely to pay a higher price for product sourced from a World Heritage Area, but this has to be weighed up against higher freight costs. In addition, processors argued local market share (Western Australia and eastern Australia) is being lost to cheap imported crab meat available locally in supermarkets.

Prior to the closure, the trap supply chain included two buyers in Carnarvon but one closed during the closure. Since 2013/2014 (when fishing recommenced) the trap supply chain consists of the single active vessel operator in a business vertically integrated with a processing plant that has adapted to change by diversifying to whole crabs and a range of value added crab products. General questionnaire data shows products rely on specialist machinery that have high capital costs ($Millions) operated in a climate controlled factory with high operating costs – particularly labour, electricity, rental and site development.

There are several steps in the trap crab processing process. The first is grading of the product. The largest crabs and those that are in the best condition which are cooked, frozen, vacuum packed and sold whole. Small and damaged crabs have the leg and body meat handpicked at the local facility in Carnarvon. Crab meat is used to produce products including crab cakes (cooked patties with herbs). Value adding processes and technologies and quality control help position Shark Bay swimmer crabs for premium market position (Musgrave and Slattery 2008, Abacus Fisheries 2015). A small amount of the value added product is sold locally in Western Australia but most is air freighted out of Perth Airport. Some product is destined for international markets, including China, but most is sold wholesale at the Melbourne and Sydney fish markets to east coast restaurants and wholesalers.

The prawn trawl supply chain for crabs differs substantially from the trap sector, in part due to the type of vessels and fishing operation. Prawn trawlers are at sea for more than 20 days at a time and freeze crabs on board packed in boxes. Once landed, most (85%) of the catch volume is transported by freezer truck to Fremantle. The product is then exported as frozen crabs for hand picking overseas. This saves on labour costs and capital costs, because overseas labour is cheaper in existing overseas factories, but reduces local employment in Australia and increases transport costs. The crab meat (Figure 4.9) is then mostly re-imported to Australia; with a smaller amount sold overseas. The remaining 15% of prawn trawl crab catch is sold directly onto the domestic market, either in Western Australia, or air-freighted to the east coast.

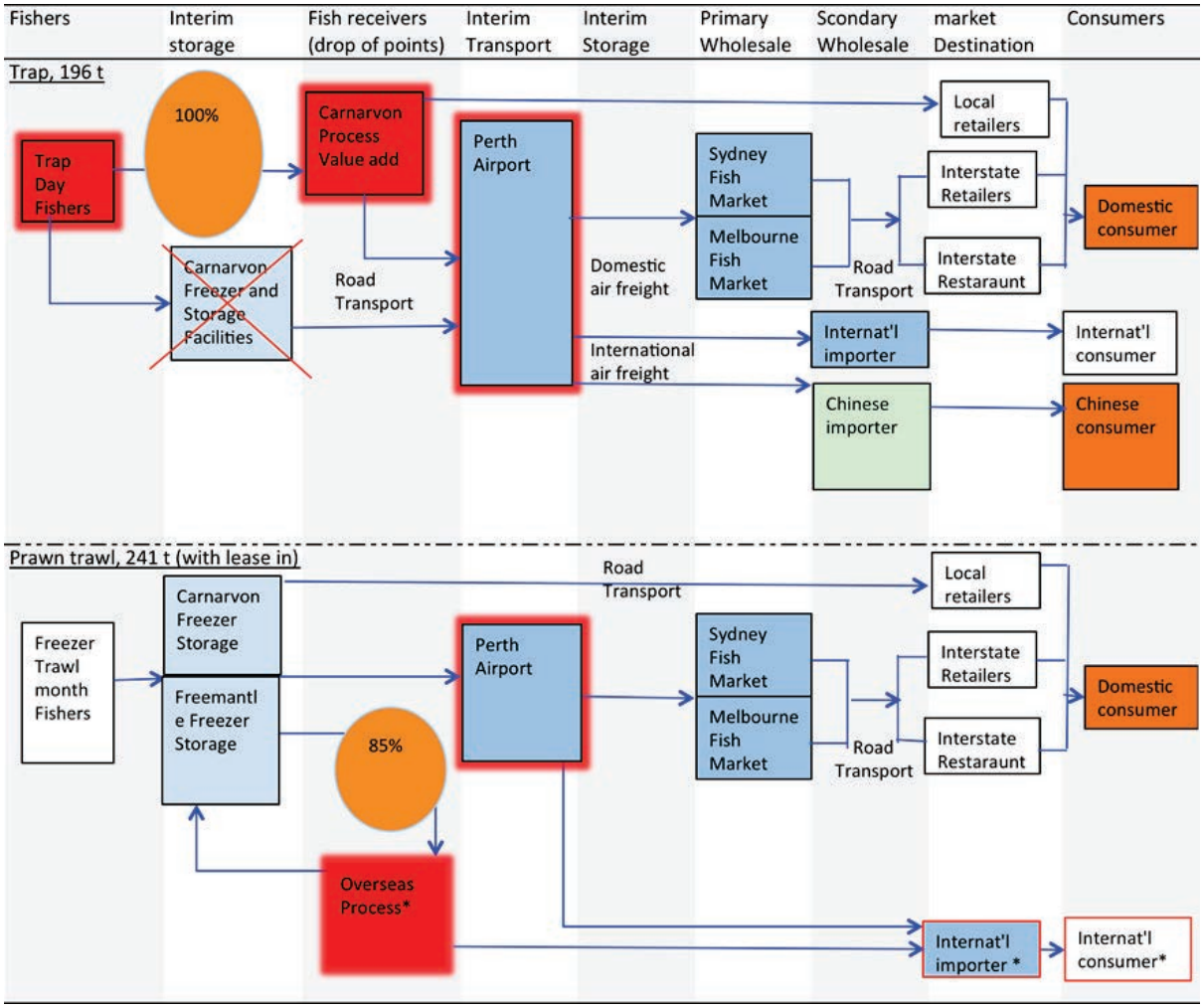

Figure 4.8. Crab supply chains for trap and prawn trawl showing 2014 configuration with a recent reduction in trap volumes and increasing export volumes in prawn trawl. Red cross indicates the closure of a storage facility during the closure.

Figure 4.9. Crab meat exported by the prawn trawl sector of the Shark Bay Blue Swimmer Crab fishery for hand picking overseas and re-imported.

4.6 Employment and flow on benefits

Since the closure, employment and flow-on benefits have changed substantially. Essentially these changes occurred in the trap fishery due to reduced catch volume, a reduction in the number of active vessels from 5 to 2.5, and reductions in associated spending.

Direct labour spending provides both economic and social benefits to the region. Direct labour spending for trap based on interview data fell by 46% from $0.713 million prior to the closure to $0.386 million after the closure (Table 4). For the prawn trawl sector, direct labour attributed to crabs (assumed to be 10% of the labour cost) increased by 10% with inflation to $0.462 million. Interview data suggests that the value of the crab catch to the community exceeds this monetary value. Most prawn-trawl skippers interviewed indicated that towards the end of the season in particular, the crab catch is needed to retain crew as the prawn catch tends to decrease near the end of the season. This need is met by providing a pay structure incentive that returns a higher proportion of the catch value for crabs to the crew (in comparison to the catch value of prawns). This incentive has been deliberately developed to retain experienced crew until the end of the season. Without this incentive, and end of season bonuses, some crew fail to complete the season or return the following season. Hence the prawn-trawl fishery relies on the crab catch and other byproduct species to maintain a skills base in Carnarvon.

Upstream expenditure (on goods and services provided to vessels) in the trap fishery has fallen by 42% since the closure (Table 4). The major declines were in the fuel and maintenance costs due to the reduction in the number of vessels operating. According to interview data, additional indirect labour for trap vessels, including trap repairs and vessel slipping/painting, is provided by fishing crews in the off-season. This provides a social benefit by helping to maintain a skills base in the region.

Table 4. Major regional spending by the Shark Bay blue swimmer crab Fishery prior to a major closure (2010/2011) and after the closure (2013/2014).

Regional spending, Carnarvon/Denham	(2010)/2011	(2013)/2014
Direct labour spending		
Trap	$713,842	$385,805
Prawn trawl	$416,476	$462,751
Upstream spending - trap only		
Fuel	$683,865	$409,500
Bait	$31,838	$17,688
Ice	$35,438	$19,688
Vessel repairs and maintenance	$272,250	$151,250
Downstream spending		
Processing labour Carnarvon	$1,045,638	$482,586
Total	$3,199,346	$1,929,267

The most substantial negative effect of the closure on flow on benefits was the impact on downstream processing. The associated labour spending has fallen by just over half (54%) representing $0.563 million in lost annual wage spending. This loss is an under-estimate because it does not include data from the packer/processor who did not re-open following the

closure. Again the social cost to the community of the lost skills could be just as important as its economic loss to the fishery and the associated cost of training new staff if the trained process labour leave the region and do not return.

4.7 Scenario evaluation

4.7.1 Crab trap scenarios

The effect of price changes on profit was explored by varying the baseline price of $5.24 per kg between plausible limits of $4 and $10/kg (Table 5). The effect of changing volume was explored by varying per vessel crab catches in the trap fishery between 50 and 200 tonnes (Figure 4.10).

Scenario analysis of crab trap operations indicates returns could be positive if a modest increase in volume can be achieved. At a volume of around 125 tonnes, a price of around $7 per kg can deliver a profit to a business that takes all its catch using one vessel. For example, a fishing business catching 125 t and selling at $7/kg is predicted to return an economic profit of $229K.

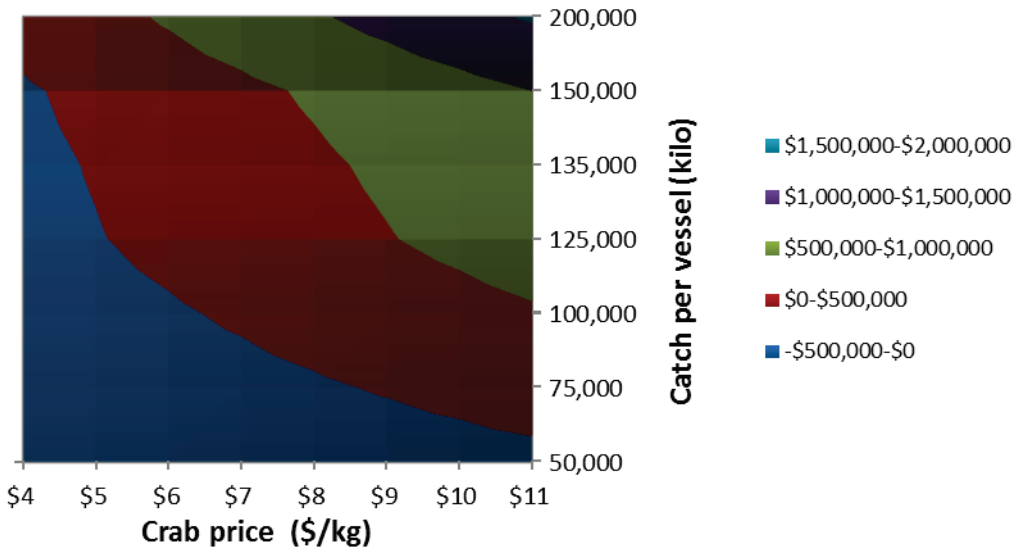

Figure 4.10. Contour plot showing the relationship between crab catches and prices and the estimated economic profit interval per vessel per annum for the crab trap sector.

Any further increase in prices and volume would provide substantial mitigation against economic risks. An increase in volume from 125 to 135 t/year, with a price of $7/kg, has the potential to increase profit by 31% from $229K to $299K. Potentially an increase in price will have more impact on profit than increases in volume. If a 125 t/year business could increase the price obtained for crabs from $7/kg to $8/kg, profit would increase 55% from $229K to $354K.

It is important to consider some scenarios that are unlikely or not plausible. It seems unlikely for a single vessel business to catch more than 150 t/year, given the stock has not yet recovered, and 200 t/year is outside the range of catch history. Similarly a price of $11/kg

does not seem plausible in the current situation where competition with cheap imports is occurring.

Table 5. Estimated economic profit ($'000) for the trap sector at varying crab prices per kilo for different catch levels per vessel.

	Crab Price						
Crab catch per vessel (t)	$4/kg	$5/kg	$6/kg	$7/kg	$8/kg	$9/kg	$10/kg
50 t	-$446	-$396	-$346	-$296	-$246	-$196	-$146
75 t	-$346	-$271	-$196	-$121	-$46	$29	$104
100 t	-$246	-$146	-$46	$54	$154	$254	$354
125 t	-$146	-$21	$104	$229	$354	$479	$604
135 t	-$106	$29	$164	$299	$434	$569	$704
150 t	-$46	$104	$254	$404	$554	$704	$854
200 t	$154	$354	$554	$754	$954	$1,154	$1,354

4.7.2 Prawn trawl scenarios

Scenario evaluation was similar to the trap fishery for the prices which were varied from $4 to $10/kg (Table 6). However catch volumes were set lower and were varied from 5 to 30 tonnes. The base case uses an estimated prawn catch of 100 tonnes per vessel. Results show that a catch of greater than 10 tonnes of crabs per vessel is needed to make a profit (Figure 4.11).

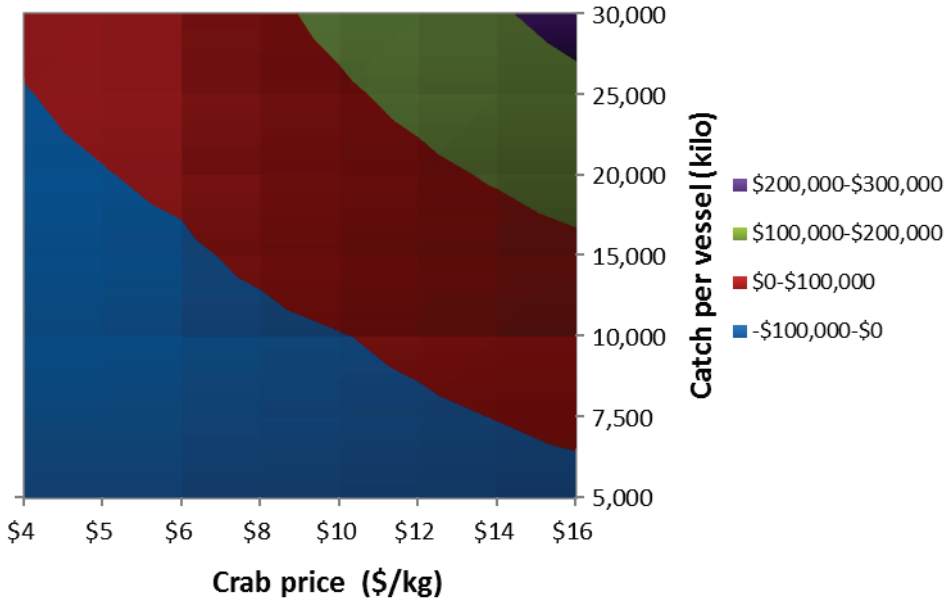

Figure 4.11. Contour plot showing the relationship between crab catches and prices and the estimated economic profit interval per vessel per annum for the prawn trawl sector.

At current prices of $5.24/kg volume needs to reach 25 tonnes of crabs per vessel. This is because prawn vessel costs are mostly fixed annually or monthly and offset against the prawn catch (see Section 3.3.2).

Table 6. Estimated profit ($'000) for the prawn trawl sector at varying crab prices per kilo and catch levels per vessel.

	Crab price						
Crab Catch per vessel (t)	$4	$5	$6	$7	$8	$9	$10
5 t	-$51	-$48	-$45	-$38	-$32	-$26	-$20
7 t	-$45	-$40	-$35	-$26	-$17	-$8	$1
10 t	-$38	-$32	-$26	-$14	-$2	$10	$22
15 t	-$26	-$17	-$8	$10	$28	$47	$65
20 t	-$14	-$2	$10	$35	$59	$83	$108
25 t	-$2	$13	$28	$59	$89	$120	$150
30 t	$10	$28	$47	$83	$120	$156	$193

The crab catch becomes crucial to the prawn trawl sector when king and tiger prawn catches fall to100 tonnes or lower per vessel (Table 7). At 100 tonnes of prawns, prawn vessels will need to catch between 15 and 20 tonnes of crabs (all else being equal) to break even. At current prices of $13/kg for prawns and $5.24/kg for crabs, the prawn catch will need to be 103 tonnes (and 7.5 tonnes of crabs) to break even. These scenarios are optimistic because the costs do not include interest to service the buyback debt.

In a similar kind of scenario analysis the price of crab and prawns (king and tiger) can be varied (Table 8). At the current prawn catch of around 100 tonnes and a crab catch of 7.5 tonnes, the price for prawns needs to be slightly over $13.51 per kilo to break even regardless of the price of crabs.

Table 7. Estimated economic profit ($'000) for the prawn trawl sector at varying crab catches and prawn catches (king and tiger prawns) per vessel.

	Prawn catch							
Crab catch	60 t	70 t	80 t	100 t	105 t	110 t	120 t	130 t
5 t	-$445	-$346	-$246	-$47	$3	$53	$152	$252
7.5 t	-$437	-$338	-$238	-$39	$11	$61	$160	$260
10 t	-$429	-$330	-$230	-$31	$19	$69	$168	$268
15 t	-$413	-$314	-$214	-$15	$35	$85	$184	$284
20 t	-$397	-$298	-$198	$1	$51	$101	$200	$300
25 t	-$381	-$282	-$182	$17	$67	$116	$216	$316
30 t	-$366	-$266	-$166	$33	$83	$132	$232	$332

Table 8. Estimated economic profit ($'000) for the prawn trawl sector at varying crab prices and prawn prices (king and tiger prawns) per vessel.

	Crab price						
Tiger & king prawn price	$4/kg	$5/kg	$6/kg	$7/kg	$8/kg	$9/kg	$10/kg
$9/kg	-$351	-$346	-$342	-$337	-$333	-$328	-$324
$10/kg	-$274	-$270	-$265	-$261	-$256	-$252	-$247
$11/kg	-$198	-$193	-$189	-$184	-$180	-$175	-$170
$12/kg	-$121	-$117	-$112	-$107	-$103	-$98	-$94
$13/kg	-$45	-$40	-$35	-$31	-$26	-$22	-$17
$14/kg	$32	$37	$41	$46	$50	$55	$59
$15/kg	$109	$113	$118	$122	$127	$131	$136

4.7.3 Quota leasing scenarios

During the 2013/14 season, crab quota was leased from the trap to the prawn trawl sector. Assuming vessels can double the retained crab bycatch without targeting (an additional 7.5 tonnes to a total of 15 tonnes), leasing in quota at $2.20 per kilo could increase turnover by $39.3K and increase a prawn trawl vessel's gross margin from $140 to $156K. The prawn trawl sector would need to lease an additional 12,802 kg of quota per vessel to return an economic profit of zero. This seems realistic if the quota lease price remains as low as $2.20 per kilo.

Even though the trap sector did not lease in quota, the sector would need to lease in 5 tonnes per vessel of crab quota on top of the 59 tonnes allocated for an economic profit of zero (at current lease prices of $2.20/kg and crab price of $5.24/kg).

5 Discussion

5.1 Catch and price data and GVP

The crab trap and prawn trawl fisheries collect reliable daily logbook catch and effort data. These are supplemented by fishery independent survey data. Any future increases in TACC are dependent on confidence that these data show increases in overall abundance.

Price data was a key uncertainty in the estimation of GVP for most years prior to the 2013/14 season. This occurred because previously there had been no consensus between the fishery and management on how the beach price should be set. In this study we used only the official Western Australia beach prices obtained from ABARES for past years. Prices reported by survey participants were mostly higher than the official ABARES figures but this is difference was attributed to the need to adjust for freight costs. This provides confidence in the estimate of GVP for the 2013/2014 season. Subsequently industry and management have reached agreement on how the beach price will be set which will underpin monitoring of trends in the economic performance of the fishery.

Interview data found prices fluctuate by season in the trap sector but not for the prawn trawl sector. This can be partly explained by the difference in the structure of the supply chains and the product destination. The domestic market for whole crabs peaks over the Australian Christmas (summer) holiday season. The largest and most valuable crabs taken by the trap sector supply this market. In contrast, a higher proportion of crabs caught by the prawn trawl sector are exported for hand picking overseas, where there is not such an obvious seasonal peak in the price.

This study estimated GVP fell from $3.37 Million prior to the closure in 2010/2011 to zero during the closure then recovered to $1.75 Million 2013/2014 season. Previous studies have estimated the GVP of the Shark Bay Crab catch peaked at 828 t worth over $6 Million in 2010 (Harris et al. 2014). This equates to a price of $7.24/kg.

The uncertainty in GVP estimates are largely attributable to sectoral differences in reported crab prices and the lack of regional price data collection by official authorities to verify the prices reported by the fishers and processors. A remedy sought in this study (to overcome price uncertainty) was to undertake scenario analyses where the price is varied between an assumed maximum and minimum value. It would seem essential for future management of the Shark Bay crab fishery to develop an improved price data collection system for crab landing prices. Beach price data verified with receipts is needed to measure GVP with greater precision. Price data information is a key component of all economic indicators.

It is important to note that GVP is a simplistic indicator of economic performance. This choice was constrained mainly by the lack of consistent price data in catch history. Now that there is agreement on how price data will be collated it may be possible to develop other indicators in future studies.

5.2 Profitability

Two key steps were taken to increase the reliability of the profit analysis. The analysis of current profitability used the 2013/2014 price as the baseline, which was consistently validated around $5.24. The scenario analysis used a price range of between $4 and 10, which encompassed all historical price values. The range of catch volumes used in scenario analysis was checked against the historical range and found to be consistent.

Profitability is sensitive to volume, price and costs, and currently the crab trap fishery has an estimated gross margin of $85K and a negative economic profit of $180K per vessel. The prawn trawl fishery, that catch crabs as byproduct, had an estimated gross margin of $134K and a negative economic profit of $39K per annum. Some cost efficiencies are probably achieved by businesses that operate two or more vessels (horizontal integration) – but it was not possible to ascertain accurate estimates of cost efficiencies in this current study.

It is worth considering how, and to what extent, the fishery can change the volumes, cost and price factors to increase profitability to gain a positive economic profit, essential to ensure long-term business sustainability. If the stock continues to recover, an increase in the TACC is possible in the long term. At present volume is limited because the stock is recovering. Increasing the volume of the catch taken by some vessels may be possible by leasing in quota. Highest returns will be achieved by taking highest catches around Christmas and Easter, when prices are highest on the domestic market.

There are mixed opinions on whether the fishery has the capacity to achieve higher prices. Achieving a higher price is dependent on the clean green image of value added product. Cheaper imported crab meat, available in supermarkets, challenges this potential. Beach prices for crab trap have been relatively low since 2005. Our scenario analysis found a price of $7.26/kg was needed for the trap fishery at current volumes, which is a substantial increase from the current price. Alternatively, at current prices, a 38% increase in volume would be needed to break even. Such an increase in volume is not plausible, at least in the short term, given that the stock is still in its initial stage of recovery. For the 2013/14 catch, the under and over catches were attributed to quota trading due to the change in management arrangements rather than the sustainability or availability of the stock.

Consideration of variable costs indicates there is limited scope to increase gross margins by cost savings. A key variable cost is fuel, forming an important component of variable costs as it does in many fisheries. Industry confirmed that their business profits are particularly sensitive to this externality.

Key downstream costs are comprised of road and air freight costs. Operators believe air freight costs are likely to increase. This will impact on the profit margin for large crabs that are air-freighted to the east coast, but not necessarily the prawn trawl caught product shipped and processed overseas. For prawn trawlers there are also costs (or increasing debts) associated with the buyback, a process that has reduced the number of prawn trawl vessels during the last 10 years. Respondents were reluctant to discuss debt levels, which makes this

buyback cost difficult to assess. If there is substantial debt associated with the buyback then some scenarios exploring profitability could have under-estimated costs (Section 3.5).

Fixed costs differ between the prawn trawl and crab trap sectors. The prawn trawl sector currently has a positive gross margin but a small net economic loss. Prawn trawl has higher fixed costs than trap but these are offset against returns from the target species (prawns). This means any increase in crab catch has a positive effect on returns, without substantial additional costs. This provides a powerful incentive for the prawn trawl sector to lease in quota from the trap sector.

Gross margins account for variable costs but exclude depreciation and debt and interest payments. Most (13 out of 18) prawn trawl vessels are more than 25 years old meaning that with current net economic losses in the prawn trawl sector there will not be the financial resilience to replace hulls or maintain expensive on board freezers in the long term.

The fishery has taken some steps to control labour costs in fishing and processing. Most trap and all prawn trawl fishing vessels pay the skipper and crew using catch shares, which is typical for fishing operations. One trap vessel pays the crew a daily rate. This structure provides higher returns to the business during peak times and provides a "safety net" for the crew when catches are low. Processors have different avenues by which they keep their costs low, for example by using skilled 457 visa workers, using high tech processing machinery, or sending product overseas for processing then re-importing it. The latter cost saving needs to partly offset the additional freight costs.

5.3 Supply chain, employment and flow on benefits

Overall it is evident that the two-year closure has had a significant impact on the structure of the supply chains and this change is likely to be difficult to reverse. Both supply chains are now vulnerable to any additional reduction in catch in the future. Both trap and prawn trawl supply chains have vulnerable points in the supply chain with 85–100% of volume throughput.

Since the closure the trap fishery has seen substantial reductions in direct and indirect (processing) labour spending totalling $0.891 Million. Together with reduction in spending on key vessel inputs totalling $0.425 million these are significant losses for the small regional economy. Perhaps equally significant is the loss of skilled labour in skippers, crew and trained factory staff. The prawn trawl sector has increased spending on processing crabs but this occurs overseas and does not provide benefit for the local community, hence there is a direct trade-off between economic and social objectives of the fishery.

6 Conclusion

This report provides a reference point for the socio economic performance of the Shark Bay Blue Swimmer Crab Fishery in 2013/14 as it commenced recovery while implementing substantial management changes after a period of closure. Four socio-economic criteria were developed and analysed, focussing on the 2013/14 year.

In 2013/14, gross value of production was $1.75 million dollars. In that year the prawn trawl fishery took most of the crab catch (58%) totalling 196 tonnes whereas the trap fishery took only 176 t. These figures represent a substantial over-catch of crabs compared to the TACC by the prawn trawl fishery and a substantial under-catch by the trap fishery. These under/over-catches are attributed to quota trading in response to management changes rather than changes in the stock status or availability.

The estimated net economic profit for typical vessels in both the trawl and trap fisheries was negative. That means they will be unable to afford to replace vessels and equipment in the longer term. Fishing businesses in the trap sector in particular struggled with low volume and low prices. There seems little scope to increase volume in the short term at least due to the recovering status of the stock. There are mixed views on whether higher prices are possible. The cost structures for the prawn trawl and trap fisheries are distinct. The prawn catch can cross-subsidise the crab catch in the prawn trawl sector, providing resilience against periodic declines in crab catches. This is not the case in the single species trap sector.

The supply chains for trap and prawn trawl crab catches are separate. Each has a single horizontally integrated business (more than one fishing boat) that dominates the supply chains across the process stage. The low number of processors serving the fishery lowers its resilience but integration contributes to efficiency and profitability. In the trap sector this business is vertically integrated from fishing to value adding processes to marketing and export. These business integrations improve economies of scale and profitability and have the potential to affect price structure.

The trap fishery supply chain contributes to local flow on benefits and regional employment by value adding to the product in the Shark Bay regional area. High factory capital and labour costs means that much of the product from the trawl supply chain is now being processed overseas. Overall the value of direct labour spending, upstream spending (fuel, bait etc.) and downstream spending was worth $1.93 to Carnarvon/Denham in 2013/2014.

Scenario analysis found that a trap fishing business could achieve a long-term profit with a catch of around 125 t sold at a price of $7/kg. A prawn trawl business could become economically sustainable with a catch of 25 t of crabs per year even with the 2013/2014 price of $5.24/kg. These results indicate the prawn trawl fishery has greater economic resilience than the crab trap fishery.

Overall the results of this study imply that an average fishing business will not be sustainable in either the prawn trawl or crab trap fisheries over the longer term under the current management arrangements and economic conditions. The new management arrangements provided the possibility for fishers to develop strategies to buffer individual businesses, both trap and prawn trawl, against fluctuations in price and catch.

7 Appendices

7.1 Appendix A. Industry General Questionnaire

About this survey

This survey is aimed at determining key aspects of the swimmer crab fishery in WA. The survey is entirely voluntary although we do encourage you to participate. Your participation will increase the accuracy of the information we need to determine the i) value of the industry, ii) industry profitability, iii) flow on effects, and iv) direct and indirect employment. If you have any queries about this study or this survey please contact Ross Daley at the above contact details.

This survey consists of 5 sections and should take you around 15 minutes to complete. Thank you very much for your participation.

Fishing information

Are you in the trap or trawl fishery for Swimmer crabs

(please name)

Vessel description and length

(meters)

1 Quota information

1.1 How much quota for crabs do you own at present?

(number of units OR kilo/year)

1.2 Do you catch any other fish (or hold licences/quota for any other species)?

(name species)

1.3 Did you go fishing in the 2013/2014 season?

(yes or no)

1.4 IF YES – did you catch all your quota?

(yes or no)

1.5 IF YES – did you trade (lease) any of your quota?

(Number leased in or out)

1.6 Have you sold or bought any of quota?

(Number sold or bought)

2 Catch information

Please answer the following questions for the last time you fished for crab

2.1 When was the last time you fished for crabs?

(year)

2.2 At what time of the year did you get the *highest* catches?

(Name months)

2.3 At what time of the year did you get the *lowest* catches?

(Name months)

2.4 When you last fished for crabs did the catch vary a lot over any given year?

(yes or no OR kilo difference)

2.5 Approximately how much was your turnover from crab fishing last time you went fishing?

($ per year)

2.6 Has your income from crab fishing increased or decreased over the past 5 years?

(Increased or decreased)

2.7 **FOR TRAWL FISHERS** – what is the approximate proportion of vessel time used for fishing crabs?

(proportion of total vessel time)

2.8 **FOR TRAWL FISHERS** - Approximately how much was your turnover from other fishery?

($ per year)

3 Price information

Please answer the following questions for the last time you fished for crab

3.1 What was the *highest* price for crabs you received (in which year)?

($/kg)

3.2 What was the *lowest* price for crabs you received (in which year)?

($/kg)

3.3 At what time of the year did you get the *highest* price?

(Name months)

3.4 Who did you sell your catch to (e.g. processor – retailer – direct to consumer)?

(Please name)

3.5 Do you know where your product ends up after you have sold it (e.g. China – Sydney)?

(Briefly explain)

4 Supply chain information

We would like to find out which particular **local** goods and services your business depends on (referred to as up-stream industries) and supplies to (referred to as downstream industries).

4.1 Please tick if you buy the following items or services locally in Shark Bay

Bait	
Supplies (food etc.)	
Clothes used for fishing	
Tackle	
Fuel (diesel/petrol)	
Boat slipping	
Mechanics (motor)	
Electrical repairs	
Fit out gear for the boat (ropes / nets /traps)	
Vessels	
Dinghy	
Other	

4.2 Please tick if you supply your fish/catch to any of the following businesses in Shark Bay

Restaurants	
Processors	
Hotels/accommodation	
Consumers (straight off the boat)	
Local fish sellers/punts	
Fish and chips shops	
Other	

5 Employment and other information

Please answer the following questions for the last time you fished for crab

5.1 How many people do you employ in fishing for crabs (and how many are family members)?

(Number employed)
(Family members)

5.2 How much of your income (as a percentage) is dependent on fishing for crab?

(% of total)

5.3 How much time do you spend on work related to crab fishing that is unpaid (e.g. average number of days you spend doing the books or repairs)

(hours/week or month)

5.4 How did you get involved in crab fishing? (e.g. family history)

(Explain briefly)

5.5 How long do you think you'll keep doing it (if possible)?

(Years)

5.6 What will you do if you stop fishing for crab?

(name activity)

5.7 Are there any health and occupational health and safety issues associated with crab fishing?

(Please list)

5.8 Please identify any significant changes you've observed in the industry that are important to you and why?

(Please name)

5.9 Why do you go crab fishing (e.g. cross subsidising another fishery, easy to do, fun)?

(Please name)

Survey Number:

7.2 Appendix B: Industry Coasting Questionnaire

1. QUOTA AND PRICING	Units	YOUR ESTIMATE
Total units of quota caught from this vessel	number	
Number of quota units owned	number	
Number of quota units leased OUT	number	
Number of quota units leased IN	number	
Total units leased to others	kilo	
Total catch last 12 months	kg/quota unit	
Kilo per quota entitlement	%	
Proportion of quote units leased	$/kg	
Average price OF CRAB	$/kg	
Cost of leasing quota	$	
Market purchase price of units		
2. TRIP	**Units**	**YOUR ESTIMATE**
Average distance travelled	nautical miles/trip	
Length of typical fishing trip (days)	days	
Number of days fished per year (days)	days	
Number of shots/potlifts per day	potlifts/day	
Fishing trips per annum (number)	number	
Time spent steaming as proportion of trip	%	
Fuel usage per day (liters)	liters	
Number of deckhands per trip	number	
3. OPERATING (trip) COST	**Units**	**YOUR ESTIMATE**
Fuel and oil - vessel	$/trip OR $/year	
Bait	$/day OR $/trap OR $/year	
Food for crew	$/day at sea OR $/year	
Ice blocks	$/trap OR $/year	
Replacement pots	$/trap	
Number of pots replaced per year	Number	
Ropes	$/year	
Protective clothing & cleaning products	$/year	
4. ANNUAL VESSEL COST	**Units**	**YOUR ESTIMATE**
Mooring fees	$/year	
Slippage and haulage fees	$/year	
Slippages per annum	Number	
5. LABOUR	**Units**	**YOUR ESTIMATE**
Deckhand pay	% of catch	
OR deckhand pay	$/year	
OR average daily deckhand pay	$/day	
Superannuation	% of wages	
Opportunity cost of skipper time or wage	$/year	
6. REGISTRATION FEES	**Units**	**YOUR ESTIMATE**
Vessel licence fee	$/year	
Vehicle registration	$/year	
Survey fees - dinghy	$/year	
Survey fees - vessel	$/year	
7. LICENCE FEES	**Units**	**YOUR ESTIMATE**
Life raft survey fees	$/year	
Personal fishing licence	$/year	
Unit renewal fees	$/year	
Fishing licence fees	$/year	
8. INSURANCE	**Units**	**YOUR ESTIMATE**
Insurance fees - dinghy	$/year	
Insurance fees - vessel hull and engine	% of value	
Vehicle insurance	$/year	
Personal insurance	$/year	

9. OFFICE EQUIPMENT	Units	YOUR ESTIMATE
Office equipment setup	$	
Purchase satellite phone	$	
Life - office equipment	years	
Life - satellite phone	years	
10. OFFICE CONSUMABLES	**Units**	**YOUR ESTIMATE**
Office supplies	$/year	
Postage	$/year	
Books and publications	$/year	
Satellite phone	$/year	
Phone/internet	$/year	
11. ACCOUNTING	**Units**	**YOUR ESTIMATE**
Accounting and business administration	$/year	
12. MEDICAL /TRAINING	**Units**	**YOUR ESTIMATE**
First Aid course, other	$/year	
13. MISCELLANEOUS	**Units**	**YOUR ESTIMATE**
Tools	$/year	
Advertising	$/year	
14. CAPITAL COST and ANNUAL DEPRECIATION	**Units**	**YOUR ESTIMATE**
Dinghy (hull only)	$	
Outboard for dinghy	$	
Purchase price electronic equipment	$	
Purchase price - pump	$	
Purchase price - genset	$	
Purchase price hydraulics	$	
Purchase price - vessel (excl gear)	$	
Purchase price - vessel engine	$	
Purchase price - survey equipment	$	
Purchase price - vehicle	$	
15. LIFE - CAPITAL ITEMS	**Units**	**YOUR ESTIMATE**
Life - Dinghy (hull only)	years	
Life - outboard dinghy	years	
Life - electronic equipment	years	
Life - pump	years	
Life - genset	years	
Life - hydraulics	years	
Life - vessel	years	
Life - vessel engine	years	
Life - vessel survey equipment	years	
Life - vehicle	years	
16. CAPITAL EQUIPMENT repairs & maintenance	**Units**	**YOUR ESTIMATE**
Repairs/maintenance - dinghy	$/year	
Repairs/maintenance - outboard dinghy	$/year	
Repairs/maintenance - vessel (excl slippage fees)	$/year	
Repairs/maintenance - vessel engine	$/year	
Repairs/maintenance - vessel electronic equipment	$/year	
Repairs/maintenance - other vessel equipment	$/year	
Vehicle service cost	$/year	
17. ASSET/QUOTA RELATED COST	**Units**	**YOUR ESTIMATE**
Investment in units	$	
Cost of leasing units	$	
18. DEBTS AND INTEREST REPAYMENTS	**Units**	**YOUR ESTIMATE**
Borrowing on vessel and other business assets	$	

7.3 Appendix C:

Date	Contact group	Contact type	Location
3/09/14	Trap fisher	Interview	Coogee
4/09/14	Trawl rep	Interview	Fremantle
4/09/14	Processor	Interview	Fremantle
5/09/14	Science project plan	Project plan	Hillarys
6/10/14	Processor	Phone calls	
6/10/14	Trawl rep	Phone call	Fremantle
6/10/14	Processor	Phone call	
7/10/14	Processor	Phone call	
8/10/14	Processor	Phone calls	
9/10/14	Processor	Interview	Fremantle
10/10/14	Processor	Phone calls	
10/10/14	Trawl rep	E-mail	Fremantle
10/10/14	Trawl owner	E-mail	Fremantle
10/10/14	Trawl owner	Interview	Fremantle
10/10/14	Trawl owner	Phone call	
11/10/14	Trawl operator	Interview	Carnarvon
12/10/14	Trawl owner	Interview	Carnarvon
12/10/14	Trawl owner/operator	Interview	Carnarvon
12/10/14	Trawl operator	Interview	Carnarvon
12/10/14	Trawl operator	Interview	Carnarvon
12/10/14	Trawl operator	Interview	Carnarvon
12/10/14	Trawl operator	Interview	Carnarvon
13/10/14	Trap fisher	Interview	Carnarvon
13/10/14	Trawl owner	Interview	Carnarvon
14/10/14	Processor	Interview	Carnarvon
16/10/14	Science data meeting	Data meeting	Hillarys
12/12/14	Trawl operator	Interview	Carnarvon
18/12/14	Processor	E-mail, request for price data	
4/01/15	Trap Fisher	Phone call, follow up questions	
5/01/15	Processor	Phone call, text, employment data	
5/01/15	Processor	Phone call request for price data	
20/01/15	Science data	Phone call	
27/01/15	Science data	E-mail	

7.4 Appendix D: Fish prices

Average annual fish prices for the trawl sector ($/kg)

Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
King Prawns	$13.45	$12.60	$12.00	$10.05	$11.00	$10.50	$10.36	$11.90	$12.60	$12.33
Tiger Prawns	$14.50	$15.70	$14.60	$12.45	$11.85	$12.00	$12.33	$14.60	$13.40	$13.33
Coral Prawns	$4.40	$4.00	$2.50	$2.00	$2.00	$2.50	$3.00	$3.80	$3.50	$3.33
Endeavour prawns	$6.85	$6.70								$7.27
Scallops					$3.90	$3.90	$4.05	$5.00		
Crabs							$4.50	$5.80	$5.50	$5.24

7.5 Appendix E1: Model assumptions crab trap sector- General

General	Units	Most likely
Discount rate	%	6%
Superannuation	% of wages	9.5%
Fishery	**Units**	Most likely
Crab price	$/kg	$4.55
Crab quota (for one vessel)	kg	89,000
Quota units leased IN	kg/year	0
Quota units leased OUT	kg/year	0
Crab catch	kg/year	89,000
Cost of leasing quota	$/kg	n/a
Fishing trips	**Units**	
Number of trips per year	Number	185
Length of a trip	days	1
Number of days fished per year	days	185
Number of hours/trip	Hours/trip	10
Number of shots/traplifts per day	Trapslifts/day	300
Average distance travelled	nm/trip	40
Time spent steaming as proportion of trip	%	20%
Fuel usage	**Units**	
Fuel usage per hour	liters/hour	35
Fuel usage per trip	liters/trip	350
Fuel rebate	$/liter	$0.38
Central costs	**Units**	
Cost of fuel	$/liter	$1.80
Cost of traps replacement	$/trap	$130
Cost of trap refurbishment	$/trap	$60
Number of traps replaced	Number/year	10
Number of traps refurbished	Number/year	75
Vessel number	**Units**	
Number of vessels	Number	1
Lease quota		
Crab quota	kg	7,500
Quota units leased IN	kg/year	75,000
Quota leased IN (Yes or NO)	Y or N	n
Quota units leased OUT	kg/year	0
Cost of leasing quota	$/kg	$2.20
Market purchase price of quota units	$/kg	n/a
Labour and payment methods	**Units**	
Skipper pay method (F=Fixed annual, O=Opportunity cost)	F or O	F
Number of deckhands per trip	Number	1
Deckhand pay method (A=annual, T=per trap)	A or T	T
Deckhand pay per trap	$/trap	$3.00

7.6 Appendix E2: Modelled total costs, crab trap sector

	Units	Estimated annual cost per vessel *	Proportion of costs
ANNUAL OPERATING	$/year	$117,710	17.4%
ANNUAL LEASING	$/year	$0	0.0%
TOTAL ANNUAL VESSEL	$/year	$7,000	1.0%
TOTAL ANNUAL LABOUR	$/year	$296,134	43.7%
TOTAL ANNUAL LICENCE AND REGISTRATION	$/year	$29,803	4.4%
TOTAL ANNUAL INSURANCE	$/year	$18,301	2.7%
TOTAL OFFICE CONSUMABLE	$/year	$3,450	0.5%
TOTAL ACCOUNTING AND OTHER	$/year	$3,500	0.5%
TOTAL REPAIRS AND MAINTENANCE COST	$/year	$60,500	8.9%
TOTAL DEPRECIATION CAPITAL EQUIPMENT	$/year	$109,889	16.2%
TOTAL DEBT AND INTEREST PAYMENT	$/year	$31,200	4.6%
TOTAL ANNUAL COST	**$/year**	**$677,486**	
TOTAL ANNUAL RETURNS - LEASED QUOTA	$/year	$0	
TOTAL RETURNS (turnover) - CATCHING CRABS	$/year	$466,360	

* Based on 89 tonnes catch per vessel and crab price of $5.24/kg

7.7 Appendix E3: Model assumptions, prawn trawl sector – General

General	Units	Most likely
Discount rate	**%**	6%
Superannuation	% of wages	9.5%
Trawl / crab proportion		
Average time spent crabbing as proportion of trip	%	5.9%
Fishery	**Units**	Most likely
Crab quota	kg	7,500
Quota units leased IN	kg/year	7,500
Quota leased IN (Yes or NO)	Y or N	n
Quota units leased OUT	kg/year	0
Cost of leasing quota	$/kg	$2.20
Market purchase price of quota units	$/kg	n/a
Fishing trips	**Units**	
Number of trips per year	Number	10
Length of a trip	days	23
Number of days fished per year	days	230
Number of hours/trip	Hours/trip	552
Number of shots per day	shots/day	6
Average distance travelled	nm/trip	1,200
Time spent steaming as proportion of trip	%	8%
Fuel usage	**Units**	
Fuel usage per hour	liters/hour	65
Fuel usage per trip	liters/trip	35,880
Fuel rebate	$/liter	$0.38
Central costs	**Units**	
Cost of fuel	$/liter	$1.80
Cost of wires and warps refurbishment	$/net	$5,000
Cost of replacement nets	$/net	$5,000
Number of nets replaced & refurbished	Number/year	3
Vessel number	**Units**	
Number of vessels	Number	2
Labour and payment methods	**Units**	
Skipper and deck hand pay method is share of catch (S)	S= share	S
Number of deckhands per trip	Number	5
Skipper + Deckhand pay method = share of prawn catch	%	21%
Skipper + Deckhand pay method = share of crab catch	%	39%

7.8 Appendix E4. Modelled total costs, prawn trawl sector

	Units	Estimated annual cost per vessel *	proportion of cost
TOTAL ANNUAL OPERATING COST	$/year	$568,863	37.4%
TOTAL ANNUAL LEASING COST	$/year	$0	0.0%
TOTAL ANNUAL VESSEL COST	$/year	$24,000	1.6%
TOTAL ANNUAL LABOUR COST	$/year	$252,574	16.6%
TOTAL ANNUAL LICENCE AND REGISTRATION FEES	$/year	$279,966	18.4%
TOTAL ANNUAL INSURANCE COST	$/year	$16,383	1.1%
TOTAL OFFICE CONSUMABLE COST	$/year	$60,000	3.9%
TOTAL REPAIRS AND MAINTENANCE COST	$/year	$40,500	2.7%
TOTAL DEPRECIATION CAPITAL EQUIPMENT	$/year	$199,883	13.1%
TOTAL DEBT AND INTEREST PAYMENT COST	$/year	$80,000	5.3%
TOTAL ANNUAL COST	**$/year**	**$1,522,169**	
TOTAL ANNUAL RETURNS - LEASED QUOTA	$/year	$0	
TOTAL RETURNS (turnover) - CATCHING CRABS & PRAWN	$/year	$1,403,250*	

*Based on 7.5 tonnes crabs per vessel and landing price of $5.24/kg (and 100t of prawns at a price of $13/kg)

7.9 Appendix F. References

Aitchison, J. 1955. On the distribution of a positive random variable having a discrete probability mass at the origin. Journal of the American Statistical Association. 50:901–908.

Bellchambers, L.M., Smith, K.D. and Harris, D. 2006. An assessment of the blue swimmer crab fishery in Geographe Bay, Fisheries Research Report No. 158, Department of Fisheries, Western Australia, 40p.

http://fishnet/library/publications/frr158.pdf

Burnham, K.P. and Anderson , D.R. 2002. Model selection and multimodel inference: A practical information-theoretic approach.

Bureau of Meteorology. 2011. Monthly weather review Western Australia December 2010. Australian Government, Bureau of Meteorology.

Bureau of Meteorology. 2012. Record-breaking La Niña events : an analysis of the La Niña life cycle and the impacts and significance of 2010-11 and 2011-12 La Niña events in Australia. http://www.bom.gov.au/climate/enso/history/ln-2010-12/

Caddy, J.F. and Mahon R. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fisheries Technical Paper 379.

Caputi, N., de Lestang, S., Feng, M. and Pearce, A. 2009. Seasonal variation in the long-term warming trend in water temperature off the Western Australian coast. Marine and Freshwater Research 60: 129-139.

Caputi, N., G. Jackson and A. Pearce. 2013. The marine heat wave off Western Australia during the summer of 2010/11 – 2 years on. Fisheries Research Report No. 250, Department of Fisheries, Western Australia, 40pp.

Caputi, N., Feng, M., Pearce, A., Benthuysen, J., Denham, A., Hetzel, Y., Matear, R., Jackson, G., Molony, B., Joll, L. and Chandrapavan, A. 2015a. Management implications of climate change effect on fisheries in Western Australia. Part 1. Environmental change and risk assessment. FRDC Project No. 2010/535. Fisheries Research Report No. 261. Department of Fisheries, Western Australia. 176pp

Caputi, N., Feng, M., Pearce, A., Benthuysen, J., Denham, A., Hetzel, Y., Matear, R., Jackson, G., Molony, B., Joll, L., and Chandrapavan, A. 2015b. Management implications of climate change effect on fisheries in Western Australia. Part 2. Case studies. FRDC Project No. 2010/535. Fisheries Research Report No. 261. Department of Fisheries, Western Australia. 156pp

Caputi, N., Kangas, M., Denham, A., Feng, M., Pearce, A., Hetzel, Y. and Chandrapavan, A. 2016. Management adaptation of invertebrate fisheries to an extreme marine heat wave event at a global warming hot spot. Ecology and Evolution. 6 (11): 3583-3593.

Cerrato, R. M.1990. Interpretable statistical tests for growth comparisons using parameters in the von Bertalanffy equation. Canadian Journal of Fisheries and Aquatic Sciences. 47**:** 1416–1426.

Chaplin, J., Yap, E.S., Sezmiş, E. and Potter, I.C. 2001. Genetic (microsatellite) determination of the stock structure of the blue swimmer crab in Australia. Fisheries Research and Development Corporation, FRDC project 98/118.

Chandrapavan, A., Johnston, D., Sporer, E.S., O'Donoghue, S. and Cyers, C. 2013. Shark Bay Blue Swimmer Crab Fishery Status Report. In: *Status Reports of the Fisheries and Aquatic*

Resources of Western Australia 2012/13: The State of the Fisheries eds. W.J. Fletcher and K. Santoro, Department of Fisheries, Western Australia, pp. 158-163.

Chandrapavan, A., Kangas, M.I., Johnston, D., Caputi, N., Hesp, A., Denham, A., Sporer, E. 2018. Improving confidence in the management of the blue swimmer crab (*Portunus armatus*) in Shark Bay. Part 1: Rebuilding of the Shark Bay Crab Fishery. FRDC Project No. 2012/15. Fisheries Research Report No. 285. Department of Fisheries, Western Australia.

de Lestang. 2002. Biology of the blue swimmer crab, *Portunus pelagicus* (Linnaeus), in Western Australia. PhD Thesis. Murdoch University.

de Lestang, S., Hall, N.G. and Potter. I.C. 2003a. Reproductive biology of the blue swimmer crab, *Portunus pelagicus* (Decapoda: Portunidae) in five water bodies on the west coast of Australia. Fisheries Bulletin 101:745–757.

de Lestang, S., Hall, N.G., and Potter, I.C. 2003b. Do the age compositions and growth of the crab *Portunus pelagicus* in marine embayments and estuaries differ?. Journal of the Marine Biological Association of the UK, 83: 971 – 978.

de Lestang, S., Bellchambers, L.M., Caputi, N., Thomson, A.W., Pember, M.B., Johnston, D.J. and Harris, D.C. 2010. Stock-Recruitment-Environment Relationship in a *Portunus pelagicus* Fishery in Western Australia. In: Kruse GH, Eckert GL, Foy RJ, Lipcius RN, Sainte-Marie B, Stram DL, Woodby D (eds.), Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant, University of Alaska Fairbanks.

doi: 10.4027/bmecpcc.2010.06.

Department of Fisheries (DoF). 2011. Resource Assessment Framework (RAF) for finfish resources in Western Australia. Fisheries Occasional Publication No. 85. Department of Fisheries, WA.

Department of Fisheries (DoF). 2015. Harvest strategy policy and operational guidelines for the aquatic resources of Western Australia.. Fisheries Management Paper, Department of Fisheries, Western Australia. No. 271**;** 44pp

England, M.H., Ummenhofer, C.C., Santoso, A., 2006. Interannual rainfall extremes over southwest Western Australia linked to Indian Ocean Climate Variability. Journal of Climate 19: 1948-1969.

Feng, M, McPhaden, M.J, S.-P. Xie S.P, and Hafner, J. 2013. La Niña forces unprecedented Leeuwin Current warming in 2011. Scientific Reports Scientific Reports 3: 1277

DOI::10.1038/srep01277.

Fletcher, D. 2008. Confidence intervals for the mean of the delta-lognormal distribution. Environmental and Ecological Statistics 15(2): 175-189. doi: 10.1007/s10651-007-0046-8

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods and Software. 27: 233-249.

Francesconi, K. and Clayton, D. 1996. Shark Bay: Management Paper for Fish Resources. Fisheries Management Paper No. 91. Department of Fisheries, Western Australia. 118pp.

Hanumara, R.C. and Hoenig, N.A. 1987. An empirical comparison of a fit of linear and non-linear models for seasonal growth in fish. Fisheries Research. 5 (4): 359-381.

Harris, D., Johnston, D., Sporer, E., Kangas, M., Felipe, N. and Caputi, N. 2014. Status of the Blue Swimmer Crab Fishery in Shark Bay, Western Australia. Fisheries Research Report No. 233. Department of Fisheries, Western Australia. 84p.

Hobday, A. and Pecl, G. 2013. Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. Reviews in Fish Biology and Fisheries: 1-11.

Johnston, D., Harris, D., Caputi, N., de Lestang, S. and Thomson, A. 2011. Status of the Cockburn Sound Crab Fishery. Fisheries Research Report No. 219. Department of Fisheries, Western Australia. 104pp.

Johnston, D., Harris, D., Syers, C., and Lunow, C. 2012. Gascoyne Coast Blue Swimmer Crab Fishery Status Report. In: *Status Reports of the Fisheries and Aquatic Resources of Western Australia 2011/12: The State of the Fisheries* eds. W.J. Fletcher and K. Santoro, Department of Fisheries, Western Australia, pp. 161-166.

Kangas, M. I., Chandrapavan, A., Hetzel, Y.L., and Sporer, E.C. 2012. Minimising gear conflict and resource sharing issues in the Shark Bay trawl fisheries and promotion of scallop recruitment. Fisheries Research Report No 229. Department of Fisheries Western Australia. 136p.

Lai, J., Ng, P.K.L and Davie, P.J.F. 2010. A revision of the *Portunus pelagicus* species complex (Crustacea: Brachyura: Portunidae) with the recognition of four species. Raffles Bulletin of Zoology. 58 (2): 199–237.

Lloyd-Jones, L.R., Nguyen, H.D., McLachlan, G.J., Sumpton, W. and Wang Y. 2016. Mixture of time-dependent growth models with an application to blue swimmer crab length-frequency data. Biometrics: doi:10.1111/biom.12531

Melville-Smith, R., Bellchambers, L. M. and Kangas, M. 2001. The collection of fisheries data for the management of the blue swimmer crab fishery in central and lower coasts of Australia. Final FRDC Report 98/121.

Nahas, E.L. 2004. Physical processes controlling circulation and frontal zones in Shark Bay, Western Australia. Masters Thesis. University of Western Australia.

Pearce, A., R. Lenanton, G. Jackson, J. Moore, M. Feng, and D. Gaughan. 2011. The “marine heat wave” off Western Australia during the summer of 2010/11. Research Report 222, Department of Fisheries, Western Australia, 36 pp.

Pearce, A.F. and M.Feng. 2007. Observations of warming on the Western Australian continental shelf. Marine and Freshwater Research. 58: 914-920.

Pearce, A.F. and Feng, M. 2013. The rise and fall of the "marine heat wave" off Western Australia during summer of 2010/11. Journal of Marine Systems:139-156.

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Reynolds, R. W., Smith, T. M., Liu, C., Chelton, D. B., Casey, K. S. and Schlax, M. G.2007. Daily high-resolution-blended analyses for sea surface temperature. Journal of Climate. 20: 5473-5496.

Ryan, K.L., Hall, N.G., Lai, E.K., Smallwood, C.B., Taylor, S.M., and Wise, B.S. 2015. State-wide survey of boat-based recreational fishing in Western Australia 2013/14. Fisheries Research Report No. 268, Department of Fisheries, Western Australia. 208pp.

Schaefer, M.B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bulletin, Inter-American Tropical Tuna Commission 1:25-26.

Smith, K.D., Hall, N.G., de Lestang, S. and Potter I.C. 2004. Potential bias in estimates of the size of maturity of crabs derived from trap samples. ICES Journal of Marine Science. 61: 906-912.

Somers, I.F. 1988. On a seasonally oscillating growth function. Fishbyte 6:8–11

Sumpton. W.D., Potter, M.A. and Smith G.S. 1994. The biology of the commercial sand crab *Portunus pelagicus* L. In a subtropical Australian embayment. Asian Fisheries Science. 7: 103 – 113.

Waddell, P.A., Thomas, P.W.E. and Findlater, P.A. 2012. A Report on the Gascoyne River Catchment Following the 2010/11 Flood Events. Department of Agriculture and Food: South Perth, Australia.

Walters, C. and Martell, S.J.D. 2002. Stock assessment needs for sustainable fisheries management. Bulletin of Marine Science 70: 629-638.