Maximise yield or minimise risk in the Blacklip Abalone fishery: using biological data to direct fishing strategies

Final Report to the Fisheries Research and Development Corporation

Ben Stobart, Stephen Mayfield and Rowan Chick

November 2018

FRDC Project No. 2015-017

ISBN: 978-1-876007-11-9

Maximise yield or minimise risk in the Blacklip Abalone fishery: using biological data to direct fishing strategies. Final Report to the Fisheries Research and Development Corporation.

2015-017

2018

This publication (and any information sourced from it) should be attributed to Stobart, B. Mayfield, S. and Chick, R. South Australian Research and Development Institute (Aquatic Sciences) 2018, *Maximise yield or minimise risk in the Blacklip Abalone fishery: using biological data to direct fishing strategies. Final Report to the Fisheries Research and Development Corporation,* Adelaide, November.

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

Researcher Contact Details

Name:	Ben Stobart
Address:	Lincoln Marine Science Centre
	PO box 1783, Port Lincoln, SA
Phone:	0448911066
Fax:	08 8207 5415
Email:	ben.stobart@sa.gov.au

FRDC Contact Details

Address:	25 Geils Court
	Deakin ACT 2600
Phone:	02 6285 0400
Fax:	02 6285 0499
Email:	frdc@frdc.com.au
Web:	www.frdc.com.au

In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

Contents

Tables

Figures

Acknowledgments

We thank the following individuals and organisations that contributed to this project:

The Fisheries Research and Development Corporation (FRDC) for funding.

The Abalone Industry Association of South Australia (AIASA), in particular Jonas Woolford, Samara Miller, John Haagmans and Bill Ford for support and discussion throughout development of this project.

Fishers and licence holders for logbook data and commercial shell samples. Special thanks to divers who collected blacklip for the project – Thomas McNab, Bill Ford, Jay Haagmans, Bill Bascombe, Jonas Woolford, Tobin Woolford, Dion Edmonds, Darren Guidera, Tyrone Craig and all associated crew.

SARDI staff for collection of biological data, particularly Dr Nicole Hancox, Jay Dent, Doug Graske and Damian Matthews. Dr Katherine Heldt for assistance with R coding.

Streaky Bay Marine Products and associated divers for collection of biological data from Point Westall.

Collection prior to 2016 was predominantly funded by Primary Industries and Regions South Australia (PIRSA), through licence fees

Jim George and Kane Williams from Western Abalone Processors for providing price data and Kane Williams for providing access to Western Abalone Processors for processing of blacklip and processor staff for providing assistance where necessary.

Interstate scientists and agencies for contributions and data sharing, including Dr Corey Green (Fisheries Victoria), Institute of Marine and Antarctic Studies (Tasmania) and DPI Fisheries (New South Wales).

We thank Assoc Prof Qifeng Ye for her role as editor of this report and Drs Lachie McLeay and Jason Earl and Professor Gavin Begg for formally reviewing this report.

Abbreviations

AIASA	Abalone Industry Association of South Australia
Blacklip	Blacklip Abalone (*Haliotis rubra*)
Greenlip	Greenlip Abalone (*Haliotis laevigata*)
SAAF	South Australian Abalone Fishery
TACC	Total allowable commercial catch
WZ	Western Zone

Executive Summary

The primary goal of this research was to identify attributes of the seasonal biology of Blacklip Abalone (*Haliotis rubra*; hereafter referred to as blacklip) that may be beneficial for optimising fishing strategies. Specifically, the research identified the optimum months to harvest blacklip so that they yield the highest achievable bled meat returns for any given shell length. This is possible because blacklip weigh more and bleed less during certain months of the year. The optimum months were identified using a model adapted from previous work carried out on Greenlip Abalone (*Haliotis laevigata*; hereafter referred to as greenlip) in the Western Zone (WZ) of the South Australian Abalone Fishery (SAAF). By adapting fishing strategies to harvest blacklip during the optimum months, fishers can either (1) harvest fewer blacklip for the same total allowable commercial catch (TACC) taken, or (2) adopt a co-management strategy where they harvest the current number of abalone that are heavier and thus allow a higher TACC. Thus the project results provide the opportunity to change the seasonal timing of harvest to reduce exploitation rate, increase landed revenue, or achieve a combination of these two management objectives. These outcomes are consistent with the priorities of industry - to reduce risk to Australian abalone fisheries, optimise harvests and improve fishing efficiency - because wild Australian abalone stocks have recently been in decline and quota reductions have increased in prevalence. Abalone fisheries are also experiencing a reduction to their profitability. With limited options to reduce risk to the resource, or increase efficiency, one way to help achieve either, or a combination of these goals, is to identify biological properties of abalone stocks that may maximise the yield harvested per recruit.

The origin of this project stems from a request from the Abalone Industry Association of South Australia to evaluate whether seasonal differences in abalone weight and blood loss could be used to improve their fishery. Initial work on greenlip in the WZ of the SAAF identified the optimum period for fishing to be in autumn and led to changes in their fishing strategy. This project follows the success of the greenlip work by addressing the need for additional information on the seasonal biology of blacklip to determine the best time to fish this species. Obtaining this information for blacklip was a high priority because this species constitutes 82% of the Australian abalone catch and the potential return from any benefits to changing fishing strategies could be significant.

The model we use requires information on the biology of blacklip that was not available for this species in South Australia. Thus, a large component of the project involved obtaining the necessary biological data to run the model from the WZ. The majority of the data used in the model were obtained in 2016 using a spatially (5 sites hundreds of km apart) and temporally (monthly) stratified sampling design across this zone. Longer-term information was also obtained from one of the WZ sites, Taylor Island, spanning the period May 2014 to December 2016. In addition, the

availability of data to run the model for blacklip fisheries in Tasmania, Victoria and New South Wales was assessed.

The three main objectives of the project were achieved for the SAAF. These were to (1) quantify the seasonal variation in the shell size to whole weight and the whole weight to recovered meat weight ratios; (2) incorporate these findings into the model previously developed for greenlip and explore the outcomes of fishing scenarios developed on in consultation with industry; and (3) provide the outputs from the scenarios, number of abalone and expected value, to enable industry and managers to use the information to maximise the efficiency of their blacklip fisheries. There were insufficient data available from other states to run the model.

The outputs from the steady state model adapted for this study demonstrated that the optimal month to harvest blacklip in the WZ of the SAAF is February. The model also showed that the difference in bled meat return for the same number of blacklip between January and April is small, and thus the benefits accruable in February can also mostly be obtained by harvesting during these four months. Potential benefits from changing fishing to the best time of year are considerable, with the difference between the best and worst months to harvest leading to a 13% reduction in the number of blacklip harvested (TACC unchanged) or the potential for a 15% increase in the TACC (number of blacklip harvested unchanged). In the WZ of the SAAF, fishing is already mostly occurring at the time of year when blacklip yield the highest achievable bled meat returns for any given shell length, so potential benefits to changing their fishing strategy would, at best, be approximately a 3% reduction in number of blacklip harvested or a 4% increase in TACC. The model could not be run for the other states due to insufficient data. However, it is reasonable to assume that the magnitude of seasonal benefits may be similar to those observed in the WZ and worth investigating further. We note that, with the exception of relatively small changes in whole weight that were observed throughout the year, the benefits we describe above would not apply to the substantial blacklip fisheries that service the live market because these are sold as a whole in-shell weight and bleeding occurs subsequent to sale. However, the potential benefits of harvesting live animals at their highest potential weight for a given length should also be explored further.

The potential benefits to industry of fine tuning fishing strategies to take advantage of biological cycles are evident from this and a previous study on greenlip. For the WZ of the SAAF, the seasonal difference between greenlip and blacklip harvest indicate that a good model for the fishery would be to harvest blacklip between January and April and greenlip from April to June/July. For other states, where blacklip are not harvested for the live market, it is also likely that there are benefits to be obtained from using the seasonal variation in blacklip meat weights and bled meat weights to target the optimal months for fishing. However, if these advantages are to be realised, additional local information on the seasonal biology of blacklip will need to be obtained as there are likely to be differences in the months of optimal harvest between the states. Before investing in obtaining additional information, a prior evaluation of the feasibility of making changes to fishing strategies in these states should be undertaken. For example, if current fishing is restricted to certain periods of the year due to weather, changes will not be possible even if yields can be improved by fishing more during other months. Our findings also have implications for the management of blacklip fisheries, as changes to the fishing strategies can leave a large number of blacklip unfished each year. For example, changes to the WZ fishing could leave 3% (~12,500 abalone) of blacklip currently caught in the water each year. While this may not be a large proportion of the total caught each year, the effect will be cumulative over time and may be a good strategy to help reduce the risk of overfishing.

Finally, those engaged in abalone research should bear in mind the high variability in blacklip weights and meat recoveries observed during this project when designing future work. Unless sampling is conducted under strict guidelines and in a structured manner, trends may be obscured by natural variation. The fact that much of the data already available for this species could not be used here, is testament to the challenges facing those regularly obtaining biological information for this species.

Keywords

Blacklip Abalone, *Haliotis rubra*, steady-state model, fishery management, fishing strategy, quota fishery, maximising yield, reducing risk to fishery.

1 Introduction

Abalone (Family Haliotidade, Genus *Haliotis*) are gastropod molluscs that are highly sought after by Asian seafood markets due to their fine flavour and association with special celebrations. In particular, wild caught abalone command high prices at international high-end restaurants because they are considered to be a premium, clean, product. The demand for abalone has kept their prices high and led to the establishment of valuable fisheries in many parts of the world (Hamasaki and Kitada 2008, Mayfield et al. 2012). However, despite their high value, many abalone fisheries have either collapsed or are in decline (Mayfield et al. 2012a, Cook 2016). Until recently, Australian abalone fisheries were the exception to this trend, having provided 50 years of sustained production and constituting about 50% of the global harvest of wild abalone (Gordon and Cook 2004, Mayfield et al. 2012, Cook 2016). However, in recent years the Australian wild abalone stocks have also begun to decline, leading to quota reductions in many Australian fisheries (Flood et al. 2014, Stewardson et al. 2016). In addition, the profitability of these fisheries has declined considerably since their peak in 2000/01 (Magnusson et al. 2016).

The impact of reductions to the Australian abalone quotas has been considerable because, although the fisheries only make up 3% of Australia's wild-catch by volume (~ 4,600 t), they constitute 16% of the total wild-catch value of ~AU$ 200 million (Mayfield et al. 2012). There is, thus, a pressing need to "fish smart" to ensure the sustainability of the stocks, improve profitability and, where necessary, to rebuild quotas to previous levels. Reduction of quotas has been the primary tool used to address the recent declines (Anon 2015, Anon 2017a and b, Mundy and Jones 2017, Stobart et al. 2017), with some fisheries reducing their total allowable commercial catch (TACC) by 50% over a period of several years (Flood et al. 2014). Unfortunately, there is little prospect for these abalone fisheries to mitigate some of the loss associated with the TACC reductions by increasing their efficiency and profitability. This is because major technological advances that may ameliorate the low profitability (e.g. introduction of cages, larger vessels, fishing off-anchor, and the use of Nitrox) have already been implemented across most fleets.

One avenue that does remain for fishers to increase efficiency or reduce exploitation is to identify biological properties, such as periodic changes in the weight or behaviour (e.g. seasonal aggregation) of abalone, to increase yields harvested per recruit. In particular, this is feasible for species that exhibit seasonally variable biology that may be taken into account in harvest strategies. For example, periodic changes in recovered weight can be used to allow potential increases in yield (in weight) for the same number of fished individuals, or a reduction in exploitation rate without the need for a quota reduction. This approach was recently taken for greenlip in the South Australian Abalone Fishery (SAAF; Stobart et al. 2013). Greenlip were found to weigh more and bleed less in autumn. This information was incorporated into a steady state model that showed a change to fishing solely during April and May would lead to a 13% reduction in the number of abalone harvested for the same quota. Alternatively, the original number and sizes of abalone could be harvested in autumn leading to a 13% increase in landed weight, which would equate to a 16.5% increase in revenue (Stobart et al. 2013). The exact cause of the variation in greenlip weight and extent of blood loss through the year remains unknown, but it is thought to be associated primarily with the reproductive cycle, and/or with other factors such as the availability of food (Stobart et al. 2013). Greenlip spawn from October to January with a peak in December (Shepherd and Laws 1974), a period that coincides with times of minimum meat recovery and weight.

The above research on greenlip was acknowledged by the Western Zone (WZ) of the SAAF and resulted in changes to their seasonal greenlip fishing patterns from 2014 (Stobart and Mayfield 2016). Previously, a large proportion of the greenlip quota had been harvested early in the year, primarily to service the Chinese New Year market, so there had been limited incentive to fish later in the year. However, the demonstration of the potential benefits to fishing in autumn (Stobart et al. 2013) and importantly, support from processors, led to less fishing in January-February and an increase in fishing in autumn. This change was made possible because greenlip is primarily marketed as a frozen product and thus could be held in reasonably long-term storage to supply the Chinese New Year market in the following year, without any change in the quality of product. The change in fishing period allowed fishers to shift their greenlip fishing season while maintaining the same quota. The rationale behind this change was that fewer abalone would need to be harvested for the same weight, thus ultimately improving the stocks and increasing catch rates. While the long-term benefits of taking fewer abalone each year have not yet been demonstrably realised, there is evidence that catch rates increased in 2015 and 2016, and that this was, at least partially, due to the change in fishing practice (Stobart and Mayfield 2016). Longer-term benefits of this change are likely to include an increase in stock abundance that should increase the population's reproductive potential and increase catch rates, with the latter increasing the profitability of the fishery (Stobart et al. 2013). An additional benefit of changing the fishing period was that divers were able to benefit from harvesting larger, higher value, greenlip with relatively less effort.

Blacklip constitute 82% of the Australian abalone catch, so considerable benefits could also be obtained from changes to their fishing season if they exhibit similar, or other, useful seasonal biological traits to those observed in greenlip. However, the changes in blacklip meat weight throughout the year are not likely to be as clear as they are for greenlip because the reproductive cycle of blacklip is known to be less discrete (Shepherd and Laws 1974), thus annual variation in meat recovery and weight would not be expected to be as focussed as that observed for greenlip. In addition, the fact that much of the blacklip harvested is done to service a whole in shell or live market means that benefits to these fisheries are more likely through extension of this research and its general influence on harvest strategies. The benefits to making changes to blacklip fishing may still be large when one considers the much larger volume of this species landed.

This project was developed to look for similar benefits to those identified in the greenlip study in the WZ of South Australia (Stobart et al. 2013). It addresses the need for additional information on the seasonal biology of blacklip required to modify the model, previously developed for greenlip, so that fishing scenarios could be explored for blacklip. This includes information on the commercial catch length frequency, whole weight to shell length relationship, bled meat recovery by month and sale price of blacklip abalone. This information was previously lacking for the SAAF because available data did not have the spatial and temporal resolution necessary to populate the model. The project provided the opportunity to initiate a first phase of this work to conduct structured biological sampling over a large spatial scale in South Australia, and addresses the general lack of data on blacklip. Sampling was restricted to the WZ of the SAAF due to its relatively high cost, but a potential second phase has also been proposed to obtain similar information from other areas within South Australia, or other states. In a bid to identify whether there is a strong need for these data, the project also included an evaluation of pre-existing data from all the states that have blacklip fisheries (South Australia, Victoria, Tasmania and New South Wales). Thus, a further objective of the project was to determine whether appropriate data exists for these states that could be used to apply the model to different fisheries.

The model outputs, i.e. estimates of the number of abalone harvested and catch value under different fishing scenarios, enable the identification of the months in which the best return in meat weight for a given shell length can be obtained, allowing the “fine-tuning” of monthly fishing. Two harvest strategies were explored with the model: (1) maintaining the current TACC and evaluating the resulting change in number of abalone harvested and (2) maintaining the current number of abalone harvested and evaluating the resulting change in landed catch (hereafter referred to as C_{number} and C_{TACC}). These model outputs provide industry and managers with key information necessary to maximise the efficiency of blacklip fisheries.

2 Objectives

The primary goal of this project was to obtain the necessary biological information for blacklip to explore different harvest strategies in order to identify which may provide the “best return” by enabling (1) a decrease in fishing pressure while maintaining the current TACC (C_{number}); or (2) an increase in the TACC without altering fishing mortality (C_{TACC}). The following objectives were adopted to achieve this aim:

1. Quantify the seasonal and spatial variation in the blacklip shell size/whole and weight/meat weight ratios.

2. Incorporate the biological data into the existing greenlip model and apply under the monthly fishing scenarios developed in consultation with Industry.

3. Provide model outputs from each fishing scenario that detail the number of abalone harvested and their value.

3 Methods

This project had three main components: 1) obtaining a dataset of bled meat weights from the WZ of South Australia with good spatiotemporal coverage; 2) using the data obtained to adapt the existing model for greenlip abalone to work for blacklip; and 3) reviewing data available in other states to determine whether the model could already be used for those jurisdictions and, if not, identifying the data needs that would need to be addressed to be able to use the model in the future.

3.1 South Australia - Western Zone blacklip sampling

The first component of the project involved obtaining the necessary data to quantify the seasonal blacklip catch and the seasonal and spatial variation in (1) the blacklip shell size to whole weight; and (2) whole weight to recovered meat weight ratios. Both of these biological relationships were necessary to run the model and evaluate alternate fishing scenarios, and involved both access to commercial fishing records and monthly sampling conducted in the WZ of the SAAF.

3.1.1 *The Western Zone blacklip fishery*

The WZ blacklip fishery has 22 licence holders and spans over 1000 km of the South Australian coastline between Cowell in Spencer Gulf and the South Australian border with Western Australia (Figure 3.1). The fishing season extends from 1 January to 31 December each year. Catches are usually shucked at sea and, consequently, quotas are issued in bled meat weight. The minimum legal size for blacklip in the WZ is 130 mm shell length. While, post-quota, the blacklip catch has been relatively stable, over the past six years it has decreased through a combination of reductions to the TACCs and unanimous, voluntary agreements within the commercial sector to under-catch the legislated TACC. Overall, these represent a 36% decrease in the WZ blacklip catch.

Fishers complete a catch and effort logbook for each fishing day and submit those data to the South Australian Research and Development Institute (SARDI) at the end of each month. TACC decisions for the SAAF are based on a species-specific, spatially structured harvest strategy (PIRSA 2012) that excludes population-dynamic modelling. Conventional abalone models (e.g. Breen and Kim 2003, Gorfine et al. 2005) are not incorporated into the harvest strategy because of either data limitations (i.e. when applied to each spatial unit) or their poor representation of the spatial structure of the stock (i.e. when applied to the zone).

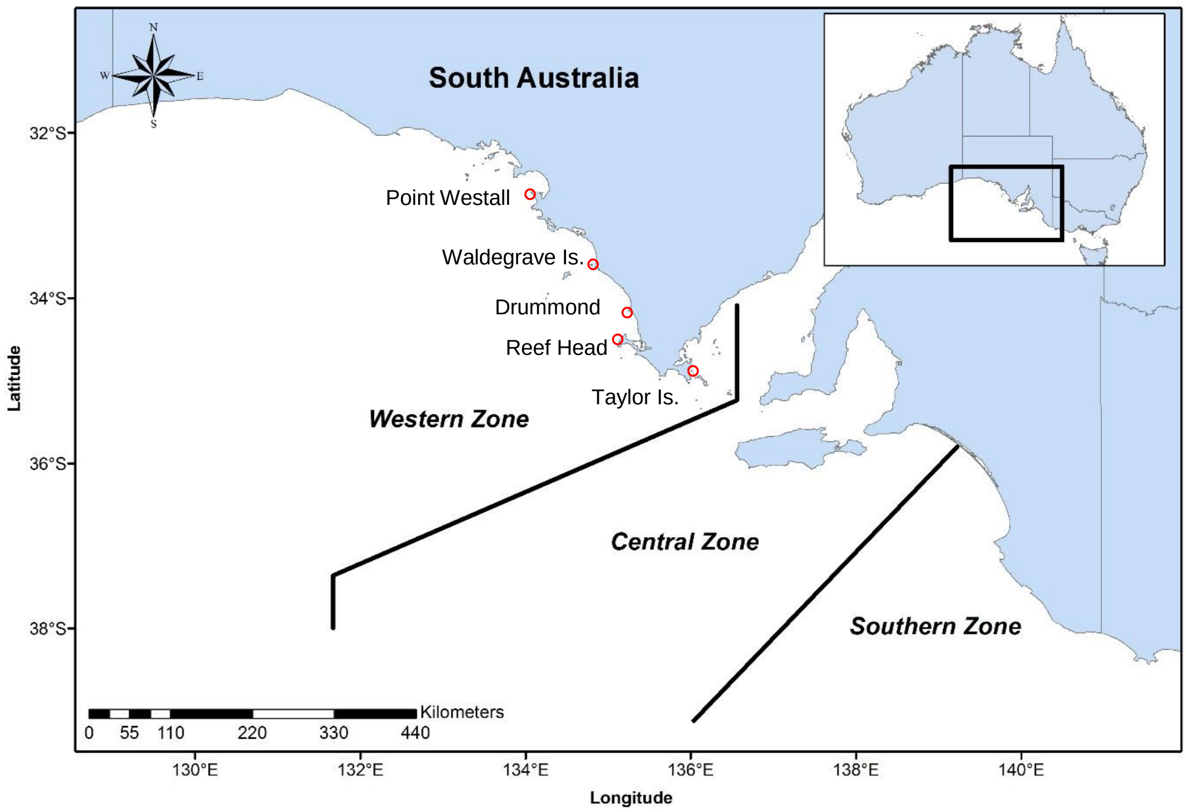

Figure 3.1 Location of the South Australian abalone fishing zones and survey sites (red circles).

3.1.2 *Data sources*

Data for this project were comprised of fishery-dependent catch data and data collected through monthly independent biological sampling. Some biological data from undersize blacklip was also available from previous sampling programs undertaken by SARDI. The data obtained were necessary to run the model used to estimate the number of abalone harvested under different fishing scenarios. The fishery-dependent data consisted of daily catches recorded in logbooks as bled meat weight. This was used to determine the mean monthly proportion of the catch harvested in recent years (average for the five-year period between 2010 and 2014) that is used for comparison with other scenarios of interest in the model.

Independent biological sampling was undertaken monthly at five sites across the WZ of the SAAF. Sites were spread across the large geographic extent of the WZ and are representative of the key blacklip fishing areas. The sites were also chosen for their accessibility throughout the year, reflecting the inclement weather that can restrict access to some sites at certain times. The selected sites were Taylor Island, Reef Head, Drummond, Anxious Bay and Point Westall (Figure 3.1). For each site, sampling was conducted within 2 km of a single central site GPS location. The Taylor Island site was sampled monthly by SARDI from May 2014 to December 2016 with 3 months not sampled due to poor weather during this period. The SARDI samples were processed at the Port Lincoln Marine Science Centre. The four remaining sites were sampled by commercial fishers from January 2016 to December 2016, with SARDI processing the samples from Reef Head, Drummond and Anxious Bay at Western Abalone Processors in Port Lincoln and Industry members, who were trained by SARDI staff, processing the samples from Point Westall at Streaky Bay Marine Processors. Additional samples were also obtained by commercial fishers from Streaky Bay in January and February 2017. Site details and numbers of blacklip sampled are provided in Table 3.1 below.

Table 3.1. Blacklip abalone collection site and sampling summary.

Site	Latitude	Longitude	No. months sampled	No. blacklip	Size range (mm)	Max whole weight (g)	Max recovered meat weight (g)
Point Westall	32º 54.805'S	134º 04.125'E	14	644	130-191	1100	416
Waldegrave Is.	33º 35.632'S	134º 46.371'E	12	583	130-198	1296	386
Drummond	34º 10.252'S	135º 14.604'E	12	622	130-180	1076	396
Reef Head	34º 29.779'S	135º 7.804'E	10	545	132-195	1402	421
Taylor Is.	34º 52.607'S	136º 0.904'E	28	909	125-201	1266	456

A power analysis was used to determine the optimal number of animals to sample each month, with the target of at least 30 animals established prior to the commencement of the project based on samples obtained from Taylor Island. The power analysis indicated that a minimum sample size of 24 blacklip would be necessary for a 2-tailed hypothesis test at an α level of 0.05. Based on this information, for each sampled month and site, 30-50 legal-sized abalone were landed in the shell and processed. The sample size above that identified as statistically necessary was done as a contingency against any loss of samples or processing error – outlined below. Where weather permitted, sampling was conducted during the second and/or third week of each month.

All sampled abalone were carefully removed from the seabed using an abalone iron, transferred to cooler boxes with seawater and transported to the processing location in as little time possible. If the abalone were not considered to be in good enough condition on arrival for processing they were rejected. Sample processing involved measurement of shell length, shell weight, whole weight, meat weight, bled-meat weight (after 20-24 hours) and determination of sex. Viscera weight was obtained by subtracting meat weight from the sum of meat weight and shell weight. To measure the bled meat weight, after the first weigh the shucked meat was placed in a numbered plastic bag and held on ice, for 20-24 hours before re-weighing. The use of 24 hours as a time period was validated by means of a bleeding trial of 28 blacklip taken from Taylor Island during summer. These animals were shucked in the laboratory, placed in individual plastic bags and reweighed at regular intervals over a 48-hour period. The trial indicated that most blood loss occurs within the first six hours post-shucking, and that weight loss after 20 hours is minimal (Figure 3.2). For this trial a temperature logger was also placed inside one of the abalone bags. Within six hours of placing abalone on ice the bag contents were cooled from a temperature at processing of approximately 20°C, to a storage temperature on ice of 2-4°C (Figure 3.3). This on-ice temperature was expected to remain the same for all samples processed at the Port Lincoln Marine Science Centre, and is consistent with the chiller temperatures used at the processors where blacklip were processed for this study. All reweighed meats were allowed to drain (but were not dried) for a few seconds before they were weighed.

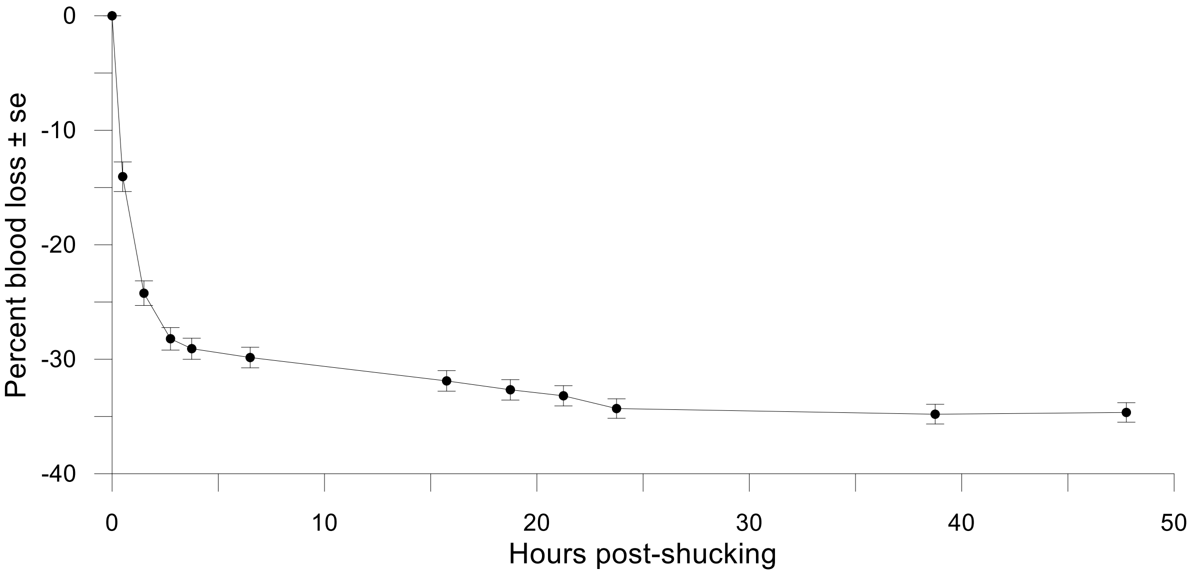

Figure 3.2. Percent blood loss post-shucking for blacklip from Taylor Island (n=28)

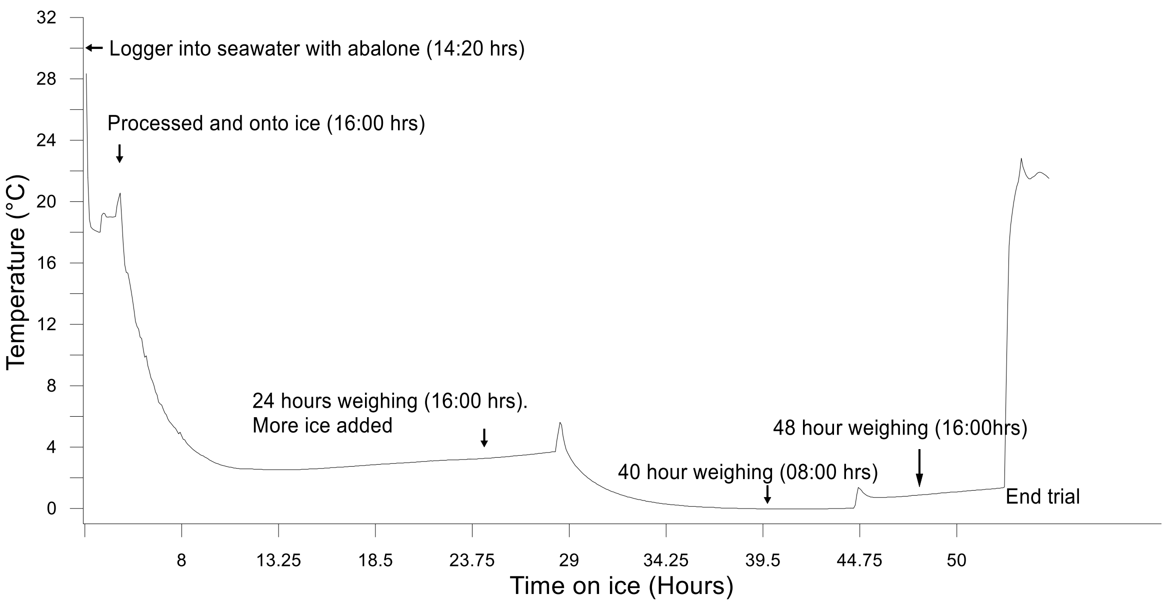

Figure 3.3. Temperature variation for blacklip on ice during summer for determination of 24 and 48-hour bled weights.

3.2 The Model

Shell lengths obtained from this project were also used in the model to determine the mean proportion of the total catch harvested each month in 26, three–millimetre, shell-length bins spanning 130 to 208 mm shell length. In addition, the WZ blacklip sampling data were used to determine the monthly relationships between (1) shell length and whole weight; and (2) a whole weight-bled meat weight relationship. This information was also required to run the model.

To quantify the blacklip shell length and whole weight relationship we fitted individual measurements of shell length ($\tilde{L}_i$) and whole weight ($\tilde{W}_i$) to an allometric function ($\hat{W}(L,m) = a(m)\cdot L^b$) where months ($m$), are numbered from 1st (January) to 12th (December). A constant exponent (b = 3) fitted optimally to all months and a maximum likelihood estimate for the coefficient, $a(m)$ was obtained for each of the 12 months. The likelihood standard deviation (of residuals) was assumed to increase allometrically with increasing L and thus also with predicted weight $\hat{W}(L)$ as $\hat{\sigma}(L) = \sigma_0 \cdot \left[\hat{W}(L)\right]^{\sigma_1}$ adapting this allometric error structure from the GROTAG growth model of Francis (1988). Values of a, σ_0, and σ_1 were estimated by numerically maximising the normal likelihood numerically

$$\prod_i \frac{1}{2\pi\cdot\hat{\sigma}^2\left(\tilde{L}_i\right)} \exp\left[-\frac{\left(\hat{W}\left(L_i\right)-\tilde{W}_i\right)^2}{2\cdot\hat{\sigma}^2\left(\tilde{L}_i\right)}\right]$$

(Rice 1995, McGarvey and Fowler 2002) using Excel Solver. To smooth the monthly variation of $a(m)$ over the 12-month fishing season, a fourth-order polynomial was fitted to the twelve estimated monthly values of $a(m)$ by ordinary least squares (Figure 3.4) with the values for December before, and January to March after the year, repeated to improve the polynomial fit to a yearly cycle. This interpolation to estimate the coefficient $a(m)$ was warranted because b was fixed at three for all months, rather than also being estimated monthly. The $a(m)$ values for all 12 months were obtained from the fitted polynomial (Figure 3.4) and used in the allometric function to derive whole weight from shell length. Blacklip whole weight, by bin and month ($\hat{W}\left(\bar{L}(l), m\right)$), was then computed using the estimated allometric relationship applied at the mid-point of each 3-mm shell-length bin, $\bar{L}(l)$.

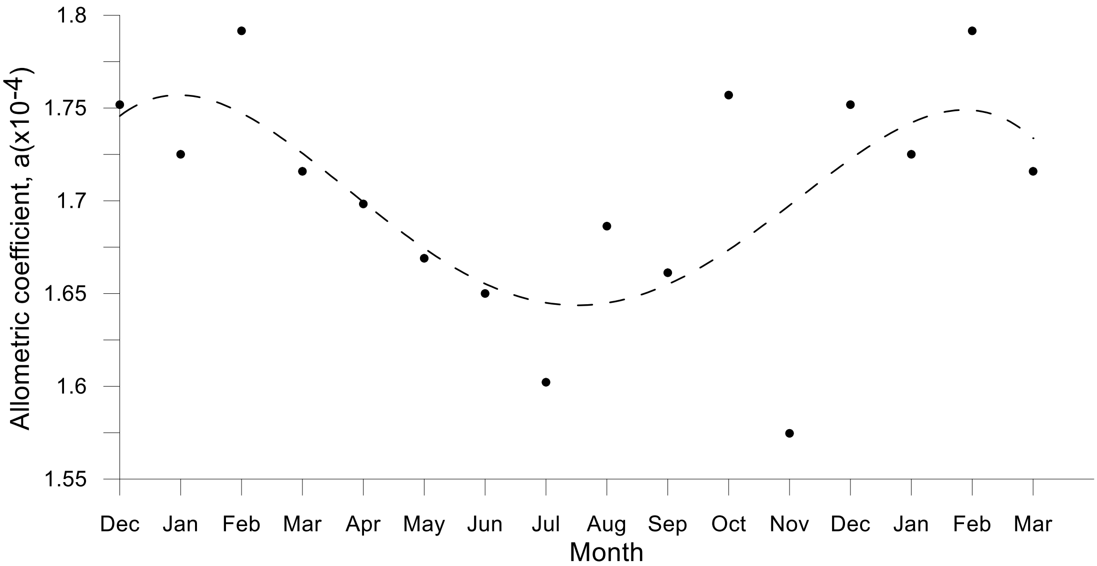

Figure 3.4. Allometric whole-weight versus length coefficient (α^{-4}) by month. The pointd of the first and 13-15th months replicate December and January to March, respectively, to improve the fourth order polynomial curve (dashed line) to be fitted to a yearly cycle using least squares.

Second, estimates of mean bled meat weight by month, as a percentage of whole weight, were derived directly from the mean monthly percentage bled meat weight for the combined sites and full sampling period (2014-2016).

A deterministic steady-state, annualised spreadsheet model was used, adapted from Stobart et al. (2013) and was designed to produce two outputs: (1) the expected number of blacklip harvested by month and (2) the total revenue from the catch by month. These outputs were used to explore two harvest strategy options under varying fishing scenarios (see below). The harvest strategy options were to: (1) maintain the current TACC and evaluate the change in number of abalone harvested; or (2) maintain the current number of abalone harvested and evaluate the potential change to the TACC without altering fishing mortality. A third option could also be to adopt a combination of these two options. For simplicity, we only explored the two main options and, for convenience, these are being referred to as C_{number} (maintain TACC, change number) and C_{TACC} (maintain number, change TACC), respectively.

For C_{number}, we used the current WZ TACC, of 74.6 t meat weight, to determine the number and value of blacklip harvested for all scenarios. C_{TACC} used the same model, but the TACC was varied such that the number of blacklip harvested under each scenario matched the number harvested under Scenario 1 with the current TACC of 74.6 t (C_{number}; *n* = 370,507 blacklip). The model calculations occur in a series of steps, replicated monthly, with the data, analyses and equations underpinning each of these calculations provided below.

3.2.1 *Estimating the TACC and total number of blacklip harvested*

For each fishing scenario simulated, computation of the total number of abalone landed during each month required five calculation steps applied sequentially to the input starting data. The starting data were the length-frequency distribution of blacklip in the commercial catch, $\tilde{P}_N(l)$. Input data are denoted by a tilde over the variable name. Proportions (P) and catch totals (C) are differentiated by descriptor subscripts $N, W,$ and M denoting blacklip number, whole weight, and bled meat weight, respectively. The two principal independent variables, 3-mm shell length bin and month are, respectively, denoted by the subscripts *l* and *m*. The proportion of the TACC harvested each month ($P_{TACC}(m)$) was pre-specified for each intra-seasonal fishing scenario tested (e.g. for the monthly catch for each state and zone between 2010 and 2014/15 see Figure 4.13). Each monthly TACC was computed as $TACC(m) = P_{TACC}(m) \cdot TACC$. The five calculation steps are as follows:

1) Month-specific, shell length – whole weight allometric relationships were used to convert the mid-point value of each 3-mm bin range to a whole weight (W).

2) The whole weight ($\hat{W}\left(\bar{L}(l),m\right)$) of an individual blacklip in each shell length bin, l, was then converted to the recovered (i.e. landed, shucked and sold) bled meat weight ($W_M\left(l,m\right)$) using the mean monthly recovery proportion ($\tilde{P}_{M(W)}\left(m\right)$) estimated using the blacklip collection data:

$$W_M\left(m,l\right)=\tilde{P}_{M(W)}\left(m\right)\cdot\hat{W}\left(\bar{L}(l),m\right)$$

3) For each month, catch in bled meat weight for each shell length bin, l, denoted $C_M\left(l,m\right)$, was calculated as:

$$C_M\left(m,l\right)=TACC\left(m\right)\cdot\frac{\tilde{P}_N\left(l\right)\cdot W_M\left(l,m\right)}{\sum_l \tilde{P}_N\left(l\right)\cdot W_M\left(l,m\right)}.$$

4) The total number of blacklip harvested in each shell length bin, l, each month, m, denoted $C_N\left(m,l\right)$ was computed as:

$$C_N\left(m,l\right)=\frac{C_M\left(m,l\right)}{W_M\left(m,l\right)}.$$

5) The total number of blacklip harvested in each month ($C_N\left(m\right)$) was computed as the sum over all shell length bins:

$$C_N\left(m\right)=\sum_l C_N\left(m,l\right).$$

Finally, the total number harvested for the year becomes

$$C_N=\sum_m C_N\left(m\right).$$

Steps 1 to 5 were repeated for each month and summed to estimate the total number of abalone that would be harvested annually for each of the fishing scenarios examined.

The same model and approach were used for C_{TACC}. However, for C_{TACC}, the TACC was varied such that the number of blacklip harvested under each scenario was the same as that harvested under the current fishing pattern for blacklip for each state examined (e.g. for the monthly catch for each state between 2010 and 2014/15 see Figure 4.13).

3.2.2 *Estimating catch revenue*

Seasonal variation in the price of blacklip was ignored in the model because blacklip is mostly sold as a canned product, with little variation in the cost with size. Monthly revenue (AU$) was calculated by multiplying monthly catch in weight by price, $\tilde{price}\left(g\right)$ that for the purpose of this analysis was fixed at AU$95 per kg, the approximate price for blacklip meat provided by Western Abalone Processors in 2015.

Thus, the gross revenue of production by month, $GVP(m)$, was calculated as:

$$GVP(m) = \sum_{g=1}^{3} TACC(m) \cdot \tilde{P}_W(g,m) \cdot \tilde{p}rice(g)$$
.

Monthly estimates of $GVP(m)$ were summed to calculate the total annual revenue of the abalone harvested for each of the fishing scenarios examined under C_{number} or C_{TACC}.

3.2.3 *Fishing season scenarios tested*

The model was used to estimate C_{number} for each fishing zone in each state based on the total catch from each state from Stewardson et al. (2016) and mean proportion of the catch harvested, by month, between 2010 and 2014/15, along with the estimated annual revenue derived from the TACC based on the fixed cost of AU$95 per kg. Following this, the effects of changing the proportion of catch caught each month were explored by: 1) using the WZ of South Australia TACC to estimate the C_{number} for each month of the year assuming the entire TACC was caught in that month; 2) examining the effects of changes to the WZ fishery where ten alternative fishing scenarios were used to evaluate C_{number} or C_{TACC}, compared with the mean proportion of the TACC harvested in the WZ, by month, between 2010 and 2014 (Table 4.1); and 3) where requested, C_{number} and C_{TACC} were calculated to examine the effects of changes to fisheries in other states and zones under fishing scenarios identified by them to be of interest. These outputs were compared with the mean proportion of the respective TACC harvested for the state or zone, by month, between 2010 and 2014. The TACCs used for these evaluations were those for the respective states and zones in 2015. All of the proposed alternative scenarios are fictitious and were designed to provide a range of possible strategies and to better reflect the biological, market and economic differences among fisheries.

3.3 Other blacklip fisheries

More extensive sampling from other zones in the SAAF or interstate was not conducted due to the high cost of sampling. However, the information to run the model should ideally be obtained for each fishery being assessed because the biology of blacklip is likely to vary geographically and thus affect the model outputs. Acknowledging the need to incorporate locally obtained data into the model, this project also includes an evaluation of pre-existing data from the Central and Southern Zones of the SAAF and other states that have blacklip fisheries (Victoria, Tasmania and New South Wales) to establish whether there is already enough information available to run the blacklip model. The SARDI abalone database was used to evaluate whether there was suitable information for the South Australian Central and Southern Zones while, for the other states, those responsible for relevant data were contacted and sent an excel spreadsheet with sheets for catch (for period 2010-2014/15), commercial catch length-frequency by month, biological (bled meat weights and length-weight relationship) and processor (details of processors for each state so they could be contacted regarding processing trends and pricing of product) information.

3.4 Economic information

This project included the intent to obtain information relating to the market value of blacklip, the different markets that blacklip is sold to, and the sale format (*i.e.* live, canned etc.). This information was required to inform discussion on the benefits and practicality of making changes to the fishing season identified with the model. In order to obtain this information, we first identified the key processors in each state and then conducted a telephone interview for which we used a pre-determined set of questions (see Appendix 3). Unfortunately, following a series of five interviews this component of the project was ended because it soon became apparent that processors, while all very interested and generally supportive of the project, were reluctant to provide confidential information on their markets and value of their product. The information that was obtained is not provided in this report as it is considered confidential.

4 Results

4.1 Objective 1

This section addresses Objective 1 - to quantify the seasonal and spatial variation in the blacklip shell size/whole weight ratio (how much a blacklip of a given shell length weighs) and the percentage bled meat weight recovery (recovered meats for a given shell length).

4.1.1 *Western Zone sampling outcome*

The intended sampling regime for this project was to sample all five chosen WZ sites once a month throughout 2016. In spite of the inclement weather conditions that prevail in the WZ, this goal was largely achieved (see Table 3.1). In addition, as a precursor to this study, SARDI initiated opportunistic sampling at Taylor Island in 2014 to enable the evaluation of the extent of inter-annual variation in blacklip meat recovery. In total, 28 months were sampled from Taylor Island during this period.

One of the main challenges to sampling was ensuring the high quality of live abalone from which to obtain bled meat weights. The long journeys from fishing sites to the processing facility in Port Lincoln (up to 190 km) made delivery of “healthy” blacklip, that were not already bleeding or temperature stressed, difficult. However, careful handling of the animals by divers and shellers meant that only one collection at the beginning of the project was rejected due to the poor quality of animals on arrival at the processors. Despite the care taken, it is reasonable to assume that blacklip that were collected in Anxious Bay, the furthest site from a processor (Western Abalone Processors in Port Lincoln), would be more prone to loss of condition and bleeding prior to sampling than blacklip collected from the other sites located closer to the processors.

With the exception of Anxious Bay, where the median size of collected blacklip was smaller, the size range of blacklip collected at the sampling sites was very similar (Figure 4.1). Frequency distributions of blacklip shell length differed between months at the scale of the WZ (Figure 4.2). This difference was more apparent at the scale of “sites” where there was clear variation between months (Figure 4.3). The different size distributions at this finer scale can complicate the interpretation of differences of some metrics between months as the variation in whole weight or meat weight will be influenced by shell sizes sampled where the relationship between length and weight is not linear (see Section 4.1.2 below).

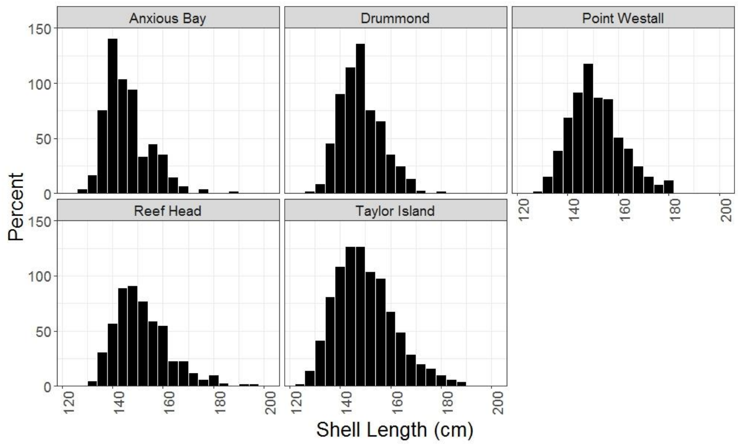

Figure 4.1. Frequency distributions of sampled blacklip shell lengths by sites.

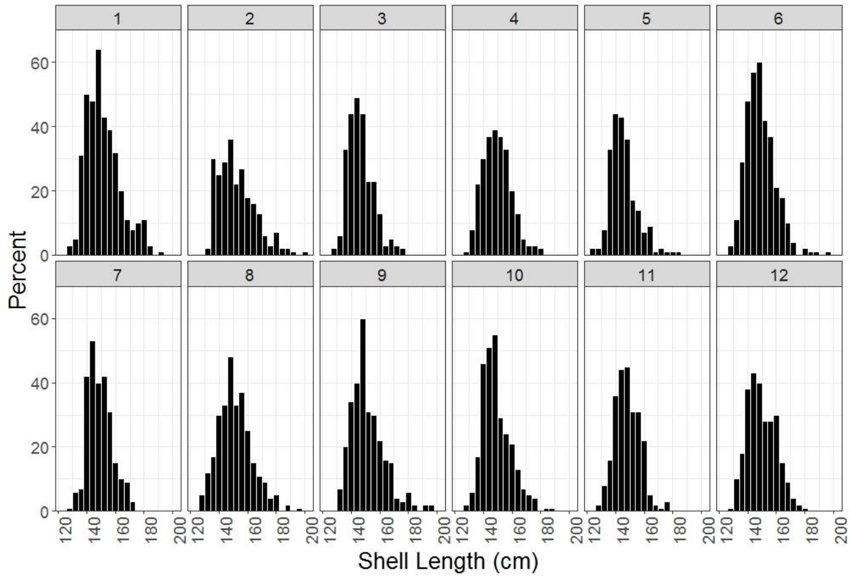

Figure 4.2. Frequency distributions of sampled shell lengths (all sites) in the WZ by month (1-12).

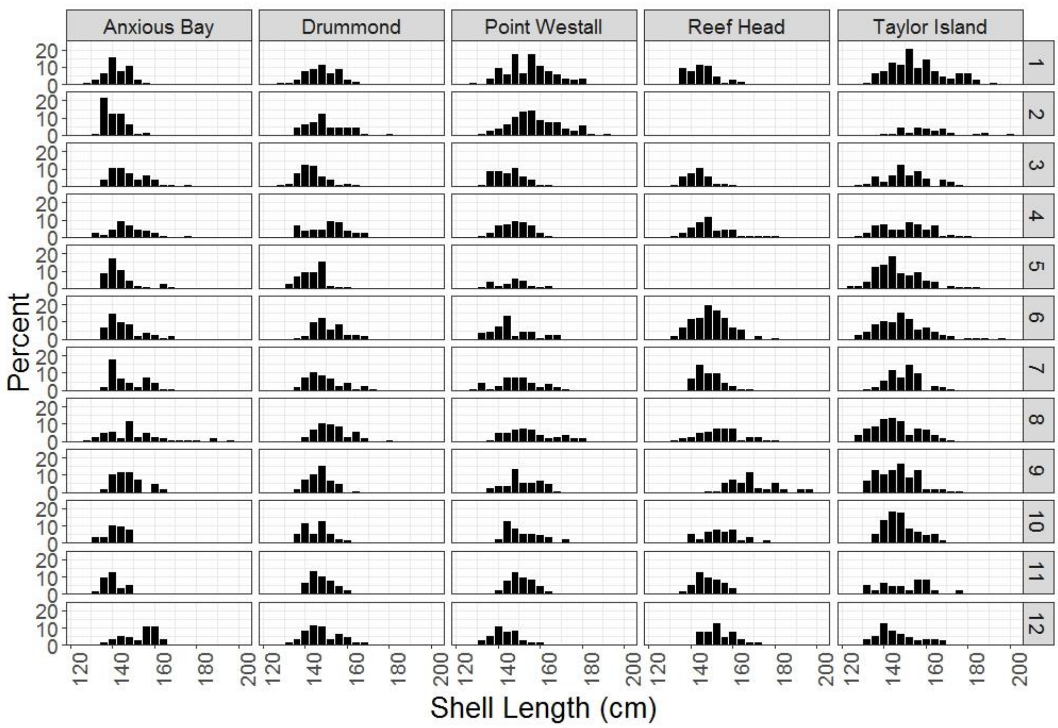

Figure 4.3. Frequency distributions of sampled shell lengths by site and month (1-12).

4.1.2 *Variation in blacklip weight and meat recovery to shell length ratios*

The shell length to whole weight ratio for the WZ is best described with a power curve (R^2 = 0.93), as is also the shell length to bled meat weight ratio (R^2 = 0.89; Figure 4.4), indicating that as shell length increases the weight of blacklip increases at an almost exponential rate. This relationship was the same irrespective of sex (see Appendix 5). In contrast, there was no detectable relationship between shell length and the percentage of meat recovery, suggesting that recovery does not vary much with size (R^2 = 0.003; Figure 4.5). There was high variability in the meat weights for a given shell length. For example, for a 160 mm blacklip the whole and bled meat weight can vary by 87% (range 500 g – 935 g; Figure 4.4a) and 96% (range 154 g – 302 g; Figure 4.4b), respectively. This high variability, at least partially, includes variation between the sites and months the samples were obtained. The difference in meat recovery for the same shell length was less variable, ranging from 22% to 42% (Figure 4.5).

Plotted by month, the distribution of blacklip g/mm shell length prior to shucking does not vary substantially among months (Figure 4.6), while at 24-hours post shucking there is some evidence that the distribution of g/mm shell length has higher values from January to April (Figure 4.7). The interpretation of this information is complicated by the effect of blacklip size, as the length frequency distributions of the monthly samples were not always similar. This problem can be accounted using monthly regressions of shell length to recovered meat weight. The regressions (R^2 ranged from 0.47 to 0.7) suggest that there is a difference in recovery among months (Figure 4.8a) with, for example, meat recovery from a 160 mm blacklip estimated from the regression curves being highest between February and April and lowest in November (Figure 4.8b). The average difference in weight between February and March and June to December is 12%.

The pattern observed from the percent recovery information, which is not influenced by the size of abalone sampled (see Figure 4.5), also suggests that for all sites, the highest recovery from whole weight occurs between January and May (Figure 4.9) and that recovery from June to December is lower. A similar metric, recovery from meat weight at 0-hours, also showed the same trend. While there was variation in the annual pattern between the five study sites, they all had periods of higher meat recovery in the first five months of the year (Figure 4.10). The anomalously low recovery value for Anxious Bay in February may be the result of some loss of condition during transport from this more remote location. Longer-term sampling from Taylor Island also suggests that the magnitude of the annual variation in recovery between months varies, as does the exact timing in any given year, although the general pattern of higher recovery in summer-autumn and lower recovery in winter-spring remains throughout the three years sampling that was conducted at this location (Figure 4.11).

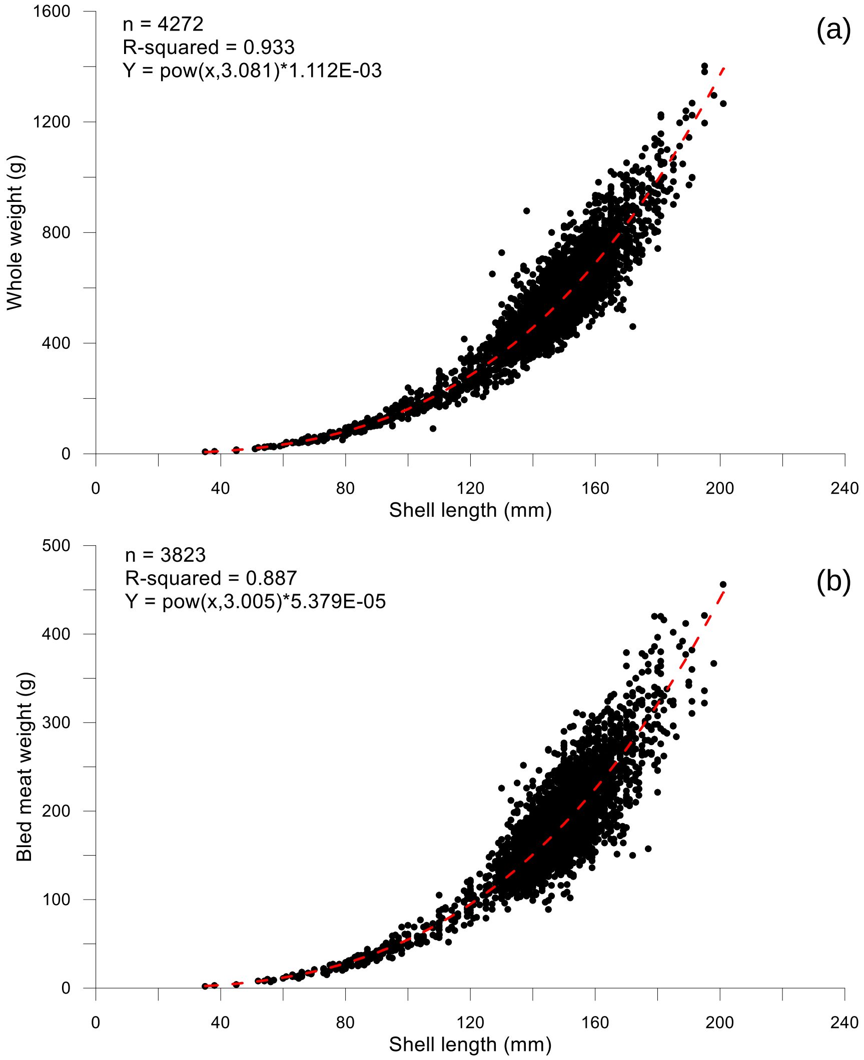

Figure 4.4. Relationships between shell length and (a) whole weight and (b) bled meat weight for the WZ of South Australia. n = number of sampled blacklip.

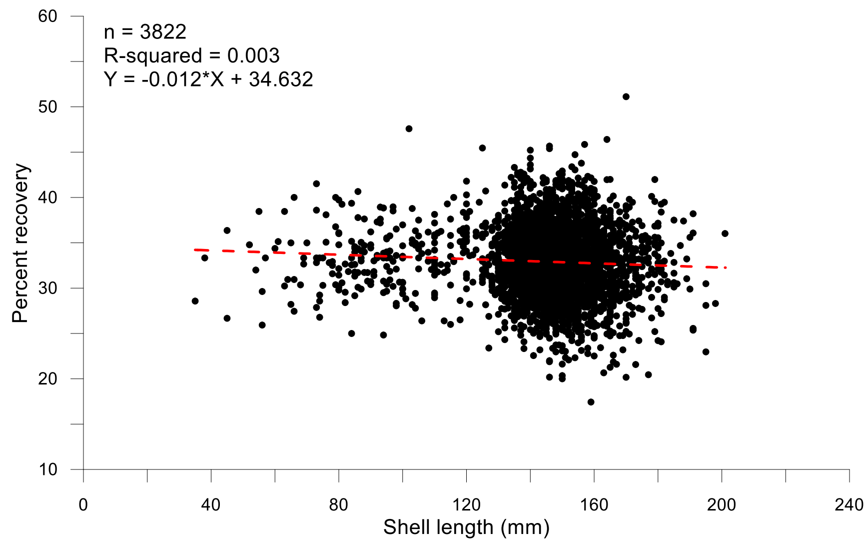

Figure 4.5. Relationship between shell length and percent meat recovery (24 hours) for the WZ of South Australia. n = number of sampled blacklip.

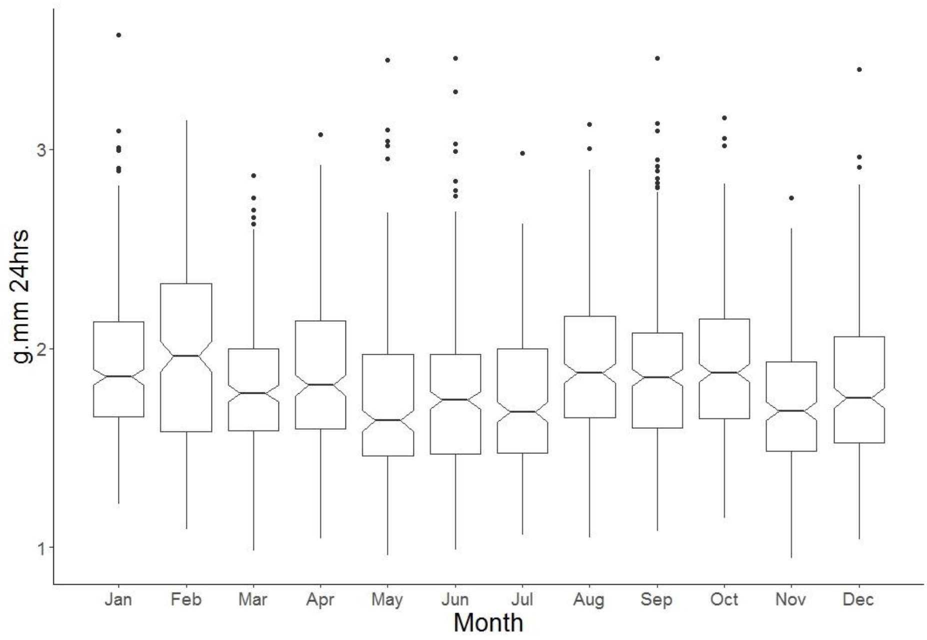

Figure 4.6. Boxplots showing variation in g/mm shell length for blacklip sampled by months at shucking (0 hours). Box shows the 25 and 75 percentile, transverse box line is median and the notch is the 95% confidence interval. Whiskers and dots represent remaining data and outliers, respectively.

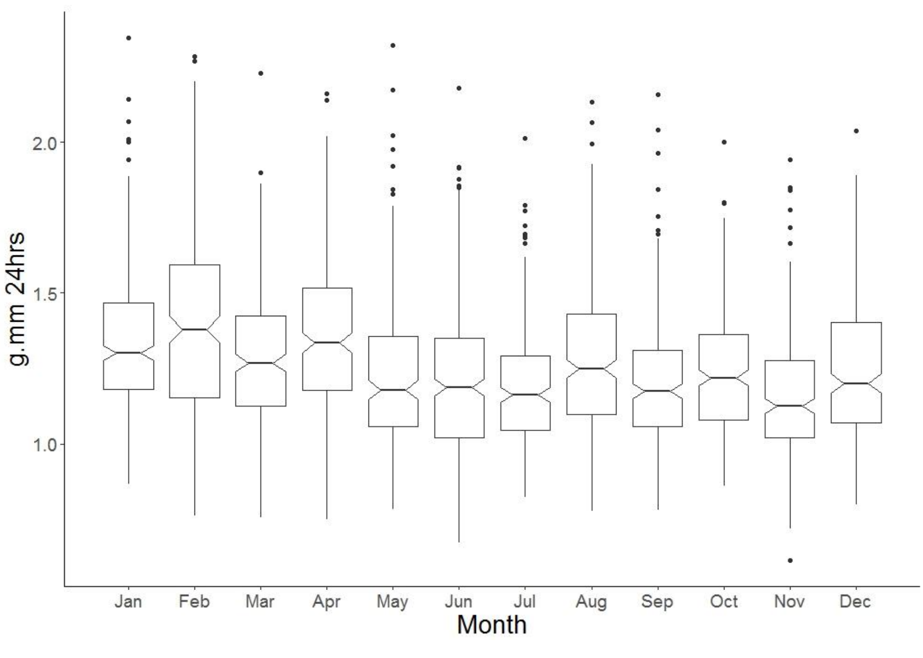

Figure 4.7. Boxplots showing variation in g/mm shell length for blacklip sampled by months 24 hours post-shucking (24 hours). Box shows the 25 and 75 percentile, transverse box line is median and the notch is the 95% confidence interval. Whiskers and dots represent remaining data and outliers, respectively.

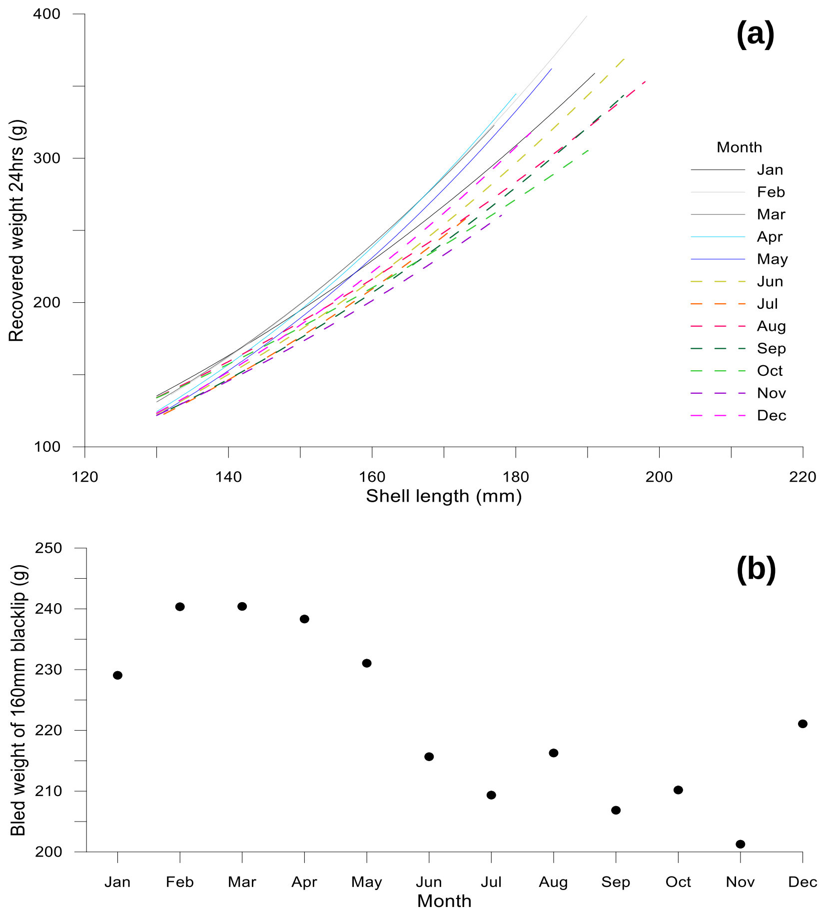

Figure 4.8. (a) Western Zone regression curves for recovered meat weight by month (all sites combined); and (b) estimated recovered meat weight for a 160mm shell length blacklip by month estimated from the regressions.

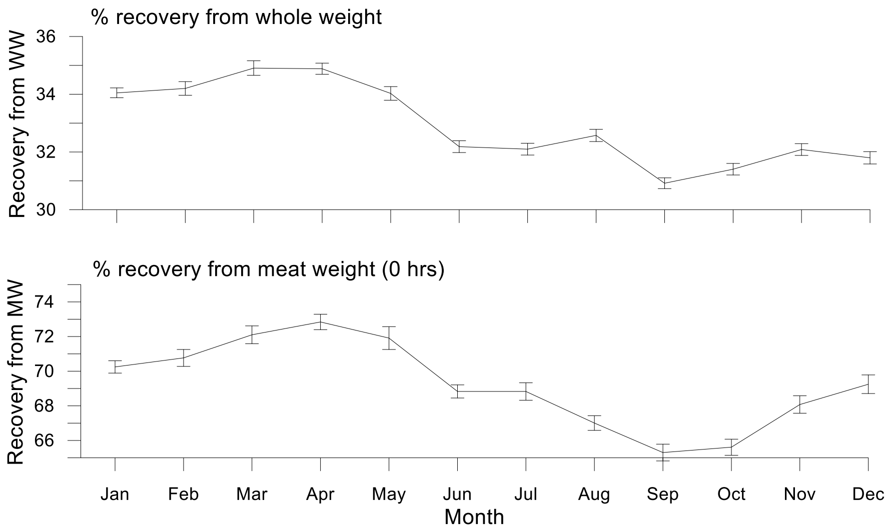

Figure 4.9. Plots of percent recovery from whole weight (WW) and meat weight at 0 hours (MW) at 24 hours post-shucking ± se, by month for all sites combined.

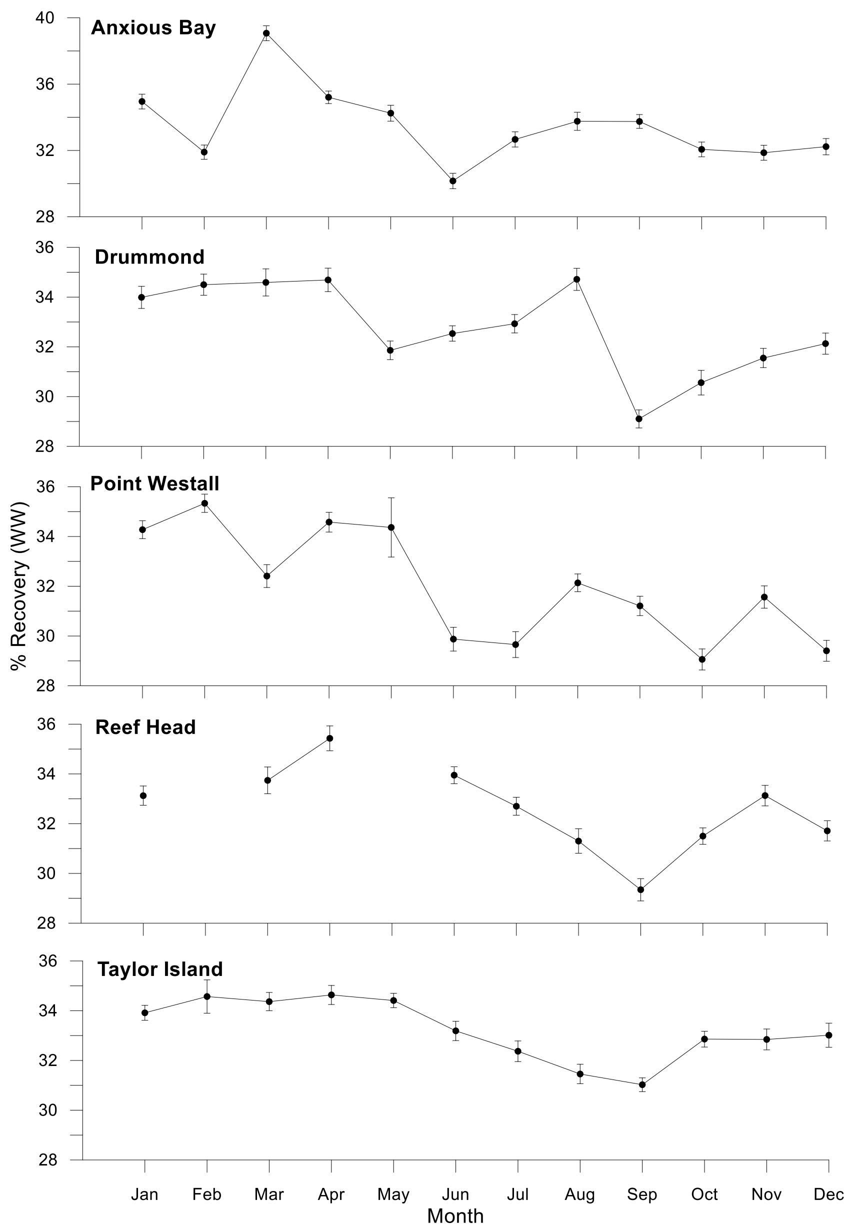

Figure 4.10. Plots of percent recovery from whole weight (WW) at 24 hours post-shucking ± se by month, for blacklip from the five study sites (period 2014 to 2017).

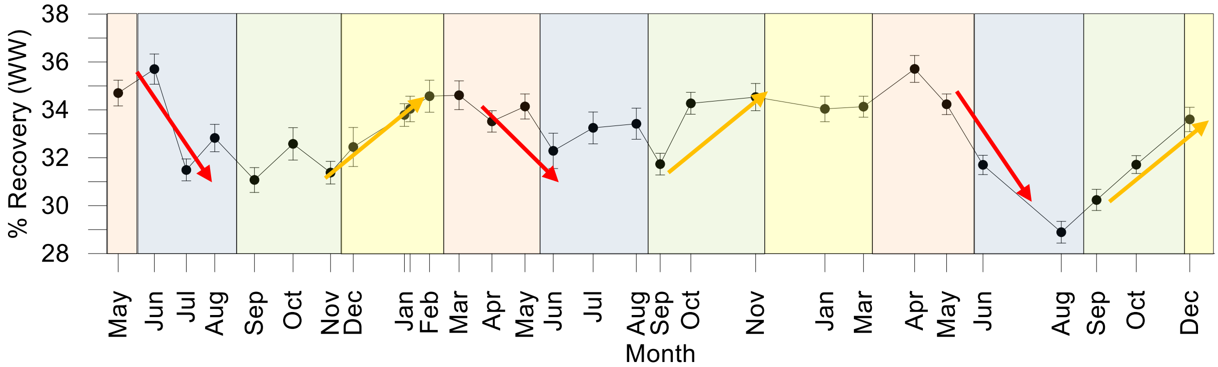

Figure 4.11. Plot of percent recovery from whole weight (WW) at 24 hours post-shucking ± se for blacklip from Taylor Island, by month (note tick spacing reflects days within months) between May 2014 and December 2016. Rectangles indicate autumn (orange), winter (blue), spring (green) and summer (yellow). Red and orange arrows indicate general declines and increases in percent recovery, respectively.

4.1.3 *Existing data available for the study*

Blacklip fisheries operate in South Australia (SA), Tasmania (TAS), New South Wales (NSW) and Victoria (VIC). Catch by month information in these four states was the most readily available for use in this study (Figure 4.12). In addition, shell weight to meat weight and bled meat recovery information was available from NSW, TAS and SA. However, of these states, the only state with representative spatio-temporal coverage was TAS, although the methodology for obtaining the meat weights was not consistent so it was not possible to determine whether meat weights were for recently shucked or fully bled samples. These inconsistencies meant that it was not possible to use the Tasmanian data to determine the annual pattern of meat recovery necessary to populate the model for TAS. While SA had the most complete range of data necessary to populate the model (i.e. catch and meat recovery information), particularly from the WZ, the information also lacked good spatiotemporal coverage, thus the need for the additional sampling undertaken in the WZ for this project. Additional data were provided by NSW that included the necessary biological data of length, whole weight, meat weight and bled meat weight of 50 individuals from 18 sites, although these data lacked temporal replication and no relevant economic information. NSW also provided the number of landed abalone and their total weight for the period 1999 to 2017, but these data lacked information on shell length and were therefore not used in the model (see Appendix 4).

The model could, therefore, not be tailored to represent conditions in TAS, NSW and VIC because the data available were either incomplete, lacked good spatiotemporal coverage or were unreliable. Consequently, the outputs provided from the model are all based on information from the WZ of the SAAF and should therefore be considered with some caution when extrapolating to other states, because the annual trends in biology between the states are not likely to be the same.

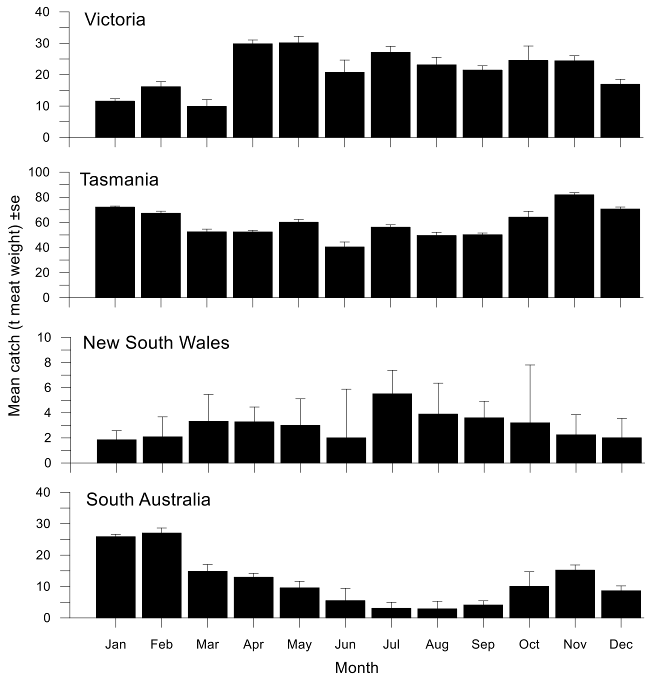

Figure 4.12. Mean catch per month (t meat weight ± se), by state for the period 2010-2014.

4.2 Objectives 2 and 3

This section addresses Objective 2 – to incorporate the biological data into the existing greenlip model and applying it under monthly fishing scenarios developed in consultation with Industry - and Objective 3 – to provide the model outputs for the scenarios tested, detailing the number of abalone harvested and their value.

4.2.1 *Variation in monthly catch*

There are considerable differences in the amount of catch harvested each month between states and between zones within states (Figure 4.12, Figure 4.13). Monthly differences likely reflect restrictions in access to the resource due to weather conditions as well as market forces. For example, the harvest from all South Australian zones and the Tasmanian Western Zone are low in winter due to adverse weather conditions during that period.

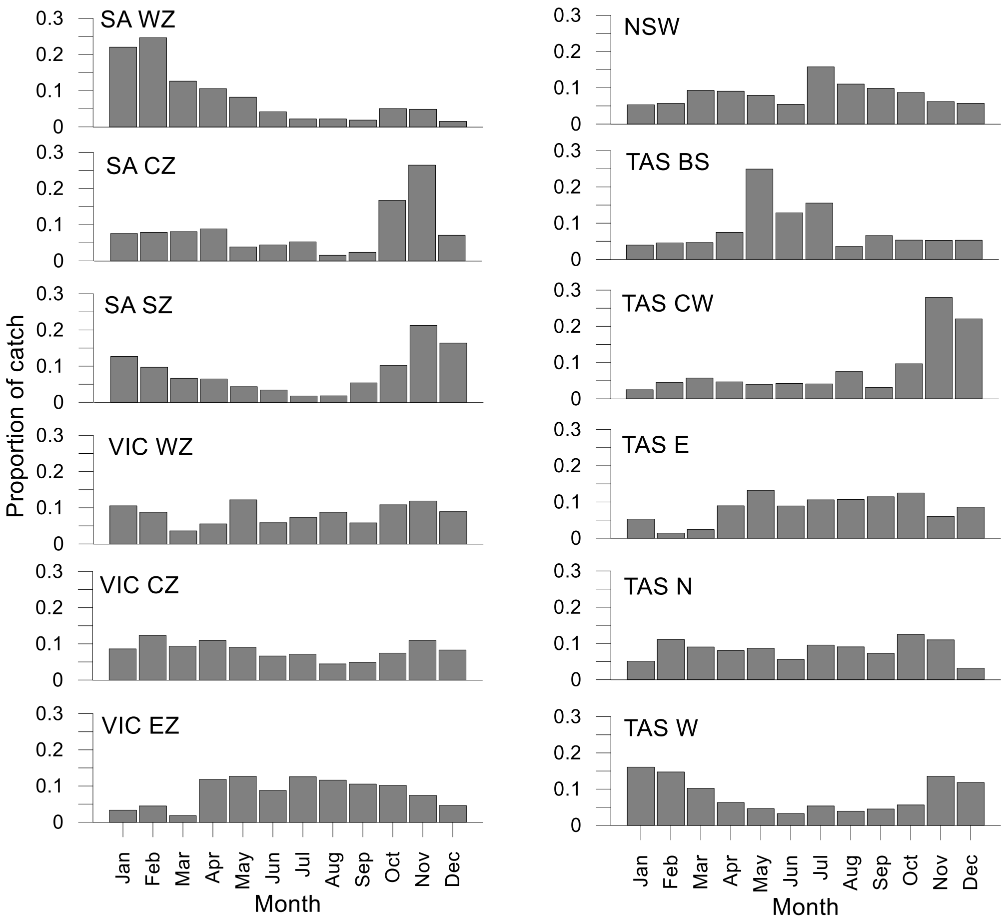

Figure 4.13. Proportion of blacklip catch by month for South Australia (SA), Victoria (VIC), New South Wales (NSW) and Tasmania (TAS) for the period 2010-2014. For SA and VIC, WZ = Western Zone, CZ = Central Zone, EZ = Eastern Zone and SZ = Southern Zone. For TAS BS = Bass Strait Zone, CW = Central West Zone, E = Eastern Zone, N = Northern Zone and W = Western Zone.

4.2.2 *Model outputs*

There were insufficient data to apply the model to each state. Therefore, the model outputs provided below rely exclusively on data from the WZ of the SAAF and, with the exception of this zone, should be interpreted with caution.

The optimal period for harvesting blacklip is best obtained from the model by simulating the number of abalone extracted for a given TACC fully harvested in each month of the year. Using the WZ of the SAAF TACC of 74.58 t as an example, the model estimates that the best time to harvest the blacklip quota is January to March, with February being the best month of all, while the worst time is August to October, with September being the worst month for harvest (Figure 4.14). The difference between fishing the entire quota in either February and September would be 13% fewer blacklip harvested if this was done in February under C_{number} or a 15% higher TACC under C_{TACC}. While we used WZ information to run the model, the shape of this curve would also apply to the other states, but the number of abalone would differ depending on their respective TACCs.

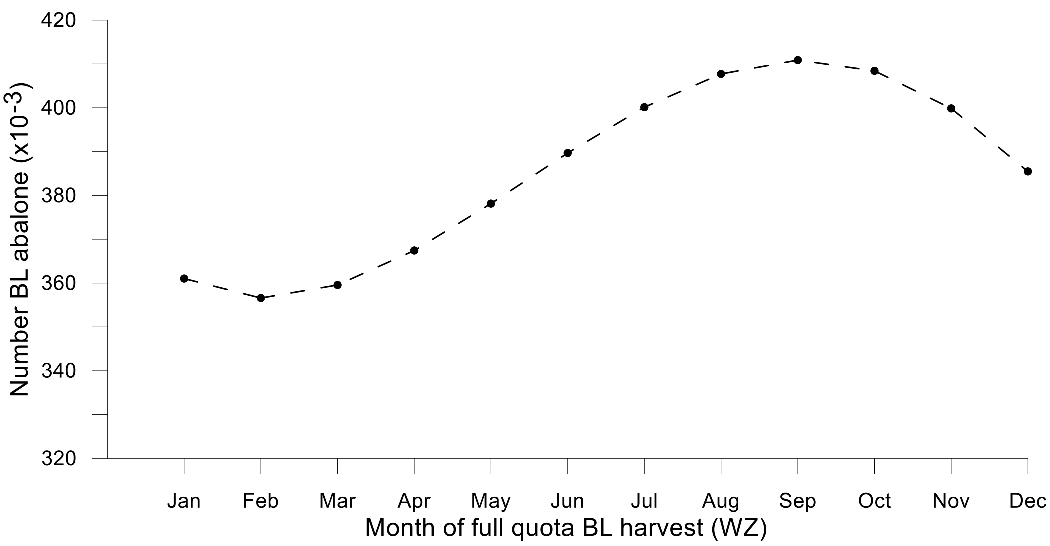

Figure 4.14. Number of blacklip abalone harvested x10^{-3} if all the WZ TACC was harvested in the shown month (dashed line and dots).

For the WZ of the SAAF, the monthly proportion of catch extracted between 2010 and 2014 (Figure 4.15A) was already similar to the optimal period for fishing at the beginning of the year identified using the model (Figure 4.14). Optimisation of this harvest to exclusively fish the quota in February and March would lead to the extraction of 3.4% fewer blacklip under C_{number}, or an increase in the TACC of 3.5% equivalent to an additional AU$246,000 under C_{TACC} (Figure 4.15, Table 4.1). Other alternatives that would lead to benefits to the fishery include scenarios 2-5, while fishing later in the year under scenarios 6-10 would be detrimental. In particular, Scenario 8 would lead to fishing 9.5% more blacklip (C_{number}) or an 8.7% reduction to the TACC at a loss of $AU 616,000 ($C_{TACC}$).

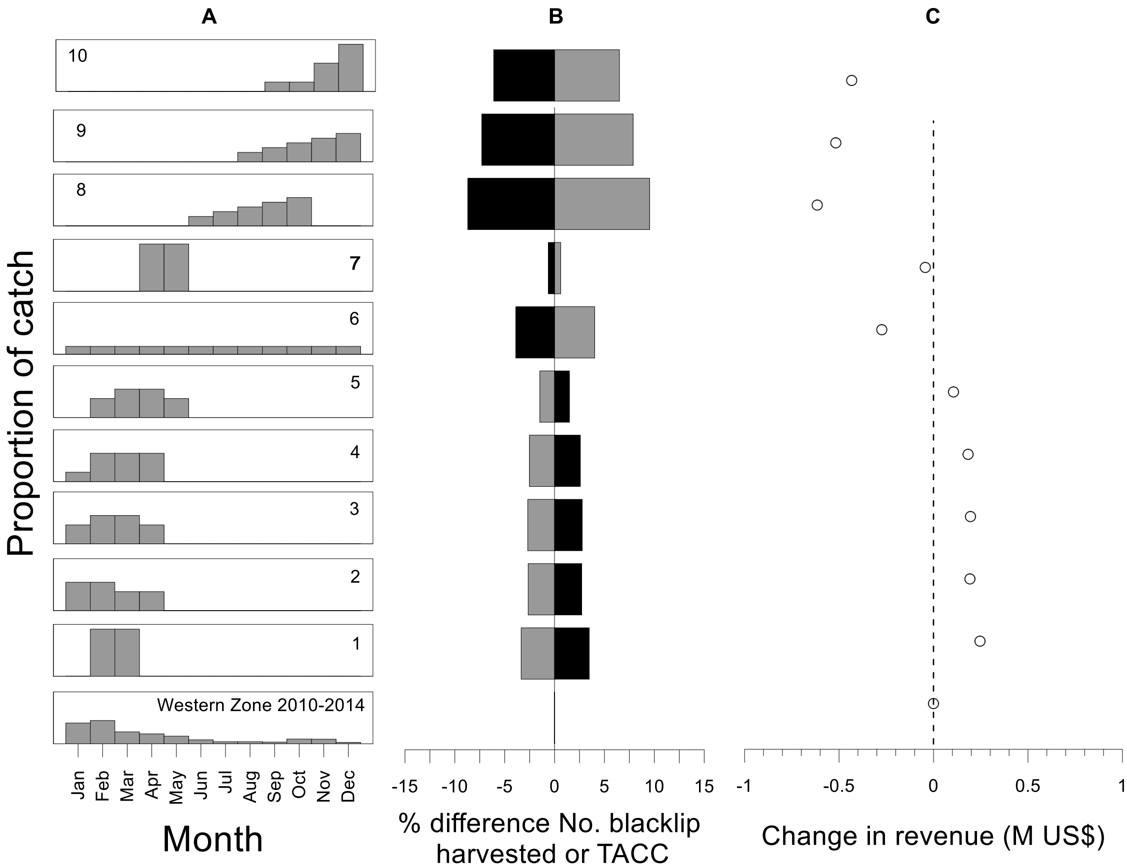

Figure 4.15. (A) The Western Zone 2010-2015 fishing and 10 scenarios with variable proportions, $P_{TACC}(m)$, of the TACC fished by month. For each, the model was used to estimate the total number of blacklip harvested and the associated revenue (C_{number}) or the TACC (C_{TACC}); (B) percent difference in number of blacklip harvested (grey bars) and of the TACC (black bars) compared with WZ 2010-2014; (C) change in revenue while maintaining the same number of blacklip obtained under WZ 2010-2014 (C_{TACC}). Dollar revenues for (C) are estimated from the steady-state model.

Applied to all states using their average monthly catch between 2010 and 2014, the model estimate for the number of blacklip extracted each year under current fishing regime ranges from the lowest in the Central Zone of South Australia (33,237 blacklip) to the highest in the Western Zone of TAS (1,408,642 blacklip; Figure 4.16). The total for all of the Australian blacklip fisheries combined is ~5.13 million blacklip per annum. The differences in efficiency of extraction, here defined as the number of blacklip extracted per kg of TACC, were relatively small, being the most efficient in the SA WZ (4.97 blacklip/kg; Figure 4.16) and the least efficient in the TAS EZ (5.25 blacklip/kg). The most efficient extraction possible would require the harvest of the entire TACC in February (Figure 4.14), and would yield 4.7 blacklip per kg of TACC. Thus, for example, if the TAS EZ were to catch the entire TACC in February, and assuming the same annual variation in meat weight and recovery as the WZ of the SAAF used in the model, this would be equivalent to leaving approximately 95,700 blacklip in the water for the same TACC (10.5% fewer blacklip harvested).

Two other states, Tasmania and New South Wales, suggested using the model to run scenarios that were of interest to them. In the case of Tasmania, the current output to all zones was compared to a scenario where fishing did not take place from January to March, while for New South Wales the current fishing practice was compared with a scenario in which most fishing would occur in July to September (Table 4.2). In both cases, the model indicated that the proposed scenarios would lead to either more abalone extracted under C_{number} or the TACC would be less under C_{TACC}. This is not surprising, as both scenarios involved fishing less at the optimum time of year. However, these outputs are based on a model that uses WZ of the SAAF data, so the outcome may change significantly when data from these states becomes available.

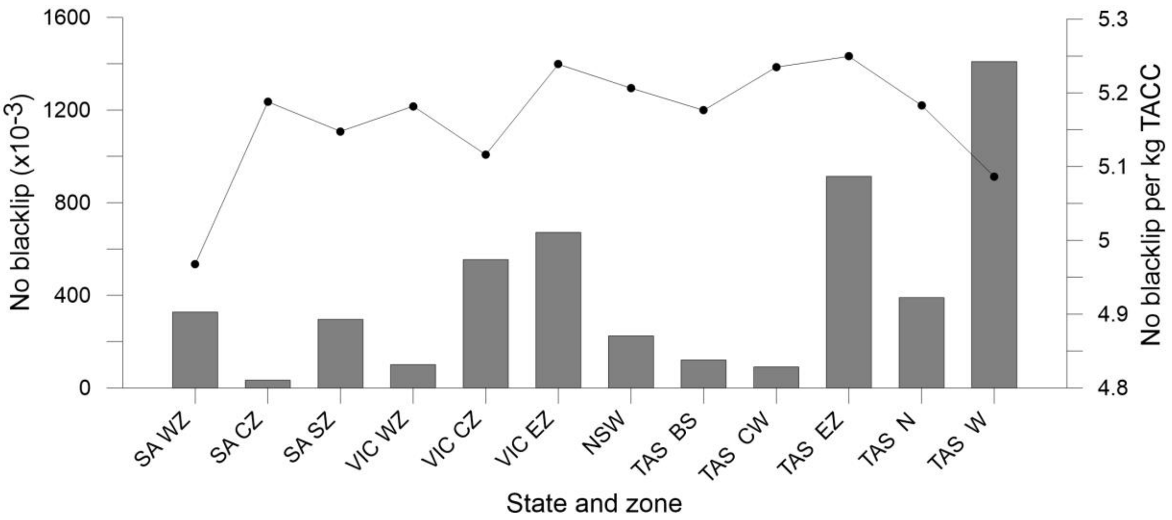

Figure 4.16. Model output showing the number of blacklip harvested annually by state and zone ($x10^{-3}$; grey bars) and number per kg of TACC by state and zone (black line). Note that the model was run based on SA WZ blacklip data.

Table 4.1. Scenarios showing the proportion of the TACC for the Western Zone of South Australia fished by month and the estimates for C_{number} and C_{TACC} obtained using the model. Differences (DIF) are the comparison of outputs for the current fishing practice (2010-2014) and each scenario.

	Scenarios										
Month/Outputs	**2010-14 fishing**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Jan	0.22		0.30	0.20	0.10		0.08				
Feb	0.25	0.50	0.30	0.30	0.30	0.20	0.08				
Mar	0.13	0.50	0.20	0.30	0.30	0.30	0.08				
Apr	0.11		0.20	0.20	0.30	0.30	0.08	0.50			
May	0.08					0.20	0.08	0.50			
Jun	0.04						0.08		0.10		
Jul	0.02						0.08		0.15		
Aug	0.02						0.08		0.20	0.10	
Sep	0.02						0.08		0.25	0.15	0.10
Oct	0.05						0.08		0.30	0.20	0.10
Nov	0.05						0.08			0.25	0.30
Dec	0.02						0.08			0.30	0.50
C_{number}											
TACC (t MW)	74.58										
No blacklip	370,507	358,070	360,682	360,536	361,178	365,044	385,406	372,788	405,776	399,690	394,617
DIF No. blacklip		-12,437	-9,825	-9,971	-9,328	-5,463	14,899	2,281	35,269	29,183	24,110
C_{TACC}											
TACC	74.58	77.17	76.61	76.64	76.51	75.70	71.70	74.12	68.10	69.13	70.02
DIF TACC		2.59	2.03	2.06	1.93	1.12	-2.88	-0.46	-6.48	-5.45	-4.56
Value M AU$	7.0851	7.3312	7.2781	7.2810	7.2681	7.1911	6.8112	7.0418	6.4693	6.5678	6.6522
DIF value M AU$		0.2461	0.1930	0.1959	0.1830	0.1060	-0.2739	-0.0433	-0.6158	-0.5173	-0.4329

Table 4.2. Scenarios showing the proportion of the TACC for the Tasmanian Bass Strait (BS), Central West (CW), Eastern (E), Northern (N) and Western (W) zones, and New South Wales (NSW, fished by month and the estimates for C_{number} and C_{TACC} obtained using the model for a single scenario of interest to each zone (e.g. BS 1). Differences (DIF) are the comparison of outputs for the current fishing practice (2010-2014) and each scenario.

	Scenarios											
Month/Outputs	**TAS BS**	**BS 1**	**TAS CW**	**CW 1**	**TAS E**	**E 1**	**TAS N**	**N 1**	**TAS W**	**W 1**	**NSW**	**NSW1**
Jan	0.04		0.03		0.04		0.05		0.16		0.05	0.03
Feb	0.05		0.05		0.01		0.11		0.15		0.06	0.03
Mar	0.05		0.07		0.02		0.09		0.10		0.09	0.03
Apr	0.08	0.09	0.05	0.07	0.09	0.10	0.08	0.11	0.06	0.11	0.09	0.03
May	0.24	0.26	0.05	0.07	0.14	0.14	0.09	0.12	0.05	0.09	0.08	0.03
Jun	0.13	0.14	0.05	0.07	0.09	0.10	0.06	0.08	0.03	0.08	0.05	0.03
Jul	0.15	0.17	0.04	0.06	0.11	0.12	0.10	0.12	0.05	0.10	0.16	0.3
Aug	0.04	0.05	0.08	0.10	0.11	0.12	0.09	0.12	0.04	0.09	0.11	0.3
Sep	0.07	0.08	0.04	0.06	0.11	0.12	0.07	0.10	0.05	0.09	0.10	0.15
Oct	0.05	0.07	0.08	0.10	0.13	0.14	0.12	0.15	0.06	0.10	0.09	0.05
Nov	0.05	0.07	0.25	0.26	0.06	0.07	0.11	0.14	0.13	0.18	0.06	0.05
Dec	0.05	0.07	0.20	0.22	0.09	0.09	0.03	0.06	0.12	0.17	0.06	0.05
C_{number}												
TACC (t MW)	23.26	23.26	17.29	17.29	174.01	174.01	75.20	75.20	277.00	277.00	43.11	43.11
No blacklip	120,380	121,869	90,232	91,492	914,753	920,461	389,880	398,812	1,408,642	1,462,481	224,470	231,376
Value M AU$	2.21	2.21	1.64	1.64	16.53	16.53	7.14	7.14	26.31	26.31	4.10	4.10
C_{TACC}												
TACC		22.97		17.06		172.93		73.51		266.80		41.83
DIF TACC		-0.28		-0.24		-1.08		-1.68		-10.197		-1.29
Value M AU$		2.18		1.62		16.43		6.98		25.35		3.97
DIF value M AU$		-0.03		-0.02		-0.10		-0.16		-0.97		-0.12

4.2.3 *Economic information and state harvest differences*

Obtaining information on the market value of blacklip was complicated by the confidential nature of this information. Therefore, with the exception of the basic information provided below, we do not provide details of findings in this report.

At the beginning of this project, the approximate value of blacklip used for the model was AU$95 per kg; thus, we used this value for all model outputs. Where markets are concerned, with the exception of one Tasmanian processor that concentrates on domestic sales, the main markets for all other processors interviewed are in Asia, with the key period serviced being directly linked to Chinese New Year that typically falls between January and February. All processors had diverse ways of marketing abalone that included live sales (primarily from Tasmania), frozen, canned, vacuum packed and dried. With the exception of the live abalone, all of these product storage formats enable abalone to be held for long periods of time prior to sale. We note that a high proportion of Australian blacklip is exported live. This is due to the large amount of live blacklip exported from Tasmania, which comprises the highest proportion of total blacklip catch in Australia (57% of Australian blacklip catch in 2015; Stewardson et al. 2016)). In addition, there is also live catch exported from some of the other states such as New South Wales, Victoria and, to a lesser extent, South Australia.

5 Discussion

The outputs from the steady state model adapted for this study to quantify the number of blacklip harvested and the associated revenue demonstrate that the optimal month to harvest blacklip in the WZ of the SAAF is February. This is because, using the strategy C_{number} or C_{TACC}, February harvests provide the lowest number of blacklip for a given TACC, or provide potential increases in TACC if the number of blacklip harvested remain unchanged. The model also shows that the difference between months from January to April is small, and thus the benefits described above can be obtained from focussing the primary harvest period during these four months. The benefits are due to the combined effect of blacklip weighing more in February and meat recovery being best from January to May. Notably, in contrast with greenlip (Stobart et al. 2013), the monthly differences in blacklip whole weight and percent recovery are less. In addition, in the WZ the two species also have different periods for optimal harvest, with the optimal time to harvest greenlip being between April and June (Stobart et al. 2013).

We have provided model outputs for other states and zones based on the South Australian data as an example of the benefit one may obtain for their given catches if the annual variation in whole weight and meat recovery had similar timing and magnitude. Unfortunately, the months when these benefits may accrue and their magnitude remains unknown, and it is unlikely that the optimal time for harvest and the changes in weight and percent recovery will be the same in all States. This is because the different fisheries are separated by large distances and influenced by different regimes of temperature and other environmental variables typical to those of South Australia. For example, Tasmania is located further south and subject to the influence of different ocean currents and weather patterns. As the annual temperature variation in Tasmania is larger than that observed in South Australia (Stobart et al. 2015), the period of optimal meat recovery may be more focussed and both whole weight and percent recovery may vary more throughout the year.

The biological factors underpinning the seasonal variation in whole weight and bled meat weight described in this study are largely unknown but, as also suspected for greenlip (Stobart et al. 2013), is likely that it is associated with the reproductive cycle and storage of energy. Observations made on blacklip reproduction during this study (see Appendix 5) suggest that, based on the proportion of animals that could be visually assigned a sex (i.e. there was a low percentage of unclassified gonads), the primary reproductive period for blacklip in the WZ of South Australia occurs between March and September (Figure 9.9, Appendix 5), although some reproductively active animals were observed throughout the year. This period falls within the spawning window described in a previous study by Shepherd and Laws (1974) that, depending on the area, identified the spawning season to occur between March and December, with January and February the period of least spawning. Similarly, Litaay and DeSilva (2003) found that blacklip in southeast Victoria were most reproductively active between October and December. The large variability in the timing of blacklip reproduction was highlighted by Shepherd and Laws (1974) and may in part account for the high variability in whole and recovered meat weights observed for blacklip in this study. This contrasts with the more discrete reproductive cycle known to occur in greenlip (October to December; Shepherd and Laws 1974) along with a more clearly defined cycle in whole weight and meat recovery (Stobart et al. 2013). We also note that the timing of reproduction recorded for Victoria (Litaay and DeSilva 2003) is later in the year than that we expect for the WZ in South Australia, reinforcing the point made in the above paragraph, that there are likely to be differences in the biological cycles between locations.

It is noteworthy that, for some fisheries, the benefits relating to bled weight explored in this project are not relevant. For example, the Tasmanian blacklip are primarily sold into the live market on pre-shucking weight, and thus the post-shucking weight loss becomes irrelevant, although this does not preclude any benefits from blacklip of a given shell length weighing more at certain times of the year. Reduced harvests or fishery closures within Tasmania are often more about losses due to mortality during transport that probably outweigh within year variation in weight and meat recovery (C. Mundy personal communication). In addition, irrespective of any optimal time to harvest live blacklip associated with whole weight variation, abalone will still need to be harvested throughout the year to supply market demand in Tasmania and other states that service the live market (e.g. NSW or Victoria). This contrasts with blacklip that are harvested and processed for longer-term storage as a frozen or canned product, as is primarily the case in South Australia, as these can be fished at the optimal time of the year and held in stock until required, thus maximising the meat return for a given number of blacklip harvested. A further consideration is weather which may limit any changes to fishing strategies if fishing is not possible during the proposed months.

With few exceptions, Australian blacklip fisheries are currently subject to quotas that are less than they were in recent years, reflecting a period of reduced productivity (e.g. Tasmania - Mundy and Jones 2017; South Australia - Burnell et al. 2016, Stobart et al. 2017), the consequence of disease (e.g. VIC WZ; Mayfield et al. 2011) and/or overfishing (e.g. Burnell and Mayfield 2017). Thus, the most applicable use of our model would be to reduce the risk to the fishery by fishing an un-amended TACC (C_{number}) during the optimal harvest period at the beginning of the year (in SA, other states yet to be determined), thus removing fewer blacklip. Overall, the difference between fishing the optimal month of the year (February) and the least optimal (September) is ~13% fewer blacklip or an increase in TACC of ~15%, so the benefits could be considerable. However, the real difference is not this large as all fisheries will already be extracting a proportion of their catch at the optimal time of the year. For example, the model output for the WZ of South Australia indicates that fishing the annual quota over the first four months of the year under C_{number} leads to almost 10,000 blacklip left in the water each year. This equates to ~3% fewer blacklip harvested per annum from the WZ compared with current levels of harvest because the fishery is already well aligned with the optimal fishing period. In the case of the WZ, despite there being a relatively small benefit to changing the period of fishing, the long-term cumulative benefit of leaving 3% of blacklip in the water, while largely unknown, would potentially be worth pursuing to increase blacklip abundance/reproductive potential and thus reduce risk to the fishery. Excluding the live trade, given the potential for leaving large numbers of blacklip unfished where fishing is not already targeting the best period, the benefits to other blacklip fisheries would be worth exploring if new information on the periods of high and low weight and recovery can be determined.

Finally, this study clearly demonstrates that despite strict methodological guidelines for sample collection and processing, there was substantial variation in blacklip whole weights within samples for a given shell length and bled meat weights. This variation highlights the need for careful design, large sample sizes and consistent sampling for any comparative study involving this species. Our study also highlighted the general lack of very basic information required to answer simple questions relating to the biology of blacklip. In addition, where data were available for some states, we were not able to use it because there was insufficient temporal and/or spatial coverage or in the case of bled meat weights, where the methodology for obtaining the information changed through time without the changes being adequately documented. Again, given the high variability observed in blacklip known to have been sampled consistently, this should be borne in mind when designing future collections to enable data to be used as broadly as possible.

6 Conclusion

The overall aim of this project was to determine whether attributes of the seasonal biology of blacklip abalone could be used to benefit fishing strategies. This was achieved by addressing the three objectives set out from the beginning of the project, which were to (1) quantify the seasonal variation in the shell size to whole weight and the whole weight to recovered meat weight ratios; (2) incorporate these findings into the model previously developed for greenlip and explore the outcomes of fishing scenarios decided on in consultation with Industry; and (3) provide the outputs of harvest scenarios (number of abalone and expected value) to enable industry and managers to evaluate strategies that may maximise the efficiency of their blacklip fisheries.

All of the project objectives were achieved and it has been established that in the WZ of the SAAF blacklip exhibit seasonal variation, weighing more and bleeding less during the months of January to April. This variation is less than that observed for greenlip in a previous study (Stobart et al. 2015), but is large enough to be considered by managers and industry in planning fishing strategies, with the difference between the optimal month for fishing (February) and the least optimal (September) equivalent to fishing 13% fewer blacklip for any given TACC extracted in February. Notably, the WZ fishery is already fishing close to the optimal period needed to benefit from the blacklip seasonal variation, but changes to the fishing strategy could still yield worthwhile benefits associated with the potential to leave 3% of the annually caught blacklip unfished.

The proportion of TACC taken in each month varies in other states. Consequently, there is potential to explore the value of adjusting the timing of fishing strategies to take advantage of within season changes in body weight and meat recovery exhibited by blacklip in this study. However, unfortunately there is currently insufficient data available to adapt the model to run for other states and so the real benefits remain unknown. As a rough guide in this report, we highlight the potential benefits that could be gained if the magnitude and timing of seasonal variation in whole weight and bled meat weight were the same as those observed for SA. In view of the missing information and potential benefits to be gained from changing fishing strategies documented in this report, there is strong argument to obtain the basic biological information needed to run the blacklip model for TAS, VIC and NSW. This will enable the refinement of the fishing strategies in these other states to ensure the blacklip resource is being utilised as effectively and efficiently as possible.

7 Implications

The agreement for this project highlighted one primary output, the improvement of advice for the management of blacklip abalone. For the WZ of the SAAF, the model outputs have shown that a large proportion of the blacklip catch is already being harvested at the appropriate time to provide maximum return while taking as few blacklip as possible for a given TACC. However, there is also a component of the catch being harvested in the latter months of the year that is the least favourable time to be fishing. This information was communicated to fishers during a workshop in September 2017 and through other venues (see Section 9), with management advice recommending that fishing be focussed at the beginning of the year. Importantly, for the WZ the optimal time for blacklip fishing (months) is before that for greenlip, which makes harvesting easier for fishers as they can spread fishing through the first six to seven months of the year, starting with blacklip and ending on greenlip.

Despite the relatively small variation in meat weight and recovery observed for blacklip, the benefits that can be obtained in the WZ from altering fishing practices for blacklip are still worth pursuing. Prioritising fishing at the beginning of the year could lead to either leaving between 9,000 and 12,000 blacklip in the water each year under the current TACC (C_{number}) or a potential increase in TACC worth between $200,000 and $250,000 ($C_{TACC}$). For the other states, given that in many cases blacklip are currently harvested late in the year when blacklip may not be in prime condition, and in instances where harvesting is not for a live market there would also likely be worthwhile benefits to changing fishing strategies to fish the best months.

This study revealed the general lack of suitable biological information on blacklip across all states. Where data are available (e.g. NSW and Tasmania) there were not spatially and temporally consistent enough to allow the identification of the optimum fishing months. Consequently, all of our model outputs are based on data obtained during this project from the WZ of South Australia. It is likely that the seasonal biological patterns for blacklip at the different locations outside South Australia are not the same and, consequently, the outputs from the model that are based on input data obtained from the WZ of South Australia should be considered with caution where computed for the other states and the Central and Southern zones of South Australia. This makes it difficult to provide reliable management advice for these other states (NSW, TAS and VIC). The solution to this problem will be to undertake similar sampling work in these states to obtain the information necessary for the model at a meaningful spatial and temporal scale.

8 Recommendations

Blacklip fisheries within South Australia should consider tailoring the timing of harvest to make the most of the findings from this project. In particular, fishing between June and December should be discouraged. Notably, a large proportion of fishing in the Central and Southern Zones currently occurs during the less favourable, latter half of the calendar year. These fisheries may benefit from changing their fishing strategies accordingly, but should also conduct sampling to confirm the findings from the Western Zone still apply. An economical way of doing this would be to sample bi-monthly to determine if the trend in bled meat weight is similar to that of the WZ, and then increase sampling frequency if required.

A similar sampling strategy could be adopted for the other states, particularly those that do not have the dominant supply provided to the live market, to pinpoint the best months for fishing. Obtaining good spatial and temporal information on bled meat weights would enable the tailoring of potential management responses in these fisheries so that increased yields or reductions in exploitation rates may be fully realised. Further data from these states would also enable a comparison with the results obtained for the WZ of South Australia in this project. This may be achieved through further independent biological sampling, as the application for this project also included the provision for a second phase to address these data gaps. Alternatively, industry may wish to obtain fishery dependent information in a structured manner for inclusion in the SARDI model.

While the benefits to altering fishing periods identified during this study are relatively small, if adopted and aggregated across all of the Australian fisheries they would represent either a significant number of blacklip left in the water each year (C_{number}) or a large dollar value due to TACC increases (C_{TACC}). With abalone stocks mostly declining across Australia (Stewardson et al. unpublished), the option of leaving more animals in the water is likely to aid stock re-building, the primary goal of the current TACC reductions.

Beyond the specific findings of this project, we have demonstrated that considerable benefits may be obtained from careful consideration of the biology of harvested species in their management. It is likely that other species will also have life cycles that allow fine-tuning of harvests to maximise returns and/or resource security and managers and fishers should therefore consider these.

8.1 Further development

The lack of suitable biological information on blacklip required to answer simple questions relating to the biology of blacklip needed to run the model, needs addressing. This lack of information has now been addressed for the South Australian WZ, but is still lacking for other zones within South Australia and other states. Obtaining the necessary information for these locations will help improve the efficiency of their blacklip fisheries. In addition, due to the highly variable nature of biological measurements made on abalone within samples identified during this study, we highlight the need for biological information to be obtained in a highly structured and consistent manner. Studies on abalone and other species would also benefit from the consideration of alternative uses of the data from fisheries that may help them to operate as effectively and efficiently as possible, or allow changes that may help secure the resource. These should be important considerations given the high cost of obtaining samples and the potential benefits that may arise from targeted sampling.

9 Extension and Adoption

The information and key messages obtained from this research have been provided to the target audience. The audience includes abalone industry members from South Australia, Victoria, New South Wales and Tasmania, managers and researchers. This has been achieved through a series of presentations, a workshop in Port Lincoln and an international abalone symposium presentation. In addition, a scientific manuscript is being prepared for publication in a peer reviewed international journal. The sequence of extension is as follows:

- Presentation on the project at the 9th International Abalone Symposium in South Korea in October 2015 titled "Maximise yield or minimize risk in the blacklip abalone fishery: using biological data to direct harvest strategies".
- Update presentation given at Abalone Industry Association of South Australia (AIASA) Annual General Meeting on the 14th October 2016. Dean Lisson (president of the ACA) was also present at the meeting.
- Update presentation given to the Abalone Council of Australia (ACA) in Adelaide on the 14th June 2017.
- Blacklip project workshop in Port Lincoln on the 19th September 2017 with invitation to attend extended to all states involved. The workshop presentation that outlined the project provided to interested parties.
- Presentation on the project provided to the Central Zone (CZ) of South Australia management and divers in October 2017. The presentation included modelled scenarios for the CZ.
- Scientific manuscript using project outcomes in preparation.
- We are exploring ways to improve the efficiency and profitability of the fishery in cooperation with Jonas Woolford, president of AIASA, and Julian Morrison (Econsearch) because there is interest in the WZ of South Australia to use the project information to encourage fishers to catch a higher proportion of their quota at the beginning of the year, and to consider other efficiencies. An analysis of different scenarios involving the time of fishing and reducing the number of vessels in the fleet has already been undertaken by SARDI and Econsearch. The results will be discussed in a one-day workshop hosted by Econsearch, due to be held in Adelaide on the 14th August 2018. The outcomes will be presented to interested fisheries and either included in the peer reviewed publication being prepared or as a separate, stand alone, publication.
-

9.1 Project coverage

9.1.1 *Project materials developed*

A scientific manuscript is currently being prepared and will be submitted to an international peer-reviewed journal in due course.

10 References

Anon (2015). Victorian wild harvest abalone fishery management plan. Victoira, Victoria Department of Economic Development, Jobs, Transport and Resources.

Anon (2017a). Abalone resource of Western Australia harvest strategy 2016-2021. Perth, Department of Fisheries, Western Australia**:** 31.

Anon (2017b). Assessment of the NSW abalone fishery, NSW Department of Primary Industries**:** 15.

Beltrán-Lugo, A. I., A. N. Maeda-Martínez, R. Pacheco-Aguilar and H. G. Nolasco-Soria (2006). "Seasonal variations in chemical, physical, textural, and microstructural properties of adductor muscles of Pacific lions-paw scallop (*Nodipecten subnodosus*)." Aquaculture **258**: 619-632.

Breen, P. and S. Kim (2003). The 2003 stock assessment of paua (*Haliotis iris*) in PAU7. New Zealand Fisheries Assessment Report 2003/35**:** 112.

Burnell, O., S. Mayfield, G. Ferguson and J. Carroll (2016). Central Zone Abalone (*Haliotis laevigata and H. rubra*) Fishery. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000611-7. Research Report Series No. 927. 93pp.

Burnell, O., S. and S. Mayfield (2017). Status of the Central Zone Greenlip (Haliotis laevigata) and blacklip abalone (H. rubra) fisheries in 2016. Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000611-8. Sardi Research Report Series No. 958. 25pp.

Cook, P. A. (2016). "Recent trends in worldwide abalone production." Journal of Shellfish Research **35**(3): 581-583.

Flood, M., I. Stobutzki, J. Andrews, C. Ashby, G. Begg, W. Fletcher, C. Gardner, L. Georgeson, K. Hartmant, P. Hone, P. Horvat, L. Maloney, B. McDonald, A. Moore, A. Roelofs, K. Sainsbury, T. Saunders, T. Smith, C. Stewardson, J. Stewart and B. Wise (2014). Status of key Australian fish stocks reports 2014. Canberra, Fisheries Research and Development Corporation.

Francis, R. I. C. C. (1988). "Maximum likelihood estimation of growth and growth variability from tagging data." New Zealand Journal of Marine and Freshwater Research **22**: 42-51.

Gordon, H. R. and P. A. Cook (2004). "World abalone fisheries and aquaculture update: supply and market dynamics." Journal of Shellfish Research **23**(4): 935-939.

Gorfine, H., B. Taylor, M. Cleland, M. Haddon, A. Punt, D. Worthington and I. Montgomery (2005). Development of a spatially-structured model for stock assessment and TAC decision analysis for Australian Abalone Fisheries., Final Report to Fisheries Research and Development Corporation. Project No. 1999-116. Primary Industries Victoria, Queenscliff**:** 108.

Hamasaki, K. and S. Kitada (2008). "The enhancement of abalone stocks: lessons from Japanese case studies." Fish and Fisheries 9(3): 243-260.

Liggins, G. and Upston, J (2010). Investigating and managing the *Perkinsus*-related mortality of blacklip abalone in NSW. FRDC Project No. 2004/084. Industry & Investment NSW – Fisheries Final Report Series No. 120. Fisheries Research and Development Corporation.

Litaay, M., De Silva, S. S. (2003). "Spawning season, fecundity and proximate composition of the gonads of wild-caught blacklip abalone (*Haliotis rubra*) from Port Fairy waters, south eastern Australia." Aquatic Living Resources **16**: 353-361.

Magnusson, A., S. Fargher and J. Morison (2016). Economic and social indicators for the South Australian abalone fishery 2014/15. Adelaide, Econsearch**:** 93.

Mayfield, S., R. McGarvey, H. K. Gorfine, H. Peeters, P. Burch and S. Sharma (2011). "Survey estimates of fishable biomass following a mass mortality in an Australian molluscan fishery." Journal of Fish Diseases **34**(4): 287-302.

Mayfield, S., C. Mundy, H. Gorfine, A. M. Hart and D. Worthington (2012). "Fifty Years of Sustained Production from the Australian Abalone Fisheries." Reviews in Fisheries Science **20**(4): 220-250.

McGarvey, R. and Fowler, A. J. (2002). "Seasonal growth of King George Whitiing *(Sillaginodes punctata)* from length-at-age samples truncated by legal minimum size." Fisheries Bulletin **100**: 545-558.

Mundy, C. and H. Jones (2017). Tasmanian abalone fishery assessment 2016. Hobart, Tasmania, IMAS, UTAS**:** 149.

PIRSA (2012). Management Plan for the South Australian commercial Abalone Fishery. Adelaide, Primary industries and Regions South Australia Fisheries and Aquaculture**:** 85pp.

Rice, J. A. (1995). Mathematical statistics and data analysis. Belmont, California, Duxbury Press**:** 594pp.

Shepherd, S. and H. Laws (1974). "Studies on southern Australian abalone (Genus Haliotis). II. Reproduction of five species." Marine and Freshwater Research **25**(1): 49-62.

Stewardson, C., J. Andrews, C. Ashby, M. Haddon, K. Hartmann, P. Hone, P. Horvat, S. Mayfield, A. Roelofs, K. Sainsbury, T. Saunders, J. Stewart, I. Stobutzki and B. Wise (2016). Status of Australian Fish Stocks Reports 2016. Canberra, Fisheries Research and Development Corporation.

Stewardson, C., J. Andrews, C. Ashby, M. Haddon, K. Hartmann, P. Hone, P. Horvat, S. Mayfield, A. Roelofs, K. Sainsbury, T. Saunders, J. Stewart, I. Stobutzki and B. Wise (in prep). Status of Australian Fish Stocks Reports 2018. Canberra, Fisheries Research and Development Corporation.

Stobart, B. and S. Mayfield (2016). Assesssment of the Western Zone Greenlip Abalone (*Haliotis laevigata*) Fishery in 2015. Fisheries Stock Assessment report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000373-2. SARDI Report Series No. 920. 67pp.

Stobart, B., S. Mayfield and K. Heldt (2017). Western Zone blacklip (*Haliotis rubra*) and greenlip (*H. laevigata*) abalone fisheries in 2016. Fisheries Stock Assessment report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2017/000331-1 **:** SARDI Report Series No. 964. 91pp.

Stobart, B., S. Mayfield and R. McGarvey (2013). "Maximum yield or minimum risk: Using biological data to optimize harvest strategies in a southern Australian molluscan fishery." Journal of Shellfish Research **32**(3): 899-909.

Stobart, B., S. Mayfield, C. Mundy, A. J. Hobday and J. R. Hartog (2015). "Comparison of in situ and satellite sea surface-temperature data from South Australia and Tasmania: how reliable are satellite data as a proxy for coastal temperatures in temperate southern Australia?" Marine and Freshwater Research **67**: 612-625.

11 Appendices

Appendix 1. Researchers and project staff

The following Research Scientists conducted this project:

- Dr Ben Stobart
- Dr Stephen Mayfield
- Dr Craig Mundy
- Dr Julian Morrison
- Dr Natalie Molschaniwskyj
- Dr Rowan Chick

The following project staff were engaged in this project:

- Dr Nicole Hancox
- Jay Dent
- Damian Matthews
- Douglas Graske

The following abalone divers contributed to this project:

Jay Haagmans
David Delaine
Thomas McNab
Dion Edmunds
Damon Edmunds
Jonas Woolford
Tobin Woolford
Bill Ford
Bob Ford
Bill Bascomb
Tyrone Craig
Tobias Craig
Darryl Carrison
Amanda Bichard

Appendix 2. Intellectual Property

No intellectual property identified. This report and resulting manuscripts are intended for wide dissemination and promotion.

Appendix 3. Processor interview questionnaire

FRDC Blacklip season project

Processor interview questions (2016)

NAME:

PROCESSORS:

LOCATION:

CONTACT NUMBER:

1. What species do you process?
2. For Blacklip (*last season-2015*): What is your market? (Live, canned, frozen, other?)
3. What is the typical species split (percent or weight of each)?
4. What countries do you export to? Do you sell to Australian market as well?
5. What is the current differential (or prices) for the different markets?
6. What are your major costs (What are the differences in the costs, for example, live may pay more but freight costs will be greater)?
7. Do you grade for any of your markets, if so how? (By size, colour, freshness, weight, other?)
8. If you grade, do you price grades differently? What are the prices (or alternatively what is the price differential?)
9. Does demand vary through the year and does grading vary?
10. If demand varies, can you provide your preferred percent split by month of the year? Do you hold inventory of unprocessed or processed product to meet peaks in demand?
11. How long do (or could) you hold each kind of product?
12. What proportion of the state catch do you process?
13. Do you process multiple zones?
14. Do you process from more than one state?
15. Do you have any other comments or questions about the project?

Thank you

Appendix 4. New South Wales count data

Estimates of the mean whole weight for blacklip per month show that the greatest weight return for all Spatial Management Units (SMUs) in New South Wales occurs in July (Figure 11.1). The difference between maximum and minimum values is small, ranging from 2g for SMU2 to 31g for SMU4, with an average of 15g. The data from NSW lacks length information, and thus any comparison between months relies on the assumption that the overall size distribution of landed abalone between months is the same. This assumption is reasonable given the span of years for the data and the number of entries (155,931). However, this data also lacks information on bled meat weight and the higher weight in July may simply be a reflection of changes in weight associated with the reproductive cycle. Thus, unfortunately it does not provide an indication of the harvest month that would provide the best return in bled meat weight.

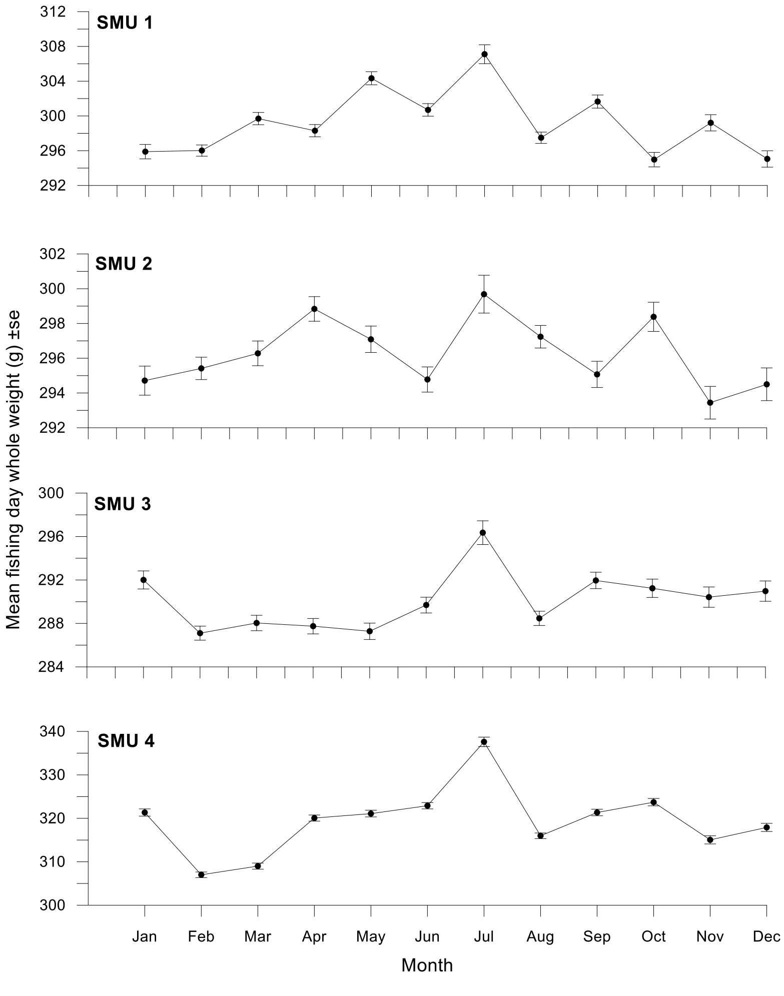

Figure 11.1. Mean whole blacklip weight per fishing day (g ±se) for each of the four spatial management units (SMU) in NSW, by month, for the period 1999 to 2017.

Appendix 5. Blacklip reproduction

Sampling for this project enabled the collection of basic information on the sex ratio and reproductive traits for blacklip. This information is useful because the reproductive cycle is likely to be closely linked to the variation in meat recovery observed throughout the year as reproduction is likely to be associated with variability in meat condition (e.g. in scallops - Beltrán-Lugo et al. 2006). With the exception of the period October to January, the sex ratio estimated, by month, for all locations sampled was generally close to 1:1 (Figure 11.2). The exceptions may in part be related to the difficulty encountered assigning sex during the same four-month period because there was a higher percentage of gonads that could not be assigned a sex between October and February (Figure 11.3). This also suggests that a higher proportion of blacklip were reproductive between March and September. While highly variable, viscera weight was at its highest in May and lowest during February and September (Figure 11.4). There is no evidence that the whole weight to shell length or percent recovery to shell length relationships differ between the sexes, as indicated by their similar relationships (Figure 11.6 and Figure 11.5).

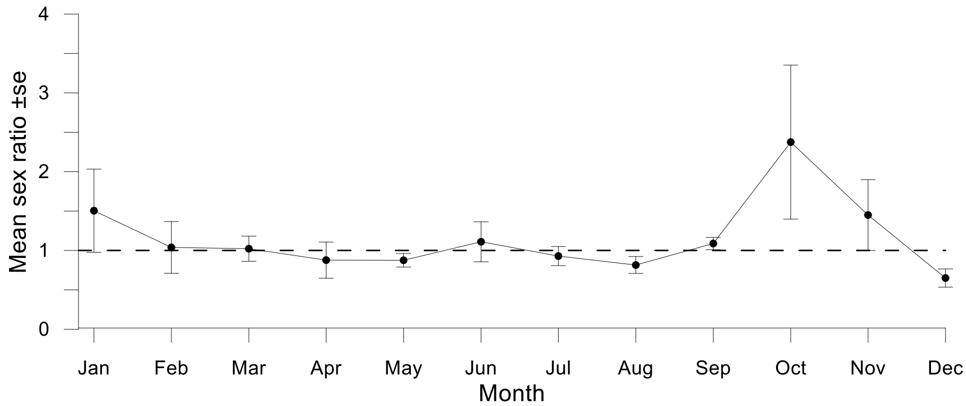

Figure 11.2. Sex ratio (no females/ no males) ±se of blacklip, by month, for all sites sampled in the Western Zone. Dashed line indicates a ratio of 1:1.

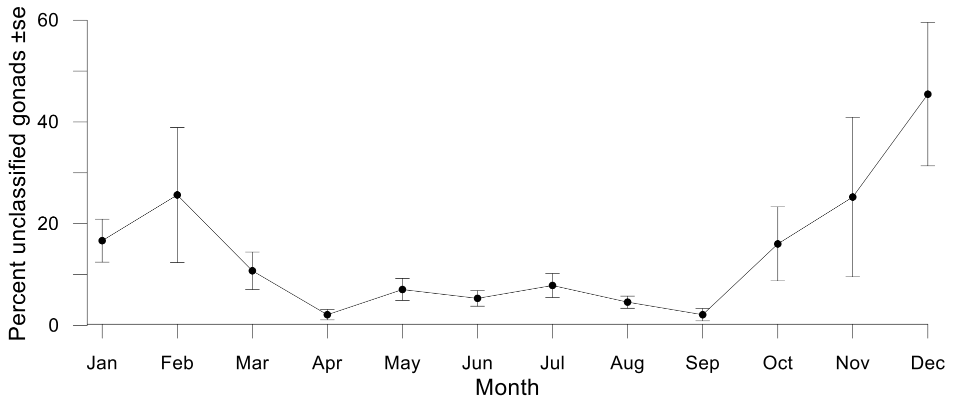

Figure 11.3. Percent of gonads that could not be assigned to a sex ±se, by month, for all sites sampled in the Western Zone.

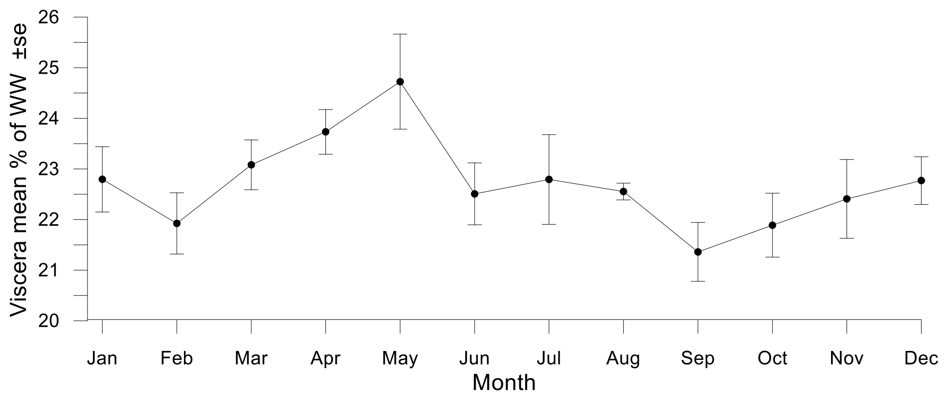

Figure 11.4. Mean viscera as a percentage of whole weight (WW), by month, for all sites sampled in the Western Zone.

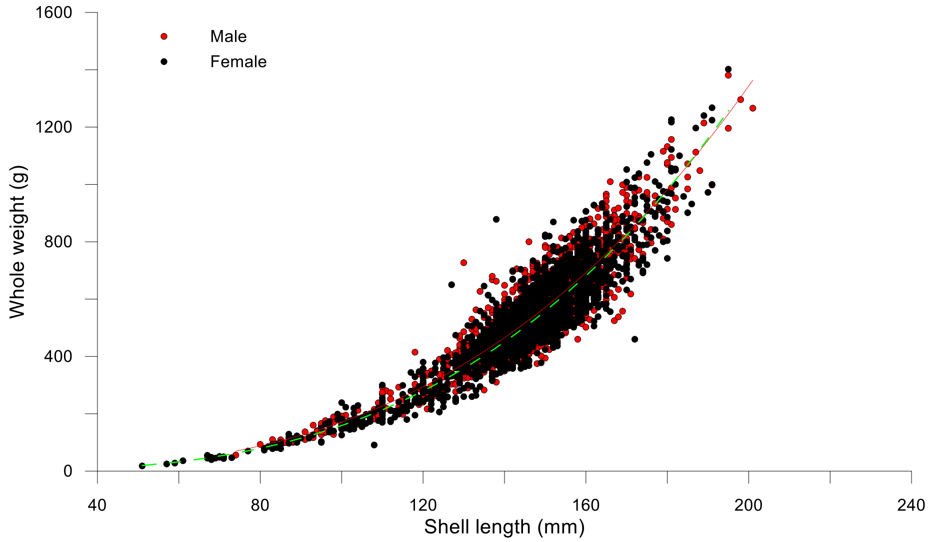

Figure 11.5. Whole weight to shell length relationship for male and female blacklip (see legend). Fitted power curves for male (Y = pow(X,2.973) * 0.00019, n = 1799, R-squared = 0.87) and female (Y = pow(X,3.0956) * 0.00010, n = 1987, R-squared = 0.91) are shown as solid red line and dashed green lines, respectively.

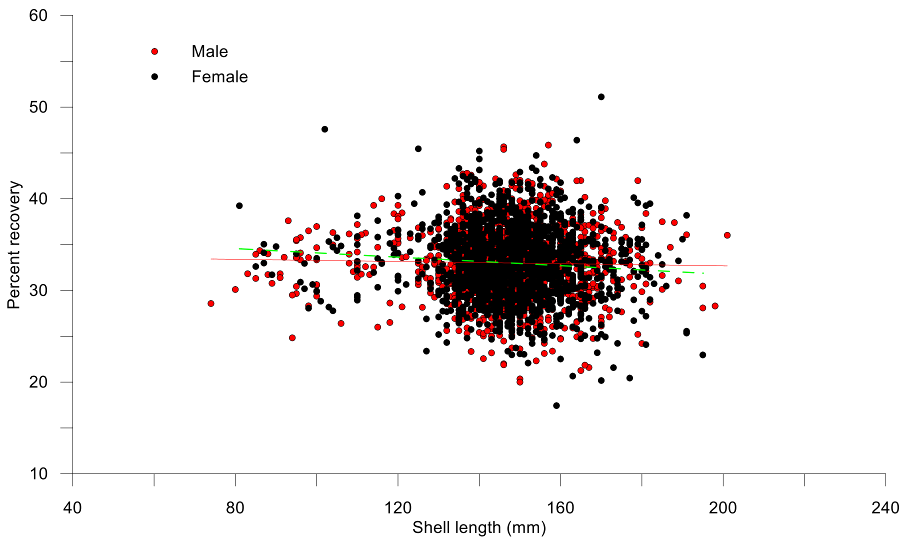

Figure 11.6. Percent meat recovery (24hrs) to shell length relationship for male and female blacklip (see legend). Fitted linear regressions for male (Y = -0.0059X + 33.8679, n = 1679, R-squared = 0.0005) and female (Y = -0.02331X + 36.4338, n = 1668, R-squared = 0.007) are shown as solid red line and dashed green lines, respectively.

FRDC FINAL REPORT CHECKLIST

Project Title:	Maximise yield or minimise risk in the blacklip abalone fishery: using biological data to direct fishing strategies		
Principal Investigators:	Ben Stobart and Stephen Mayfield		
Project Number:	2015/017		
Description:	Through this project we (1) quantified the seasonal variation in the shell size to whole weight and the whole weight to recovered meat weight ratios for blacklip in the Western Zone of the South Australian Abalone Fishery; (2) incorporated the findings into the model previously developed for greenlip and explored the outcomes of fishing scenarios decided on in consultation with Industry; and (3) provided the outputs from the scenarios, number of abalone and expected value, to enable Industry and managers to use the information to maximise the efficiency of their blacklip fisheries. We also requested data from other states (Tasmania, Victoria and New South Wales) to run the model, but determined that there was insufficient data available to run the model. The model outputs demonstrate that the optimal month to harvest blacklip in the WZ of the SAAF is February. It also shows that the difference between January and April is small, and thus the benefits accruable in February can mostly be obtained from focussing the primary harvest period during these four months. Potential benefits from changing fishing to the best time of year are considerable, with the extremes leading to a 13% difference in the number of blacklip harvested or potential for a 15% difference in the TACC. In the case of the WZ of the SAAF, fishing is already mostly occurring at the best time of year, so potential benefits to changing their fishing strategy are considerably less. As there was insufficient data available from other states to run the model the timing and true extent of benefits to changing their fishing strategies could not be explored further. However, it is reasonable to assume that the magnitude of seasonal benefits may be similar to those observed in the WZ and worth investigating further.		
Published Date:	19 November	Year:	2018

ISBN:	978-1-876007-11-9	ISSN:	N/A
Key Words:	Blacklip abalone, *Haliotis rubra*, steady-state model, fishery management, fishing strategy, quota fishery, maximising yield, reducing risk to fishery		

Please use this checklist to self-assess your report before submitting to FRDC. Checklist should accompany the report.

	Is it included (Y/N)	Comments
Foreword (optional)	N	
Acknowledgments	Y	
Abbreviations	Y	
Executive Summary	Y	
– What the report is about	Y	
– Background – why project was undertaken	Y	
– Aims/objectives – what you wanted to achieve at the beginning	Y	
– Methodology – outline how you did the project	Y	A very brief outline of
– Results/key findings – this should outline what you found or key results	Y	
– Implications for relevant stakeholders	Y	
– Recommendations	Y	
Introduction	Y	
Objectives	Y	
Methodology	Y	

Results	Y	
Discussion	Y	
Conclusion	Y	
Implications	Y	
Recommendations	Y	
Further development	Y	
Extension and Adoption	Y	
Project coverage		
Glossary	N	
Project materials developed		
Appendices	Y	Total of five