Fisheries

Central Zone Abalone (*Haliotis laevigata* and *H. rubra*) Fishery

O. Burnell, S. Mayfield, G. Ferguson and J. Carroll

SARDI Publication No. F2007/000611-7
SARDI Research Report Series No. 927

SARDI Aquatic Sciences
PO Box 120 Henley Beach SA 5022

October 2016

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

Central Zone Abalone (*Haliotis laevigata* and *H. rubra*) Fishery

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

O. Burnell, S. Mayfield, G. Ferguson and J. Carroll

SARDI Publication No. F2007/000611-7
SARDI Research Report Series No. 927

October 2016

This publication may be cited as:
Burnell, O., Mayfield, S., Ferguson, G. and Carroll, J. (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. SARDI Research Report Series No. 927. 93pp.

South Australian Research and Development Institute
SARDI Aquatic Sciences
2 Hamra Avenue
West Beach SA 5024

Telephone: (08) 8207 5400
Facsimile: (08) 8207 5406
http://www.pir.sa.gov.au/research

DISCLAIMER
The authors warrant that they have taken all reasonable care in producing this report. This report has been through the SARDI Aquatic Sciences internal review process, and has been formally approved for release by the Research Chief, Aquatic Sciences. Although all reasonable efforts have been made to ensure quality, SARDI Aquatic Sciences does not warrant that the information in this report is free from errors or omissions. SARDI Aquatic Sciences and the authors do not accept any liability for the contents of this report or for any consequences arising from its use or any reliance placed upon it.

© 2016 SARDI
This work is copyright. Apart from any use as permitted under the *Copyright Act* 1968 (Cth), no part may be reproduced by any process without prior written permission from the authors.

Printed in Adelaide: October 2016

SARDI Publication No. F2007/000611-7
SARDI Research Report Series No. 927

Author(s): O. Burnell, S. Mayfield, G. Ferguson and J. Carroll

Reviewer(s): M. Steer, R. McGarvey (SARDI) and Dr B. M. Steer (PIRSA)

Approved by: J. Nicol
Sub-Program Leader – Plant Ecology, Inland Waters & Catchment Ecology

Signed:

Date: 21 October 2016

Distribution: PIRSA Fisheries, Central Zone Abalone Fishery Licence Holders, SAASC Library, SARDI Waite Executive Library, Parliamentary Library, State Library and National Library

Circulation: Public Domain

TABLE OF CONTENTS

ACKNOWLEDGEMENTS ix
EXECUTIVE SUMMARY 1
1. General Introduction 3
1.1. Overview 3
1.2. History and description of the fishery 4
1.2.1. Commercial fishery 4
1.2.2. Recreational fishery 6
1.2.3. Illegal, unregulated and unreported catches 6
1.2.4. Economic importance 6
1.3. Fishery management plans 11
1.3.1. Previous management plans 11
1.3.2. The current Management Plan 11
1.4. Previous Stock Assessments 15
1.5. Fisheries biology of abalone 16
1.5.1. Biology of greenlip in the Central Zone 17
1.5.2. Biology of blacklip in the Central Zone 18
2. Greenlip 19
2.1. Introduction 19
2.2. Methods 19
2.2.1. Fishery-dependent data 19
2.2.2. Fishery independent data 22
2.3. Results 27
2.3.1. Central Zone 27
2.3.2. Spatial assessment units 28
2.3.3. Risk-of-overfishing in SAUs and zonal stock status 42
2.4. Discussion 45
3. Blacklip 51
3.1. Introduction 51
3.2. Methods 51
3.3. Results 54
3.3.1. Central Zone 54
3.3.2. Spatial and temporal distribution of catch and effort 55
3.3.3. Risk-of-overfishing in SAUs and zonal stock status 59
3.4. Discussion 62
4. General Discussion 66
4.1. Information for assessment of the CZ abalone fishery 66
4.2. Current status of greenlip and blacklip in the CZ 69
4.3. Harvest strategy for the CZ 69
4.4. Future research needs 71
5. References 73
Appendix 1. Quality Assurance 81
A.1.1 Research planning 81
A.1.2 Data collection 81
A.1.3 Data entry, validation, storage and security 81
A.1.4 Data and statistical analyses 81
A.1.5 Data interpretation and report writing 82

Appendix 2. Abalone Biology **83**
Appendix 3. CPUE estimates of greenlip in the Central Zone **85**
Appendix 4. Catches by mapcode **88**
Appendix 5. Harvest strategy PI plots **90**
Appendix 6. CPUE estimation rules for BL **92**
Appendix 7. Running mean CPUE estimation rules **93**

LIST OF TABLES

Table 1-1 Stock status terminology for the Status of Key Australian Fish Stocks Reports (reproduced from Flood *et al.* 2014) 4
Table 1-2 Management milestones in the South Australian Central Zone Abalone Fishery.. 8
Table 1-3 TACC (tonnes, meat weight) for the CZ of the SAAF from 1990 to 2015. * indicates reduction in TACC associated with implementation of the marine park sanctuary zones. 8
Table 1-4 Summary of the PIs and the formulae and data constraints underpinning their utilisation in the harvest strategy. 12
Table 1-5 Range of harvest-decision rules following identification of the risk-of-overfishing by the harvest strategy.. 13
Table 2-1 The area (km^2) of each strata from the Tiparra Reef and West Yorke Peninsula (Hardwicke Bay, Port Victoria and Corny Point) SAUs used for the estimates of harvestable biomass, including the percentage of GPS points and the number of leaded-lines surveyed within each stratum...... 26
Table 2-2 Outcome from application of the harvest strategy described in the Management Plan against the greenlip fishery in the CZ. Grey shading identifies the performance indicators and their respective scores. Coloured shading identifies the risk-of-overfishing category (see Figure 1-3). ND indicates no data. 44
Table 3-1 Outcome from application of the harvest strategy described in the Management Plan against the blacklip fishery in the CZ. Grey shading identifies the performance indicators and their respective scores. Coloured shading identifies the risk-of-overfishing category (see Figure 1-3)......... 61

LIST OF FIGURES

Figure 1-1 Fishing Zones and mapcodes of the South Australian Abalone Fishery. ... 9

Figure 1-2 Spatial assessment units (SAUs; coloured blocks), fishing areas (numbered areas) and mapcodes (numbered and lettered areas) of the CZ of the South Australian Abalone Fishery. 10

Figure 1-3 Histograms showing the probability distributions of obtaining total scores across (a) six PIs for SAUs of high importance and (b) three PIs for SAUs of medium importance. Distributions were generated by Monte Carlo simulations (*n* = 5000). Status index probabilities above and below ±10 (high) and ±8 (medium) were accummulated in these upper and lower bin classes, respectively, for each of the six and three PI distributions. 13

Figure 1-4 SAUs of the CZ Abalone Fishery, ranked in order of importance (High (H); Medium (M); and Low (L)) by percent of ten year (2006-2015) total catch for greenlip (green bars) and blacklip (black bars). SAU name abbreviations: Peninsula (Pen.); Island (Is.), Spencer Gulf (SG). Each SAU appears twice – once for greenlip and once for blacklip. 14

Figure 2-1 (A) Greenlip catch (t, meat weight) and individual shell records (number) for each SAU (TR: Tiparra Reef; CE: Cape Elizabeth; WYP: West Yorke Peninsula; SYP: South Yorke Peninsula; EYP: East Yorke Peninsula; F: Fleurieu; SKI: South Kangaroo Island; WKI: West Kangaroo Island); and (B) days fished with greenlip catch >5kg (number) and daily shell records (number) for each SAU from 2011-15. Solid lines are linear fit for each fishing year. Dashed black line indicates 1:1 return ratio of shell measurements for days fished. 22

Figure 2-2 Total catch of greenlip for the CZ (t, meat weight; dark green) from 1968-2015. From 1979 to 2015, catch from Tiparra Reef (light green bars) is superimposed on total catch; these data were unavailable from 1968 to 1978. CPUE (kg.hr^{-1}, ±SE) is shown by red line. 27

Figure 2-3 Bubble plot showing the spatial distribution of the greenlip catch (% of total catch, green symbols) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ from 1979 to 2015. 29

Figure 2-4 Total catch and CPUE of greenlip for SAUs aggregated by importance. (A) high, (B) medium and (C) low importance (t, meat weight;) from 1979-2015. CPUE (kg.hr^{-1}¸±SE) is shown by red lines. Stacked bars of catch are colour coded to reflect SAUs – Figure 1-2. Gaps in the time series of CPUE data indicate insufficient data (<10 fisher days). 31

Figure 2-5 Tiparra Reef (high importance). Catch (t, meat weight; green bars), CPUE (kg.hr^{-1}, ±SE, red line), the proportion of large greenlip (>155 mm, blue line) and the catch-cap (t, meat weight, black symbols) from 1979 to 2015. Gaps in the time series of the proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). 34

Figure 2-6 (A) Tiparra Reef (high importance). Fishery-independent survey estimates of all greenlip (*i.e.* total number.m^{-2}; green bars), and those greenlip ≥135 mm SL (black bars) and <135 mm SL (red bars) from 1968 to 2015 (timed-swims) and 2010 to 2015 (leaded-lines). Gaps in the time series indicate no surveys done. * indicates estimates of timed-swim densities derived from leaded-line densities. Blue line indicates the ratio of legal (≥135mm) to sub-legal (<135mm) greenlip. Panel on LHS is for timed-swims. Central panel is for all consistent leaded-lines from 2010 to 2015 (n=31). Panel on RHS is for all consistent leaded-lines from 2013 and 2015, that were informed by GPS logger data (n=55). After 2001 the number of timed-swims undertaken increased, and greater consistency was introduced to the survey locations (indicated by the dashed line). (B) length frequency counts binned by 10mm increments on the 31 consistent leaded-lines from Tiparra Reef between 2010 and 2015. Dashed line indicates the legal length of greenlip in the CZ (≥135mm). 35

Figure 2-7 West Yorke Peninsula (high importance). Catch (t, meat weight, green bars), CPUE (kg.hr^{-1}, ± SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). 38

Figure 2-8 West Yorke Peninsula (high importance). Fishery-independent survey estimates of all greenlip (*i.e.* total number.m^{-2}; green bars), and those greenlip ≥135 mm SL (black bars) and <135 mm SL (red bars) from 2006 to 2015. Panels on LHS are for leaded-lines that have been consistently surveyed (Hardwicke Bay, n=6; Port Victoria, n=11; Corny Point, n=17). Panels on RHS are all leaded lines from 2015, that were informed by GPS logger data (Hardwicke Bay, n=26; Port Victoria, n=17; Corny Point, n=17). Gaps in the time series indicate no surveys undertaken. 39

Figure 2-9 Medium importance SAUs. Catch (t, meat weight, green bars), CPUE (kg.hr^{-1}, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). 40

Figure 2-10 Low importance SAUs. Catch (t, meat weight, green bars), CPUE (kg.hr^{-1}, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). 43

Figure 3-1 (A) Blacklip catch (t, meat weight) and individual shell records (number) for each SAU (TR: Tiparra Reef; CE: Cape Elizabeth; WYP: West Yorke Peninsula; SYP: South Yorke Peninsula; EYP: East Yorke Peninsula; F: Fleurieu; SKI: South Kangaroo Island; WKI: West Kangaroo Island); and (B) Days fished with blacklip catch >5kg (number) and daily shell records (number) for each SAU from 2011-15. Solid lines are linear fit for each fishing year. Dashed black line indicates 1:1 return ratio of shell measurements for days fished. 53

Figure 3-2 Total catch of blacklip for the CZ (t, meat weight, black bars) from 1968-2015. From 1979 to 2015, catch for Kangaroo Island (grey bars) is superimposed on total catch. $CPUE_Y$ (kg.hr^{-1}, red line) and $CPUE_{3Y}$ (kg.hr^{-1}, green line) are shown by red and green lines, respectively. 54

Figure 3-3 Bubble plot showing the spatial distribution of the blacklip catch (% of total catch) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ from 1979 to 2015. 56

Figure 3-4 For the fishing grounds off Kangaroo Island from 1979 to 2015: (A) Annual catches of blacklip and greenlip showing total annual effort (red circles) and effort when only greenlip were caught (orange diamonds); and (B) average daily proportion of blacklip in the total catch from KI and the West Kangaroo Island (WKI) and South Kangaroo Island (SKI) SAUs............................ 56

Figure 3-5 For the fishing grounds off Kangaroo Island from 1979 to 2015: (A) time at three depth ranges (blue bars) and the percentage of total time at 10-20 m (red circles); (B) total annual catch of blacklip (black bars; t meat weight) with catches when blacklip comprised at least 85% of the daily catch superimposed (grey bars). Red line shows the percentage of the total blacklip catch taken for days when blacklip comprised at least 85% of the daily catch; and (C) time at three depth ranges (greyscale bars) and percentage of time at 10-20 m depth (red circles) for those days when the blacklip catch was at least 85% of daily catch... 57

Figure 3-6 West Kangaroo Island (medium importance). Catch (t, meat weight, black bars), $CPUE_Y$ ($kg.hr^{-1}$, ±SE, red line), $CPUE_{3Y}$ ($kg.hr^{-1}$, green line), the proportion of large blacklip (>155 mm, blue line) and the percentage of the total blacklip catch (light blue line) each year from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). 59

Figure 3-7 Catch (t, meat weight, black bars), $CPUE_Y$ ($kg.hr^{-1}$, ±SE, red lines), $CPUE_{3Y}$ ($kg.hr^{-1}$, green lines) and the proportion of large blacklip (>155 mm, blue line) in each of the SAUs of low importance in the CZ blacklip fishery from 1979 to 2015. Gaps in the time series of the CPUE and proportion large indicate insufficient data (<10 fisher days or <100 individuals, respectively). Note different scales on the Y-axes for catch and CPUE........................ 60

ACKNOWLEDGEMENTS

Funds for this research were provided by Primary Industries and Regions South Australia (PIRSA), obtained through licence fees. SARDI Aquatic Sciences provided substantial in-kind support. The Central Zone Abalone Licence holders, fishers and Mr Michael Tokley provided length measurements of abalone in the commercial catch. We also thank the SA Abalone Fishery (Central Zone) licence holders and divers who have contributed to our understanding of processes that can affect change in the patterns of data presented in this report. Adam Linnett provided the photograph for the cover page, with permission. We are grateful to Toby Fox, Jay Dent, Andrew Hogg, Matt Lloyd and Alex Dobrovolskis, amongst others, for essential field support. Damian Matthews created Figures 1-1 and 1-2 and Jay Dent created figures A5-1 and A5-2. Dr Ben Stobart provided assistance in the analysis, interpretation of data and the finalisation of the document. PIRSA Fisheries and Aquaculture provided information on estimates of illegal catch. This report was formally reviewed by Dr Belinda McGrath-Steer (PIRSA Fisheries and Aquaculture), Drs Michael Steer and Richard McGarvey (SARDI), and Professor Gavin Begg, Research Chief, SARDI Aquatic Sciences. It was formally approved for release by Dr Jason Nicol, Acting Science Leader – Inland Waters and Catchment Ecology – SARDI Aquatic Sciences.

EXECUTIVE SUMMARY

This report provides an assessment of stock status for *Haliotis laevigata* and *H. rubra* (hereafter referred to as greenlip and blacklip, respectively) in the Central Zone (CZ) in 2015.

This assessment was informed by both the harvest strategy in the Abalone Fishery Management Plan and the traditional weight-of-evidence assessment using the National Fishery Status Reporting Framework (NFSRF; Flood *et al.* 2014). Previous comparison between these has identified the need for a review of the harvest strategy, which is currently underway.

Data spanning four spatial scales were integrated in this assessment: CZ, spatial assessment units (SAUs), SAUs aggregated by importance and mapcodes (MCs).

GREENLIP

Greenlip comprises 88% of the combined abalone total allowable commercial catch (TACC; 52.4 t *i.e.* greenlip and blacklip) in the CZ.

Application of the harvest strategy resulted in the CZ greenlip fishery being categorised as 'under-fished'. Consistent with the harvest strategy, there was some evidence of stock improvement and/or stability: long-term (25 years) stable catch consistent with the TACC; relatively high catch rates in most SAUs; the survey estimate of harvestable biomass and catch per unit effort (CPUE) increasing between 2013 and 2015 in the Tiparra Reef SAU; the survey harvestable biomass estimate yielding a low exploitation rate in Hardwicke Bay; and the establishment of new fishing grounds.

In contrast, other evidence suggests greenlip stocks are in a weak position. For Tiparra Reef, that historically supported over 90% of the TACC, this evidence includes the (1) low and declining sub-legal-sized and pre-recruit greenlip density; (2) high ratio of legal-sized to sub-legal-sized greenlip; (3) relatively low, legal-sized greenlip density; and (4) high exploitation rate. These have occurred despite the introduction of a 'catch-cap' from 2005 to constrain catches and reduce fishing pressure.

The evidence for the West Yorke Peninsula SAU is the (1) rapid decline (>25%) in CPUE in the Corny Point fishing ground; (2) high exploitation rate; and (3) high ratio of legal-sized to sub-legal-sized greenlip in the Corny Point and Port Victoria fishing grounds.

Several medium and low-importance SAUs – West Kangaroo Island, South Kangaroo Island, East Yorke Peninsula and Cape Elizabeth – show declining trends in catch and/or CPUE. In addition to these contrasting lines of evidence for the CZ greenlip fishery, there are also insufficient data with which to distinguish between the two primary hypotheses explaining the ongoing spatial re-distribution of catch in this fishery (i.e. a sustainable rotational fishing strategy versus a sequential depletion of the stocks).

Consequently, the CZ greenlip fishery remains classified as '**transitional depleting**'.

BLACKLIP

Blacklip comprises 12% of the combined TACC in the CZ.

Application of the harvest strategy resulted in the CZ blacklip fishery being categorised as 'under-fished'.

There is some evidence to suggest blacklip stocks may be improving. This evidence includes: (1) the increase in catch rate between 2014 and 2015 for the CZ and the West Kangaroo Island SAU; and (2) a reduction in the proportion of large blacklip harvested that, in conjunction with this CPUE increase, may reflect a potential small recruitment to the fishable stock.

In contrast, (1) the small recent and current catches harvested at relatively low catch rates; (2) little evidence of stock recovery despite substantial (40%) reductions in the TACC; (3) low (CZ, West Kangaroo Island SAU) and/or declining (South Kangaroo Island SAU) catch rates; (4) apparent spatial contraction of the fishery, principally into two MCs in the West Kangaroo Island SAU; (5) record low catches from the South Kangaroo Island SAU, an area that historically supported catches over 5 $t.y^{-1}$; and (6) increases in the proportion of fishing effort for blacklip in waters of 10-20 m depth suggests blacklip stocks remain in a weak position.

Consequently, the CZ blacklip fishery remains classified as '**transitional-depleting**' under the NFSRF.

Key CZ statistics from 2013 to 2014 are summarised in the Table below:

Key statistics for the CZ fishery from 2013 including number of licences (No. licences); total allowable commercial catch (TACC), total commercial catch (TCC), catch per unit effort (CPUE), stock status from the harvest strategy in the management plan and from the national fishery status reporting framework (NFSRF). tmw = tonnes meat weight, $kg.hr^{-1}$ = kilograms per hour.

Zone		Greenlip					Blacklip				
Season	No. licences	TACC (tmw)	TCC (tmw)	CPUE ($kg.hr^{-1}$)	Stock Status (Harvest Strategy)	Stock Status (NFSRF)	TACC (tmw)	TCC (tmw)	CPUE ($kg.hr^{-1}$)	Stock Status (Harvest Strategy)	Stock Status (NFSRF)
2013	6	47.7	47.9	22.7	Under fished	Transitional depleting	8.1	8.4	19.2	Sustainably fished	Transitional depleting
2014	6	47.7	47.5	23.4	Under fished	Transitional depleting	8.1	7.5	19.0	Sustainably fished	Transitional depleting
2015	6	46.0	45.7	22.9	Under fished	Transitional depleting	6.4	6.4	21.1	Under fished	Transitional depleting

1. GENERAL INTRODUCTION

1.1. Overview

This fishery assessment report for the Central Zone (CZ) of the South Australian Abalone Fishery (SAAF) updates recent fishery assessment (Mayfield *et al*. 2010, 2014a; Chick and Mayfield 2012;) and stock status reports (Mayfield and Carlson 2005a, 2009; Mayfield and Ferguson 2015). The report covers the period 1 January 1968 to 31 December 2015 and is part of the ongoing assessment program for the fishery undertaken by SARDI Aquatic Sciences. Similarly to recent CZ reports, data from Cowell, historically a separately managed area within the CZ (see Mayfield *et al*. 2008b,c), are explicitly excluded. The aims of the report are to (1) determine the risk-of-overfishing in spatial assessment units (SAUs) of 'high' and 'medium' importance; (2) determine and assess the current status of the greenlip abalone (*Haliotis laevigata*; hereafter referred to as greenlip) and blacklip abalone (*H. rubra*; hereafter referred to as blacklip) fisheries in the CZ using the spatially-explicit, quantitative assessment of stock status specified in the Fishery Management Plan for the commercial Abalone Fishery (PIRSA 2012); (3) to compare the stock status classification from the harvest strategy to the weight-of-evidence analysis using the National Fishery Status Reporting Framework (NFSRF – Table 1-1; Flood *et al.* 2012; 2014) because the new harvest strategy has several limitations including over-optimistic stock status classifications (*e.g.* Mayfield *et al.* 2014a; Stobart *et al.* 2014a, 2014b, 2015); (4) evaluate the spatial and temporal changes in the fishing patterns of commercial divers in the CZ, the data exclusion rules for estimating catch rates, and the potential influence of both of these on estimates of catch per unit effort (CPUE) for both species; (5) identify uncertainty associated with the assessment; (6) evaluate the effectiveness of the harvest strategy for the fishery; and (7) identify future research needs.

The report is divided into four sections, including this general introduction which (1) outlines the aims and structure of the report, (2) describes the CZ abalone fishery including the level of recreational and illegal harvest, (3) provides a summary of previous and current management arrangements, including a description of the harvest strategy detailed in the Management Plan, (4) provides a synopsis of previous stock assessment reports on the fishery, and (5) summarises biological knowledge for abalone in the CZ. Sections 2 and 3 provide an assessment of the fishery-dependent and fishery-independent data for greenlip and blacklip, respectively. Where appropriate, this includes spatial and temporal analyses of catch, effort, CPUE, the proportion of large abalone in the commercial catch and fishery-independent survey data. These sections also include application of the harvest strategy that determines the risk that stocks within SAUs of 'high' and 'medium' importance are over-fished and the stock status of the greenlip and blacklip fisheries in the CZ, as outlined in the Management Plan. Section 4, the General Discussion, (1) identifies areas of uncertainty in current knowledge and assessment of the fishery; (2) compares assessments of the greenlip and blacklip fisheries in the CZ; (3) provides a formal evaluation of the harvest strategy described in the Management Plan; and (4) outlines future research needs for the fishery.

Table 1-1 Stock status terminology for the Status of Key Australian Fish Stocks Reports (reproduced from Flood *et al.* 2014)

	Stock status	Description	Potential implications for management of the stock
	Sustainable	Stock for which biomass (or biomass proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e. not recruitment overfished) and for which fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished	Appropriate management is in place
↑	Transitional–recovering	Recovering stock—biomass is recruitment overfished, but management measures are in place to promote stock recovery, and recovery is occurring	Appropriate management is in place, and the stock biomass is recovering
↓	Transitional–depleting	Deteriorating stock—biomass is not yet recruitment overfished, but fishing pressure is too high and moving the stock in the direction of becoming recruitment overfished	Management is needed to reduce fishing pressure and ensure that the biomass does not deplete to an overfished state
	Overfished	Spawning stock biomass has been reduced through catch, so that average recruitment levels are significantly reduced (i.e. recruitment overfished). Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect
	Environmentally limited	Spawning stock biomass has been reduced to the point where average recruitment levels are significantly reduced, primarily as a result of substantial environmental changes/impacts, or disease outbreaks (i.e. the stock is not recruitment overfished). Fisheries management has responded appropriately to the environmental change in productivity	Appropriate management is in place
	Undefined	Not enough information exists to determine stock status	Data required to assess stock status are needed

1.2. History and description of the fishery

1.2.1. Commercial fishery

Management arrangements have evolved since the inception of the SAAF in 1964. A review of the management history is provided by Shepherd and Rodda (2001) and Mayfield *et al.* (2011a) and major management milestones are listed in Table 1-2. Summaries of the fishery can be found in Prince and Shepherd (1992), Zacharin (1997), Keesing and Baker (1998), Nobes *et al.* (2004), Mayfield *et al.* (2011a, 2012) and PIRSA (2012). The SAAF expanded rapidly in the late 1960s, exceeding 100 entrants by 1970. Licences were made non-transferable in 1971 to reduce the number of operators in the fishery. By 1976 the number of operators had declined to 30 and an additional five licences were issued. There are currently 34 licence holders in the fishery as one licence was voluntarily surrendered from the Western Zone (WZ) as a result of the implementation of the marine park sanctuary zones.

In 1971, the SAAF was divided into three zones (Western, Central and Southern; Figure 1-1). The CZ of the SAAF includes all coastal waters of South Australia between 136°30'E and 139°E (Figure 1-2). The fishing season extends from 1 January to 31 December each year.

Greenlip and blacklip comprise 88% and 12% of the total allowable commercial catch (TACC) in the CZ, respectively (Table 1-3). The greenlip TACC remained stable at 47.7 t meat weight between 1994 and 2014. In contrast, the TACC for blacklip was reduced three times and by over 50% since 2004. Initial reductions were from 14.1 t (1994 - 2004) to 9.9 t (2005) and 9.9 t to 8.1 t (2006). In 2015, the blacklip (from 8.1 t to 6.4 t) and greenlip (from 47.7 t to 46.0 t) TACCs were decreased as a result of the implementation of the marine park sanctuary zones.

Since 1997, the fishery has operated under the control of a formal Management Plan (Zacharin 1997; Nobes *et al.* 2004; PIRSA 2012) and is managed through a regime of input (*e.g.* limited entry) and output (*e.g.* minimum legal length (MLL), TACC) controls. The historical and current management arrangements in the CZ are summarised in Table 1-2 and include a MLL of 130 mm shell length (SL) that was introduced for both species in 1971 and the introduction of quotas from 1990. From 2001, fishers voluntarily harvested greenlip and blacklip at 135 mm SL. For greenlip, this was formalised into licence conditions from 1 January 2013.

A research logbook is completed for each fishing day and submitted to SARDI Aquatic Sciences at the end of each month. These commercial catch and effort data for this fishery have been collected since 1968. The logbook provides information on the date of fishing, fishing area, amount of time spent fishing, whether or not an underwater vehicle was used, diving depth and total catch landed. Few changes have been made to the data collection system. However, in 1978, sub zones and fishing blocks were replaced by spatially smaller fishing areas (map numbers) and mapcodes (map letters; see Figure 1-1 and Figure 1-2). Supplementary voluntary data fields (*e.g.* global positioning system (GPS) position, number of abalone harvested) were added to the logbook in 2002. The logbook and commercial length structure data supplied by divers and licence holders are used by SARDI Aquatic Sciences to analyse the levels of catch, effort, CPUE and proportion of large abalone in the fishery. In addition, fishers have periodically used GPS and depth loggers to record more detailed information on fishing location and duration

(Mundy 2012). Since 1 January 2013, use of these loggers has been mandated through licence conditions. The fishery-dependent data are supplemented by fishery-independent surveys of abalone density and population structure from high importance SAUs. In 2015, the Tiparra Reef and West Yorke Peninsula SAUs were surveyed. In combination with fishery-dependent data, analyses on these fishery-independent survey data underpin assessments of the fishery.

1.2.2. Recreational fishery

The total recreational catch of abalone in South Australia in 2013/14 was estimated at 5,149 abalone (Giri and Hall 2015). This was similar to the estimate from Jones (2009) of 5,147 abalone for the 2007/08 survey and about 30% of the estimated harvest of 17,780 abalone for the period May 2000 to April 2001 (Henry and Lyle 2003). Based on the zone-specific estimates of Jones (2009), the total recreational harvests of greenlip and blacklip in the CZ in 2013/14 were estimated to be approximately 1,648 abalone (32% of state-wide catch), the majority of which are likely to be greenlip (Giri and Hall 2015).

1.2.3. Illegal, unregulated and unreported catches

Illegal, unregulated and unreported (IUU) catch is difficult to estimate. PIRSA rely on field observations and intelligence reports that document quantities of abalone when estimating the IUU catch. During 2015, PIRSA received 45 information reports relevant to the CZ. Eleven reports contained estimates of illegally harvested abalone which totalled 347.4 kg (meat weight). Applying the mean weight per information report (31.58 kg/report) to the 45 provides an estimated illegal harvest equivalent to 1.42 t abalone or 2.5% of the TACC. This estimate excludes IUU take where a caution, expiation or brief has been compiled. It should also be noted that PIRSA would not have been advised of all illegally harvested abalone and as such the actual extent of IUU is expected to be higher.

1.2.4. Economic importance

Econsearch provides an annual assessment of the economic performance of the SAAF as required by the Minister for Agriculture, Food and Fisheries to meet the obligations of Section 7 of the *Fisheries Management Act 2007* (Paterson *et al.* 2013; Rippin *et al.* 2014; Fargher *et al.* 2015). Catch value (gross value of production - GVP) in the fishery increased rapidly between 1997/98 and 2000/01, but followed a declining trend in subsequent years associated with a decline in the price of abalone that was linked to an increase in the value of the Australian dollar (Rippin *et al.* 2014). Until 2013/14, GVP closely followed changes in average price because total catch had remained relatively stable. However, in 2013/14, the total catch of abalone in the SAAF dropped by 25% (principally through the Southern Zone TACC not being harvested, see Mayfield *et al.* 2015, as well as seasonal changes in the timing of harvest from the Western Zone) so GVP was impacted by both changing levels of catch and changes to average price. In 2013/14 the SAAF catch was valued at AU$22.1 million dollars, directly and indirectly generating 247 full time jobs, both lower than the previous assessment in 2012/13.

Paid labour, which accounts for the largest share of total cash costs to the SAAF, decreased by 16% between 2012/13 and 2013/14 (Fargher *et al.* 2015). Other major costs include interest, management costs and fuel. With the exception of interest repayments and insurance, most fixed costs were lower in 2013/14. Profitability of the fishery fell in 2013/14, for example, profit at full equity in 2013/14 was 36% lower than the previous year. The average cost of management per licence holder has remained relatively stable since 2004/05 and in 2013/14 was AU$73,292. However, the combination of a small increase in management costs and a decrease in value of the catch have resulted in licence fees being 11.3% of GVP in 2013/14.

Table 1-2 Management milestones in the South Australian Central Zone Abalone Fishery.

Date	Milestone
1964	Fishery started
1971	>100 licences; licences made non-transferable
	Fishery divided into three Zones (Western, Central and Southern)
	MLL set at 130 mm SL for all species
1976	Number of licences in CZ capped at six
1978	Change in spatial reporting of catch and effort data
1980	Licences became transferable
1990	Quota introduced to the CZ.
	TACCs set at 47.4 t and 13.7 t (meat weight) for greenlip and blacklip
1993	Abolition of owner-operator regulation
1994	CZ greenlip TACC increased from 47.4 t to 47.7 t (meat weight)
	CZ blacklip TACC increased from 13.7 t to 14.1 t (meat weight)
1997	Management Plan implemented (Zacharin 1997)
2002	Voluntarily increase in harvest length to 135 mm SL in the CZ
2004	Management Plan revised (Nobes *et al*. 2004)
	Fishery assessed against the Principles of Ecologically Sustainable Development
2005	CZ greenlip catch capped at 30 t (meat weight) in FA 21 (Tiparra Reef and Cape Elizabeth)
	CZ blacklip TACC reduced from 14.1 to 9.9 t (meat weight)
2006	CZ blacklip TACC reduced from 9.9 to 8.1 t (meat weight)
2009	Catch-cap increased to 33.3 t (meat weight) in FA 21 (Tiparra Reef and Cape Elizabeth)
2010	Catch capped at 1.6 t (meat weight) in Port Victoria (mapcode 22A)
	Catch capped at 1 t (meat weight) in Hardwicke Bay (mapcode 24A)
2011	Catch-caps removed from Port Victoria and Hardwicke Bay
2012	Management Plan revised (PIRSA 2012) – new harvest strategy
2013	Catch-cap in FA 21 amended to 18 t (meat weight) from the Tiparra Reef SAU
	Tiparra Reef closed in January, February and December
	Use of GPS and depth loggers mandated in CZ
	MLL for greenlip legislated at 135 mm SL in CZ
2015	CZ greenlip TACC reduced from 47.7 to 46.0 t (meat weight) and CZ blacklip TACC reduced from 8.1 to 6.4 t following implementation of the marine park sanctuary zones

Table 1-3 TACC (tonnes, meat weight) for the CZ of the SAAF from 1990 to 2015. * indicates reduction in TACC associated with implementation of the marine park sanctuary zones.

Fishing season	Greenlip abalone	Blacklip abalone
1990–1993	47.4	13.7
1994–2004	47.7	14.1
2005	47.7	9.9
2006–2014	47.7	8.1
2015	46.0*	6.4*

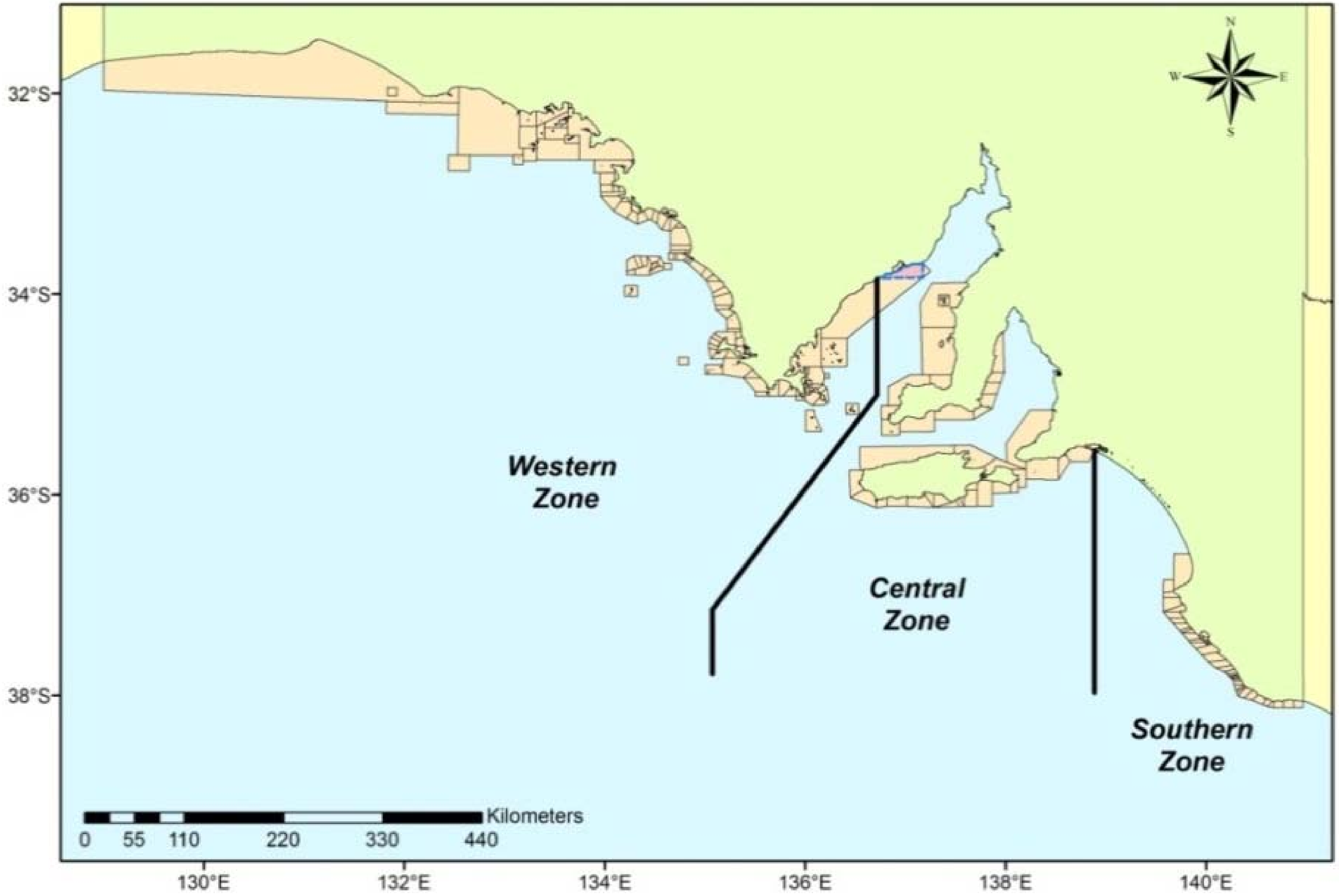

Figure 1-1 Fishing Zones and mapcodes of the South Australian Abalone Fishery.

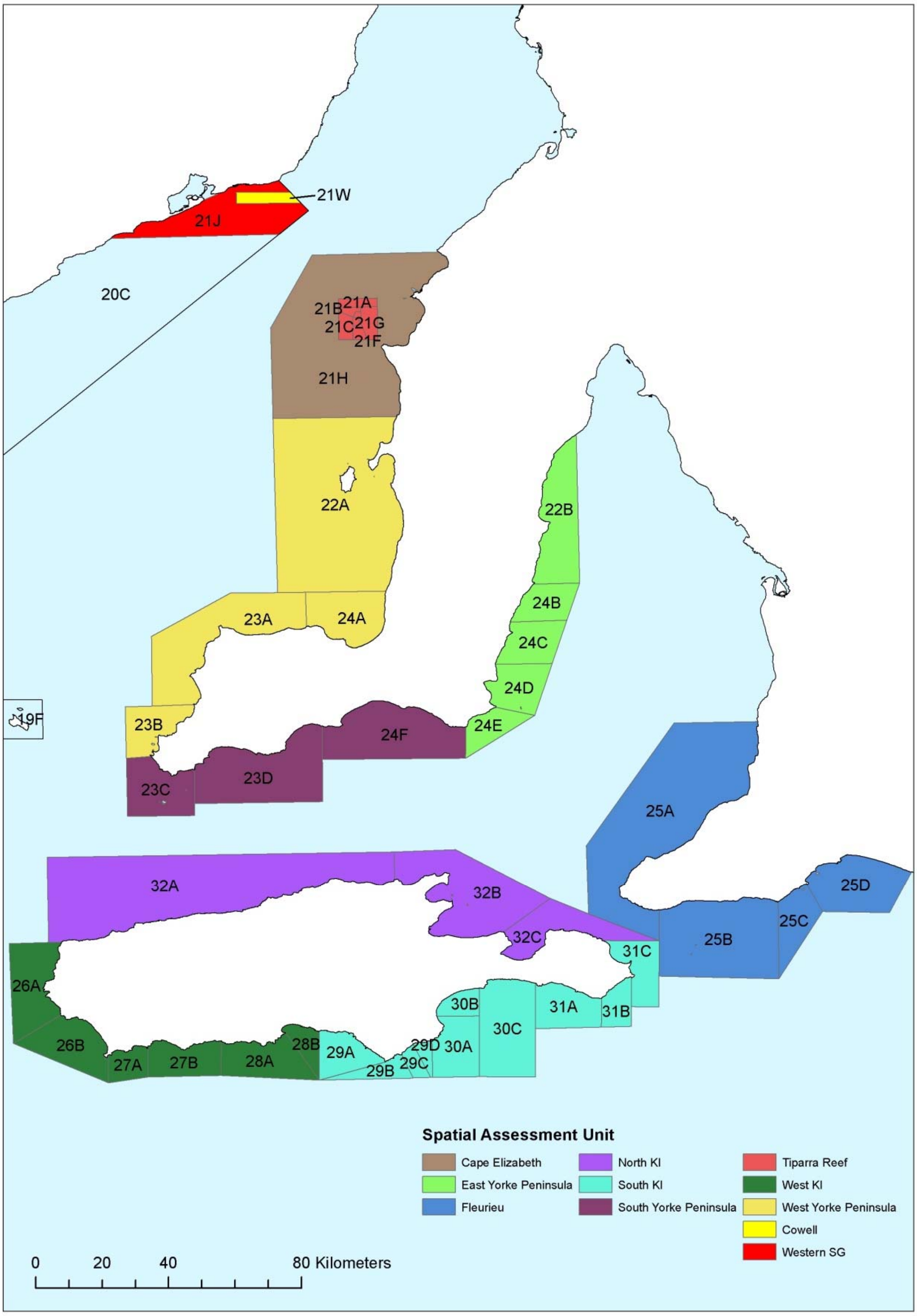

Figure 1-2 Spatial assessment units (SAUs; coloured blocks), fishing areas (numbered areas) and mapcodes (numbered and lettered areas) of the CZ of the South Australian Abalone Fishery.

1.3. Fishery management plans

1.3.1. Previous management plans

The first Management Plan for the South Australian Abalone Fishery (Zacharin 1997) identified biological, economic, environmental and social management objectives, associated strategies, performance indicators (PIs) and reference points to manage the fishery. The key PIs were (1) CPUE ($kg.hr^{-1}$), (2) size composition of the commercial catch, and (3) abundance of legal-sized and pre-recruit-sized abalone observed on fishery-independent surveys ($number.m^{-2}$). Reference points were percentage changes in these measures between years and across five consecutive years which, when exceeded, triggered a series of management actions including Ministerial notification.

Zacharin (1997) was superseded in 2004 by the second Management Plan for the fishery (Nobes *et al*. 2004). Nobes *et al.* (2004) had similar (1) management objectives and associated strategies for the fishery and (2) management actions following triggering of PIs, but used a broader suite of PIs – spanning a wide range of fishery-dependent and fishery-independent data – applied to individual fishing areas within a statistical framework. This approach had two key advantages (Chick *et al*. 2009) – a broad suite of PIs that captured the complex population structures of abalone (Saunders and Mayfield 2008; Mayfield and Saunders 2008; Miller *et al*. 2009; Saunders *et al*. 2009a,b). A key disadvantage was the need to continually assess the fishery against a large number of PIs that, when triggered, seldom provided consistent inferences about stock status.

1.3.2. The current Management Plan

The third, and current, Management Plan (PIRSA 2012) includes a formal, species-specific, spatially-explicit harvest strategy for the SAAF that has two key components. These components are (1) determining the risk that each SAU is over-fished using a suite of PIs (Table 1-4) and indicating the overall status (depleted, over-fished, sustainably-fished, under-fished or lightly-fished) of each species in each zone; and (2) a decision-making process which integrates information from multiple sources (*e.g.* divers, licence holders, fishery managers, compliance officers, researchers) to make management decisions for each SAU. These management decisions are constrained by harvest-decision rules (Table 1-5) that, in turn, are determined by the risk-of-overfishing in each SAU (Figure 1-3). SAUs are the spatial scale at which monitoring and assessments are undertaken and are intended to reflect distinct abalone populations (termed metapopulations; Morgan and Shepherd 2006; Mayfield and Saunders 2008; Miller *et al*. 2009, 2014). There are 11 SAUs identified for the CZ, that are the same for greenlip and blacklip (Figure 1-2), categorised into importance by catch (Figure 1-4).

Table 1-4 Summary of the PIs and the formulae and data constraints underpinning their utilisation in the harvest strategy.

Performance indicator	Description	Formulae	Data constraints / comments
Catch	Total catch, expressed as a percentage of the TACC	$\text{Catch} = \frac{\sum \text{Species Catch (t)}}{\text{TACC}}.$	Note: the performance indicator for catch at Tiparra Reef differs from that for remaining SAUs. It is the proportion of catch from FA 21 harvested from Tiparra Reef (MCs 21A-G)
%Large	Proportion of large abalone in the commercial catch	$\text{PropLarge} = \frac{\text{N Large}}{\text{Total N}},$	All measurements >5 mm SL below the MLL excluded; Minimum sample size: 100 measurements of shell length Blacklip and greenlip >155 mm SL defined as large
CPUE	Commercial catch-per-unit effort (kg.hr^{-1})	$CPUE_{Wt} = \frac{\sum_{i=1}^{n} w_i \frac{C_{PSi}}{E_i}}{\sum_{i=1}^{n} w_i},$	All records where: total catch was >300 kg; CPUE (total catch/total effort) was >50kg/hr; fishing effort was >8hr; fishing effort was <3hr; the reported catch of both species was zero; or the species for which CPUE was being estimated was <30% of the total catch were excluded. Minimum sample size: 10 records
Density$_{legal}$	Density of legal-sized abalone on surveys	$\text{Density}_{\text{Legal}} = \frac{\sum \text{Legal counted}}{\text{Total area surveyed}}$	>90% of survey completed Greenlip and blacklip ≥135 mm SL defined as legal-sized
Density$_{pre\text{-}recruit}$	Density of pre-recruit (*i.e.* those that will exceed MLL within ~2 yr) abalone on surveys	$\text{Density}_{\text{Pre-recruit}} = \frac{\sum \text{Pre-recruit counted}}{\text{Total area surveyed}}$	>90% of survey completed Greenlip and blacklip 90 <135 mm SL defined as pre-recruits
Total mortality	Measure of the difference between the MLL and the mean length of legal-sized abalone. For consistency with other PIs, it is expressed as 1/total mortality	$Z = K\frac{(L_{\infty} - \bar{L})}{(\bar{L} - \text{MLL})},$	Minimum sample size: 100 measurements of shell length

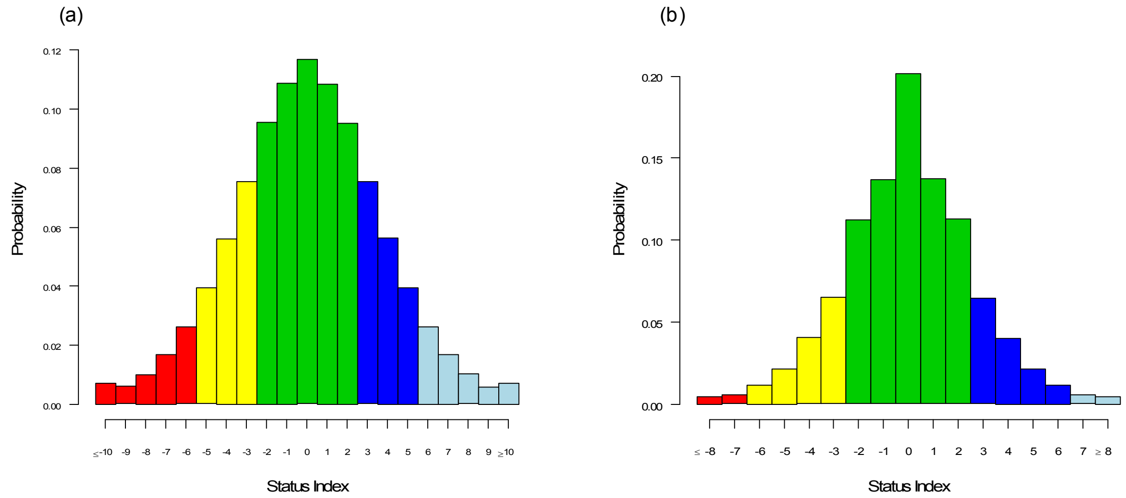

Figure 1-3 Histograms showing the probability distributions of obtaining total scores across (a) six PIs for SAUs of high importance and (b) three PIs for SAUs of medium importance. Distributions were generated by Monte Carlo simulations (n = 5000). Status index probabilities above and below ±10 (high) and ±8 (medium) were accummulated in these upper and lower bin classes, respectively, for each of the six and three PI distributions.

Table 1-5 Range of harvest-decision rules following identification of the risk-of-overfishing by the harvest strategy.

Risk-of-overfishing category	**Harvest-decision rules (% change in catch contribution)**
RED	At least 30% reduction
YELLOW	10-30% reduction
GREEN	10% reduction to 10% increase
BLUE	Up to 30% increase
LIGHT BLUE	Up to 50% increase

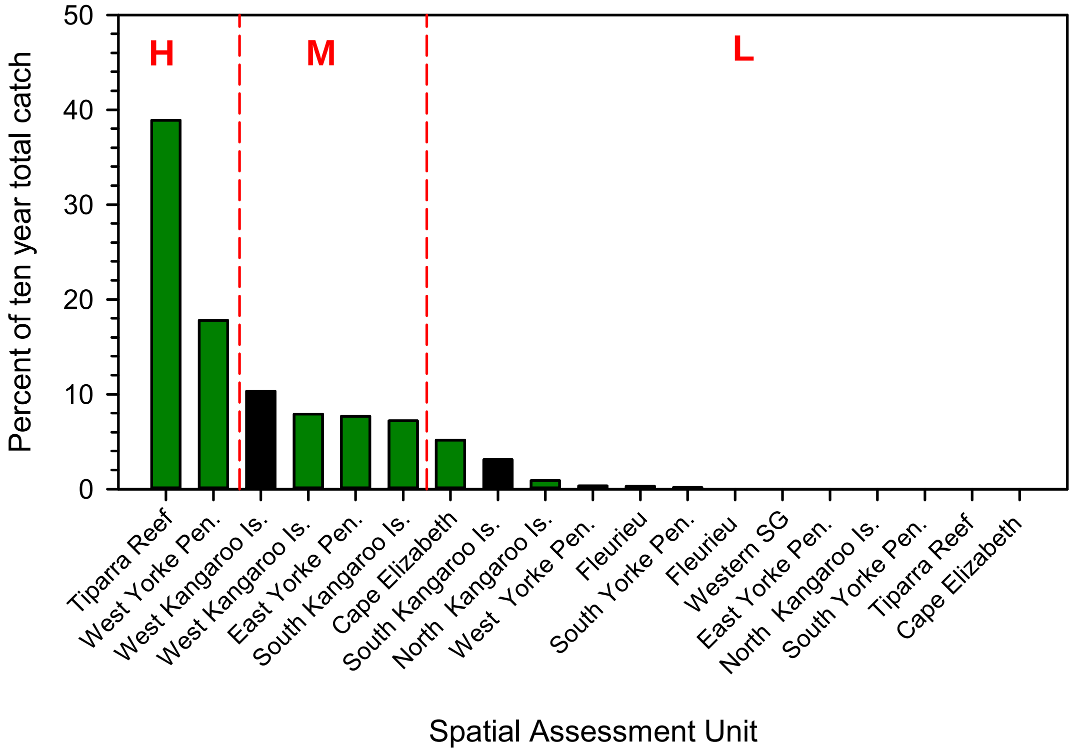

Figure 1-4 SAUs of the CZ Abalone Fishery, ranked in order of importance (High (H); Medium (M); and Low (L)) by percent of ten year (2006-2015) total catch for greenlip (green bars) and blacklip (black bars). SAU name abbreviations: Peninsula (Pen.); Island (Is.), Spencer Gulf (SG). Each SAU appears twice – once for greenlip and once for blacklip.

1.4. Previous Stock Assessments

The first assessment of the South Australian abalone resource was published by the South Australian Department of Fisheries in 1984 (Lewis *et al*. 1984). In 1996, the abalone research arrangements were reviewed (Andrew 1996). That review highlighted the need for (1) expansion of the fishery-independent surveys to include blacklip in all three zones of the fishery, (2) evaluation of the impacts of the 'fish-down' areas on blacklip populations in the Southern Zone, (3) comprehensive re-assessment of the distribution of commercial catch and effort, and (4) estimation of both the recreational and illegal catch.

Fishery research reports were produced annually between 1998 and 2000 (Rodda *et al*. 1998, 2000; Shepherd *et al*. 1999). The development of a Management Reporting System for the commercial catch and effort data permitted a re-evaluation of the commercial catch and effort information, particularly with respect to the distribution of effort and catch since the start of the fishery (Keesing *et al*. 2003).

The 2001 stock assessment report provided fishery statistics for all three zones of the fishery (Mayfield *et al*. 2001). The first dedicated CZ report (Mayfield and Ward 2002) synthesised all fisheries data for the CZ from 1968 to 2001. Assessment reports have been updated each year since, with the exception of 2007, 2009 and 2013 (Mayfield and Ward 2003; Mayfield *et al*. 2004, 2005b, 2006, 2008a, 2010, 2014a; Chick and Mayfield 2012;; Mayfield and Ferguson 2015).

For greenlip and blacklip, the most recent stock assessment report for the CZ classified both stocks as 'transitional depleting' under the national framework for reporting stock status (Mayfield *et al.* 2014a). This was in direct contrast to the harvest strategy outcomes, which classified the stocks as 'under-fished' and 'sustainable' for greenlip and blacklip, respectively. For greenlip, the assessment concluded that (1) Tiparra Reef remains the most important SAU in the CZ, despite significant redistribution of catch to other SAUs; (2) both weight-of-evidence and harvest strategy ('red' risk-of-overfishing category) determined that harvestable biomass of greenlip on Tiparra Reef had declined substantially. Notably, the catch of 9 t from Tiparra Reef in 2013 was 50% below the 18 $t.yr^{-1}$ 'catch-cap'; (3) the combined catch harvested from SAUs other than Tiparra Reef was the highest on record; and (4) there was evidence of recent decreases in catch rate in many SAUs where catches have increased over recent years, including South Kangaroo Island, West Kangaroo Island, East Yorke Peninsula and Cape Elizabeth. For blacklip, the assessment found evidence for declines in abundance, including (1) reductions in catch rate across multiple spatial scales – CZ, key blacklip SAUs, FAs and mapcodes – to levels at, or among, the lowest on record; (2) increasing levels of fishing effort in deeper water; and (3) high proportions of the TACC harvested from the West Kangaroo Island SAU..

1.5. **Fisheries biology of abalone**

Abalone (Family: Haliotidae; Genus: *Haliotis*) are marine gastropods inhabiting reefs from the shallow subtidal zone to depths commonly around 30 m (Geiger 2000). They have a global distribution in tropical and temperate waters with the richest abalone faunas found in Australia, Japan and South Africa (Geiger 2000). Over 50 species of abalone are currently recognised (Geiger 2000).

Large genetic differences exist between the northern and southern temperate species and within the southern temperate species assemblages (Brown 1991). Even on more localised scales, genetic variation can occur (Brown and Murray 1992; Elliott *et al*. 2000, 2002; Hancock 2000; Temby *et al*. 2007; Miller *et al*. 2009, 2014; Mayfield *et al*. 2014c), demonstrating limited dispersal among 'metapopulations' (Fleming 1997; Miller *et al*. 2009).

Abalone have separate sexes, with spawning generally being seasonal and synchronised. Fertilisation success is strongly influenced by adult density (Babcock and Keesing 1999). Larval duration typically ranges between 5 and 10 days and is predominantly influenced by water temperature. Larvae are lecithotrophic and dispersal distances are strongly influenced by larval behaviour and local hydrodynamics (Prince *et al*. 1987, 1988). Recruitment may vary widely from year to year and the relationship between stock size and subsequent recruitment is uncertain (McShane *et al*. 1988; Prince *et al*. 1988; Shepherd 1990; McShane 1991; McShane and Smith 1991; Shepherd *et al*. 1992).

Growth rates are highly variable and largely dependent on water temperature, water movement and the quantity and species of macroalgae available for consumption (Day and Fleming 1992). Initial rates of growth of settled larvae are high and can be length-dependent (Shepherd 1988). Typically, growth rates are described by a von Bertalanffy model (Shepherd and Hearn 1983), although alternative and more complex models are being used (Bardos 2005; Haddon *et al*. 2008). Recently settled abalone prefer habitats with encrusting coralline algae (Shepherd and Turner 1985; Shepherd and Daume 1996) that provide an important source of food, and protection from predation (Shepherd and Cannon 1988).

Through their ontogeny the diet of abalone shifts from crustose coralline algae (individuals 5-10 mm SL) to drift algae (Shepherd and Cannon 1988). In some species, including blacklip, brown algae and detritus make up a high proportion of the diet (Guest *et al*. 2008). Other abundant algae may be largely avoided, ostensibly due to non-palatability. Small abalone are preyed upon by a range of predators, including fish, crabs, starfish and octopus. Shells are frequently bored by whelks that then feed on the foot muscle. Boring polychaetes also erode the shells and spire (Shepherd 1973).

1.5.1. Biology of greenlip in the Central Zone

Greenlip are distributed throughout southern Australia, ranging from Corner Inlet (Victoria) to Cape Naturaliste (Western Australia; Lindberg 1992). They commonly inhabit reefs at depths between 1 and 30 m, occurring in clusters of local populations, separated from other similar clusters over a range of spatial scales. This pattern of disaggregated spatial distribution is reflected in the population genetics with clusters representing putative 'metapopulations' (Shepherd and Brown 1993; Morgan and Shepherd 2006; Mayfield *et al*. 2014c).

The length at sexual maturity of greenlip can vary significantly among areas. Fifty percent of individuals were sexually mature (L_{50}) between 75 and 89 mm SL (Tiparra Reef; Table A2-1). Greenlip were recorded as spawning synchronously between October and March at both West Island and Tiparra Reef (Shepherd and Laws 1974; SARDI unpublished). These data match the pattern of larval settlement onto artificial collectors in Thorny Passage (Keesing *et al*. 1995; Rodda *et al*. 1997). Sex ratios seldom differ from 1 male: 1 female (SARDI, unpublished data). Relationships between biological components including shell length, whole weight, meat weight, bled-meat weight and fecundity for greenlip from Tiparra Reef and West Island are well established (Table A2-2 and Table A2-3). Fresh meat and bled-meat weights represent approximately 42% and 34% of whole weight, respectively (SARDI, unpublished data).

The growth rates of juvenile greenlip vary spatially and temporally; sub-adult growth rates in the CZ ranged between 15.4 and 20.9 mm.yr^{-1} (Table A2-4). Adult greenlip growth is non-linear and can be represented by the parameters k and L_{∞} from the von Bertalanffy growth equation. The rate of growth (k) ranged from 0.41 (Tiparra Reef) to 0.48.yr^{-1} (West Island) and the average maximum attainable length (L_{∞}) between 130.8 mm (Tiparra Reef) and 137.9 mm SL (West Island; Table A2-5). Rates of natural mortality also vary temporally and spatially. Natural mortality rates (M) of greenlip at West Island were 0.26 year^{-1}, which was greater than that observed at Tiparra Reef (M = 0.22 year^{-1}; Table A2-6). For juvenile greenlip at West Island, M was 0.24 month^{-1} (0-8 months) and individuals between 1 and 4 years of age had natural mortality rates of 0.23-0.4 $year^{-1}$ (Shepherd and Baker 1998).

1.5.2. Biology of blacklip in the Central Zone

Blacklip are distributed throughout southern Australia between Coffs Harbour (New South Wales) and Rottnest Island (Western Australia). They commonly occur in shallow water (0-30 m depth) along rocky coastlines. Blacklip have a fine-scale population structure (Brown 1991) with significant genetic differentiation occurring at very small spatial scales (Shepherd and Brown 1993; Temby *et al*. 2007; Miller *et al*. 2009).

The length at which 50% of the blacklip population are sexually mature (L_{50}) can vary significantly among areas. Asymptotic maximum size (L_{50}) was reached at 76.0 and 109.2 mm SL at West Island and Vennachar Point, respectively (Table A2-7). Blacklip spawn during summer and autumn, although spawning is poorly synchronised (Shepherd and Laws 1974). The annual spawning cycle may be driven by seasonal fluctuations in water temperature (Shepherd and Laws 1974). Relationships between SL and fecundity for blacklip stocks around Kangaroo Island have been established (Table A2-8).

Rates of growth vary throughout the life history stages of abalone with smaller animals growing faster than larger ones. The rate of growth is, however, dependent on environmental conditions that often vary spatially and temporally. Emergent blacklip growth is non-linear and can be represented by the von Bertalanffy growth model. The model parameter *k* ranged from 0.32 (Tiparra Reef) to 0.34 $year^{-1}$ (West Island) while L_∞ varied between 138.8 (West Island) and 142.6 mm SL (Tiparra Reef; Table A2-9).

As for growth, rates of natural mortality vary spatially and temporally. Natural mortality rates of blacklip were estimated at 0.36 $year^{-1}$ at West Island and 0.21 $year^{-1}$ at Tiparra Reef (Table A2-10).

2. GREENLIP

2.1. Introduction

This section of the report provides spatial and temporal analysis of the fishery-dependent and fishery-independent data for greenlip in the CZ from 1 January 1968 to 31 December 2015, and an assessment of the current stock status. Data are presented at four spatial scales. These are (1) the whole greenlip fishery (*i.e.* all areas of the CZ combined); (2) spatial assessment unit (SAU; *e.g.* Tiparra Reef, West Yorke Peninsula, see Figure 1-2); (3) SAUs aggregated by importance (*e.g.* high, medium and low); and (4) mapcodes from high and medium importance SAUs (MC; *e.g.* MC 22A). This section also includes a formal analysis of the fishery's performance and stock status based on the harvest strategy described in the Management Plan for the fishery (PIRSA 2012), which determines (1) the risk that greenlip stocks in the high and medium SAUs are overfished; and (2) the zonal stock status for greenlip. In addition, the fishery-dependent, catch and effort data were used to test the sensitivity of the data exclusion rules for estimating CPUE. In the discussion, we assess the current status of greenlip stocks in the CZ comparing the harvest strategy and the traditional weight-of-evidence assessment.

2.2. Methods

This assessment used both fishery-dependent and fishery-independent data. Fishery-dependent data comprised catch (t, meat weight), CPUE (kg meat weight.hr^{-1}), proportion of large (>155 mm SL) greenlip in the commercial catch and fishing location (mapcode, and data from GPS and depth loggers that have been mandated since January 2013). Fishery-independent data consisted of (1) estimates of greenlip densities for all greenlip (*i.e.* total), greenlip individuals <135 mm SL (*i.e*. sub-legal-sized), ≥135 mm SL (*i.e*. legal-sized) and 90-134 mm SL (*i.e.* pre-recruits); and (2) length-frequency distributions from fishery-independent surveys (Table 1-4). The quality assurance program is outlined in Appendix 1.

2.2.1. Fishery-dependent data

Catch, effort and CPUE

Commercial catch and effort data have been collected since 1968 by fishers completing a research logbook for each fishing day. Catch (t, meat weight) was determined from all daily logbook returns.

CPUE (kg.hr^{-1}; meat weight) was calculated as the catch-weighted mean of daily CPUE (Burch *et al*. 2011; see Table 1-4), where the percentage of greenlip in the catch for each daily record was used as a weighting factor in calculating the arithmetic mean of daily

CPUE records. Annual CPUE estimations are made following the exclusion of daily records where (1) greenlip is <30% of total catch; (2) total catch is >300 $kg.day^{-1}$; (3) total catch rate is >50 $kg.hr^{-1}$; (4) fishing effort is >8 hr; or (5) fishing effort is <3 hr. CPUE estimations are made provided a minimum of 10 daily records are available. The small proportion of records (<1%) where multiple daily dives were entered as separate days were ignored and retained in the data analysis. Limited daily records (*i.e.* n <10) prevented calculation of CPUE in some years at some spatial scales.

Data constraints that exclude likely unrealistic or outlying catch rate values are important for minimising potential bias in CPUE estimates (Hart *et al.* 2009; Mayfield *et al.* 2014a). Two steps were undertaken to evaluate the effect of current data constraints on CPUE estimation. First, the volume and timing of excluded records was evaluated. After the application of the species catch and fishing effort constraints the overall percentage of records excluded was small, and similar to those reported for the Western Zone of the SAAF (Burch *et al.* 2011). Between 1979 and 2015, 1.2% and 0.8% of records were excluded under the daily catch (>300 $kg.day^{-1}$) and catch rate (>50 $kg.hr^{-1}$) constraints, respectively. However, there was a distinct temporal pattern of increased record exclusion evident in those years with high CPUE estimates (Figure A3-1). The period with the greatest record exclusion (*i.e.* 2000-2004) coincided with periods of high relative abundance for the fishery (*i.e.* high historical CPUE). This pattern was particularly strong for years when there were a high number of daily catches >300 kg at both the zonal scale (Pearson's correlation coefficient (r) = 0.69) and in the Tiparra Reef SAU (r = 0.64), suggesting the daily catch constraint of 300 kg may need to be reconsidered.

Second, using alternative data constraints for catch rate with all daily catches included (*i.e*. daily total catch rule discarded), annual CPUE estimates were generated for the CZ and the Tiparra Reef SAU. Three alternative methods were tested. These were (1) 5% quantiles; (2) 2.5% quantiles; and (3) removal of the highest and lowest record. All three of these methods truncated the data used for each CPUE estimate by removing the highest and lowest (1) 5% of values; (2) 2.5% of values; and (3) single value, respectively, prior to CPUE estimation. All three alternate methods had a similar influence on CPUE estimates, whereby they retained data during periods of historically high catch that increased CPUE estimates, whilst also ensuring a more equitable distribution of excluded values across fishing years (Figure A3-1). Visual and Pearson's correlation (Zone: r range 0.98-1.00; Tiparra Reef SAU: r range 0.98-1.00) comparisons demonstrated high levels of consistency in temporal trend among the four CPUE estimation methods tested. Given this strong correlation, the existing data exclusion rules have been retained in this assessment for continuity with historical data.

In addition to testing the data constraint rules for estimating CPUE, the use of frequency distributions as an alternative method of presenting CPUE data for greenlip was examined because these can provide information about stock abundance that is not evident from mean catch rates (Tarbath *et al.* 2014). Bubble plots of the percentage of daily catch records, binned by 5 $kg.hr^{-1}$ increments, were inspected for all days where greenlip were ≥30% of the daily catch. All records ≥50 $kg.hr^{-1}$ were pooled in the highest category. The percentage of daily catch records that were (1) ≥30 $kg.hr^{-1}$ and (2) <15 $kg.hr^{-1}$ were also calculated and presented as a 3-yr mean (*e.g.* for 2014, the 3-yr mean was calculated using all of the catch records from 2013, 2014 and 2015). This facilitated interpretation of temporal patterns in CPUE by reducing inter-annual variability. Observed patterns in the distribution of CPUE values are presented (Figure A3-2 & A3-3) and described (see Results) at several spatial scales, including the whole CZ, SAUs aggregated by importance and SAUs of high importance.

<u>Length-frequency distribution of catch</u>

The proportion of large greenlip (>155 mm SL) in annual catches was determined from the catch-sampling data comprising shell length measurements from the catch. From January 2002 to June 2005, these data were obtained by SARDI measuring samples provided by commercial fishers. Data from July 2005 to December 2007, and from January 2008 to December 2015, were provided by the Abalone Industry Association of SA (AIASA) and Michael Tokley, representing the CZ licence holders, respectively, and supplemented by SARDI sampling on commercial vessels. A small number of divers also provided SARDI with shell-length data directly during this period. No catch-sampling data were provided in 2010 and 2011. Limited data (*i.e. n* <100 SL measurements) prevented calculation of this metric in some years at some spatial scales.

Commercial length-frequency data are important for determining temporal changes in the length structure and mean length of the catch. However, for these data to contribute meaningful information to assessment of the fishery they need to be representative of the fishery, fleet and catch (see Burch *et al.* 2011). Notably, the number of commercial greenlip shell measurements provided for each SAU generally increased with catch (Figure 2-1), but in some SAUs the number of greenlip fishing days for which shell samples have been provided was substantially below that expected from the daily catch and effort logs (Figure 2-1). This difference persisted through 2013, 2014 and 2015, during which provision of shell sample data was mandatory for each fished day. For example, in 2015, there were 122 days of fishing in West Yorke Peninsula SAU where greenlip catch exceeded 5 kg meat weight, but shell sample data were provided for 75 of these days. Overall, these data appear to poorly represent the commercial fishery. In particular, the absence of data for 2010 and 2011, prevents calculation of the 'propLarge' PI in these years for SAUs of high and medium importance.

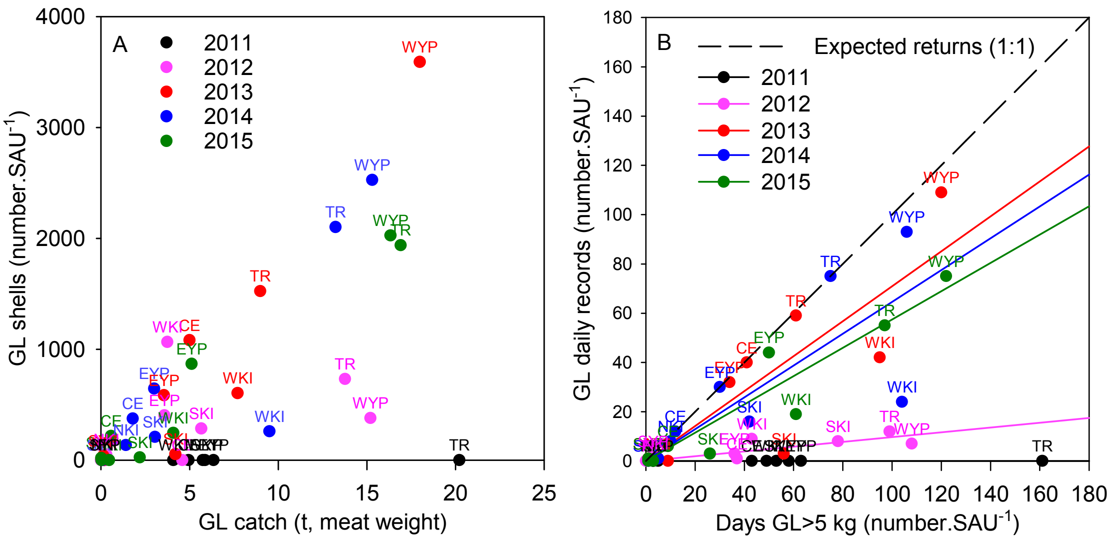

Figure 2-1 (A) Greenlip catch (t, meat weight) and individual shell records (number) for each SAU (TR: Tiparra Reef; CE: Cape Elizabeth; WYP: West Yorke Peninsula; SYP: South Yorke Peninsula; EYP: East Yorke Peninsula; F: Fleurieu; SKI: South Kangaroo Island; WKI: West Kangaroo Island); and (B) days fished with greenlip catch >5kg (number) and daily shell records (number) for each SAU from 2011-15. Solid lines are linear fit for each fishing year. Dashed black line indicates 1:1 return ratio of shell measurements for days fished.

2.2.2. Fishery independent data

Estimates of greenlip density were obtained from fishery-independent diver-surveys conducted by SARDI. For this assessment, data were available from two SAUs. These were the Tiparra Reef and West Yorke Peninsula SAUs. For both SAUs, temporal changes in greenlip density (where available) and estimates of harvestable biomass have been provided.

<u>Tiparra Reef</u>

Fishery-independent surveys at Tiparra Reef have been undertaken in most years since 1968 using the timed-swim method (relative abundance; Shepherd 1985). Prior to 2002, the location and number of timed-swims used to estimate relative abundance varied among years. From 2002 onward, the number of timed-swims undertaken increased, and greater consistency was introduced to the survey locations, subsequently increasing the reliability of density estimates. More recent surveys from 2010 onwards, have used the leaded-line method (absolute abundance; McGarvey *et al*. 2008) to further improve the reliability and accuracy of estimates of greenlip density. In 2010 and 2012, surveys were conducted using both methods, but in 2011, 2013 and 2015 only the leaded-line method was used.

Density estimates are provided for greenlip in three size categories for both methods. These are total, legal-sized and sub-legal-sized greenlip. The latter two categories now reflect the revised MLL for greenlip in the CZ from 2013 (i.e. 135 mm SL). Leaded-line survey locations have varied among years. Consequently, data from those leaded lines surveyed in all five years (n = 31) and those leaded-lines surveyed in 2013 and 2015, following provision of detailed fishing location data (see below; n = 55) are presented. Repeated measures analysis of variance (ANOVA) was used to compare the density of legal-sized and sub-legal sized greenlip among years since leaded-lines commenced (Maceina *et al.* 1994; Hart and Fabris 2007). Prior to analysis, densities from each of the 31 leaded-line transects were SQRT(×+1) transformed to meet the assumptions of homogeneity and normality. To account for spatial auto-correlation detected between the 31 leaded-lines using the Moran's I test, each transect was allocated to a stratum (i.e. high, medium or low) based on fishing intensity from GPS data. Strata was then incorporated as a between-subjects factor in the Repeated Measures ANOVA design and data were re-checked for spatial autocorrelation using Moran's I. There was no evidence of spatial autocorrelation between leaded-lines within each stratum. Within-subjects tests were undertaken using the Greenhouse-Geisser factor to correct for violations of sphericity. *Post hoc* comparisons are reported where the main-test was significant without correction for multiple comparisons.

Greenlip densities from timed-swims between 2010 and 2015, required for application of the harvest strategy, were estimated in a two-stage process. First, the mean proportional density difference for each greenlip size class between the "paired" 2010 and 2012 leaded-line and timed-swim surveys was determined. These values were then applied to the density estimates from the leaded-line surveys to "scale" these to projected densities for the timed-swims. This method was selected because it provided values in the mid-range of the three alternate methods considered.

GPS data that describe fishing location were used to identify the most important fishing grounds on Tiparra Reef. Data where vessels were moving at ≥5 km.hr^{-1} were excluded from all analyses. Based on these data, the same three strata were surveyed in 2013 and 2015, encompassing areas of high (stratum 1), medium (stratum 2) and low (stratum 3) fishing intensity (Table 2-1). The total area in which surveys were conducted was 3.2 km^2. The leaded-line method was used to estimate the bled-meat weight (BMW) harvestable biomass of greenlip (*i.e.* ≥ 135 mm SL) within this survey area following the approaches described in Carlson *et al*. (2006), McGarvey *et al*. (2008) and Mayfield *et al*.

(2008b,c, 2011b). Greenlip were collected from Tiparra Reef in spring and used to establish the SL to BMW relationship required to estimate harvestable biomass ($BMW = 5.65x10^{-4}*SL^{2.507}$).

As only a subset of the fishing grounds on Tiparra Reef were included in the harvestable biomass estimate, these estimates were 'scaled' to the Tiparra Reef SAU using three methods (1) assuming the area surveyed represents the area from which 77% of the catch was harvested (based on the GPS data); (2) assuming the area surveyed represents the area from which 75% of the catch was harvested (mean estimate from commercial divers following their assessment of the survey design); and (3) determining the area that contained a further 13% of GPS points (*i.e.* stratum 4 - total area encompassing 90% GPS points) and adding the estimated harvestable biomass of greenlip in this area to the biomass estimate for strata 1-3. The harvestable biomass of greenlip in this area (2.8 km^2) was estimated using a predicted survey density for stratum 4 that was based on the mean percentage difference in densities between strata 1 and 2 (20%) and strata 2 and 3 (50%; *i.e.* 35% below that in stratum 3). The 2013, estimates were scaled using the same three methods to enable a temporal comparison of greenlip harvestable biomass in the Tiparra Reef SAU. This included a revision of the upper estimate of harvestable biomass, obtained from Method 3.

In 2015, the survey spanned the period from 9 September to 18 November. The reported catch from Tiparra Reef at the mid-point of the survey (*i.e.* 11 October 2015) and the total catch from Tiparra Reef in 2015 were used with the scaled estimates of harvestable biomass to estimate the potential range of exploitation rates from this SAU in 2015. The same scaling of estimates was undertaken in 2013 (see Mayfield *et al.* 2014a). This approach required three key assumptions: natural mortality and recruitment were zero from 1 January to 11 October 2015 and the SL-meat weight relationship is time invariant. While it is reasonable to assume that recruitment would be offset by natural mortality, seasonal variation in greenlip meat weights (Stobart *et al*. 2013b) suggests that the survey estimates of biomass would be under, rather than overestimated.

West Yorke Peninsula

Fishery-independent leaded-line surveys were undertaken in 2015 at three locations in the West Yorke Peninsula SAU (*i.e.* Hardwicke Bay, Port Victoria and Corny Point). The locations of the sixty leaded-lines were based on GPS logger data from January 2013 to March 2015. Data where vessels were moving at ≥10 $km.hr^{-1}$ were excluded from all analyses. Data from historical leaded-line surveys were available in some years between 2006 and 2011 at Hardwicke Bay and Port Victoria. Therefore, where GPS logger data overlapped with historical survey sites, historical lines were maintained to allow temporal comparisons.

Based on the GPS data, three strata were surveyed in each of the locations, which encompassed areas of high (stratum 1), medium (stratum 2) and low (stratum 3) fishing intensity (Table 2-1). Hardwicke Bay encompassed the largest total area (21.7 km^2), followed by Port Victoria (7.6 km^2) and Corny Point (4.0 km^2). The percentage of GPS points and number of leaded-lines surveyed in each strata are listed in Table 2-1. Greenlip were collected from Hardwicke Bay and Corny Point in spring, and used to establish a shell length to bled meat weight relationship that was required to estimate harvestable biomass ($BMW_{Hardwicke\ Bay} = 9.33x10^{-7}*SL^{3.750}$ and $BMW_{Corny\ Point} = 3.20x10^{-6}*SL^{3.515}$). For Port Victoria, no samples were collected. Therefore, all available data from the West Yorke Peninsula and Tiparra Reef SAU were combined to establish the SL to BMW relationship for this fishing ground ($BMW_{Port\ Victoria} = 5.63x10^{-5}*SL^{2.952}$).

As only a subset of the fishing grounds within the West Yorke Peninsula SAU were included in the harvestable biomass estimate, these estimates were 'scaled' to the SAU level using two methods (1) assuming the area surveyed represents the area from which 85% of the catch was harvested (based on the GPS data); and (2) determining the area outside the surveyed locations where GPS data densities were equivalent to those in each of the three fishing intensity strata and adding the estimated harvestable biomass of greenlip in these areas to the biomass estimate obtained from the surveyed strata. The harvestable biomass of greenlip in this area (2.3 km^2) was estimated using a predicted survey density for each of these strata derived from the combined mean densities obtained from all leaded-lines surveyed in these strata at the Hardwicke Bay, Port Victoria and Corny Point survey locations. This area contained a further 3.5% of GPS points, totalling to 89% GPS points encapsulated after scaling. This approach was different to Method 3 for Tiparra Reef because, from the GPS data, the fishing grounds in the West Yorke Peninsula SAU appear much more spatially discrete compared to the more continuous fishing grounds at Tiparra Reef.

In 2015, the surveys at the three locations occurred from 27 July to 7 October. The mid-point of these surveys was 7 September, 14 August and 25 September at Hardwicke Bay, Port Victoria and Corny Point, respectively, with an aggregated mid-point of 5 September. The total catch from West Yorke Peninsula up to this aggregated mid-point was used to scale estimates of harvestable biomass to provide an estimate of the potential range of exploitation rates from this SAU.

Table 2-1 The area (km^2) of each strata from the Tiparra Reef and West Yorke Peninsula (Hardwicke Bay, Port Victoria and Corny Point) SAUs used for the estimates of harvestable biomass, including the percentage of GPS points and the number of leaded-lines surveyed within each stratum.

	High (Stratum 1)			Medium (Stratum 2)			Low (Stratum 3)			Stratum 4		
	Area (km2)	GPS points (%)	Survey lines (#)	Area (km2)	GPS points (%)	Survey lines (#)	Area (km2)	GPS points (%)	Survey lines (#)	Area (km2)	GPS points (%)	Survey lines (#)
Tiparra Reef												
Tiparra Reef	0.4	21.0	15	0.9	30.2	16	1.9	25.9	20	2.8	13	0
West Yorke Peninsula												
Hardwicke Bay	1.6	13.4	5	7.6	25.9	11	12.5	13.3	10			
Port Victoria	1.0	3.5	4	3.1	3.8	6	3.5	2.5	7			
Corny Point	0.4	8.7	7	1.1	11.4	6	2.5	3.0	4			
Other	0	0	0	0.2	1.1	0	2.1	2.3	0			

2.3. **Results**

2.3.1. Central Zone

Total catch was stable at approximately 47.6 t.yr^{-1} between 1994 and 2014 (Figure 2-2). In 2015, the TACC was reduced to 46.0 t following implementation of the marine park sanctuary zones, resulting in a decline of total catch to 45.7 t. Prior to the implementation of a TACC (1990), the average annual catch was 44.3 t, which includes the maximum recorded catch of 84.2 t in 1989. Thus, current catches are about 3% greater than the annual average before implementation of a TACC.

CPUE was relatively stable from 1985 to 1999 (average: 20 kg.hr^{-1}). In 2000, it increased to 28 kg.hr^{-1} and was at the highest recorded level of 29 kg.hr^{-1} in 2001. After 2001, a decreasing trend was evident for the next decade, before stabilising at approximately 23 kg.hr^{-1} from 2011 to 2015. This five-year period comprised the lowest catch rates since 1999. The distribution of daily CPUE records in the CZ has shown distinct temporal trends over time (Figure A3-2). The percentage of high daily CPUE (*i.e.* ≥30 kg.hr^{-1}) shows four distinct phases: a gradual decline from about 20% in the early 1980s to <10% between 1990 and 1999; a sharp increase from 2000, to the maximum recorded value of 56% in 2001; a gradual decline from 2005 to 2010; and a period of stability at (range: 16 - 23%; mean: 19%) over the last five years. In contrast, the percentage of daily catch records <15 kg.hr^{-1} declined substantially between the early 1980s and 2000, and has seldom exceeded 10% thereafter (range: 5-13%).

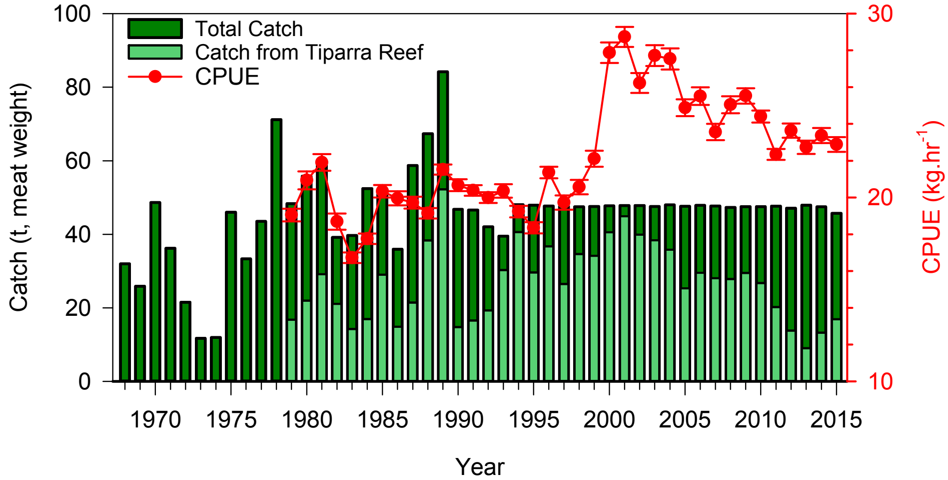

Figure 2-2 Total catch of greenlip for the CZ (t, meat weight; dark green) from 1968-2015. From 1979 to 2015, catch from Tiparra Reef (light green bars) is superimposed on total catch; these data were unavailable from 1968 to 1978. CPUE (kg.hr^{-1}, ±SE) is shown by red line.

2.3.2. Spatial assessment units

2.3.2.1. *Distribution of catch among SAUs*

Three key changes in the spatial distribution of catch are evident following TACC implementation in 1990 (Figure 2-3). Firstly, the proportion of catch harvested from the Tiparra Reef SAU increased substantially and peaked at 94% (44.9 t) in 2001. Secondly, following the imposition of a 'catch-cap' for Tiparra Reef in 2005, catches declined steadily, to a contemporary low of 19% (9 t) in 2013, with corresponding increases in catch from other SAUs over this period. Thirdly, in the past two years, catches from Tiparra Reef have again increased, with 37% (16.9 t) of the total greenlip catch in 2015 taken from this SAU, although this contribution remains small relative to the majority of years during the past two decades.

Recent trends in the distribution of catch among SAUs reflects the shift away from, and subsequent return to, Tiparra Reef (Figure 2-3). Initially, between 2005 and 2007, catch from the West Yorke Peninsula SAU increased. From 2008 to 2010, the contribution of catch from the West Yorke Peninsula SAU decreased, while catches from the East Yorke Peninsula, South Kangaroo Island, West Kangaroo Island and Cape Elizabeth SAUs increased. After 2010, catch from the West Yorke Peninsula SAU increased and, subsequently, has remained similar to historically high levels. Catch from the West Kangaroo Island SAU also reached a historical high during 2013 and 2014. Recent catches from the East Yorke Peninsula and South Kangaroo Island SAUs have generally followed a decreasing trend. Over the last two years, increasing catch from the Tiparra Reef SAU has been accompanied by sustained high catches from the West Yorke Peninsula SAU. In contrast, the combined greenlip catch from the South and West Kangaroo Island SAUs decreased by 50% between 2014 and 2015. When compared to the early 2000s, the distribution of catches among SAUs in 2015 was more equitable. Overall, these temporal patterns in the distribution of catch have resulted in two high (Tiparra Reef and West Yorke Peninsula) and three medium-importance (West Kangaroo Island, East Yorke Peninsula and South Kangaroo Island) SAUs for greenlip in the CZ in 2015.

Similar levels of spatial variability in catch among years were evident at the mapcode spatial scale (Figure A4-1). While high annual catches have been recorded from numerous mapcodes (*e.g.* 24C, 24E, 24A, 21J), these were rarely sustained over several successive years (*e.g.* East Yorke Peninsula: 24C, 24D, 24E). The most consistent high catches have been obtained from mapcodes in the West Yorke Peninsula (24A, 22A) and Cape Elizabeth (21H) SAUs. Spatial redistribution of catches among mapcodes has continued in recent seasons, including record high catches from two mapcodes with consistently low historical catch contributions (i.e. 23A, 26A) and low/declining catches from some more traditional fishing areas (i.e. 21H, 24A)

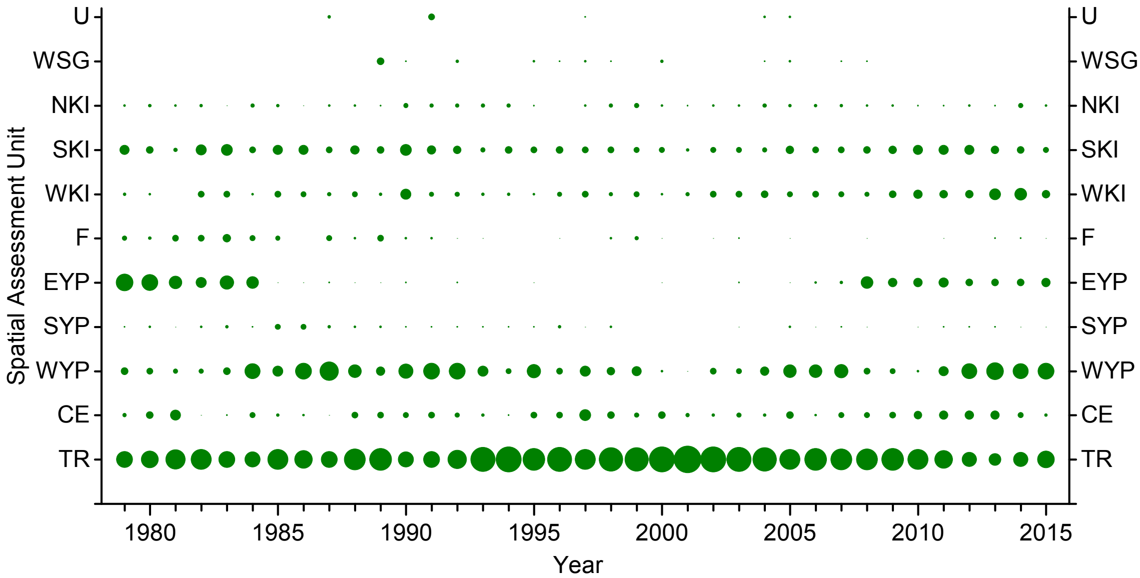

Figure 2-3 Bubble plot showing the spatial distribution of the greenlip catch (% of total catch, green symbols) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ from 1979 to 2015.

2.3.2.2. *Temporal patterns in aggregated SAUs*

The total catch from SAUs of high importance was relatively stable from 1994 to 2007, averaging 40 $t.y^{-1}$ (Figure 2-4). Since 2008, aggregated catches from these SAUs has generally declined, averaging <30 $t.y^{-1}$, although between 2014 and 2015 there was an increase of 5 t (16 %). Over recent years, the proportion of this catch harvested from the West Yorke Peninsula SAU has reached historically high levels. CPUE for the combined high-importance SAUs was relatively stable prior to 2000 (20.7 $kg.hr^{-1}$). In 2000, CPUE increased and stabilised for the next five years at record high levels (28.6 $kg.hr^{-1}$), before a third relatively stable period at a lower mean level over the last decade (25.5 $kg.hr^{-1}$). The distribution of daily CPUE records in the combined SAUs of high importance has also varied temporally (Figure A3-2). Notably, the percentage of daily CPUE records ≥30 $kg.hr^{-1}$ was relatively high from 1979 to 1982, but declined thereafter to a historic low of <2% in 1995. Days with high catch rates increased rapidly after 1999, and reached peaks of 56% of daily records ≥30 $kg.hr^{-1}$ in 2001 and 2004. Subsequently, the percentage of daily CPUE records ≥30 $kg.hr^{-1}$ has generally declined, and was 24% in 2015. The percentage of daily CPUE records <15 $kg.hr^{-1}$ in SAUs of high importance follows the same temporal pattern for this metric observed for the whole CZ.

Combined catches from SAUs of medium importance remained low following the implementation of the TACC in 1990 (Figure 2-4). In 2008, aggregated catches from these SAUs increased and were maintained at an average of 15 $t.y^{-1}$ until 2014, subsequently declining to 11 t in 2015. The CPUE for the combined medium importance SAUs increased gradually from 1990 when the TACC was implemented, and reached a maximum of 23.9 $kg.hr^{-1}$ in 2010. Subsequently, consecutive declines in CPUE were evident over the next five years. The 2015 value of 17.7 $kg.hr^{-1}$ was the lowest since 2007, and represented a total decline of 26% since 2010. Thus, in 2015, medium importance SAUs had their lowest combined catch and catch rate since 2007. As with mean CPUE, the percentage of daily CPUE records ≥30 $kg.hr^{-1}$ from SAUs of medium importance has varied through time. Peaks were evident in the early 2000s and 2010, but these were interspersed amongst periods with few daily records exceeding 30 $kg.hr^{-1}$. The percentage of high catch-rate days in 2014 and 2015 were the lowest two consecutive years on record. The percentage of daily CPUE records <15 $kg.hr^{-1}$ in SAUs of medium importance followed a declining trend until the mid-2000s, which has subsequently reversed in recent years. The percentage of low catch-rate days in 2014 and 2015 were among the highest in over 20 years.

Among low importance SAUs, the combined catch and catch rate varied over time (Figure 2-4), reflecting low levels of catch and effort in many years. Since the implementation of the TACC, catches have been harvested almost exclusively from two SAUs, Cape Elizabeth and North Kangaroo Island. These two SAUs traditionally have contrasting catch rates, with Cape Elizabeth often exceeding 30 $kg.hr^{-1}$, while those from North Kangaroo Island seldom reach 20 $kg.hr^{-1}$. Between 2000 and 2010, the combined catch rates from SAUs of low importance averaged 27.2 $kg.hr^{-1}$. Subsequently, they were generally lower, averaging 23.3 $kg.hr^{-1}$ from 2011 to 2015. Total catch and CPUE in 2015 in the combined low-importance SAUs were among the lowest on record.

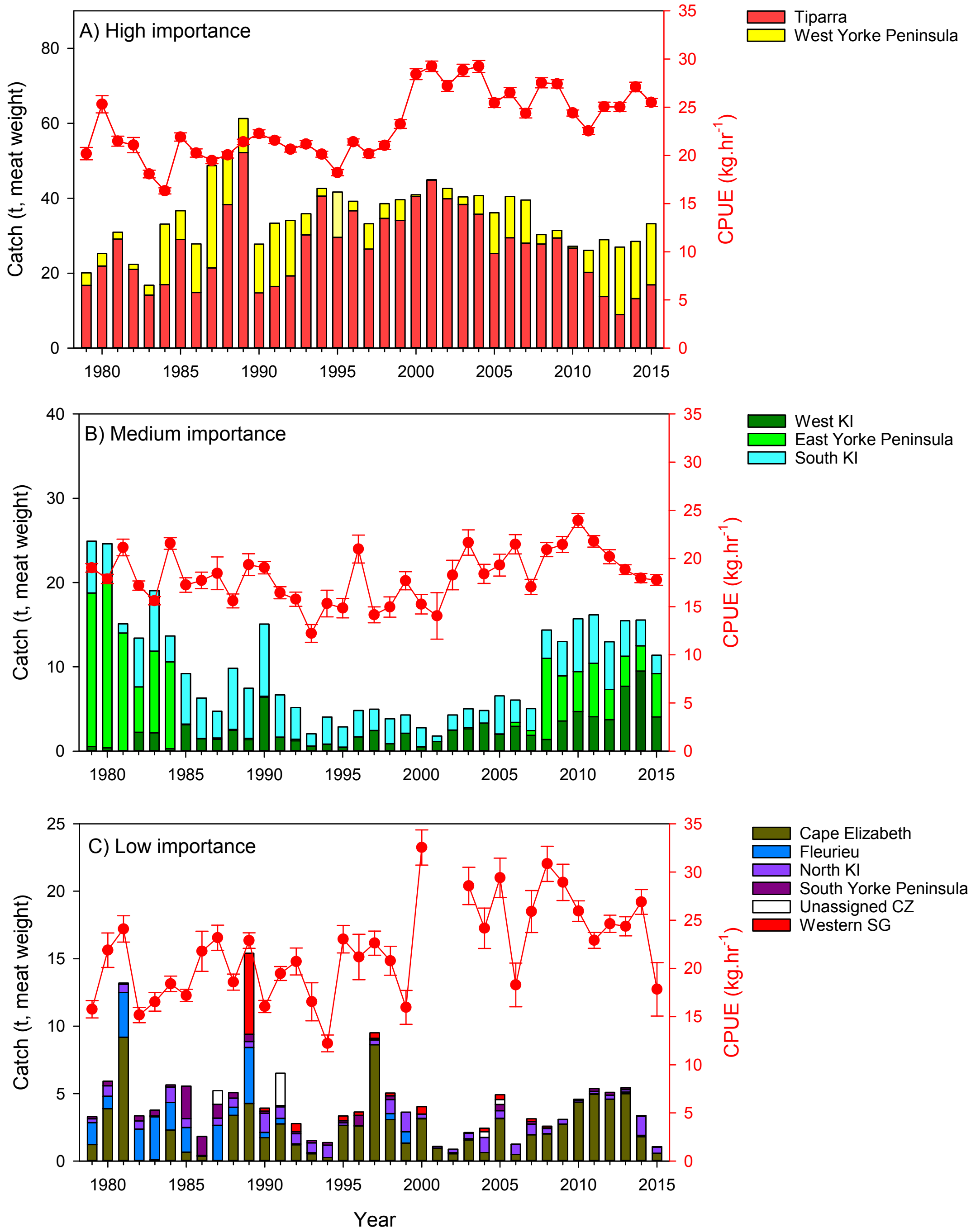

Figure 2-4 Total catch and CPUE of greenlip for SAUs aggregated by importance. (A) high, (B) medium and (C) low importance (t, meat weight;) from 1979-2015. CPUE (kg.hr-1,±SE) is shown by red lines. Stacked bars of catch are colour coded to reflect SAUs – Figure 1-2. Gaps in the time series of CPUE data indicate insufficient data (<10 fisher days).

2.3.2.3. *Temporal patterns in SAUs of high importance*

Tiparra Reef

Tiparra Reef has been the most important greenlip SAU in the CZ (59% of catch) and the SAAF (22%) since 1990. Total annual catches from Tiparra Reef increased steadily from 1979 (17 t) to 2001 (45 t), with historically large catches harvested in 1988 (38 t) and 1989 (52 t; Figure 2-5). After 2001, catches declined rapidly, particularly between 2009 and 2013, when the catch reached <10 t. In 2015, the catch from Tiparra Reef increased for the second successive year to 16.9 t, 1.1 t below the catch-cap of 18 t. The majority of catch has been harvested from MC 21B, 21C and 21D (Figure A4-2).

From 2000 to 2009, CPUE was relatively stable (29.1 $kg.hr^{-1}$) and >20% above the long-term average from 1979 to 1999 (21.3 $kg.hr^{-1}$; Figure 2-5). CPUE then decreased substantially from 2010 to 2013 (23.9 $kg.hr^{-1}$). In 2014, CPUE increased sharply to 30.1 $kg.hr^{-1}$, but then decreased to 27.9 $kg.hr^{-1}$ in 2015. The 2015 estimate was about 4% above the previous 10 year mean (2005-2014; 26.9 $kg.hr^{-1}$) and 32% above the 20-year average from 1979 to 1999 (21.2 $kg.hr^{-1}$). The distribution of daily CPUE records in the Tiparra Reef SAU followed a similar temporal trend to that at the zonal scale (Figure A3-3). Briefly, high catch rates days (*i.e.* ≥30 $kg.hr^{-1}$) were few and declining between 1979 and 1999, before rising steeply during the early 2000s. This was followed by low values in 2011 and 2012, and a subsequent increase thereafter. The percentage of days with catch rates <15 $kg.hr^{-1}$ was less variable over time. From 1979 to 1999, an average of 16% of fishing days reported catch rates <15 $kg.hr^{-1}$, with a peak of 33% in 1995. However, since 2000 the percentage of poor catch days (<15 $kg.hr^{-1}$) has been low, averaging 2%.

The proportion of large greenlip in the commercial catch varied substantially over time. Values were relatively high in 2009, 2012 and 2015, but low from 2002-04, 2006-08 and in 2013. The substantial increase in the proportion of large greenlip in the commercial catch between 2014 and 2015 resulted in the highest value on record (Figure 2-5).

Fishery-independent, timed-swim surveys were undertaken in most years until 2012. More recent surveys from 2010 onwards, have used the leaded-line method. In 2010 and 2012, surveys were conducted using both methods, enabling timed-swim estimates to be scaled from the proportional differences in greenlip density between the two methods. Timed-swim estimates indicated that the density of total, legal- and sub-legal sized greenlip on Tiparra Reef was high in 1991 (0.98 $greenlip.m^{-2}$) and 2005 (0.74 $greenlip.m^{-2}$; Figure 2-6). The highest legal-size density was observed in 2005 (0.18 $greenlip.m^{-2}$) and has decreased in subsequent surveys (Figure 2-6). Between

2011 and 2013, the timed-swim estimate of legal-sized density was approximately 0.05 greenlip.m^{-2}, the lowest period on record and about 30% of estimates in 2005. Despite this decrease, the estimate of legal-sized density remained above some years from the early 1990s. In 2015, a 22% increase from the leaded-line estimate in 2013 yielded a scaled timed-swim estimate of 0.07 greenlip.m^{-2}, the highest value since 2009. The density of sub-legal-sized greenlip was highest in 1990 and 1991, with a contemporary maximum in 2005 of 0.56 greenlip.m^{-2} (Figure 2-6). After 2005, timed-swim estimates of sub-legal-size density have declined consistently. In 2015, the scaled timed-swim estimate of density was 0.14 greenlip.m^{-2}, a 74% reduction from the contemporary maximum in 2005 and the lowest value on record.

Leaded-line surveys have been undertaken at Tiparra Reef from 2010 to 2015. Since 2010, 31 leaded-lines have been consistently surveyed each survey year. Over this period, total greenlip density has declined by 37% from 0.22 in 2010 to 0.14 in 2015 greenlip.m^{-2} (Figure 2-6). Between 2010 and 2011 mean densities of legal-size greenlip declined from 0.06 to 0.05 greenlip.m^{-2} (*i.e.* 20%), where after densities were stable at 0.05 greenlip.m^{-2} during the next two surveys (*i.e.* 2012 and 2013). In 2015, legal-size greenlip increased to 0.06 greenlip.m^{-2}, but none of these temporal changes were significant (Repeated Measures ANOVA: $F = 2.15$, $p = 0.101$). The density of sub-legal-sized greenlip has declined significantly since leaded-line surveys commenced (Repeated Measures ANOVA: $F = 12.11$, $p < 0.001$, pairwise comparisons 2010 = 2011 = 2012 > 2013 = 2015). Densities of sub-legal size greenlip were 0.16 greenlip.m^{-2} when leaded-lines commenced in 2010, subsequently declining and stabilising at 0.14 greenlip.m^{-2} in 2011 and 2012. During the last two surveys, successive declines in sub-legal-size greenlip have led to a density of 0.08 greenlip.m^{-2} in 2015, indicating a 52% decrease since leaded-lines commenced.

The ratio of legal to sub-legal-sized greenlip abalone on Tiparra Reef has changed over time (Figure 2-6). Since leaded-lines were commenced, the legal to sub-legal-sized ratio has increased substantially (*i.e.* fewer sub-legal-sized greenlip per legal-sized greenlip). This pattern was also evident in the length frequency distribution of the samples between 2010 and 2015 (Figure 2-6). The counts of abalone between 90 and 135 mm SL (*i.e.* pre-recruits) have declined over successive surveys over the past six years.

In 2013, a further 24 leaded-lines were incorporated into the survey, following the acquisition of GPS data that accurately describe fishing location. The addition of data from these new survey locations to the 31 consistently-sampled leaded lines (*i.e.* a total of 55) yielded similar estimates (and temporal patterns) of legal-sized and sub-legal-sized density (Figure 2-6). However, density estimates from the additional 24 leaded lines were excluded from the estimates of the timed-swim survey densities required for the harvest strategy due to their limited temporal replication.

The 2013 and 2015 leaded-line surveys were used to estimate the harvestable biomass in the Tiparra Reef SAU using a total of 51 leaded lines (*i.e.* 10,200 m^2). The stratified median estimate of legal-sized (*i.e.* ≥ 135 mm SL) biomass in the survey area in October 2015 was 27.3 t BMW. There was a 90% probability that the biomass exceeded 25.7 t, and a 10% probability that it was greater than 29.1 t. This was an increase of 4.1 t from the estimate of 23.2 t in 2013, and reflects both growth of existing greenlip (to larger shell lengths and meat weights) and an increase in abundance. The scaled, BMW estimates of the median harvestable biomass in the Tiparra Reef SAU in 2015 were 35.5 t (Method 1), 36.5 t (Method 2) and 37.8 t (Method 3). These reflected an increase when compared with the 2013 estimates of 30.1 (Method 1), 30.9 (Method 2) and 33.6 (Method 3).

At the mid-point of the survey (*i.e.* 11 October 2015), the reported catch from Tiparra Reef was 14.2 t. Adding this value to the scaled median estimate of harvestable biomass suggests that the estimates of harvestable greenlip biomass on Tiparra Reef in January 2015 were 49.7, 50.6 and 52.0 t. These were increases of 12.9, 13.0 and 11.7 t when compared with the 2013 estimates of 36.8, 37.6 and 40.3 t. As the total catch harvested from Tiparra Reef in 2015 was 16.9 t, these estimates suggest that the exploitation rate at Tiparra Reef in 2015 was approximately 33%. This was 10% greater than the exploitation rates of 22 to 24% estimated in 2013.

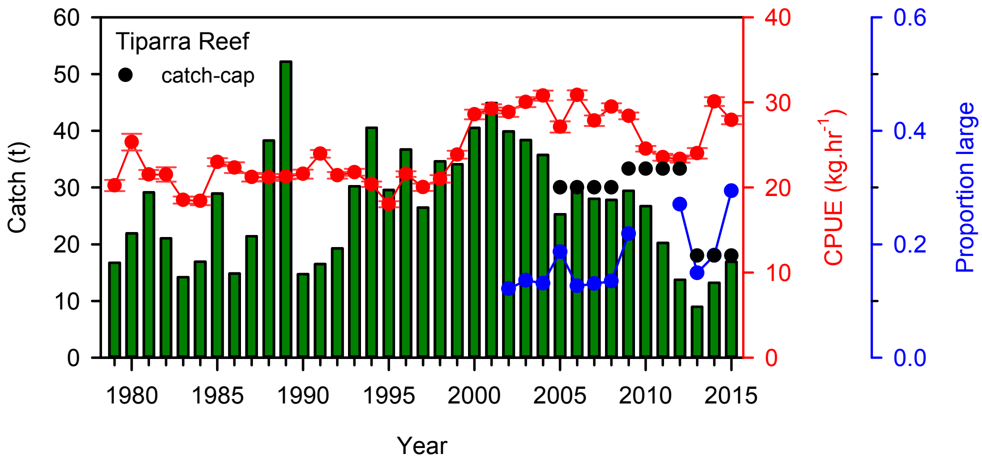

Figure 2-5 Tiparra Reef (high importance). Catch (t, meat weight; green bars), CPUE (kg.hr^{-1}, ±SE, red line), the proportion of large greenlip (>155 mm, blue line) and the catch-cap (t, meat weight, black symbols) from 1979 to 2015. Gaps in the time series of the proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

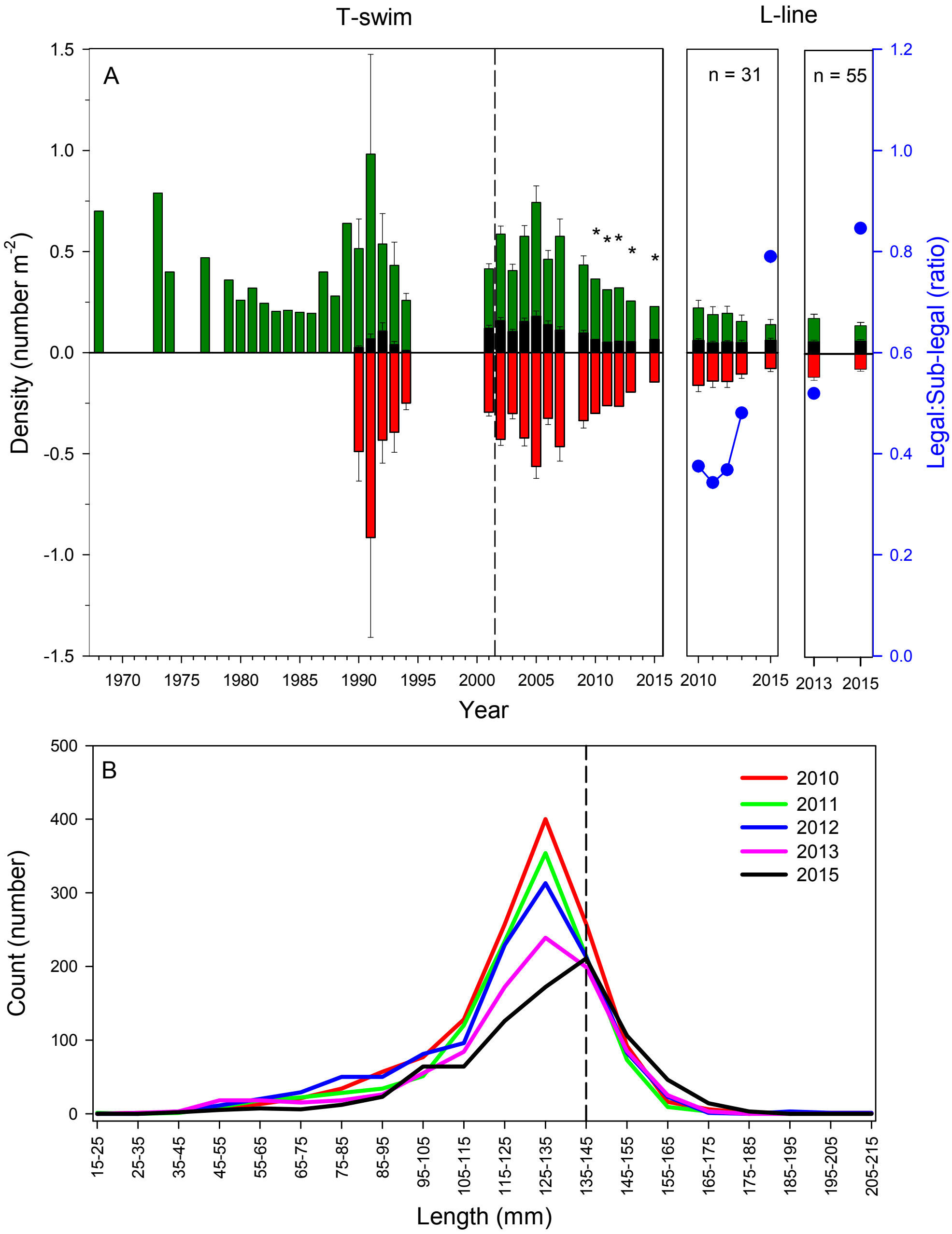

Figure 2-6 (A) Tiparra Reef (high importance). Fishery-independent survey estimates of all greenlip (*i.e.* total number.m^{-2}; green bars), and those greenlip ≥135 mm SL (black bars) and <135 mm SL (red bars) from 1968 to 2015 (timed-swims) and 2010 to 2015 (leaded-lines). Gaps in the time series indicate no surveys done. * indicates estimates of timed-swim densities derived from leaded-line densities. Blue line indicates the ratio of legal (≥135mm) to sub-legal (<135mm) greenlip. Panel on LHS is for timed-swims. Central panel is for all consistent leaded-lines from 2010 to 2015 (n=31). Panel on RHS is for all consistent leaded-lines from 2013 and 2015, that were informed by GPS logger data (n=55). After 2001 the number of timed-swims undertaken increased, and greater consistency was introduced to the survey locations (indicated by the dashed line). (B) length frequency counts binned by 10mm increments on the 31 consistent leaded-lines from Tiparra Reef between 2010 and 2015. Dashed line indicates the legal length of greenlip in the CZ (≥135mm).

West Yorke Peninsula

Catches from the West Yorke Peninsula SAU appear cyclical (Figure 2-7). For example, catches from 1984 to 1992 averaged 14.6 $t.yr^{-1}$ (range 8-27 $t.yr^{-1}$), whereas between 1996 and 2003 the average catch was 3.0 $t.yr^{-1}$. The 2nd period of increased catch, between 2005 and 2007, was shorter and had a lower mean (11 $t.yr^{-1}$). Following another period of low catches from 2008 to 2010, a 3rd cycle of substantial catches from this SAU is ongoing, with a higher mean annual catch (16.2 t) than either of the previous cycles.

Prior to 2012, catch in the West Yorke Peninsula SAU had largely been harvested from two MCs, 22A (Port Victoria) and 24A (Hardwicke Bay; Figure A4-2). Recently, however, large increases in catch have been recorded from MC 23A (Corny Point), from which historical catches were minimal. Notably, in the past two years, >50% of the catch from the West Yorke Peninsula SAU has been harvested from MC 23A, with catches substantially lower from Hardwicke Bay (*i.e.* MC 24A).

The large catches from 2012 to 2015 have been obtained at catch rates among the highest recorded for this SAU (between 23.6 and 26.7 $kg.hr^{-1}$), and at CPUE levels substantially greater than the long-term mean CPUE from 1990 to 2009 (19.6 $kg.hr^{-1}$). However, during this four-year period, the CPUE has decreased successively each year from 26.7 $kg.hr^{-1}$ in 2012 – the highest value on record – to 23.6 $kg.hr^{-1}$ in 2015, representing an overall decrease of 11% since 2012. The recent decreases in CPUE in the West Yorke Peninsula SAU were reflected in the annual estimates of CPUE for MC 24A and 23A (data not shown).

The distribution of daily CPUE values has varied over time (Figure A3-3), in part due to limited catch and effort in several years. The percentage of daily catch records exceeding 30 $kg.hr^{-1}$ has been sustained at, or among, record high levels over the last four years (average: 24%); correspondingly, this period has also produced the lowest average number of poor catch rate days (*i.e.* <15 $kg.hr^{-1}$) on record (average: 5%).

The proportion of large greenlip in the commercial catch has varied substantially through time. Values declined rapidly from 2002 to 2008, but have been substantially higher in recent years. The proportion of large greenlip abalone in this SAU in 2015 was the 2nd highest value on record.

Fishery-independent leaded-line surveys in the West Yorke Peninsula SAU were resumed in 2015 (Figure 2-8). At Hardwicke Bay, six consistent leaded-lines have been sampled intermittently since 2006. The highest density of legal-size greenlip was recorded in 2006 (0.04 $greenlip.m^{-2}$), while the lowest was in 2015 (0.01 $greenlip.m^{-2}$). This represented a 62% decrease in the density of legal-sized greenlip over this period.

No consistent temporal pattern was evident for changes in the density of sub-legal-sized greenlip in Hardwicke Bay. The highest density was recorded in 2008 (0.02 greenlip.m^{-2}), with equally low densities recorded in 2007 and 2015 (0.01 greenlip.m^{-2}). Overall greenlip densities during the 2015 survey were much greater. This was because these densities were determined from an additional 20 leaded-lines (*i.e.* n = 26) informed by GPS logger data. In 2015, the density estimates of legal- and sub-legal-sized greenlip from these 26 leaded lines were 3-fold (0.04 greenlip.m^{-2}) and 7-fold (0.06 greenlip.m^{-2}) higher than those estimated from the consistently-sampled leaded-lines, respectively.

At Port Victoria, 11 consistent leaded-lines have been sampled intermittently since 2007 (Figure 2-8). The density of both legal- and sub-legal sized greenlip in 2015 were the highest on record. For legal-sized greenlip, the density in 2015 (0.04 greenlip.m^{-2}) was more than double the density recorded in 2007 when leaded-lines were initiated (0.02 greenlip.m^{-2}). For sub-legal-sized greenlip, there has been no consistent pattern over time. Similar density estimates were obtained when an additional six leaded-lines were included in the survey design (*i.e.* total n = 17), based on GPS data of fishing location.

At Corny Point, leaded-line surveys commenced in 2015. The 17 leaded-lines surveyed yielded overall densities of 0.02 and 0.01 for legal- and sub-legal-sized greenlip.m^{-2}, respectively (Figure 2-8). These densities at Corny Point were low when compared with other areas surveyed from the CZ. Legal densities were 70%, 57% and 40% lower than Tiparra Reef, Hardwicke Bay and Port Victoria, respectively, while sub-legal densities were 82% and 76% lower than Tiparra Reef and Hardwicke Bay, respectively. However, sub-legal-sized greenlip had a similar density at Corny Point as was recorded at Port Victoria.

The 2015 leaded-line surveys were used to estimate the harvestable biomass in the West Yorke Peninsula SAU. The stratified median estimate of legal-sized (*i.e.* ≥ 135 mm SL) biomass was 114.9 t (90% probability >103.3 t, 10% probability >127.4 t), 18.3 t (90% probability >15.8 t, 10% probability >21.0 t) and 18.6 t (90% probability >15.1 t, 10% probability > 22.6 t) meat weight for Hardwicke Bay, Port Victoria and Corny Point, respectively. The total harvestable biomass estimate for these three survey areas was 151.7 t. The scaled, BMW estimates of the median harvestable biomass in the West Yorke Peninsula SAU in 2015 were 173.8 t (Method 1) and 160.6 t (Method 2).

At the mid-point of the survey (*i.e.* 5 September 2015), the reported catch from WYP was 11.0 t. Adding this value to the scaled median estimate of harvestable biomass suggests the harvestable biomass within the West Yorke Peninsula SAU in January 2015 was between 171.6 t and 184.8 t. As the total catch harvested from West Yorke Peninsula in 2015 was 16.3 t, these estimates suggest that the exploitation rate in 2015 was approximately 9%.

There was considerable spatial variation in estimated exploitation rates, due to the uneven distribution of harvestable biomass and catch among the three survey areas. The spatially-explicit exploitation rates were 2%, 19% and 33% for Hardwicke Bay, Port Victoria and Corny Point, respectively.

2.3.2.4. *Temporal patterns in SAUs of medium importance*

West Kangaroo Island

Prior to 2002, the average catch from this SAU was 1.6 $t.yr^{-1}$ (Figure 2-9). Since 2002, catches have increased, with those from 2009 to 2015 among the highest on record (average: 5.3 $t.yr^{-1}$). Notably, greenlip catches from this SAU in 2013 (7.7 t) and 2014 (9.5 t) were the highest on record, and were followed by a 57% decrease in catch to 4.1 t in 2015. A small amount of catch has historically been taken from numerous mapcodes in the West Kangaroo Island SAU (Figure A4-3). More recently, sustained increases in catch have been harvested from MC 26A, 26B and 27B. In 2013 and 2014, catch also increased from MC 28A and 28B, two mapcodes with low levels of historical catch and/or effort. In 2015, catches from all six mapcodes within this SAU decreased.

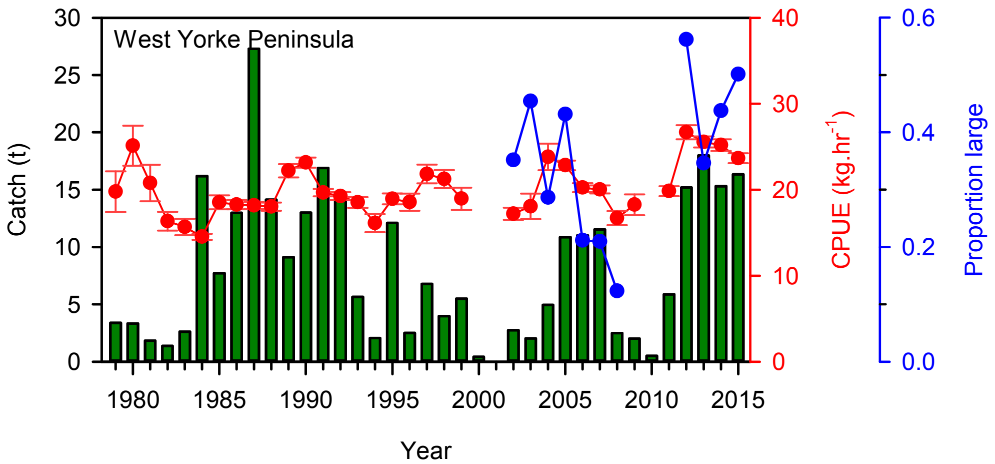

Figure 2-7 West Yorke Peninsula (high importance). Catch (t, meat weight, green bars), CPUE ($kg.hr^{-1}$, ± SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

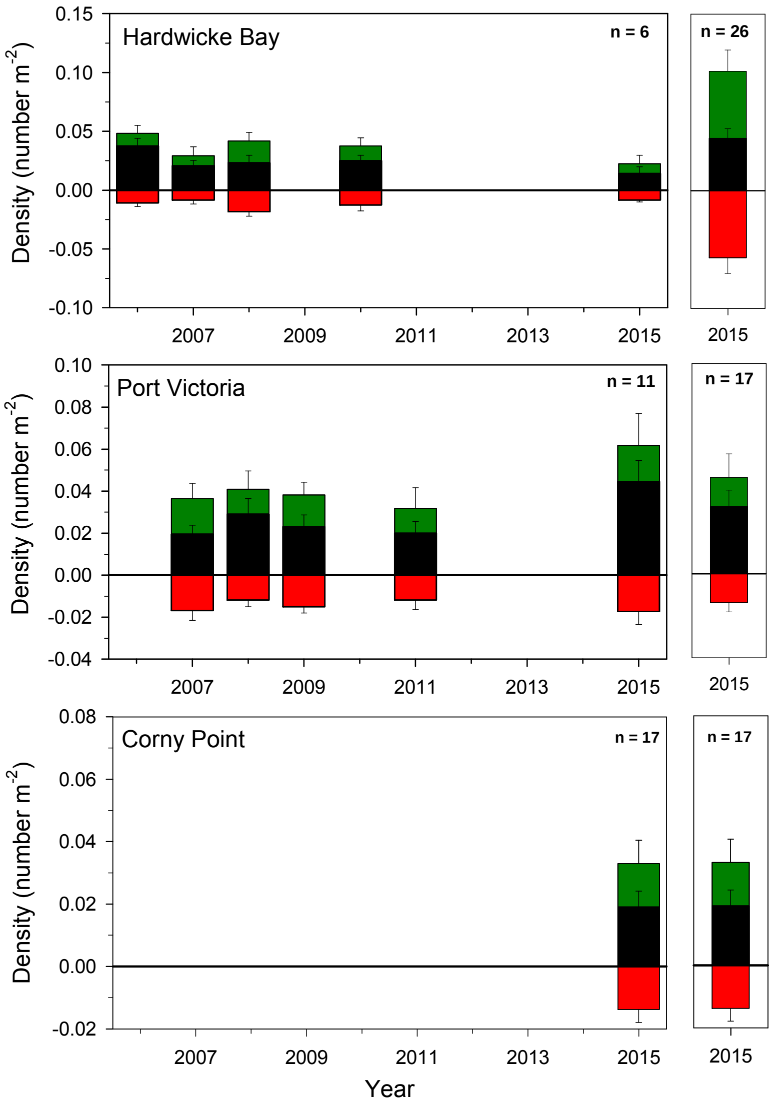

Figure 2-8 West Yorke Peninsula (high importance). Fishery-independent survey estimates of all greenlip (*i.e.* total number.m^{-2}; green bars), and those greenlip ≥135 mm SL (black bars) and <135 mm SL (red bars) from 2006 to 2015. Panels on LHS are for leaded-lines that have been consistently surveyed (Hardwicke Bay, n=6; Port Victoria, n=11; Corny Point, n=17). Panels on RHS are all leaded lines from 2015, that were informed by GPS logger data (Hardwicke Bay, n=26; Port Victoria, n=17; Corny Point, n=17). Gaps in the time series indicate no surveys undertaken.

Before 2002, CPUE fluctuated substantially between years, and often there were inadequate data (<10 fisher-days) to estimate CPUE. Since 2002, inter-annual variability in CPUE has decreased. In 2010, the CPUE of 23.3 kg.hr^{-1}, was the highest value since 1997. Subsequently, CPUE has steadily declined to 17.7 kg.hr^{-1} in 2015. This was 24% below the contemporary 2010 maximum, the lowest value since 2007 and among the lowest values on record for this SAU.

Historically, there has been a high level of inter-annual variation in the proportion of large greenlip in the commercial catch in this SAU. Over the past three years, however, this proportion has stabilised at high levels of >0.7 (Figure 2-9).

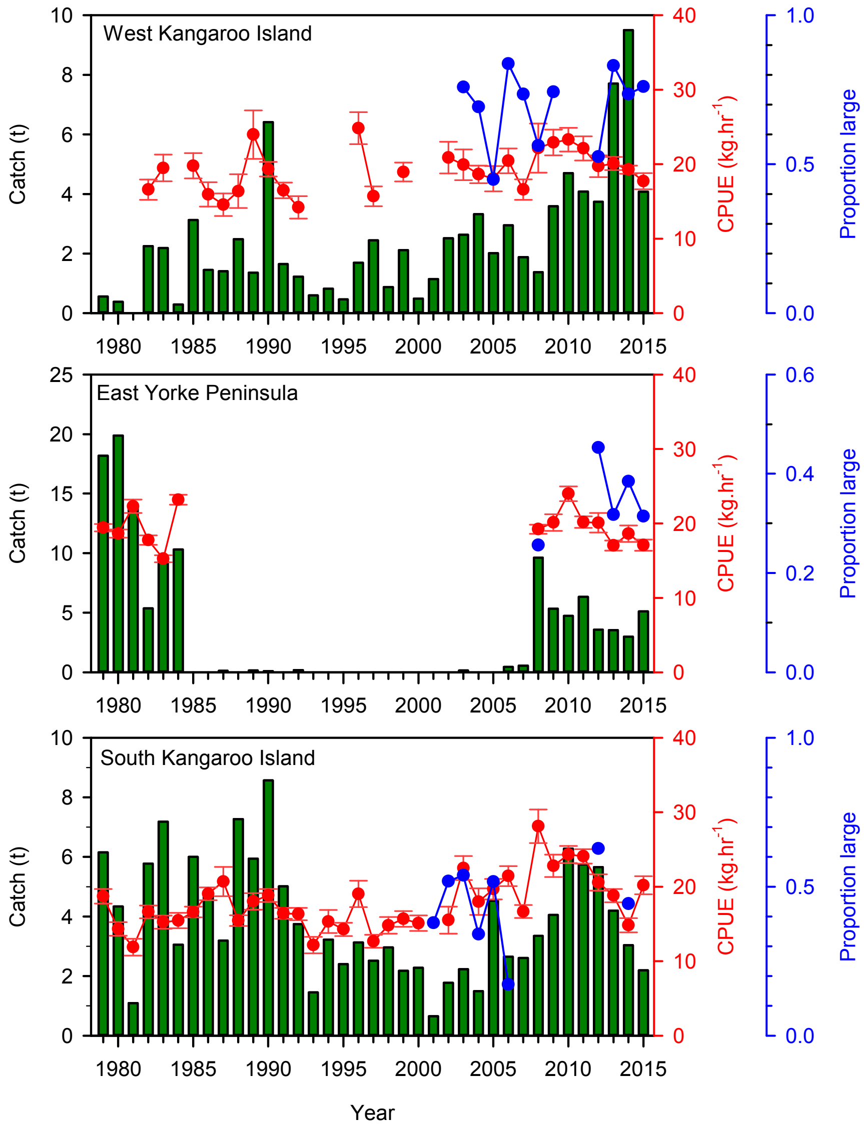

Figure 2-9 Medium importance SAUs. Catch (t, meat weight, green bars), CPUE (kg.hr^{-1}, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

East Yorke Peninsula

Large catches were obtained from the East Yorke Peninsula SAU between 1979 and 1984 (average 12.9 $t.yr^{-1}$). This was followed by >20 years of negligible catch from 1985 to 2007 (Figure 2-9). In 2008, significant catches recommenced in this SAU, averaging 5.2 $t.yr^{-1}$ over the past eight years. After initial contemporary peaks in catch (*i.e.* 2008) and CPUE (*i.e.* 2008-2010), both catch and catch rate have generally declined. The 2015 catch of 5.1 t was obtained at one of the lowest catch rates on record (17.1 $kg.hr^{-1}$). Catch from mapcodes within the East Yorke Peninsula SAU have been dominated by MC 24C and 24E, with smaller contributions from 22B and 24D (Figure A4-3). There were few data available for evaluating temporal trends in the proportion of large greenlip in this SAU, with no long-term temporal trends apparent (Figure 2-9).

South Kangaroo Island

From 1979 to 1992, average annual catch from this SAU was approximately 5 $t.yr^{-1}$, but fluctuated by up to 5 t between years over a 2-3 year cycle. The highest catch was 8.5 t in 1990 (Figure 2-9). From 1993 to 2000, catches were relatively low, averaging approximately 2.5 $t.yr^{-1}$. After a record low of <1 t in 2001, annual catches increased substantially reaching approximately 6 $t.yr^{-1}$ in 2010, the highest on record since 1990. After 2010, catch has declined each year, and was 2.2 t in 2015, representing a 63% reduction in catch over a five-year period. A small amount of catch has historically been taken from the numerous mapcodes comprising the South Kangaroo Island SAU (Figure A4-3). Since 2005, when significant catches from the South Kangaroo Island SAU re-commenced, catch was again distributed among many mapcodes. Notably, reductions in catch from 2010 are also reflected in many mapcodes, but especially 29D, 30A, 30B and 31B.

CPUE increased from the late 1990s, following the prolonged period of relatively low catch, reaching 28.1 $kg.hr^{-1}$ in 2008, the highest value on record. Since then, CPUE has generally declined, reaching 14.8 $kg.hr^{-1}$ in 2014, the lowest value since 1998 and reflective of a 50% decrease over six years. CPUE increased by approximately 30% between 2014 and 2015 (20.2 $kg.hr^{-1}$), which was similar to the mean CPUE over the past 15 years (20.5 $kg.hr^{-1}$). There were few data available to estimate the proportion of large greenlip in the commercial catch, with no evidence of any long-term trend (Figure 2-9).

2.3.2.5. *Temporal patterns in SAUs of low importance*

Catches and catch rates from low importance SAUs were variable among years (Figure 2-10). Among the low importance SAUs, catches from the Cape Elizabeth SAU have made the highest contributions to total annual greenlip catches.

Annual catches from the Cape Elizabeth SAU ranged between 9.2 t in 1981 to catches of less than 1 $t.yr^{-1}$ (*e.g.* 1982, 1987). From 2010 to 2013, annual catches were relatively stable at about 4.7 $t.yr^{-1}$, before declining to <2 and 0.5 t in 2014 and 2015, respectively. The CPUE in the Cape Elizabeth SAU generally increased between 1984 and the contemporary maximum of 36.1 $kg.hr^{-1}$ in 2005. This metric decreased rapidly between 2008 and 2011, where after it has been relatively stable at about 25.7 $kg.hr^{-1}$. There were insufficient data to estimate CPUE in this SAU in 2015. The proportion of large greenlip in the commercial catch from this SAU has varied among years, but was relatively low in 2015 (Figure 2-10)

The other low importance SAUs have made minor and intermittent contributions to catch over the last two decades, despite historical peaks prior to 1990. Consequently, there are few data available for assessment of these SAUs.

2.3.3. Risk-of-overfishing in SAUs and zonal stock status

There were two high and three medium importance SAUs for greenlip (Figure 1-4; Table 2-2). It was possible to determine the risk of being overfished for four of these SAUs (Table 2-2; Figures A5-1, A5-2). Lack of data, and the inability to calculate historical CPUE resulted in the East Yorke Peninsula SAU being categorised as ‘uncertain’. Summed PI scores ranged between -3 (Tiparra Reef) and +19 (West Yorke Peninsula; Table 2-2). The Tiparra Reef SAU was assigned to a ‘yellow', the West Yorke Peninsula and West Kangaroo Island SAUs to a 'light blue', and the South Kangaroo Island SAU to a 'green' risk-of-overfishing category (Table 2-2). The catch-weighted zonal score was 0.61. Under the harvest strategy, this score defines the status of the greenlip fishery in the CZ as ‘under-fished’ (Table 2-2).

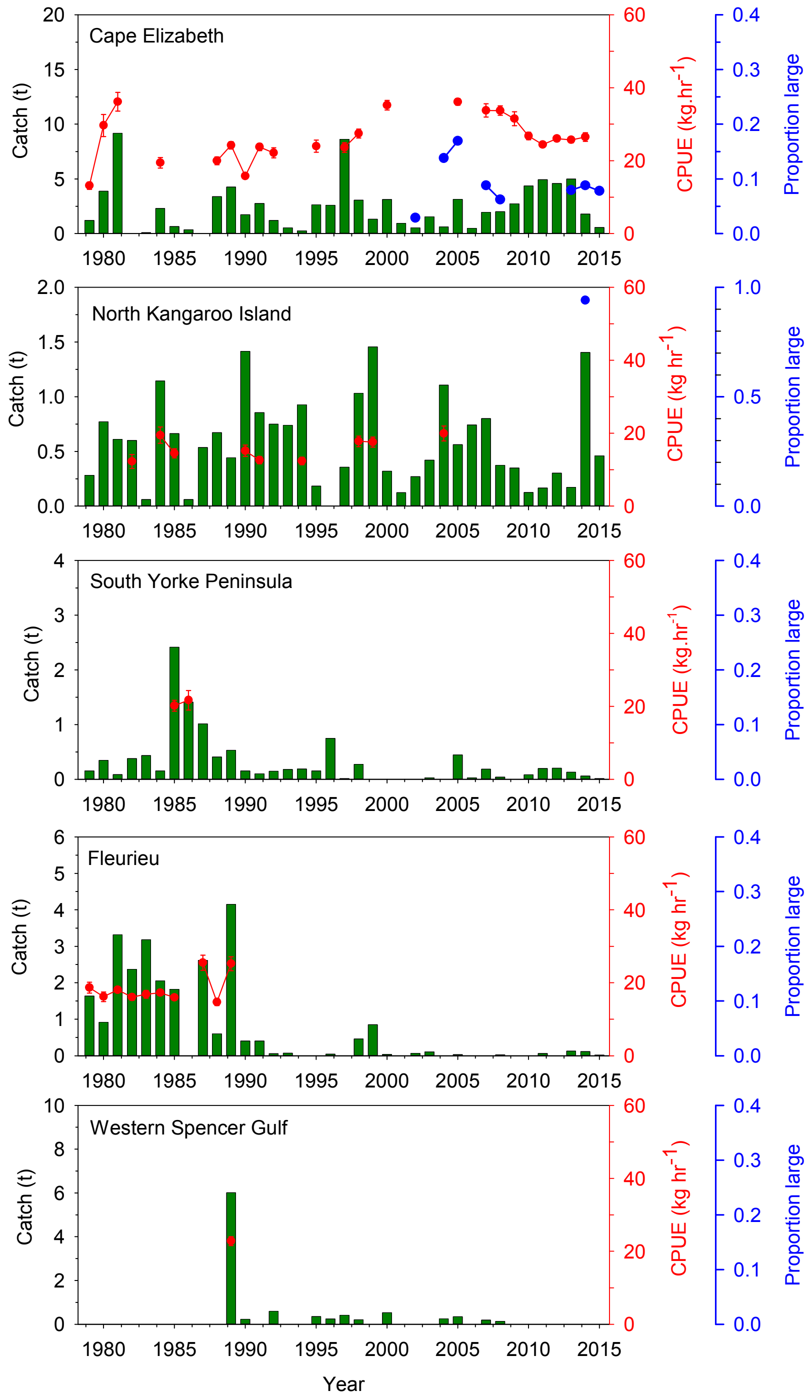

Figure 2-10 Low importance SAUs. Catch (t, meat weight, green bars), CPUE (kg.hr^{-1}, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

Table 2-2 Outcome from application of the harvest strategy described in the Management Plan against the greenlip fishery in the CZ. Grey shading identifies the performance indicators and their respective scores. Coloured shading identifies the risk-of-overfishing category (see Figure 1-3). ND indicates no data.

Spatial assessment unit	%Contribution to mean total catch (CZ) over last 10 years (06-15)	Importance	%Contribution to catch from high & medium SAU in 2015	CPUE	%TACC	%Large	Pre-recruit density	Legal density	Mortality	Combined PI score	Risk of overfishing	Catch-weighted contribution to zonal score
Tiparra Reef	38.9	High	42.8	0	0	6	-6	-3	ND	-3	-1	-0.43
West Yorke Peninsula	17.8	High	41.3	8	8	3	ND	ND	ND	19	2	0.83
West Kangaroo Island	7.9	Medium	10.3	-1	8	1	-	-	-	8	2	0.21
East Yorke Peninsula	7.7	Medium	-	ND	8	ND	-	-	-	Uncertain	Not assigned	-
South Kangaroo Island	7.2	Medium	5.5	1	0	-1	-	-	-	0	0	0.00
Cape Elizabeth	5.2	Low	-	-	-	-	-	-	-	Not assessed	-	-
North Kangaroo Island	0.9	Low	-	-	-	-	-	-	-	Not assessed	-	-
South Yorke Peninsula	0.2	Low	-	-	-	-	-	-	-	Not assessed	-	-
Fleurieu	0.1	Low	-	-	-	-	-	-	-	Not assessed	-	-
Western Spencer Gulf	0.1	Low	-	-	-	-	-	-	-	Not assessed	-	-
Unassigned Central Zone	0	Low	-	-	-	-	-	-	-	Not assessed	-	-
Sum	**85.8**		**100.0**									
											Zonal stock status	0.61

2.4. Discussion

Greenlip comprises 88% of the total abalone TACC (52.4 t *i.e.* blacklip and greenlip) in the CZ of the SAAF, which highlights the importance of greenlip to the CZ abalone fishery. The importance of this species in the CZ, as well as accessibility of the principal fishing grounds, has yielded both fishery-dependent (*i.e.* catch, catch rate, % large) and fishery-independent (*i.e.* legal density, sub-legal density and length-frequency) data for assessment. The current harvest strategy (PIRSA 2012) rationalises resources to ensure they are distributed into assessments of SAUs that support the largest catches. In 2015, following elevated catches from the West Yorke Peninsula SAU over the last decade, fishery-independent surveys were resumed in this SAU. Surveys in the West Yorke Peninsula SAU were undertaken in spring 2015 along with those at Tiparra Reef, which remained the most important SAU within the CZ. These surveys are used to estimate harvestable biomass which is a key data source for assessing stock status.

The harvest strategy in the Management Plan categorised the stock status of this fishery as 'under-fished', which was consistent with the outcome from application of the harvest strategy in 2013 (Mayfield *et al.* 2014a) and 2014 (Mayfield and Ferguson 2015). Problems associated with applying the current harvest strategy, including overly-optimistic classifications of stock status, are well established (Chick and Mayfield 2012; Stobart *et al*. 2012, 2013a, 2014a; Mayfield *et al.* 2014a), and have resulted in an early review of the harvest strategy that is currently underway. For example, in the current harvest strategy, a large contribution of the PI for catch to the combined PI scores can negate low scores for CPUE, a key index of relative abundance. Thus, an increase in the risk-of-overfishing, resulting from substantial decreases in relative abalone abundance, can be offset by large positive scores from the catch PI. In 2015, this occurred in the West Kangaroo Island SAU where the scores for these PIs were 8 and -1, respectively. The combined PI score was 8, resulting in this SAU being assigned to a 'light blue' risk-of-overfishing category. Based on the long-term reductions in CPUE and recent large declines in catch from this SAU, the assigned risk-of-overfishing category is likely over-optimistic. Similarly, because of the spatial and temporal patterns in catch, catch rate and survey density, the overall outcome from the harvest strategy application of 'under-fished' is also unlikely to be realistic. The same problems were evident for blacklip in this report (see Section 3) and will need careful consideration during the current harvest strategy review.

Total greenlip catches in the CZ have been consistent with the TACC since the implementation of this output control in 1990. Notably, despite the record catch of almost 85 t being harvested in 1989, current catches are slightly higher (3%) than the long-term mean catch prior to TACC implementation. This pattern is anomalous because, for many abalone fisheries, current catches are typically substantially lower than historic catches (Prince 2004; Mayfield *et al*. 2012).

Zonal CPUE was relatively stable from 1985 to 1999, but increased rapidly between 1999 and 2000, and again between 2000 and 2001. Subsequently, a decreasing trend was evident for the next decade, before a period of stabilisation from 2011 to 2015. Although this recent five-year period comprises the lowest period of catch rates since 1999, the CPUE during this time has remained 13% above that evident through the 1990s, that preceded the large increase in greenlip abundance evident from 2001.

Since the TACC was implemented, there have been three substantial changes in the spatial distribution of the greenlip catch among the SAUs comprising the CZ abalone fishery. First, catches from the Tiparra Reef SAU increased from 1990 to 2001, reaching 44.9 t and accounting for 94% of the total greenlip harvest in the CZ. Second, from 2001 to 2013, catches from the Tiparra Reef SAU decreased to a historical low of 9.0 t in 2013. During this period, as the TACC remained unchanged, catches from other SAUs increased, most notably the West Yorke Peninsula, South and West Kangaroo Island and East Yorke Peninsula SAUs. Third, there have been successive increases in the catch from the Tiparra Reef SAU in 2014 and 2015. These patterns may reflect changing greenlip abundance on Tiparra Reef and/or the ‘catch cap’, ‘patch rotation’ by divers and/or changing market demands for greenlip with different product quality. However, recent declines in catch and CPUE – indicating reductions in stock abundance in other SAUs – are also likely contributing factors to the most recent trend.

The Tiparra Reef SAU has been the most important SAU for greenlip in both the CZ (59% of annual catch) and the SAAF (22%) since 1990, with these rankings retained despite the reduced catch harvested from this SAU after 2001. There is evidence that the harvestable biomass of legal-sized greenlip on Tiparra Reef has improved from its weak position in 2013 (Mayfield *et al.* 2014a). This is because, between 2013 and 2015, the (1) survey-estimated density of legal-sized greenlip increase, though not significant, exceeded 20%; (2) the mean SL of legal-sized greenlip observed on the surveys in 2015 (146.4 mm SL) was larger than that observed in 2013 (144.2 mm SL). In combination with the increased density, this was reflected in a higher harvestable biomass estimate for Tiparra Reef in 2015 when compared with 2013; (3) catch and the proportion of large greenlip in the catch have increased; the catch in 2015 was 16.9 t, representing 94% of the 18-t ‘catch-cap’; and (4) CPUE in 2015 was 16% higher than that in 2013 and similar to several values in the recent high-CPUE period from 2000 to 2009.

There are, however, considerable data to suggest that short-term (*i.e.* 2-3 years) future levels of harvestable biomass are unlikely to remain at this level. First, the estimated exploitation rates at Tiparra Reef in 2013 and 2015 were approximately 23% and 33%, respectively. Thus, the estimated exploitation rate in 2015 was about 10% higher than that estimated for 2013. These exploitation rate estimates would be considered high for long-lived, slow-growing species (Thorainsdóttir and Jacobsen 2005; Mayfield *et al*. 2008b,c). Notably, at Cowell, exploitation rates of 10% have previously resulted in a rapid decline in stock abundance, putatively driven by low levels of recruitment (Mayfield *et al*. 2008b,c). Second, in contrast to commercial diver observations, there is little evidence of future recruitment to the fishable stock. The 2015 survey estimates of sub-legal sized and pre-recruit greenlip densities were at the lowest levels on record. This reflects the significant decline (>50%) in these density estimates since leaded-line surveys commenced in 2010, and indicates that there are few greenlip to replenish legal-sized and/or spawning stocks. In addition, the ratio of legal-sized to sub-legal-sized greenlip has increased substantially over recent years showing, through time, fewer sub-legal-sized greenlip for each legal-sized greenlip on Tiparra Reef. This pattern is also reflected in the length-frequency distributions of greenlip observed in the surveys as the counts of sub-legal-sized and pre-recruit greenlip have declined since 2010. Third, the estimated density of mature greenlip (*i.e.* ≥80 mm SL) in stratum 1 (the stratum with the highest mean densities) in 2015 (0.2 m^{-2}) is >30% lower than the suggested densities (0.3 m^{-2}) below which fertilisation and recruitment levels are compromised (Babcock and Keesing 1999; Zhang 2008). Fourth, densities of both sub-legal-sized and legal-sized greenlip are low in a historical context. This is in contrast to the last period of sustained, low legal-sized greenlip densities, observed during the early 1990s, when the density of sub-legal-sized greenlip remained high.

The harvest strategy outcome for the Tiparra Reef SAU categorised it as a 'yellow' risk-of-overfishing category. This represented an improvement from the 'red' risk-of-overfishing categories in 2013 and 2014, which were largely consistent with the available data and weight-of evidence assessment for this SAU. However, the low current pre-recruit and sub-legal-sized densities and their capacity to support future catches warrants careful monitoring and consideration.

In response to the generally lower catches from the Tiparra Reef SAU and the stable TACC, total catches harvested outside the Tiparra Reef SAU have increased rapidly in recent years. Over the past five years, approximately 30% of the TACC has been harvested from the West Yorke Peninsula SAU. Overall, the recent large catches from the West Yorke Peninsula SAU that have been obtained at catch rates among the highest reported for this SAU, and similar to those recorded at Tiparra Reef, suggest high levels of harvestable greenlip biomass in this SAU. This assertion was also reflected in the outcome from the harvest strategy, which allocated this SAU to a 'light-blue' risk-of-overfishing category. However, the West Yorke Peninsula SAU is one of the largest in the CZ and comprises (at least) three separate fishing areas – Corny Point, Hardwicke Bay and Port Victoria. Greenlip densities, estimates of harvestable biomass and exploitation rate, catches and fishing effort are inequitably distributed among these three fishing areas. Consequently, the status of greenlip stocks in this SAU, and their capacity to support future catches, requires spatially-explicit assessment. This assessment suggests that the Corny Point and Port Victoria fishing grounds are less likely to be able to support current or increased catches when compared to the Hardwicke Bay fishing grounds.

Hardwicke Bay (MC 24A) is the largest of the fishing areas within the West Yorke Peninsula SAU and, historically, has also yielded the largest and most consistent catches. The total catch harvested from this mapcode in 2015 was substantially smaller than, and was harvested at a CPUE about 15% below, the almost 13 t harvested from this mapcode in 2013. The 2015 survey estimates in Hardwicke Bay yielded a scaled (method 1) greenlip harvestable biomass estimate of 133.9 t. Thus, the small catch in 2015 equates to a low harvest fraction for Hardwicke Bay of 2%. Given the large biomass estimate, low exploitation rate and relatively high density of legal-sized greenlip, it is more likely that the low catch in 2015 reflects divers favouring other fishing areas in the CZ to meet current market demands for larger greenlip (Stobart *et al.* 2014a), rather than declining greenlip abundance. Consequently, it is possible that catches could be redistributed into this mapcode in future years, which highlights the importance of fishery-independent surveys for assessing abalone stock status.

Fishing grounds at Port Victoria (22A) are spatially discrete, readily accessible and nearby the traditional fishing ground of Tiparra Reef. These fishing grounds have supported high, but variable catches, often increasing during periods of lower catch from Tiparra Reef. The large catch harvested from this mapcode in 2015, at a relatively high catch rate, in conjunction with increased survey estimates of legal-sized-greenlip density between 2007 and 2015, suggests high greenlip harvestable biomass. This was confirmed by the scaled survey estimate of harvestable biomass which was 25.4 t. However, the harvest fraction was estimated at 19% in 2015 and the ratio of legal-sized to sub-legal-sized greenlip was high. The capacity of this fishing ground to yield similar (or larger) catches in future years is poorly understood.

In contrast to the other fishing areas within the West Yorke Peninsula SAU, which have recorded large historical catch and effort, significant catches from Corny Point (23A) were first obtained in 2012 (4 t). Subsequently, catches have increased further, totalling 26 t from this mapcode over four years, compared with 7 t for the previous 33 years. This spatial expansion was the likely primary driver of record high CPUEs in the West Yorke Peninsula SAU between 2012 and 2015. However, it is unlikely the Corny Point fishing area will continue to support these high catches on an ongoing basis because (1) the CPUE in this mapcode has decreased by more than 25% since 2012; (2) the estimated harvest fraction in 2015 was high at 33%; and (3) ratio of legal-sized to sub-legal-sized greenlip was high, indicating a limited capacity for future recruitment to the fishable stock.

Numerous other medium and low importance SAUs have yielded substantial catches over much of the last decade, including the West Kangaroo Island, South Kangaroo Island, Cape Elizabeth and East Yorke Peninsula SAUs. Over the past two years, catches and catch rates have not been sustained in these four SAUs. For example, in the West Kangaroo Island SAU, catch decreased by over 50% between 2014 and 2015, and the CPUE in 2015 was among the lowest since TACC implementation, having declined sequentially since 2010. This occurred despite the continued re-distribution of catches into mapcodes from which historically few greenlip have been harvested, which suggests an expansion from traditional to less-traditional fishing grounds to maintain catch. Similarly, for the Cape Elizabeth and South Kangaroo Island SAUs, the catch in 2015 was among the lowest recorded. For the latter, a small increase in CPUE was evident whilst for the former, CPUE was not able to be estimated in 2015. Temporal patterns in the East Yorke Peninsula SAU are less clear, but catches and catch rates since 2013 are generally lower than those from 2008 to 2012, following recommencement of fishing in this SAU. This likely reflects limited recovery from the high greenlip mortality following *Perkinsus olseni* infection (Goggin and Lester 1995), despite the near absence of fishing in this SAU from 1985 to 2005.

These patterns were also evident at a broader spatial scale. For the combined medium importance SAUs, the CPUE has fallen in each of the past five seasons, by a total of 25% to the lowest value since 2007. For the combined low-importance SAUs, the small catch in 2015 was harvested at one of the lowest catch rates on record. These patterns were consistent with the prognosis in the previous stock assessment (Mayfield *et al.* 2014a) and suggest that some fishing grounds in the CZ may be unlikely to support catches of similar magnitude to those harvested over the past five to eight years.

The CZ greenlip fishery was classified as ‘transitional depleting’ in 2014 under the national framework for reporting stock status (Flood *et al.* 2014). There is some evidence to suggest greenlip stocks are improving and/or remain stable. This evidence includes: (1) the long-term (25 years) stable catch consistent with the TACC; (2) relatively high catch rates in most SAUs; (3) the increase in harvestable biomass on Tiparra Reef between 2013 and 2015; (4) low exploitation rates and high harvestable biomass in

Hardwicke Bay, an area that has recently yielded catches between 6 t and 15 t; and (5) the establishment of ‘new’ fishing grounds in recent years (*e.g.* Corny Point). In contrast, other evidence suggests greenlip stocks are in a weak position. For Tiparra Reef, a SAU that historically supported over 90% of the TACC, this evidence includes the (1) low and declining sub-legal-sized and pre-recruit greenlip density; (2) high ratio of legal-sized to sub-legal-sized greenlip; (3) relatively low, legal-sized greenlip density; and (4) high exploitation rate. These have occurred despite the introduction of a ‘catch-cap’ from 2005 (currently 18 t, not always harvested) to constrain catches and reduce fishing pressure. The evidence for the West Yorke Peninsula SAU is the (1) rapid decline (>25%) in CPUE in the Corny Point fishing ground; and (2) high exploitation rate and high ratio of legal-sized to sub-legal-sized greenlip in the Corny Point and Port Victoria fishing grounds. In addition, several medium and low-importance SAUs where catches increased in response to the shift away from Tiparra Reef – West Kangaroo Island, South Kangaroo Island, East Yorke Peninsula and Cape Elizabeth – show declining trends in catch and/or CPUE. In addition to these contrasting lines of evidence for the CZ greenlip fishery, there are also insufficient data with which to distinguish between the two primary alternative hypotheses explaining the ongoing spatial re-distribution of catch in this fishery. These two hypotheses are (1) a rotational fishing strategy that is sustainable; and (2) a sequential depletion of the stocks. In the absence of clear evidence of recruitment, a substantial, widespread increase in greenlip harvestable biomass, and data to separate between the alternate hypotheses, the CZ greenlip fishery remains classified as ‘**transitional depleting**’.

3. BLACKLIP

3.1. Introduction

This section of the report provides spatial and temporal analysis of the fishery-dependent data for blacklip in the CZ from 1 January 1968 to 31 December 2015 and an assessment of the current stock status. Data are presented at three spatial scales. These are (1) the whole blacklip fishery (*i.e.* all areas of the CZ combined); (2) spatial assessment unit (SAU; *e.g.* West Kangaroo Island, see Figure 1-2); and (3) mapcodes from the single medium importance SAU (*e.g.* 26B). This section also includes a formal analysis of the fishery's performance and stock status based on the harvest strategy described in the Management Plan for the fishery (PIRSA 2012), which determines (1) the risk that blacklip stocks in high and/or medium SAUs are overfished; and (2) the zonal stock status for blacklip. In addition, the fishery-dependent, catch and effort data were used to (1) re-evaluate spatial, depth, species and temporal distribution changes in catch and effort as a proxy for diver behaviour; and (2) test alternative methods for estimating CPUE. In the discussion we assess the current status of the blacklip stocks in the CZ, comparing the harvest strategy and the traditional weight-of-evidence assessment.

3.2. Methods

This assessment used fishery-dependent data only. These data comprised catch (t, whole weight), CPUE (kg meat weight.hr^{-1}) and the proportion of large (>155 mm SL) blacklip in the commercial catch (Table 1-4). The quality assurance program is outlined in Appendix 1.

Catch, effort and CPUE

Commercial catch and effort data have been collected since 1968 by fishers completing a research logbook for each fishing day. Catch (t, meat weight) was determined from all logbook returns.

Annual CPUE (kg.hr^{-1}; meat weight; hereafter termed $CPUE_Y$) was calculated for each year as the catch-weighted mean of daily CPUE (Burch *et al.* 2011; see Table 1-4), using those daily records where blacklip catch was ≥30% of the total catch. The small proportion of records (<0.5%) where multiple daily dives are entered as separate days were ignored and retained in the data analysis. The percentage of blacklip in the catch for each daily record was used as a weighting factor in calculating the arithmetic mean of daily CPUE records. To evaluate the potential impacts on $CPUE_Y$ occurring as a result of spatial and temporal changes in diver behaviour, estimates of annual $CPUE_Y$ were derived using multiple sub-sets of the available data. For the CZ and the Western Kangaroo Island SAU these were those daily records where the proportion of blacklip in the total catch was at least 30%, 50%, 75%, 85% and 90% (Figure A6-1).

Visual and Pearson's correlation (*r*; range 0.73-0.98) comparisons among these $CPUE_Y$ estimation methods demonstrated high levels of consistency in temporal trends (after Burch *et al*. 2011). Consequently, all daily records where the proportion of blacklip in the total catch was at least 30% were confirmed as the most appropriate data to determine the $CPUE_Y$ on blacklip in the CZ (Burch *et al*. 2011; Chick and Mayfield 2012; Mayfield *et al.* 2014a). These data were considered the most appropriate, and thus applied in this assessment report, because (1) daily records where blacklip was less than 30% of the catch and likely not targeted on that fishing day were discarded; (2) the lowest number of daily records were discarded, thus ensuring $CPUE_Y$ was determined from most of the available data; and (3) temporal patterns in $CPUE_Y$ across data sets were similar. Despite this approach, limited daily records (*i.e.* n <10) prevented the calculation of $CPUE_Y$ in most years at most spatial scales.

To reduce inter-annual variability in CPUE, consequent from small datasets, three-year, running means of CPUE were also calculated using daily records from the previous three fishing years (see Hart *et al.* 2009). For example, to calculate this metric for 2015, all daily fishing records from 2013, 2014 and 2015 were utilised. Four different methods of determining the running mean were used (1) unweighted mean of all daily records across the three years; (2) unweighted mean of the three annual mean estimates; (3) weighted mean of all daily records, at a ratio of 0.5:0.3:0.2, for data 1-yr old, 2-yrs old and 3-yrs old, respectively; and (4) weighted mean of the three annual mean estimates using the same ratio as in (3).

Visual (Figure A7-1) and Pearson's correlation (Zone: 0.96-0.98; West Kangaroo Island SAU: 0.64-0.95; South Kangaroo Island SAU: 0.91-0.97) comparisons among these four CPUE running mean estimation methods demonstrated high levels of consistency in temporal trend. Method 3 (weighted mean of all daily records, hereafter termed $CPUE_{3Y}$) was chosen because this approach minimised inter-annual variability during years with few records – when compared to Methods 2 and 4 – whilst remaining more reflective of the terminal year in each three-year data estimation than was evident from Method 1. Only the estimates from Method 3 are presented in the results section of the report.

<u>Length-frequency distribution of catch</u>

The proportion of large blacklip (>155 mm SL) in annual catches was determined from the catch-sampling data comprising shell length measurements. From January 2002 to June 2005, these data were obtained by SARDI measuring samples provided by commercial fishers. Data from July 2005 to December 2007, and from January 2008 to December 2015, were provided by the AIASA and Michael Tokley, representing the CZ licence holders, respectively, and supplemented by SARDI sampling on commercial vessels. A small number of divers also provided SARDI with shell-length data directly during this period. No catch-sampling data were provided in 2010 or 2011, and limited data (*i.e.* *n* <100 SL measurements) prevented calculation of this metric in most years at most spatial scales. In this report, the proportion of large blacklip in the West Kangaroo Island SAU in 2013 differs from that provided previously because additional catch sampling records for that year were subsequently provided.

Commercial length-frequency data are important for determining temporal changes in the length structure and mean length of the catch. However, for these data to contribute meaningful information to assessment of the fishery they need to be representative of the fishery, fleet and catch (see Burch *et al.* 2011). Notably, the number of commercial blacklip shell measurements provided for each SAU generally increased with catch (Figure 3-1.A), but the number of blacklip fishing days for which shell samples have been provided was substantially below that expected from the daily catch and effort logs (Figure 3-1.B). This difference persisted through 2013, 2014 and 2015, during which provision of shell sample data was mandatory for each day fished. For example, in 2015, there were 57 days of fishing in West Kangaroo Island where blacklip catch exceeded 5 kg meat weight, but shell sample data were provided for 30 of these. Overall, these data appear to poorly represent the commercial fishery. In particular, the absence of data for 2010 and 2011, and small sample size in 2012, prevents calculation of the 'propLarge' PI in these years for the single medium importance SAU for blacklip – West Kangaroo Island.

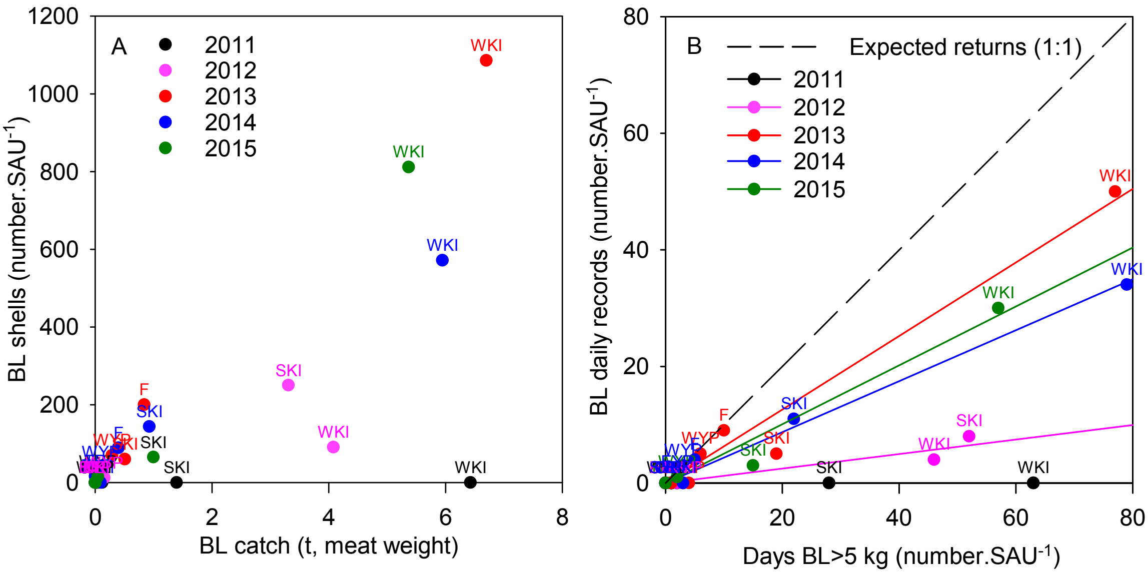

Figure 3-1 (A) Blacklip catch (t, meat weight) and individual shell records (number) for each SAU (TR: Tiparra Reef; CE: Cape Elizabeth; WYP: West Yorke Peninsula; SYP: South Yorke Peninsula; EYP: East Yorke Peninsula; F: Fleurieu; SKI: South Kangaroo Island; WKI: West Kangaroo Island); and (B) Days fished with blacklip catch >5kg (number) and daily shell records (number) for each SAU from 2011-15. Solid lines are linear fit for each fishing year. Dashed black line indicates 1:1 return ratio of shell measurements for days fished.

3.3. Results

3.3.1. Central Zone

3.3.1.1. *Catch and CPUE*

In 2015, the total catch of blacklip decreased to 6.4 t, reflecting TACC reductions following implementation of the marine park sanctuary zones. Prior to 2015, total catch of blacklip had been stable at approximately 8 $t.yr^{-1}$, since the TACC was reduced in 2006 (Figure 3-2). Decreases in annual catch from 2001 to 2006 reflect the TACC not being harvested (2002 to 2004) and sequential reductions in the TACC from 14.1 t in 2004 to 9.9 t in 2005 and 8.1 t from 2006. Current catches are at the lowest levels since 1984 and the TACC is at the lowest level since quota was introduced.

$CPUE_Y$ was relatively stable between 1990 and 2009 (range: 19.4-25.1 $kg.hr^{-1}$; average: 21.8 $kg.hr^{-1}$), where-after it has decreased. Between 2012 and 2014, $CPUE_Y$ stabilised (average: 18.9 $kg.hr^{-1}$), with these estimates being 13% below the average value from 1990 to 2009, and the lowest three year average catch rate since the period from 1984 to 1986. In 2015, $CPUE_Y$ increased to 21.1 $kg.hr^{-1}$, which was the highest value since 2011 and similar to the average value from 1990 to 2009. However, in 2015 the $CPUE_Y$ remained below the recent maxima of 22.7 $kg.hr^{-1}$ in 2009 and 25.1 $kg.hr^{-1}$ in 2003. The temporal trend in $CPUE_{3Y}$ was similar to that for $CPUE_Y$. However, despite the small increase in $CPUE_{3Y}$ between 2014 and 2015, the estimates of $CPUE_{3Y}$ from 2012 to 2015 were the lowest values since 1986 and among the lowest on record for the fishery.

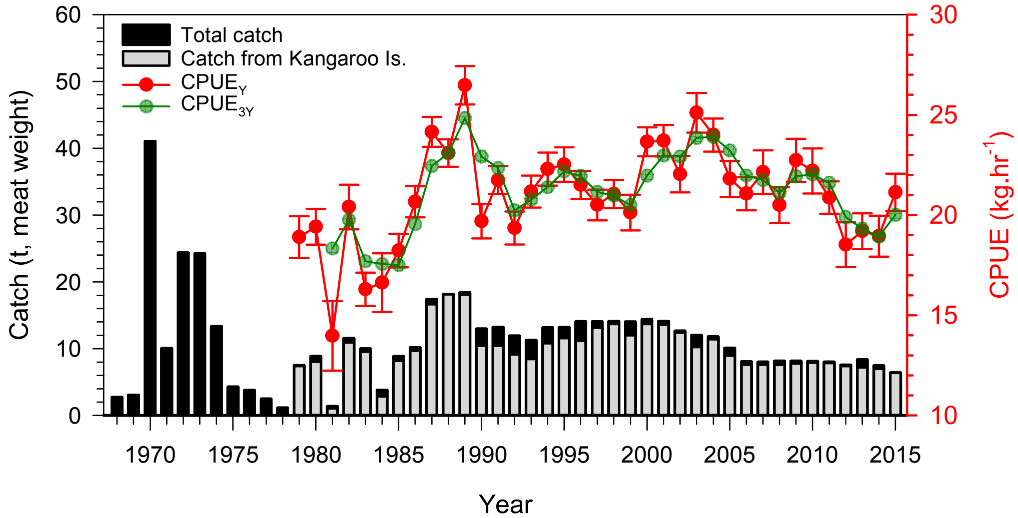

Figure 3-2 Total catch of blacklip for the CZ (t, meat weight, black bars) from 1968-2015. From 1979 to 2015, catch for Kangaroo Island (grey bars) is superimposed on total catch. $CPUE_Y$ ($kg.hr^{-1}$, red line) and $CPUE_{3Y}$ ($kg.hr^{-1}$, green line) are shown by red and green lines, respectively.

3.3.2. Spatial and temporal distribution of catch and effort

Since 1979, most of the total blacklip catch (91%; range: 75-99%) in the CZ has been harvested from Kangaroo Island (Figure 3-3). Over the last 10 years (2006-2015), 95% of the total catch has been taken from the fishing grounds surrounding Kangaroo Island (range: 86-99%). During this decade, there have been several changes in the spatial and temporal distribution of catch and effort on Kangaroo Island, with two particularly notable trends. First, the increased catch of greenlip from fishing grounds off Kangaroo Island from 2008 to 2014, which was followed by a sharp reduction in the greenlip catch from these areas in 2015 (Figure 3-4). Co-incident with this decline was a decrease in the number of days where only greenlip were harvested, and an increase in the ratio of blacklip to greenlip in the daily catch in 2015. Second, fishing effort in the 10-20 m depth range is high and has been increasing (Figure 3-5). This pattern continued in 2015 – with fishing effort in the 10-20 m depth range reaching the highest level on record (88%) – despite greenlip catch reaching its lowest level on Kangaroo Island since 2008 (Figure 3-4). Notably, this pattern was also clearly evident for days when blacklip comprised >85% of the catch, reaching a peak of 81% in 2015 (Figure 3-5).

Since 1979, most of the catch has been harvested from two SAUs (West and South Kangaroo Island; Figure 3-3). Over the past decade (*i.e.* 2006-2015), these two SAUs have contributed an average of >95% (range 86% to 99%) of the total catch each year. The percentage of catch harvested from the West Kangaroo Island SAU has gradually increased over time, while those from South Kangaroo Island have gradually decreased. In 2015, the contribution to the total catch from the West Kangaroo Island SAU was 84%, which was the second highest contribution on record. Blacklip catches from the remaining SAUs have typically been small and infrequent. Overall, there was one medium-importance (West Kangaroo Island) SAU for blacklip in the CZ in 2015.

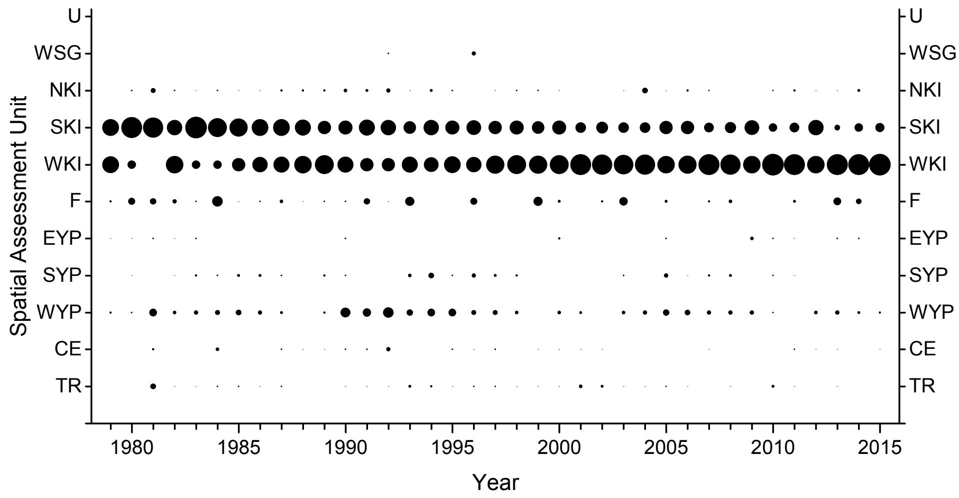

Figure 3-3 Bubble plot showing the spatial distribution of the blacklip catch (% of total catch) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ from 1979 to 2015.

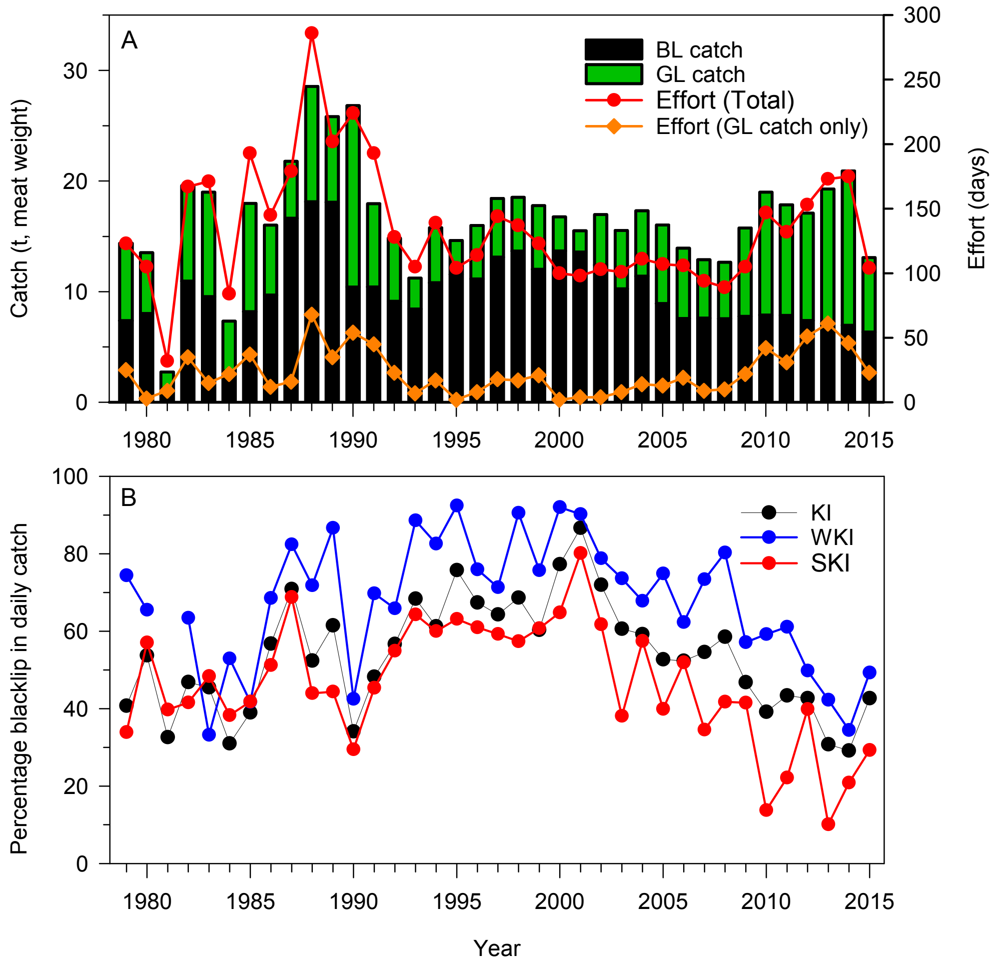

Figure 3-4 For the fishing grounds off Kangaroo Island from 1979 to 2015: (A) Annual catches of blacklip and greenlip showing total annual effort (red circles) and effort when only greenlip were caught (orange diamonds); and (B) average daily proportion of blacklip in the total catch from KI and the West Kangaroo Island (WKI) and South Kangaroo Island (SKI) SAUs.

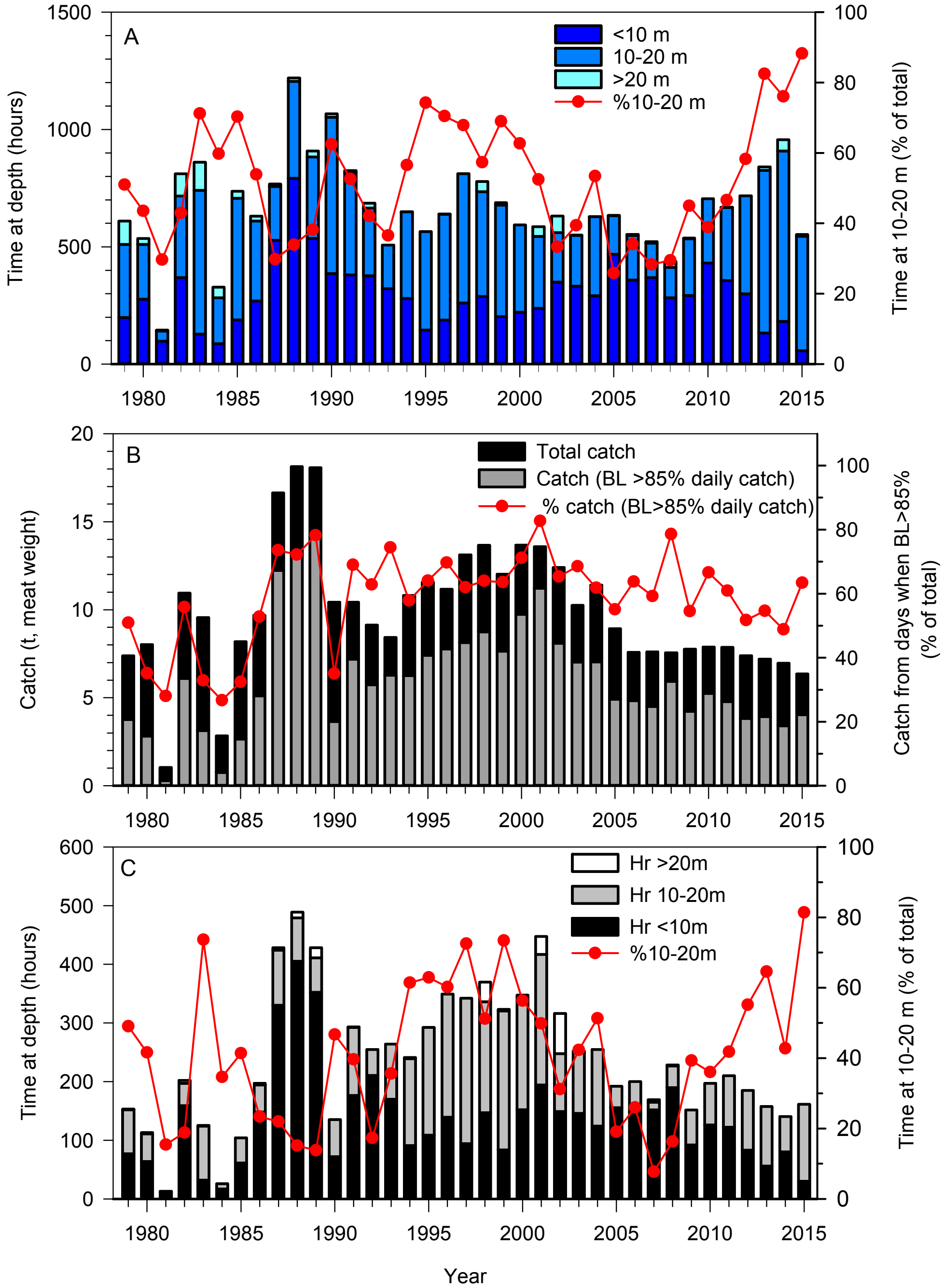

Figure 3-5 For the fishing grounds off Kangaroo Island from 1979 to 2015: (A) time at three depth ranges (blue bars) and the percentage of total time at 10-20 m (red circles); (B) total annual catch of blacklip (black bars; t meat weight) with catches when blacklip comprised at least 85% of the daily catch superimposed (grey bars). Red line shows the percentage of the total blacklip catch taken for days when blacklip comprised at least 85% of the daily catch; and (C) time at three depth ranges (greyscale bars) and percentage of time at 10-20 m depth (red circles) for those days when the blacklip catch was at least 85% of daily catch.

3.3.2.1. *Temporal patterns in the SAU of medium importance*

The only medium importance SAU for blacklip was West Kangaroo Island. This SAU has contributed an average of 55% to the annual blacklip catch since 1979, 66% since 1996 (last 20 years) and 73% since 2006 (last 10 years). This reflects a steady increase in the percentage of catch harvested from this SAU since 1991, which reached the second highest value on record (84%) in 2015 (Figure 3-6).

Catches have varied among years with peaks in 1989 (12.1 t) and 2001 (10.7 t; Figure 3-6). The catch from this SAU increased between 1990 and 1997, then remained relatively stable at an average of 8.8 t between 1997 and 2004. Catches have been substantially lower since 2005 (range: 4.6–6.9 t; average 5.7 $t.yr^{-1}$), reflecting TACC reductions. In 2015, the catch from the West Kangaroo Island SAU was 5.4 t. Most of the catch harvested from the West Kangaroo Island SAU has largely been obtained from MC 26A and 26B (Figure A4-4). Periods of high catch were reported from 27A, 27B and 28A, but these were not sustained. Catches from remaining mapcodes in this SAU have been small and intermittent.

$CPUE_Y$ was relatively stable from 1990 to 2009 (average: 24.1 $kg.hr^{-1}$), although there was some inter-annual variation through this period (range: 19.0-28.0 $kg.hr^{-1}$; Figure 3-6). Between 2009 and 2012, $CPUE_Y$ declined to 20.7 $kg.hr^{-1}$, the lowest value since 1990 and among the lowest values on record. $CPUE_Y$ has subsequently increased, reaching 22.4 $kg.hr^{-1}$ in 2015. However, the annual catch rate remained below the recent maxima of 25.7 $kg.hr^{-1}$ in 2009 and 25.9 $kg.hr^{-1}$ in 2005. As with the zonal CPUE, estimates of $CPUE_{3Y}$ exhibited similar temporal trends to $CPUE_Y$. Despite the small increase in $CPUE_{3Y}$ between 2014 and 2015 – the first since that from 2008 to 2009 – the estimates of $CPUE_{3Y}$ from 2012 to 2015 were the lowest values since 1985 and among the lowest on record for the fishery. The proportion of large blacklip in the catch was the highest on record in 2013, but has subsequently declined to levels similar to the late 2000s (Figure 3-6).

3.3.2.2. *Temporal patterns in SAUs of low importance*

With the exceptions of the West Yorke Peninsula and South Kangaroo Island SAUs, blacklip catches from most low-importance SAUs have been small and intermittent (Figure 3-7). Catches from the West Yorke Peninsula have seldom exceeded 2 $t.yr^{-1}$ and, following the larger catches in the early 1990s, have not been greater than 1 $t.yr^{-1}$. The low catches from this SAU prevented estimation of CPUE in most years.

Annual catch from the South Kangaroo Island SAU has decreased steadily from the approximately 8 $t.y^{-1}$ harvested in the late 1980s. Although relatively large catches were obtained from this SAU in 2009 (3.2 t) and 2012 (3.3 t), the catch over the last three years has not exceeded 1 t, the lowest period of catches from this SAU on record. $CPUE_Y$ was relatively stable from 1979 to 2001 (range: 15.0 - 24.5 $kg.hr^{-1}$). Since 2001, the $CPUE_Y$ has generally declined, but was relatively high in 2003, 2009 and 2011. The 2014 estimate of 12.0 kg.hr^{-1} was the lowest on record and 37% below the long-term mean from 1979 to 2001 (18.9 t.yr^{-1}). There were insufficient data to estimate $CPUE_Y$ in this SAU in 2015. From 1981 to 2009, estimates of $CPUE_{3Y}$ exhibited similar temporal trends to $CPUE_Y$. However, following a record high value of 21.9 kg.hr^{-1} in 2003, estimates of $CPUE_{3Y}$ have decreased in eleven of the past twelve years (except between 2008 and 2009). From 2012 to 2015, the $CPUE_{3Y}$ estimates between 16.2 kg.hr^{-1} and 13.6 kg.hr^{-1}, were the four lowest values on record.

3.3.3. Risk-of-overfishing in SAUs and zonal stock status

There was one medium importance SAU for blacklip, West Kangaroo Island, for which the summed PI score was 5, representing a 'dark blue' risk-of-overfishing category (Figure 1-4, Table 3-1, Figure A5-2). The catch-weighted zonal score was 1. Under the harvest strategy, this score defines the status of the blacklip fishery in the CZ as '**under-fished**' (Table 3-1).

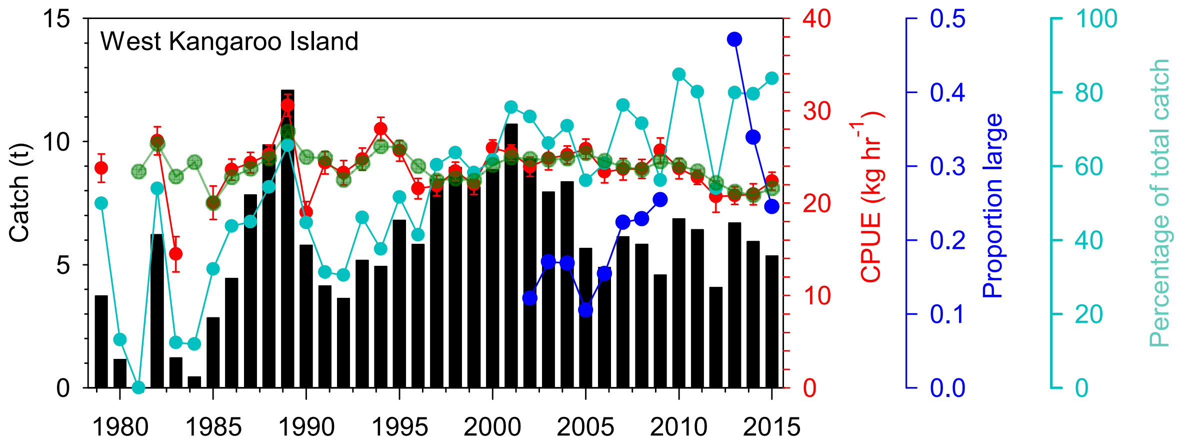

Figure 3-6 West Kangaroo Island (medium importance). Catch (t, meat weight, black bars), $CPUE_Y$ (kg.hr^{-1}, ±SE, red line), $CPUE_{3Y}$ (kg.hr^{-1}, green line), the proportion of large blacklip (>155 mm, blue line) and the percentage of the total blacklip catch (light blue line) each year from 1979 to 2015. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

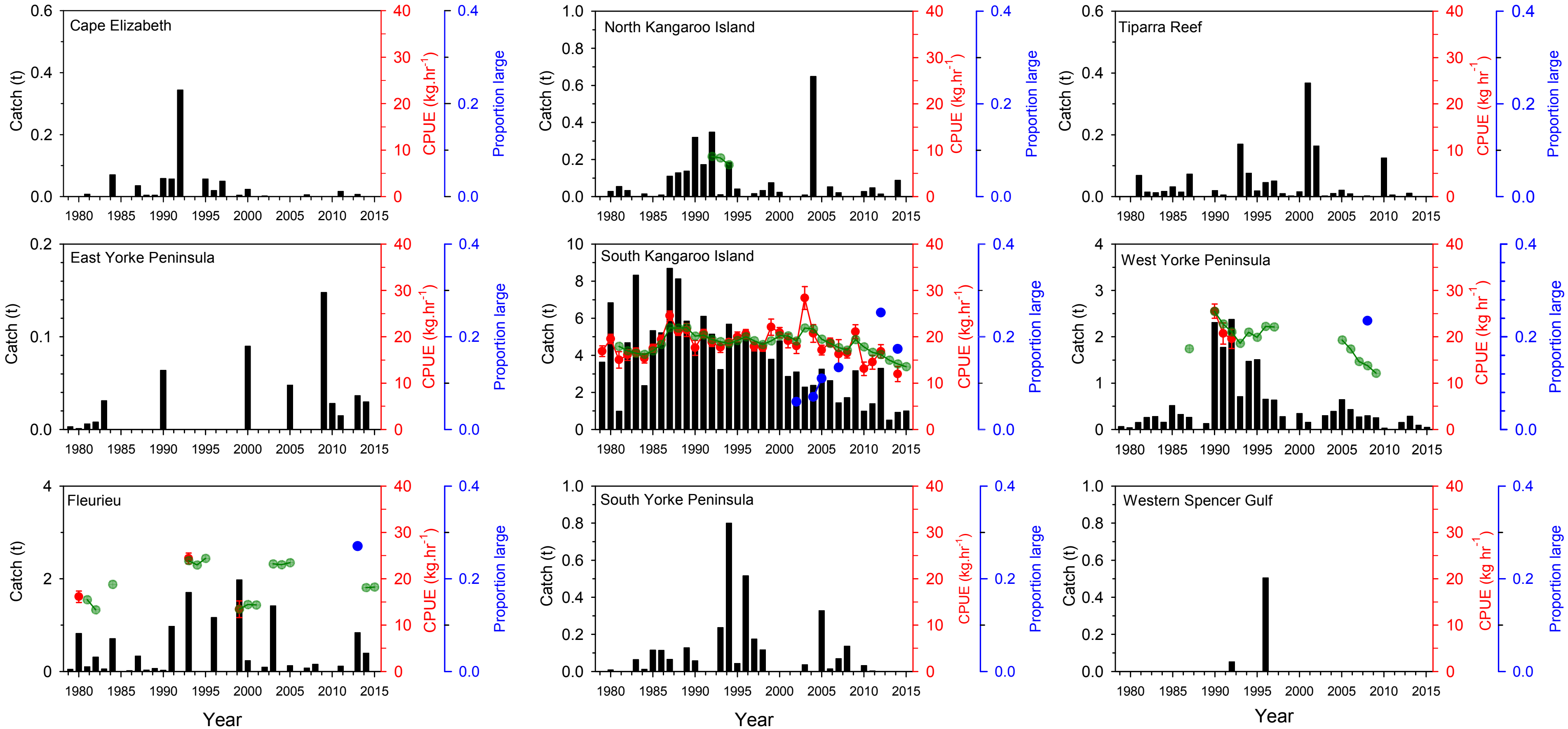

Figure 3-7 Catch (t, meat weight, black bars), CPUE$_Y$ (kg.hr^{-1}, ±SE, red lines), CPUE$_{3Y}$ (kg.hr^{-1}, green lines) and the proportion of large blacklip (>155 mm, blue line) in each of the SAUs of low importance in the CZ blacklip fishery from 1979 to 2015. Gaps in the time series of the CPUE and proportion large indicate insufficient data (<10 fisher days or <100 individuals, respectively). Note different scales on the Y-axes for catch and CPUE.

Table 3-1 Outcome from application of the harvest strategy described in the Management Plan against the blacklip fishery in the CZ. Grey shading identifies the performance indicators and their respective scores. Coloured shading identifies the risk-of-overfishing category (see Figure 1-3).

Spatial assessment unit	%Contribution to mean total catch (CZ) over last 10 years (06-15)	Importance	%Contribution to catch from high & medium SAU in 2015	CPUE	%TACC	%Large	Combined PI score	Risk of overfishing	Catch-weighted contribution to zonal score
West Kangaroo Island	10.3	Medium	100.0	-7	6	6	5	1	1.00
South Kangaroo Island	3.1	Low	-	-	-	-	Not assessed	-	-
West Yorke Peninsula	0.3	Low	-	-	-	-	Not assessed	-	-
Fleurieu	0.3	Low	-	-	-	-	Not assessed	-	-
East Yorke Peninsula	0.0	Low	-	-	-	-	Not assessed	-	-
North Kangaroo Island	0.0	Low	-	-	-	-	Not assessed	-	-
South Yorke Peninsula	0.0	Low	-	-	-	-	Not assessed	-	-
Tiparra Reef	0.0	Low	-	-	-	-	Not assessed	-	-
Cape Elizabeth	0.0	Low	-	-	-	-	Not assessed	-	-
Western Spencer Gulf	0.0	Low	-	-	-	-	Not assessed	-	-
Unassigned Central Zone	0.0	Low	-	-	-	-	Not assessed	-	-
Sum	**14.2**		**100.0**						
								Zonal stock status	**1.00**

3.4. **Discussion**

Blacklip comprises 12% of the total abalone TACC in the CZ of the SAAF. The low proportion of blacklip in the TACC has required this assessment to be entirely reliant on fishery-dependent (*i.e.* catch, effort, catch rate, % large) data. There are no fishery-independent data and these are unlikely to become available because of (1) the difficulty and high cost of accessing the fishing grounds off Kangaroo Island; and (2) the current harvest strategy for this fishery that allocates stock assessment resources to those SAUs from which most of the catch has been harvested.

The harvest strategy in the Management Plan categorised the stock status of this fishery as ‘under-fished’. This was different to the outcome from the two previous applications of the harvest strategy (Mayfield *et al.* 2014a; Mayfield and Ferguson 2015), which categorised the fishery as ‘sustainably fished’. There are several problems associated with applying the current harvest strategy to blacklip in the CZ. Firstly, the ‘under-fished’ stock status for the whole CZ was based on a single SAU of medium importance (West Kangaroo Island). The use of a single SAU to determine the stock status of the whole CZ means that the outcome from the harvest strategy is inherently biased by that SAU, with blacklip stocks in remaining SAUs effectively ignored. Thus, the harvest strategy is poorly representative of the fished stocks. Secondly, substantial decreases in relative abundance – scored through CPUE – and, thus, an increase in the risk-of-overfishing, can have the combined SAU PI score offset by large positive scores from remaining PIs and has been previously identified as a key driver of the differences in stock status derived from the weight-of-evidence and harvest strategy assessments (Chick and Mayfield 2012; Stobart *et al*. 2012, 2013a, 2014a; Mayfield *et al*. 2014a). As an example in this assessment, positive scores for the high proportion of the TACC (+6) and the high proportion of large blacklip abalone (+6) that have been harvested from the West Kangaroo Island SAU offset the large negative score for $CPUE_Y$ (-7). Consequently, the use of the current harvest strategy to determine the zonal stock status of blacklip in the CZ is considered inappropriate. This difficulty is similar to that seen in the Southern Zone (Mayfield *et al*. 2013, 2014b, 2015), where the harvest strategy cannot be used to assess greenlip stock status. The complexities associated with applying the current harvest strategy to blacklip in the CZ will need careful consideration during the current review of the harvest strategy.

Total blacklip catch in 2015 was 6.4 t. Current catches are the lowest since 1984, 50% below the mean catch from 1990 to 2006, and reflect the combination of substantial reductions in the TACC across 2005 and 2006 that were implemented in response to declining stock status (Mayfield *et al*. 2004, 2005a,b) and the TACC reduction in 2015 following implementation of the marine park sanctuary zones.

Over the last decade, reduced catches have coincided with an apparent spatial contraction of the fishery. Over 95% of the blacklip catch has been harvested from two SAUs off Kangaroo

Island – the West and South Kangaroo Island SAUs. Notably, remaining SAUs have yielded low, intermittant and/or declining catches. Since 2006, an increasing proportion of the catch has been harvested from the West Kangaroo Island SAU, and fishing grounds therein. For example, there was a relatively equitable distribution of catch among four West Kangaroo Island SAU mapcodes (26A, 26B, 27A, 27B) between the mid-1990s and mid-2000s. Subsequently, in 2015, catches from two mapcodes (26A, 26B) supported 98% of the catch from the West Kangaroo Island SAU and 82% of the blacklip TACC. This highlights the importance of the blacklip stocks in the West Kangaroo Island SAU, and particularly those off the south-western corner of Kangaroo Island, to the harvesting of the blacklip TACC.

$CPUE_Y$ increased in this SAU between 2014 and 2015, but the degree to which this reflects an increase in blacklip abundance is unclear. The most likely explanation for the inter-annual increase in $CPUE_Y$ is that the spatial changes that have occurred have substantially influenced recent CPUE estimates through a higher proportion of contributing daily records from fishing areas with higher catch rates (i.e. from map 27 to map 26) in 2015. Alternatively, in combination with the reduction in the proportion of large blacklip harvested, the increase in $CPUE_Y$ may reflect recent recruitment to the fishable stock and, consequently, an increase in the harvestable biomass. However, any recruitment pulse would be considered small given that catch rates in the West Kangaroo Island SAU remain among the lowest on record, and the proportion of large blacklip in the catch remains relatively high. The spatial extent of any potential recruitment is also poorly understood because there were insufficient recent data from other fishing grounds to estimate either the proportion of large blacklip in the catch or $CPUE_Y$. These same hypotheses also apply to interpreting the increase in $CPUE_Y$ for the CZ between 2014 and 2015, reflecting the contraction into the West Kangaroo Island SAU where catch rates are highest.

The other SAU from which blacklip catches have been obtained in recent years is the South Kangaroo Island SAU. In this SAU, catch declined steadily over three decades, with current catches approximately 10% of the historic peaks recorded in the 1980s. Likewise, the estimates for both $CPUE_Y$ and $CPUE_{3Y}$ in 2014 and 2015, respectively, were at the lowest levels on record, following ongoing declines over the last decade. The co-incidence of long-term declining catches and catch rates in the South Kangaroo Island SAU, and the increased proportion of the harvest obtained from the West Kangaroo Island SAU, suggests the spatial contraction of the fishery to the south-western corner of Kangaroo Island is at least partly driven by declines in relative blacklip abundance in the South Kangaroo Island SAU. Another potential factor is changing weather patterns related to seasonal changes in blacklip harvesting.

The proportion of time spent fishing in deeper water off Kangaroo Island (*i.e.* 10-20 m depth) has also increased in recent years. In the six years preceding 2015, the proportion of the greenlip TACC and proportion of greenlip in the daily catch from Kangaroo Island increased, prompting a review of changes in diver behaviour (Mayfield *et al.* 2014a). Mayfield *et al.* (2014a) documented the changes in diver's fishing patterns and showed that, despite these changes, a high proportion of the blacklip catch continued to be harvested on days when blacklip dominated the daily catch (*i.e.* at least 85%). This demonstrated that blacklip remained a targeted species off Kangaroo Island. Likewise, the pattern of greater time spent fishing in deeper water off Kangaroo Island was also maintained on days when blacklip dominated the catch (*i.e.* at least 85%). There were further changes in diver behaviour between 2014 and 2015, the most notable of these being an abrupt decline in the harvesting of greenlip from Kangaroo Island. Despite this reduction in greenlip catch from Kangaroo Island, the proportion of time spent fishing in deeper water (*i.e.* 10-20m depth) off Kangaroo Island in 2015 was the highest on record. While this pattern is counter-intuitive to that expected given the preferred habitat of this species is typically in shallow waters (Shepherd 1973), it may reflect the identification of blacklip stocks in deeper waters during greenlip harvesting from 2012-2014 and/or a change in prevailing weather conditions between years (e.g. increased swell and wind in 2015). Data from the Bureau of Meteorology will be required to distinguish among these hypotheses and will be evaluated in the next assessment report for the CZ scheduled for June 2018.

To address the complexity in assessing stock status from large inter-annual changes in $CPUE_Y$ and facilitate formal consideration of longer-term trends in catch rate for assessing stocks, three-year running mean estimates of CPUE (termed $CPUE_{3Y}$) were also derived in this assessment. This approach has the potential to reduce inter-annual variation, faciliating clearer interpretation of temporal trends in catch rate (Hart *et al.* 2009). The temporal trend in $CPUE_{3Y}$ for the CZ was similar to that for $CPUE_Y$. However, despite the small increase in $CPUE_{3Y}$ between 2014 and 2015, the estimates of $CPUE_{3Y}$ from 2012 to 2015 were the lowest consecutive values since 1986 and among the lowest on record for the fishery. For the West Kangaroo Island SAU, estimates of $CPUE_{3Y}$ also exhibited a similar temporal trend to $CPUE_Y$. Again, despite the small increase in $CPUE_{3Y}$ between 2014 and 2015 – the first since that from 2008 to 2009 – the estimates of $CPUE_{3Y}$ from 2012 to 2015 were the lowest consecutive values since 1985 and among the lowest on record for the fishery.

Calculation of $CPUE_{3Y}$ also enabled the estimation of historical catch rates, and thus inferences of relative abundance, for some SAUs of low importance where insufficient daily records have prevented estimation of $CPUE_Y$ (*e.g.* South Kangaroo Island, Fleurieu, West Yorke Peninsula and North Kangaroo Island). For the South Kangaroo Island and West Yorke Peninsula SAUs, the terminal value of $CPUE_{3Y}$ was at, or among, record low levels. This suggests blacklip may no longer be harvested from these SAUs due to low levels of relative abundance.

The CZ blacklip fishery was classified as 'transitional depleting' in 2014 under the national framework for reporting stock status (Flood *et al.* 2014). There is some evidence to suggest blacklip stocks may be improving. This evidence includes: (1) the increase in $CPUE_Y$ between 2014 and 2015 for the CZ and the West Kangaroo Island SAU; and (2) a reduction in the proportion of large blacklip harvested that, in conjunction with this CPUE increase, may reflect a potential small recruitment to the fishable stock. In contrast, much of the available evidence, including the (1) low recent and current catches harvested at relatively low catch rates; (2) limited evidence of stock recovery despite substantial (40%) reductions in the TACC in 2005 and 2006; (3) low (West Kangaroo Island SAU) and/or declining (South Kangaroo Island SAU) catch rates in the two SAUs from which almost all the catch is harvested; (4) apparent spatial contraction of the fishery, principally into two mapcodes in the West Kangaroo Island SAU, from a previously broader spatial distribution across both mapcodes and SAUs; and (5) record low catches from the South Kangaroo Island SAU, an area that regularly supported catches in excess of 5 $t.y^{-1}$ between 1980 and 2000 suggests blacklip stocks remain in a weak position. Consequently, the CZ blacklip fishery remains classified as '**transitional depleting**'.

4. GENERAL DISCUSSION

4.1. Information for assessment of the CZ abalone fishery

There was substantial information available for assessing the abalone stocks in the CZ in 2015 including (1) a well-documented history of the management of the fishery; (2) fine-scale catch and effort data; (3) biological data; and (4) fishery-independent survey data for greenlip at Tiparra Reef and in the West Yorke Peninsula SAU. These fishery-independent surveys provide a key data source for assessing stock status because they are not influenced by changes in diver behaviour or efficiency. In 2015, fishery-independent leaded-line surveys in the West Yorke Peninsula SAU were resumed at Hardwicke Bay and Port Victoria, and commenced at Corny Point. As at Tiparra Reef in 2013 and 2015, the survey design was informed by recent GPS logger data documenting the distribution of fishing effort. The importance of these data to increasing the precision and suitability of the surveys was highlighted by the substantially higher legal-sized greenlip densities on the new leaded lines in Hardwicke Bay, when compared to those historically established in this expansive fishing area using diver-based ‘mud’ maps.

There were several limitations to this assessment. First, with the exception of catch, decision rules are applied to all data series presented in this report (Table 1-4). These constraints are designed to exclude outliers from analyses, thereby reducing potential bias. For example, annual estimates of the catch-weighted mean of daily CPUE for blacklip (Burch *et al*. 2011) excluded records where (1) the percentage of blacklip in the catch was <30%; (2) daily effort was <3 hrs and >8 hrs; and (3) total catch/total effort was >50 kg.hr^{-1}. This approach followed a comprehensive review of current, previous and alternative decision rules to generate CPUE (Burch *et al*. 2011) and was adopted because both blacklip and greenlip can be harvested, but effort is not required to be apportioned among the species or within a fishing day. Previous reviews of the <30% species data constraint found it delivered a robust and objective estimate of blacklip CPUE in the CZ (Mayfield *et al.* 2014a). A similar review of the data constraints used for calculation of greenlip CPUE was undertaken in the current assessment. While these analyses showed that there was a temporal pattern of increased record exclusion in those years with high CPUE estimates, visual and Pearson’s correlation comparisons demonstrated high levels of consistency in temporal trend among the four (current and three alternative data constraint methods) CPUE estimation methods tested. Given this strong correlation, the existing data exclusion rules have been retained in this assessment for continuity with historical data. However, ongoing revision of the data constraints/decision rules is important to ensure they remain sufficiently robust and relevant for the assessment of the stocks in the CZ, particularly as fishing patterns have continued to change over recent years.

In addition to testing the data constraint rules for estimating CPUE, in this assessment we also considered two alternative methods for calculating and presenting CPUE. First, for greenlip, the use of frequency distributions as an alternative method of presenting CPUE data was examined because these can provide information about stock abundance that is not evident from mean catch rates (Tarbath *et al.* 2014). Notably, these bubble plots highlighted the frequency of high CPUE days in the early 2000s, confirming both the overall mean CPUE trend and the need for the CPUE data decision rules to be reviewed. Second, for blacklip, three-year running mean catch rate estimates ($CPUE_{3Y}$) were determined using four analytical methods. This approach enabled catch rates to be estimated during years with fewer fishing records and dampened inter-annual variation faciliating clearer interpretation of temporal trends in catch rate (see Hart *et al.* 2009). However, while running means can address problems associated with insufficient or patchy data, there are some shortcomings with this method of CPUE estimation. The most notable of these is the potential time lag in CPUE response to changes in stock abundance, that was minimised in this assessment by assigning a higher weighting to more recent daily fishing records. This method may have broader application to other species and zones within the SAAF, where insufficient data have limited the ability to estimate CPUE in areas with intermittent or declining fishing effort. However, future studies are required to confirm it's suitability for broad-scale use, including whether it would be more informative than an annual CPUE estimate where a large number of daily records are available.

Second, the limited fishery-independent survey data for greenlip outside the Tiparra Reef SAU, and the absence of these data for blacklip, means assessment of most abalone stocks in the CZ is heavily dependent on the interpretation of commercial catch, effort and CPUE data. The resumption of fishery-independent surveys in the West Yorke Peninsula SAU will partly address this problem in future assessments. However, currently there are insufficient data to determine reference points, preventing formal consideration of these surveys in the application of the harvest strategy in this assessment.

Third, there were limited fishery-dependent data for assessing stocks at spatial scales where catch and effort have declined. This was particularly the case for blacklip, following declines in TACC and the spatial contraction of the fishery into a single SAU (*i.e.* West Kangaroo Island), and for greenlip in several SAUs including Cape Elizabeth.

Fourth, incomplete or insufficient length-frequency data for many SAUs, made it difficult to reliably determine temporal changes in the length structure and mean length of the commercial catch in this fishery, as undertaken in NSW (Andrew and Chen 1997) and Tasmania (Tarbath and Gardner 2011). This is a result of the (1) near-absence of data from 2009 to 2011; and (2) lack of data and/or consistent under-representation of catch from some SAUs between 2013 and 2015 (*e.g.* greenlip in the South Kangaroo Island SAU).

While the availability of shell length data improved when it was introduced as a licence condition in 2013, a pattern of decreasing returns has occurred between 2013 and 2015 in the CZ. The lack of robust, representative, commercial, length-frequency data increases the uncertainty in the assessment of stock status (Burch *et al*. 2010).

Fifth, there are difficulties in interpreting temporal and spatial trends in the catch and catch rate data. Analyses of catch provide information on its temporal variation, among and within fishing areas. However, interpreting changes in the distribution of catch is complicated because fishers may move among stocks for reasons other than changes in abundance including personal preference, market demands for particular product types (*e.g.* larger or smaller abalone), access to launching sites and/or to maintain or increase expected catch rates. CPUE is a key performance indicator used to assess stock status and is based on the assumption that changes in CPUE reflect changes in the abundance of the fishable stock. Decreases in CPUE in abalone fisheries can be considered a reliable indicator of declines in abalone abundance (Tarbath and Gardner 2011).

We note that CPUE can be strongly influenced by numerous factors, including changes in abalone abundance, weather patterns and access to the fishable stocks, age and experience of the fishing fleet, concentration of fishing effort into localised areas of high abalone density, such that changes between years are not reflective of the broader fishing grounds, diver behaviour (*e.g.* number of dives from each diver in each SAU in a given year) and increasing fishing efficiency. For example, the increases in $CPUE_{Y}$ and $CPUE_{3Y}$ observed for blacklip across the CZ and in the West Kangaroo Island SAU between 2014 and 2015 likely reflects a lower proportion of daily fishing records from mapcodes with lower catch rates driven by spatial contraction, rather than an increase in blacklip abundance. Consequently, CPUE is often viewed as a biased index of change in abalone abundance (Harrison 1983; Breen 1992; Prince and Shepherd 1992; Gorfine *et al*. 2002) because catch rates may remain high (or increase) as a result of (1) improvements in technology, fishing skill and enhanced knowledge of fishing areas by fishers, enabling selective targeting of remnant stocks, thereby masking reductions in population size arising from local depletion (Officer *et al*. 2001) or (2) fishers under-estimating their total daily effort by excluding searching time, particularly in less familiar fishing grounds. This reliance on a potentially bias measure of abundance to assess stocks increases assessment uncertainty in SAUs where no fishery-independent data are available. Two potential strategies to limit this uncertainty would be to standardise CPUE (*e.g.* Hart *et al.* 2009) and/or constrain the reference period to 10 years, which minimises technological creep and associated increases in fishing efficiency (Tarbath *et al.* 2014).

4.2. Current status of greenlip and blacklip in the CZ

There were several similarities in the assessment of greenlip and blacklip. First, both stocks remain classified as '**transitional depleting**' under the national framework for reporting stock status (Flood *et al.* 2014). Second, the stock status classifications from the weight-of-evidence assessments contrasted with the outcome from the application of the harvest strategy in the Management Plan ('under-fished'). For blacklip, this difference was exacerbated by the use of a single SAU in the harvest strategy to determine the zonal stock status. Third, current catch rates on both species at many of the spatial scales considered were low and/or declining. Fourth, the assessments of both species were fundamentally dependent on fishery-dependent data, primarily catch and CPUE. The exceptions were for greenlip in the Tiparra Reef and West Yorke Peninsula SAUs where survey estimates of density, population length frequency and harvestable biomass were available. Finally, for both species, there were few data on the length structure of the commercial catch during recent years.

One substantial difference between the species was the spatial distribution of catch. For greenlip, catches have recently been re-distributed among SAUs, and among mapcodes within SAUs. This may reflect sustainable rotational harvest or spatial expansion to maintain catch. In contrast, for blacklip, the proportion of the TACC harvested from the West Kangaroo Island SAU, and mapcodes 26A and 26B, has increased substantially.

4.3. Harvest strategy for the CZ

There are several problems with the current harvest strategy for the fishery that are well documented in previous reports (*e.g.* Chick and Mayfield 2012; Stobart *et al*. 2012, 2013a, 2014a; Mayfield *et al.* 2014a), leading to the current harvest strategy review, scheduled for completion in June 2017. Some of these re-occurred in this assessment.

First, zonal stock status of blacklip was determined from a single medium-importance SAU, while stock status of greenlip was derived from five SAUs, two of high importance and three of medium importance. This limitation for blacklip arises because it comprises 12% of the TACC in this zone and, consequently, few SAUs attain a high or medium importance status. In contrast, application of the harvest strategy to determine stock status of greenlip was more representative of principal SAUs. Increasing the degree to which status assessment through the harvest strategy is representative of the fished stocks could be achieved by changing the criterion by which SAUs are assigned importance, thereby increasing the number of medium-importance SAUs formally considered by the harvest strategy. However, data limitations may also increase the number of SAUs assessed as uncertain. For example, this would have been the case for blacklip in the South Kangaroo Island SAU in this assessment because CPUE was not estimable in this SAU for 2015.

Second, there were few commercial catch sampling data for determining the proportion of large abalone harvested, which is one of the fishery-dependent PIs, particularly from 2008-2012. Although recent sampling has improved with fishers being required to measure five randomly-selected abalone from every catch-bag, for each species from SAUs of designated high and medium importance (after Burch *et al*. 2010), there were numerous days of fishing for which these data were not available. As these data are used to estimate the PI based on the proportion of large abalone in the catch, improved participation rates by fishers are required. Thus, sampling will need to conform to the required protocol to (1) improve the validity of the reference period and scores; and (2) eliminate the need to impose a score of -1 for this PI in future assessments. There are several additional problems with this PI, with its value potentially influenced by factors other than stock status. For example, a change in market demand towards large or small abalone would result in changes to the value of the PI measuring the proportion of large abalone in the commercial catch, and random sampling may be difficult to achieve. As changes to market demand could also influence CPUE, one option to resolve these problems is the use of evidence from other sources (*e.g.* divers, processors) to aid interpretation of this PI.

Third, there are difficulties associated with the PI related to catch. These difficulties arise because the PI for catch was selected as the proportion of the TACC harvested from a particular SAU to avoid TACC changes driving positive or negative scores for catch. However, if the TACC was sufficiently small such that the majority of the catch was obtained from a single SAU, a large positive score could be assigned for the catch PI. This may occur without the absolute amount harvested (*i.e.* tonnes) changing. A similar problem could arise in the absence of a TACC change. SAUs from which recent, unusually high proportions of the TACC were harvested are allocated positive scores which can substantially influence the total score and risk-of-overfishing category for that SAU. For example, in this assessment, scores of 6, -7 and 6 were assigned for the catch, CPUE and proportion large PIs, respectively, for blacklip in the West Kangaroo Island SAU. This resulted in a combined score of 5 and a blue 'risk-of-overfishing' category, which was a more optimistic interpretation of stock status in this SAU than that derived through a 'weight-of-evidence' assessment of these data. Application of the harvest-decision rules (Table 1-5) enables the catch contribution from this SAU to the TACC to be increased. However, the weight-of-evidence does not suggest there is justification for such a change because the CPUE over recent years has been low and/or declining. Three possible solutions to this problem have been identified, and are currently being formally tested during the harvest strategy review. They are (1) allocating negative scores when the proportion of the TACC harvested from a SAU exceeds the UTRP or ULRP; (2) use of supplementary decision rules that prevent an increase in catch contribution to future TACCs when the score for CPUE is zero or negative; and (3) scoring the catch PI consistently with the CPUE PI (or on the cumulative scores of remaining PIs). Thus, where the CPUE PI is scored positively (≥0), high proportions of the TACC would similarly receive positive scores.

There were also problems applying the PI for catch in the Tiparra Reef SAU, which arose from the implementation of the catch-cap in map 21 from 2005. In circumstances where catches are controlled it is inappropriate to allocate scores. To overcome this difficulty, the catch PI for this SAU was set as the percentage of the catch harvested from the Tiparra Reef SAU relative to map 21. However, this solution is not ideal because catches from FA 21 could change substantially through time, whilst the ratio remained static. If this occurred, limited information for the assessment would be obtained from this PI. There are several options for overcoming this problem. These include (1) retaining catch as a PI and developing an alternate scoring system; (2) removing the 'catch-cap' and amending the reference period for this PI across all greenlip SAUs to exclude the time period during which this restriction has been in place; (3) removing catch as a PI for this SAU; (4) removing catch as a PI for this SAU and undertaking fishery-independent surveys more frequently (*e.g.* annually); and (5) replacing the PI for catch with a different PI. Alternatively, the PI-based assessment of this SAU could be replaced with (1) a population model or (2) annual survey estimates of absolute harvestable biomass (*e.g.* Mayfield *et al*. 2008b,c, 2011b) from which a total allowable catch for this area could be set directly.

4.4. **Future research needs**

The most pressing research needs for the CZ abalone fishery are to (1) continue the evaluation of the suitability of the harvest strategy; (2) re-evaluate the appropriateness of the CPUE estimation methods for greenlip and blacklip given ongoing changes in diver behaviour and fishing patterns; (3) determine a process for integrating data (and associated PIs) from GPS and depth loggers into the current assessment framework; (4) document the infection rate and spatial distribution of *Perkinsus* in CZ greenlip, reported through the 2016 season; (5) consider options for obtaining weight-grade data across the catch of both species from processors, in lieu of commercial catch sampling (after Mayfield 2010); and (6) establishing and validating an index of recruitment (*e.g.* FRDC project 2014/010).

The first four of these are the most important. The harvest strategy is currently under review because of the discrepancies in stock status between the weight-of-evidence method and application of the current harvest strategy. This review is particularly important for the CZ, where the small number of licence holders, combined with a limited number of high and medium importance SAUs, has resulted in harvest strategy outcomes that are weighted heavily by new or recently un-fished grounds. The influence of fleet dynamics on the outcomes from the harvest strategy should also be considered through this review.

In this assessment, provisional analyses of the impact of the data decision rules for estimating CPUE were undertaken. Those analyses confirmed that, as fishing patterns have continued to change over recent years, periodic revision of the data constraints/decision rules was important to ensure they remain relevant for the assessment of CZ stocks in the CZ. Similarly, the use of frequency distributions as an alternative method of presenting CPUE data (after Tarbath *et al.* 2014) and three-year running mean catch rate estimates for blacklip also require future studies to confirm their suitability for contributing to determining stock status. In addition, analysing catch rate data to standardise external influences (*e.g.* diver, dive location, month, loss of access, technological advance, swell height and/or wave energy and wind direction and strength) should be considered.

GPS and depth logger data have been collected in the CZ since January 2013. These data have the potential to transform abalone stock assessments because the data are collected at more relevant spatial scales than the current catch and effort data (Mundy 2012; see FRDC project 2011/201) and the use of these data can ease the burden of heavy reliance on fishery-dependent data (principally catch and CPUE) for assessing these stocks. However, for these data to be used, their suitability will need to be validated.

Understanding the distribution and level of infection rate of *Perkinus* is important because this is a notifiable, infectious disease that can impact stock status, trade and market access.

5. REFERENCES

Andrew, N. L. (1996) Review of the South Australian Abalone Research and Management Plan. Report to PIRSA, 35 pp.

Andrew, N. L. and Y. Chen (1997) Optimal sampling for estimating the size structure and mean size of abalone caught in a New South Wales fishery. Fishery Bulletin 95: 403-413.

Babcock, R. C. and J. K. Keesing (1999) Fertilization biology of the abalone *Haliotis laevigata*: laboratory and field studies. Canadian Journal of Fisheries and Aquatic Sciences 56: 1668-1678.

Bardos, D. C. (2005) Probabilistic Gompertz model of irreversible growth. Bulletin of Mathematical Biology 67: 529-545.

Breen, P. A. (1992) A review of models used for stock assessment in abalone fisheries. In: S.A. Shepherd, M.J. Tegner and S.A. Guzmán Del Próo (Editors), Abalone of the World. Biology, Fisheries and Culture. Fishing News Books, Oxford, 253-275.

Brown, L. D. (1991) Genetic variation and population structure in the blacklip abalone, *Haliotis rubra.* Australian Journal of Marine and Freshwater Research 42: 77-90.

Brown, L. D. and N. D. Murray (1992) Genetic Relationships within the Genus *Haliotis*. In: S.A. Shepherd, M.J. Tegner and S.A. Guzmán Del Próo (Editors), Abalone of the World. Biology, Fisheries and Culture. Fishing News Books, Oxford, 19-23.

Burch, P., S. Mayfield and R. C. Chick (2010) A fisher-based, catch-sampling program for a large-scale, benthic molluscan fishery. Fisheries Research 106: 535-542.

Burch, P., S. Mayfield, B. Stobart, R. C. Chick and R. McGarvey (2011) Estimating species-specific catch rates in a mixed-species dive fishery. Journal of Shellfish Research 30: 425-436.

Caddy, J. F. (2002) Limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. Fisheries Research 56: 133-137.

Caddy, J. F. (2004) Current usage of fisheries indicators and reference points, and their potential application to management of fisheries for marine invertebrates. Canadian Journal of Fisheries and Aquatic Sciences 61: 1307-1324.

Carlson, I. J., S. Mayfield, R. McGarvey and C. D. Dixon (2006) Exploratory Fishing and population biology of greenlip abalone (*Haliotis laevigata*) off Cowell. Report to PIRSA. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Research Report Series No. 127, Publication No. RD04/0223-2, 35 pp.

Chick, R. C., N. Turich, S. Mayfield and J. Dent (2009) Western Zone Abalone (*Haliotis rubra* and *H. laevigata*) Fishery (Region A). Fishery Assessment Report for PIRSA. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication No. F2007/000561-3, Adelaide, 90 pp.

Chick, R. C. and S. M. Mayfield (2012) Central Zone Abalone (*Haliotis laevigata and H. rubra*). Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Research Report Series 652, SARDI Publication No. F2007/000611-4, 67 pp.

Day, R. W. and A. E. Fleming (1992) The determinants and measurement of abalone growth. In: S.A. Shepherd, M.J. Tegner and S.A. Guzmán Del Próo (Editors), Abalone of the World. Biology, Fisheries and Culture. Fishing News Books, Oxford, 141-168.

Elliott, N. G., B. Evans, N. Conod, J. Bartlett, R. Officer and N. Sweijd (2000) Application of molecular genetics to the understanding of abalone population structure - Australian and South African case studies. Journal of Shellfish Research 19: 510-524.

Elliott, N. G., J. Bartlett, B. Evans, R. Officer, and M. Haddon (2002) Application of molecular genetics to the Australian abalone fisheries: Forensic protocols for species identification and blacklip stock structure. Final report to the Fisheries Research and Development Corporation, Project Number 1999/164, CSIRO Marine Research, Hobart, 134 pp.

Fargher, S., J. Morison, and L. Rippin (2015) Economic Indicators of the South Australian Abalone Fishery 2013/14. A report to PIRSA Fisheries and Aquaculture, Econsearch, Adelaide, 73 pp.

Fleming, A. (1997) Report on the possible genetic effect on wild abalone of translocating brood stock to abalone hatcheries. Report to the Fisheries Branch, Department of Conservation and Natural Resources, 23 pp.

Flood M., I. Stobutzki, J. Andrews, G. Begg, R. Fletcher, C. Gardner, J. Kemp, A. Moore, A. O'Brien, R. Quinn, J. Roach, K. Rowling, K. Sainsbury, T. Saunders, T. Ward & M. Winning (editors) (2012) Status of key Australian fish stocks reports 2012, Canberra. Fisheries Research and Development Corporation, 421 pp.

Flood, M., I. Stobutzki, J. Andrews, C. Ashby, G. Begg, R. Fletcher, C. Gardner, L. Georgeson, S. Hansen, K. Hartmann, 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 (editors) (2014) Status of key Australian fish stocks reports 2014, Canberra. Fisheries Research and Development Corporation, 620 pp.

Giri, K. and K. Hall (2015) South Australian Recreational Fishing Survey. Fisheries Victoria Internal Report Series No. 62, Queenscliff, 65 pp.

Geiger, D. L. (2000) Distribution and biogeography of the Haliotidae (Gastropoda: *Vetigastropoda*) world-wide. Bolletino Malacologico 35: 57-120.

Goggin, C. L. and R. J. G. Lester (1995) *Perkinsus,* a protistan parasite of abalone in Australia: a review. Marine and Freshwater Research 46: 639-646.

Gorfine, H., R. Day, D. Bardos, B. Taylor, J. Prince, K. Sainsbury, and C. Dichmont (2008) Rapid response to abalone virus depletion in western Victoria: information acquisition and reefcode assessment. Final report to Fisheries Research and Development Corporation, Project No. 2007/066. The University of Melbourne, 72 pp.

Gorfine, H. K., B. T. Taylor and D. C. Smith (2002) Abalone-2001. Fisheries Victoria Assessment Report No. 43, Marine and Freshwater Resources Institute, Queenscliff, 36 pp.

Guest, M. A., P. D. Nichols, S. D. Frusher and A. J. Hirst (2008) Evidence of abalone (*Haliotis rubra*) diet from combined fatty acid and stable isotope analyses. Marine Biology 153: 579-588.

Haddon, M., S. Mayfield, F. Helidoniotis, R. Chick, and C. Mundy (2014) Identification and evaluation of performance indicators for abalone fisheries. Final report to Fisheries Research and Development Corporation, Project No. 2007/02. CSIRO, Hobart, 297 pp.

Haddon, M., C. Mundy and D. Tarbath (2008) Using an inverse-logistic model to describe growth increments of blacklip abalone (*Haliotis rubra*) in Tasmania. Fishery Bulletin 106: 58-71.

Hancock, A. T. (2000) Genetic subdivision of Roe's abalone *Haliotis roei* in south-western Australia. Marine and Freshwater Research 51: 679-687.

Harrison, A. J. (1983) The Tasmanian abalone fishery. Tasmanian Fisheries Research 26: 42 pp.

Hart, A. M. and F. P. Fabris (2007) Digital video techniques for assessing population size structure and habitat of Greenlip and Roe's abalone. Final report to Fisheries Research and Development Corporation on Project No. 2002/079. Fisheries Research Report No. 167, Department of Fisheries, Western Australia, 58pp.

Hart, A., F. Fabris and N. Caputi, (2009). Performance indicators, biological reference points and decision rules for Western Australian abalone fisheries (*Haliotis* sp.): (1) Standardised catch per unit effort. Fisheries Research Report No. 185. Department of Fisheries, Western Australia, 32pp.

Henry, G. W. and J. M. Lyle (2003) The National Recreational and Indigenous Fishing Survey. Final report to the Fisheries Research and Development Corporation, Project Number 99/158, 200 pp.

Jones, K. (2009) South Australian Recreational Fishing Survey. South Australian Fisheries Management Series Paper No. 54. PIRSA Fisheries, Adelaide, 84 pp.

Keesing, J. K., R. Grove Jones and P. Tagg (1995) Measuring settlement intensity of abalone: Results of a pilot study. Marine and Freshwater Research 46: 539-543.

Keesing, J. K. and J. L. Baker (1998) The benefits of catch and effort data at a fine spatial scale in the South Australian abalone (*Haliotis laevigata* and *Haliotis rubra*) fishery. In: Jamieson, G.S., and Campbell, A. (Editors), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management Canadian Special Publications of Fisheries and Aquatic Sciences, 125: 179-186.

Keesing, J. K., K. C. Hall, A. M. Doonan, S. A. Shepherd and J. E. Johnson (2003) A Data Management and Reporting System and Historical Analysis of Catch Records in the South Australian Abalone Fishery. Final report to the Fisheries Research and Development Corporation, Project Number 1994/167, South Australian Research and Development Institute (Aquatic Science), Adelaide, 249 pp.

Lewis, R. K., S. A. Shepherd, P. Sluczanowski and G. Rohan (1984) An assessment of the South Australian abalone resource. South Australian Department of Fisheries, 59 pp.

Lindberg, D. R. (1992) Evolution, distribution and systematics of Haliotidae. In: S.A. Shepherd, M.J. Tegner and S.A. Guzmán Del Próo (Editors), Abalone of the World. Biology, Fisheries and Culture. Fishing News Books, Oxford, 3-18.

Maceina, M.J., P.W. Bettoli and D.R. DeVries (1994) Use of split-plot analysis of variance designs for repeated-measures fishery data. Fisheries 19: 14-20.

Mayfield, S. (2010) Enhancing fishery assessments for an Australian abalone fishery using commercial weight-grade data. Fisheries Research 105: 28-37.

Mayfield, S. and I. J. Carlson (2009) Central Zone greenlip abalone (*Haliotis laevigata*) Fishery. Fishery status report for PIRSA. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Publication No. F2009/000616-1, SARDI Research Report Series No. 399,16 pp.

Mayfield, S., I. J. Carlson and R. Chick (2006) Central Zone Abalone (*Haliotis laevigata* and *H. rubra*) fishery. Fishery assessment report for PIRSA. SARDI Aquatic Sciences Publication No. RD05/0022-2. SARDI Research Report Series No. 166, 79 pp.

Mayfield, S., I. J. Carlson and R. C. Chick (2008a) Central Zone Abalone Fishery (*Haliotis laevigata* and *H. rubra*). Fishery assessment report for PIRSA. SARDI Aquatic Sciences Publication No. F2007/000611-2. SARDI Research Report Series No. 306, 65 pp.

Mayfield, S., I. J. Carlson and R. C. Chick (2010) Central Zone Abalone Fishery (*Haliotis laevigata* and *H. rubra*). Fishery assessment report to PIRSA Fisheries. Confidential. South Australian Research and Development Institute (Aquatic Sciences), Adelaide ,SARDI Aquatic Sciences Publication No. F2007/000611-3. SARDI Research Report Series No. 510, 69 pp.

Mayfield, S., I. J. Carlson and T. M. Ward (2005a) Central Zone blacklip abalone (*Haliotis rubra*) fishery. Status Report for PIRSA. SARDI Aquatic Sciences Publication No. RD05/0028-1. SARDI Research Report Series No. 113, 8 pp.

Mayfield, S., I. J. Carlson and T. M. Ward (2005b) Central Zone Abalone (*Haliotis laevigata* and *H. rubra*) fishery. Fishery assessment report for PIRSA. SARDI Aquatic Sciences Publication No. RD05/0022-1. SARDI Research Report Series No. 106, 79 pp.

Mayfield, S., R. C. Chick, I. J. Carlson and T. M. Ward (2011a) Invertebrate Dive Fisheries Can Be Sustainable: Forty Years of Production from a Greenlip Abalone Fishery off Southern Australia. Reviews in Fisheries Science 19: 216-230.

Mayfield, S., C. D. Dixon, Y. Xiao and T. M. Ward (2004) Central Zone Abalone (*Haliotis laevigata* and *H. rubra*) fishery. Fishery assessment report to PIRSA. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, South Australian Fisheries Assessment Series, Publication No. RD04/0158, 87 pp.

Mayfield, S. and G. Ferguson (2015) Status of the Central Zone Greenlip (*Haliotis laevigata*) and Blacklip Abalone (*H. rubra*) Fisheries in 2014. Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000611-6. SARDI Research Report Series No. 869, 18pp.

Mayfield, S., G. Ferguson, J. Carroll and J. Dent (2014a) Central Zone Abalone (*Haliotis laevigata* and *H. rubra*) fishery. Fishery assessment report to PIRSA, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, South Australian Fisheries Assessment Series, Publication No. F2007/000611-5. SARDI Research Report Series No. 810, 77pp.

Mayfield, S., G. Ferguson, J. Carroll, and A. Hogg (2014b) Status of the Southern Zone Blacklip Abalone (*Haliotis rubra*) fishery in 2012/13. Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Publication No. F2014/000361-1. SARDI Research Report Series No. 791, 21pp.

Mayfield, S., G. Ferguson, A. Hogg and J. Carroll (2015) Status of the Southern Zone Abalone (*Haliotis rubra and H. laevigata*) Fishery. Fishery assessment report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Publication No. F2007/000552-5. SARDI Research Report Series No. 850, 57pp.

Mayfield, S., A. Hogg, and P. Burch (2013) Southern Zone Abalone Fishery (*Haliotis rubra* and *H. laevigata*). Fishery assessment report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000552-4. SARDI Research Report Series No. 694, 64 pp.

Mayfield, S., R. McGarvey, I. Carlson, P. Burch, and J. Feenstra (2008b) Biomass of greenlip abalone (*Haliotis laevigata*) off Cowell in 2008. Report for PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000706-3. SARDI Research Report Series No. 311, 18 pp.

Mayfield, S., R. McGarvey, I. J. Carlson and C. Dixon (2008c) Integrating commercial and research surveys to estimate the harvestable biomass, and establish a quota, for an "unexploited" abalone population. ICES Journal of Marine Science 65: 1122-1130.

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

Mayfield, S., K. J. Miller, and C. M. Mundy (2014c) Towards understanding greenlip abalone population structure. Final report for the Fisheries Research and Development Corporation, Project Number 2010/013, 31 pp.

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: 220-250.

Mayfield, S., K. R. Rodda, P. A. G. Preece, B. L. Foureur and T. M. Ward (2001) Abalone fishery assessment report to PIRSA Fisheries Policy Group. South Australian Assessment Series 01/02, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 73 pp.

Mayfield, S. and T. Saunders (2008) Towards optimising the spatial scale of abalone fishery management. Final report to the Fisheries Research and Development Corporation, Project Number 2004/019. SARDI Aquatic Sciences Publication No. F2008/000082-1. SARDI Research Report Series No. 273, 148 pp.

Mayfield, S. and T. M. Ward (2002) Abalone (Central Zone). Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 02/02b, 66 pp.

Mayfield, S. and T. M. Ward (2003) Central zone abalone (*Haliotis laevigata* and *H. rubra*) fishery. Fishery assessment report to PIRSA Fisheries. South Australian Fisheries Assessment Series. Publication No. RD03/0192, 71 pp.

McGarvey, R., S. Mayfield, K. Byth, T. Saunders, R. Chick, B. Foureur, J. E. Feenstra, P. Preece and A Jones (2008) A diver survey design to estimate absolute density, biomass, and spatial distribution of abalone. Canadian Journal of Fisheries and Aquatic Sciences 65: 1931-1944.

McShane, P. E., K. P. Black and M. G. Smith (1988) Recruitment processes in *Haliotis rubra* (Mollusca: Gastropoda) and regional hydrodynamics in south-eastern Australia imply localized dispersal of larvae. Journal of Experimental Marine Biology and Ecology 124: 175-203.

McShane, P. E. (1991) Density-dependent mortality of recruits of the abalone *Haliotis rubra* (Mollusca: Gastropoda). Marine Biology 110: 385-389.

McShane, P. E. and M. G. Smith (1991) Recruitment variation in sympatric populations of *Haliotis rubra* (Mollusca: Gastropoda) in southeast Australian waters. Marine Ecology Progress Series 73: 203-210.

Miller, K. J., B. T. Maynard and C. M. Mundy (2009) Genetic diversity and gene flow in collapsed and healthy abalone fisheries. Molecular Ecology 18: 200-211.

Miller, K. J., C. M. Mundy and S. Mayfield (2014) Molecular genetics to inform spatial management in benthic invertebrate fisheries: a case study using the Australian Greenlip Abalone. *Molecular Ecology* 23: 4958-4975.

Morgan, L. E. and S. A. Shepherd (2006) Population and spatial structure of two common temperate reef herbivores: abalone and sea urchins. In: J. P. Kritzer and P. F. Sale (Editors), Marine Metapopulations. Elsevier Academic Press, Burlington. 205-246.

Mundy, C. M. (2012) Using GPS technology to improve fishery dependent data collection in abalone fisheries. Final report to the Fisheries Research and Development Corporation, Project Number 2006/029, Institute of Marine and Antarctic Studies, University of Tasmania, 122 pp.

Nobes, M., D. Casement and S. Mayfield (2004) Management Plan for the South Australian Abalone Fishery. South Australian Fisheries Management Series No. 42. Primary Industries and Resources South Australia, Adelaide, 47 pp.

Officer, R. A., C. D. Dixon and H. K. Gorfine (2001) Movement and re-aggregation of the blacklip abalone, *Haliotis rubra* Leach, after fishing. Journal of Shellfish Research 20: 771-779.

Paterson, S., L. Rippin and J. Morison (2013) Economic Indicators for the South Australian Abalone Fishery 2011/12. A report to PIRSA Fisheries and Aquaculture, Econsearch, Adelaide, 68 pp.

PIRSA (2012) Management Plan for the South Australian commercial abalone fishery. URL http://fisheriescouncil.sa.gov.au/fisheries_management_plans. Accessed 2 April 2012. Primary Industries and Regions South Australia, Adelaide, 85 pp.

Prince, J. and H. Peeters (2010) Costs-benefit analysis of implementing alternative techniques for rehabilitating reefs severely depleted by the Abalone Viral Ganglioneuritis epidemic. Final report to Fisheries Research and Development Corporation, Project No. 2008/076, Biospherics, South Fremantle, 87 pp.

Prince, J. D (2004) The decline of global abalone (genus *Haliotis*) production in the late twentieth century: is there a future? In K.M. Leber, S. Kitada, H.K. Blankenship, T. Svasand (Editors), Stock enhancement and sea ranching developments, pitfalls and opportunities. Blackwell Scientific Publications Ltd, Oxford, UK. 427-443

Prince, J. D., T. L. Sellers, W. B. Ford and S. R. Talbot (1987) Experimental evidence for limited dispersal of haliotid larvae (genus *Haliotis*: Mollusca: Gastropoda). Journal of Experimental Marine Biology and Ecology 106: 243-263.

Prince, J. D., T. L. Sellers, W. B. Ford and S. R. Talbot (1988) Confirmation of a relationship between the localized abundance of breeding stock and recruitment for *Haliotis rubra* Leach (Mollusca: Gastropoda). Journal of Experimental Marine Biology and Ecology 122: 91-104.

Prince, J. D. and S. A. Shepherd (1992). Australian Abalone Fisheries and their Management. In: S.A. Shepherd, M.J. Tegner and S.A. Guzmán Del Próo (Editors), Abalone of the World. Biology, Fisheries and Culture. Fishing News Books, Oxford: 407-427.

Rippin, L., S. Paterson and J. Morison (2014) Economic Indicators of the South Australian Abalone Fishery 2012/13. A report to PIRSA Fisheries and Aquaculture, Econsearch, Adelaide, 81 pp.

Rodda, K. R., J. K. Keesing and B. L. Foureur (1997) Variability in larval settlement of abalone on artificial collectors. Molluscan Research 18: 253-264.

Rodda, K. R., C. Styan, S. A. Shepherd and P. McShane (1998) Abalone. Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 98/02, 49 pp.

Rodda, K. R., D. Casement and H. Williams (2000) Abalone. Fishery assessment report to PIRSA fisheries Policy Group. South Australian Fisheries Assessment Series 00/02, 13 pp.

Sainsbury, K. (2008) Best Practice Reference Points for Australian Fisheries. Australian Fisheries Management Authority and the Department of the Environment, Water, Heritage and the Arts, 169 pp.

Saunders, T. and S. Mayfield (2008) Predicting biological variation using a simple morphometric marker in the sedentary marine invertebrate *Haliotis rubra*. Marine Ecology Progress Series 366: 75-89.

Saunders, T., S. Mayfield and A. Hogg (2009a) Using a simple morphometric marker to identify spatial units for abalone fishery management. ICES Journal of Marine Science 66: 305-314.

Saunders, T. M., S. D. Connell and S. Mayfield (2009b) Differences in abalone growth and morphology between locations with high and low food availability: morphologically fixed or plastic traits? Marine Biology 156: 1255-1263.

Shepherd, S. A. (1973) Studies on southern Australian abalone (genus *Haliotis*). I. Ecology of five sympatric species. Australian Journal of Marine and Freshwater Research 24: 217-257.

Shepherd, S. A. (1985). Power and efficiency of a research diver, with a description of a rapid underwater measuring gauge: Their use in measuring recruitment and density of an abalone population. In: C. T. Mitchell, Diving for Science, American Academy of Underwater Science, La Jolla, CA. 263-272.

Shepherd, S. A. (1988) Studies on Southern Australian abalone (genus *Haliotis*). VIII. Growth of juvenile *H. laevigata*. Australian Journal of Marine and Freshwater Research 39: 177-183.

Shepherd, S. A. (1990) Studies on Southern Australian abalone (Genus *Haliotis*) XII. Long-term recruitment and mortality dynamics of an unfished population. Australian Journal of Marine and Freshwater Research 41: 475-492.

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

Shepherd, S. A. and W. S. Hearn (1983) Studies on Southern Australian abalone (Genus *Haliotis*). IV. Growth of *H. laevigata* and *H. rubra*. Australian Journal of Marine and Freshwater Research 34: 461-475.

Shepherd, S. A. and J. Baker (1998) Biological reference points in an abalone (*Haliotis laevigata*) fishery. In: Jamieson, G.S., and Campbell, A. (Editors), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management Canadian Special Publications of Fisheries and Aquatic Sciences, 125: 235-245.

Shepherd, S. A. and L. D. Brown (1993) What is an abalone stock- implications for the role of refugia in conservation. Canadian Journal of Fisheries and Aquatic Sciences 50: 2001-2009.

Shepherd, S. A. and J. Cannon (1988) Studies on Southern Australian abalone (genus *Haliotis*). X. Food and feeding of juveniles. Journal of the Malacological Society of Australia 9: 21-26.

Shepherd, S. A. and S. Daume (1996). Ecology and Survival of Juvenile Abalone in a Crustose Coralline Habitat in South Australia. In: Y. Watanabe, Y. Yamashita and Y. Oozeki (Editors), Survival Strategies in Early Life Stages of Marine Resources. A.A. Balkema, Rotterdam: 297-313.

Shepherd, S. A., D. Lowe and D. Partington (1992) Studies on Southern Australian abalone (genus *Haliotis*). XIII: Larval dispersal and recruitment. Journal of Experimental Marine Biology and Ecology 164: 247-260.

Shepherd, S. A., G. P. Kirkwood, and R. L. Sandland (1982) Studies on Southern Australian Abalone (Genus *Haliotis*). III Mortality of two exploited species. Australian Journal of Marine and Freshwater Research 33: 265-272

Shepherd, S. A. and K. R. Rodda (2001) Sustainability demands vigilance: evidence for serial decline of the greenlip abalone fishery and a review of management. Journal of Shellfish Research 20: 829-841.

Shepherd, S. A., K. R. Rodda, T. Karlov, P. A. Preece and H. Williams (1999) Abalone. Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 99/02, 21 pp.

Shepherd, S.A. and L. Triantafillos (1997) Studies on southern Australian abalone (genus *Haliotis*) 17. A chronology of *H. laevigata*. Molluscan Research 18: 233-245.

Shepherd, S. A. and J. A. Turner (1985) Studies on southern Australian abalone (genus *Haliotis*) VI. Habitat preference, abundance and predators of juveniles. Journal of Experimental Marine Biology and Ecology 93: 285-298.

Stobart, B., S. Mayfield, J. Dent and D. J. Matthews (2013a) Western Zone Blacklip Abalone (*Haliotis rubra)* Fishery (Region A). Fishery Stock Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000561-5. SARDI Research Report Series No. 738, 71 pp.

Stobart, B., S. Mayfield, J. Dent and D. J. Matthews (2014a) Western Zone Greenlip Abalone (*Haliotis laevigata*) Fishery. Fishery Stock Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000373-1. SARDI Research Report Series No. 796, 67pp.

Stobart, B., S. Mayfield, J. Dent and D. J. Matthews (2014b) Status of the Western Zone Blacklip Abalone (*Haliotis rubra*) fishery in 2013. Report for PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2014/000359-1. SARDI Research Report Series No. 789, 13 pp.

Stobart, B., S. Mayfield, J. Dent, D. J. Matthews and R. C. Chick (2012) Western Zone Abalone (*Haliotis rubra* & *H. laevigata*) Fishery (Region A). Fishery Stock Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000561-4. SARDI Research Report Series No. 660, 118 pp.

Stobart, B., S. Mayfield and R. McGarvey (2013b). Maximum Yield or Minimum Risk: Using Biological Data to Optimize Harvest Strategies in a Southern Australian Molluscan Fishery. Journal of Shellfish Research 32: 899-909.

Tarbath, D. and C. Gardner (2011) Tasmanian Abalone Fishery - 2010. Institute of Marine and Antarctic Studies, University of Tasmania, Hobart, 110 pp.

Tarbath, D., C. Mundy and C. Gardner (2014) Tasmanian Abalone Fishery Assessment 2013. Institute of Marine and Antarctic Studies Report, University of Tasmania, Hobart, 120 pp.

Temby, N., K. Miller and C. Mundy (2007) Evidence of genetic subdivision among populations of blacklip abalone (*Haliotis rubra* Leach) in Tasmania. Marine and Freshwater Research 58: 733-742.

Thorainsdóttir, G.G. and L.D. Jacobsen (2005) Fishery biology and biological reference points for management of ocean quahogs (*Arctica islandica*) off Iceland. *Fisheries Research* 75: 97-106.

Zacharin, W. (1997) Management plan for the South Australian Abalone Fishery. Internal document. Primary Industries and Regions – Fisheries and Aquaculture, South Australia, 33 pp.

Zhang, Z. (2008) A simulation study of abalone fertilization. Journal of Shellfish Research 27: 857–864

Appendix 1. Quality Assurance

Quality assurance systems form an integral part of stock assessments undertaken by SARDI. These systems are designed to ensure high quality project planning, data collection and storage, analyses, interpretation of results and report writing.

A.1.1 Research planning

The requirements of PIRSA were discussed in December 2014 and subsequently provided to representatives of the CZ abalone fishery to confirm their understanding of proposed deliverables. This ensures that the research undertaken and deliverables provided are consistent with the needs of PIRSA to meet their obligations under the Fisheries Management Act 2007.

A.1.2 Data collection

The data provided by commercial fishers are checked by SARDI prior to acceptance and potential errors corrected through direct correspondence with individual commercial fishers. SARDI staff are trained to undertake FI data collection using the standardised method described in the SARDI Abalone Research Group Quality Assurance and Fishery-Independent Survey Manual (QAFISM).

A.1.3 Data entry, validation, storage and security

All logbook data are entered and validated according to the quality assurance protocols identified for the abalone fisheries in the SARDI Information Systems Quality Assurance and Data Integrity Report. The data are stored in an Oracle database, backed up daily, with access restricted to SARDI Information Systems staff. Copies of the database are provided to SARDI abalone researchers on request. All FI data are entered into Excel spreadsheets. A subset of the data (20%) is checked against the original data sheets in accordance with the Abalone Data Library Management Protocol (DLMP). Once validated, data are uploaded to an Access database stored on the network drive in Port Lincoln. The database is regularly backed up to an external hard drive and to Objective, a secure government network.

A.1.4 Data and statistical analyses

Data are extracted from the databases using established protocols. A subset (10%) of data extractions are checked to ensure extraction accuracy. This occurs in two ways. First, data are compared to those extracted previously. Second, the data extractions are undertaken by two SARDI researchers and subsequently compared. Most of the data are analysed using the open source software R. A subset (~10%) of the outputs from R are compared against estimates made in an alternative package (e.g. Excel).

A.1.5 Data interpretation and report writing

The results, their interpretation and conclusions provided in the reports are discussed with peers, PIRSA and abalone licence holders before the report is finalised. All co-authors review the report prior to the report being formally reviewed by two independent scientists at SARDI in accordance with the SARDI report review process. Following necessary revision, the report is reviewed by PIRSA to ensure it is consistent with their needs and objectives for the fishery.

Appendix 2. Abalone Biology

Table A2-1 Shell length (mm) at 50% maturity for greenlip in the CZ.

Year	Site	Length at 50% maturity (mm)	CI (95%)	Reference
1964	West Island	87.0	-	Shepherd and Laws (1974)
1969	Tiparra Reef – Lighthouse	75.0	-	Shepherd and Laws (1974)
2003	Tiparra Reef – West bottom	78.9	78.2-79.6	SARDI unpublished data
2004	Tiparra Reef – Coal ground	88.4	88.0-88.7	SARDI unpublished data
2004	Tiparra Reef – West bottom	83.3	81.7-84.9	SARDI unpublished data
2007	Tiparra Reef – Coal ground	79.9	79.3-80.4	SARDI unpublished data
2007	Tiparra Reef – Midwest bottom	75.9	70.2-81.6	SARDI unpublished data

Table A2-2 Relationship between shell length (mm) and bled meat weight (BMW, g) for greenlip in the CZ. The equation is of the form BMW = aSL^b.

Year	Site	a (x 10^{-5})	b	r	n	Reference
1997	Tiparra Reef – West Bottom	3.68	3.06	0.89	97	SARDI unpublished data#
1997	Tiparra Reef	0.42	3.51	-	-	Shepherd and Baker (1998)*
1997	West Island	0.57	3.41	-	-	Shepherd and Baker (1998)*
2003	Tiparra Reef – West Bottom	0.81	3.35	0.99	82	SARDI unpublished data*
2004	Tiparra Reef – Coal Ground	3.45	3.06	0.98	164	SARDI unpublished data*
2004	Tiparra Reef – Mid West Bottom	1.06	3.28	0.97	99	SARDI unpublished data*
2004	Tiparra Reef – West Bottom	1.06	3.29	0.99	204	SARDI unpublished data*
2007	Tiparra Reef – Coal Ground	5.78	2.95	0.94	123	SARDI unpublished data*
2007	Tiparra Reef – Mid West Bottom	1.79	3.16	0.97	129	SARDI unpublished data#
2013	Tiparra Reef – Mid West/Coalground	32.0	2.62	0.56	149	SARDI unpublished data
2015	Western Yorke Peninsula – Corny Point	0.20	3.61	0.82	100	SARDI unpublished data
2015	Western Yorke Peninsula – Hardwicke Bay	0.09	3.74	0.77	121	SARDI unpublished data

*/# indicate some/all BMW = Shell Weight * 1/3

Table A2-3 Relationship between fecundity (F, millions of eggs) and shell weight (SW, g) and between fecundity and shell length (mm) for greenlip at Tiparra Reef and West Island in the CZ. The equations are of the form F = aSL^b and F = c + dSW.

Year	Site	a	b	c	d	Reference
1986	Tiparra Reef	-	-	-1.51	0.02	Shepherd and Baker (1998)
1986	West Island	-	-	-0.36	0.015	Shepherd and Baker (1998)
2004	Tiparra Reef – Coal Ground	0.4271	3.09	-	-	SARDI unpublished data
2004	Tiparra Reef – Mid West Bottom	0.0007	4.26	-	-	SARDI unpublished data
2007	Tiparra Reef – Mid West Bottom	2 x 10^{-10}	5.01	-	-	SARDI unpublished data

Table A2-4 Mean growth rate ($mm.yr^{-1}$) of greenlip tagged and recaptured in the CZ.

Site	Length range	Growth rate ± SE	Reference
West Island	42-141	20.3±0.4	Shepherd (1988)
Tiparra Reef	51-129	20.9±0.7	Shepherd and Triantafillos (1997)
Tiparra Reef	46-157	15.4±0.8	SARDI unpublished data

Table A2-5 Growth rate parameters k (yr^{-1}) and L_∞ (mm SL) for greenlip tagged and recaptured in the CZ of the South Australian Abalone Fishery. Length ranges are shell length (mm).

Site	Length range	k ($.yr^{-1}$)±SE	L_∞±SE	Reference
West Island	42-141	0.479±0.029	137.9±1.9	Shepherd and Hearn (1983)
Tiparra Reef	51-129	0.406±0.047	130.8±2.5	Shepherd and Hearn (1983)

Table A2-6 Natural mortality rates ($M.yr^{-1}$) for adult (emergent) greenlip at two sites in the CZ.

Site	M ± SE	Reference
West Island	0.26±0.06	Shepherd *et al*. (1982)
Tiparra Reef	0.22±0.10	Shepherd *et al*. (1982)

Table A2-7 Shell length at 50% maturity (mm) for blacklip in the CZ.

Year	Site	Length at 50% maturity (mm)	CI (95%)	Reference
1964	West Island	76	-	Shepherd and Laws (1974)
1969	Tiparra Reef	93	-	Shepherd and Laws (1974)
2004	Cape Bedout	92.2	89.8-94.7	SARDI unpublished data
2004	Cape du Couedic	97.9	96.1-99.7	SARDI unpublished data
2004	Weirs Cove	99.6	98.3-100.9	SARDI unpublished data
2005	Cape Bedout	97.2	95.7-98.7	SARDI unpublished data
2007	Vennachar Point	109.2	107.4-111.0	SARDI unpublished data

Table A2-8 Relationship between fecundity (F, millions of eggs) and shell length (mm) for blacklip in the CZ. The equation is of the form $F = aSL^b$.

Year	Site	a	b	Reference
2004	Cape Bedout	9×10^{-8}	3.715	SARDI unpublished data
2004	Cape du Couedic	1×10^{-8}	4.059	SARDI unpublished data
2005	Cape Gantheaume	8×10^{-8}	3.623	SARDI unpublished data
2005	Charlies Gulch	9×10^{-13}	5.966	SARDI unpublished data
2005	Cape Bedout	2×10^{-11}	5.202	SARDI unpublished data
2007	Vennachar Point	6×10^{-9}	4.019	SARDI unpublished data
2007	Cape du Couedic	2×10^{-6}	2.907	SARDI unpublished data

Table A2-9 Growth rate parameters k (yr^{-1}) and L_∞ (mm SL) for blacklip tagged and recaptured in the CZ. Errors provided are standard errors. Length ranges are shell length (mm).

Site	Length range	k	L_∞	Reference
West Island	52-142	0.34±0.034	138.8±2.9	Shepherd and Hearn (1983)
Tiparra Reef	73-140	0.32±0.063	142.6±4.3	Shepherd and Hearn (1983)

Table A2-10 Natural mortality rates (M.yr-1) for adult (emergent) blacklip at two sites in the CZ.

Site	M	Reference
West Island	0.36±0.28	Shepherd *et al*. (1982)
Tiparra Reef	0.21±0.10	Shepherd *et al*. (1982)

Appendix 3. CPUE estimates of greenlip in the Central Zone

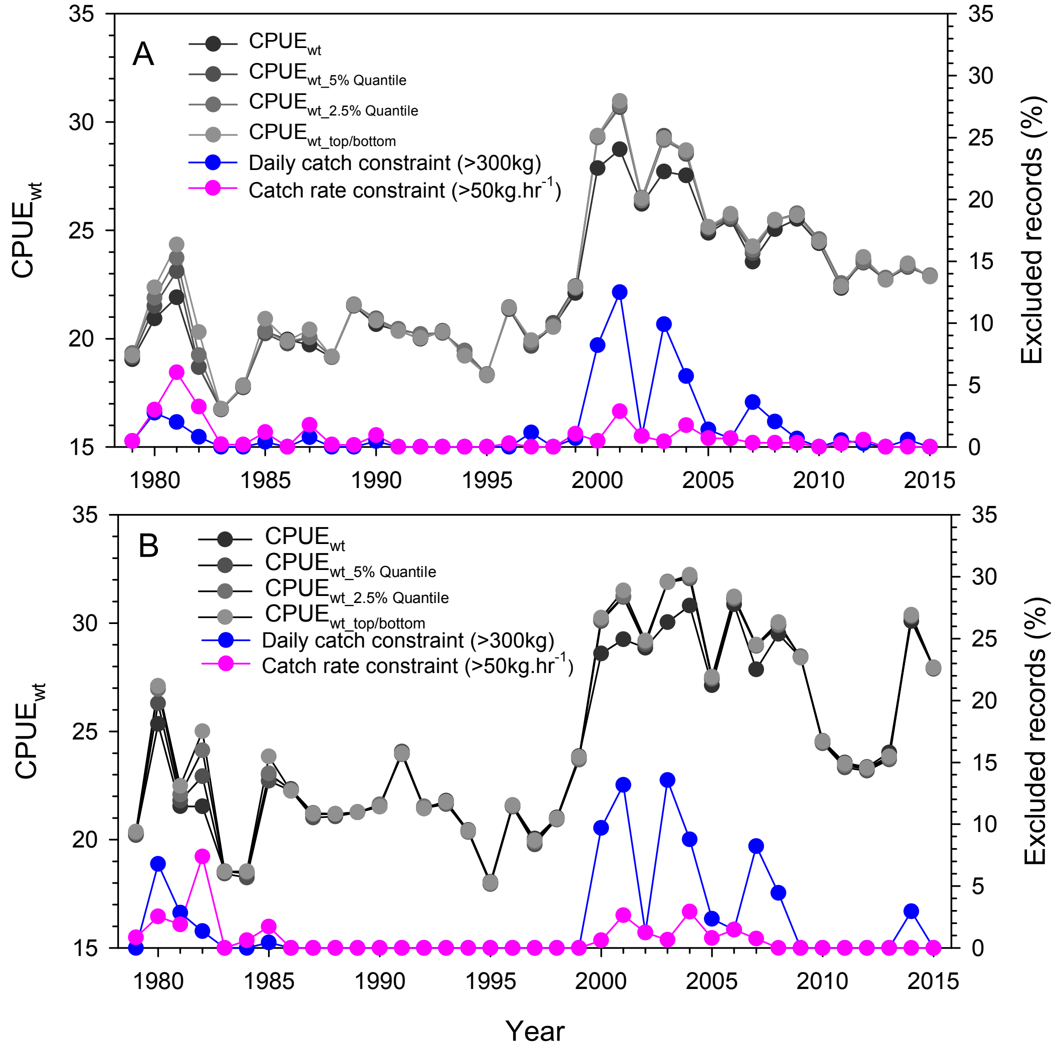

Figure A3-1 Catch rates ($CPUE_{wt}$, kg.hr^{-1}) for greenlip in the (A) Central Zone and (B) Tiparra Reef from 1979-2015 using four different data constraint methods (1) $CPUE_{wt}$ - the current data constraints for daily catch (>300 kg) and catch rate (>50 kg.hr^{-1}); (2) $CPUE_{wt\_5\%\ quantiles}$ – exclusion of upper and lower 5% of CPUE values; (3) $CPUE_{wt\_2.5\%\ quantiles}$; – exclusion of upper and lower 2.5% of CPUE values; and (4) $CPUE_{wt\_top/bottom}$ –exclusion of top and bottom CPUE value. Blue lines indicates the percentage of catch records that are currently deleted using the daily catch constraint (i.e. >300 kg). Pink lines indicates the percentage of catch records that are currently deleted using the catch rate constraint (*i.e.* >50 kg.hr^{-1}).

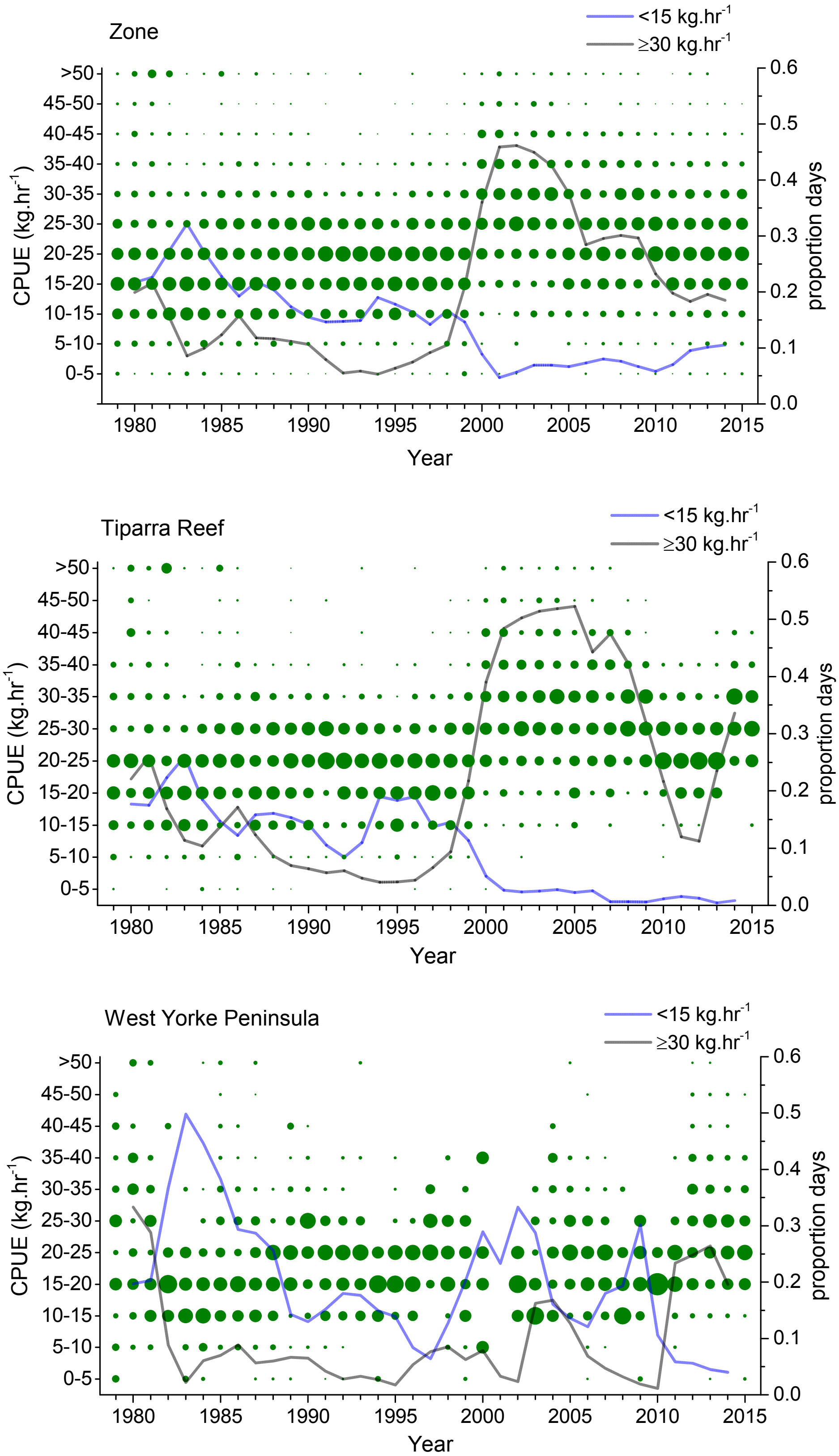

Figure A3-2 Bubble plot showing the distribution of unweighted daily CPUE (kg.hr^{-1}) for the Central Zone, and SAUs of high importance (Tiparra Reef and West Yorke Peninsula) on days when greenlip were ≥30% of the total catch from 1979-2015 The trend line indicates the proporion of fishing days with catch rates <15 kg.hr^{-1} (blue line) and ≥30 kg.hr^{-1} (black line), which is smoothed by presenting as a three year average.

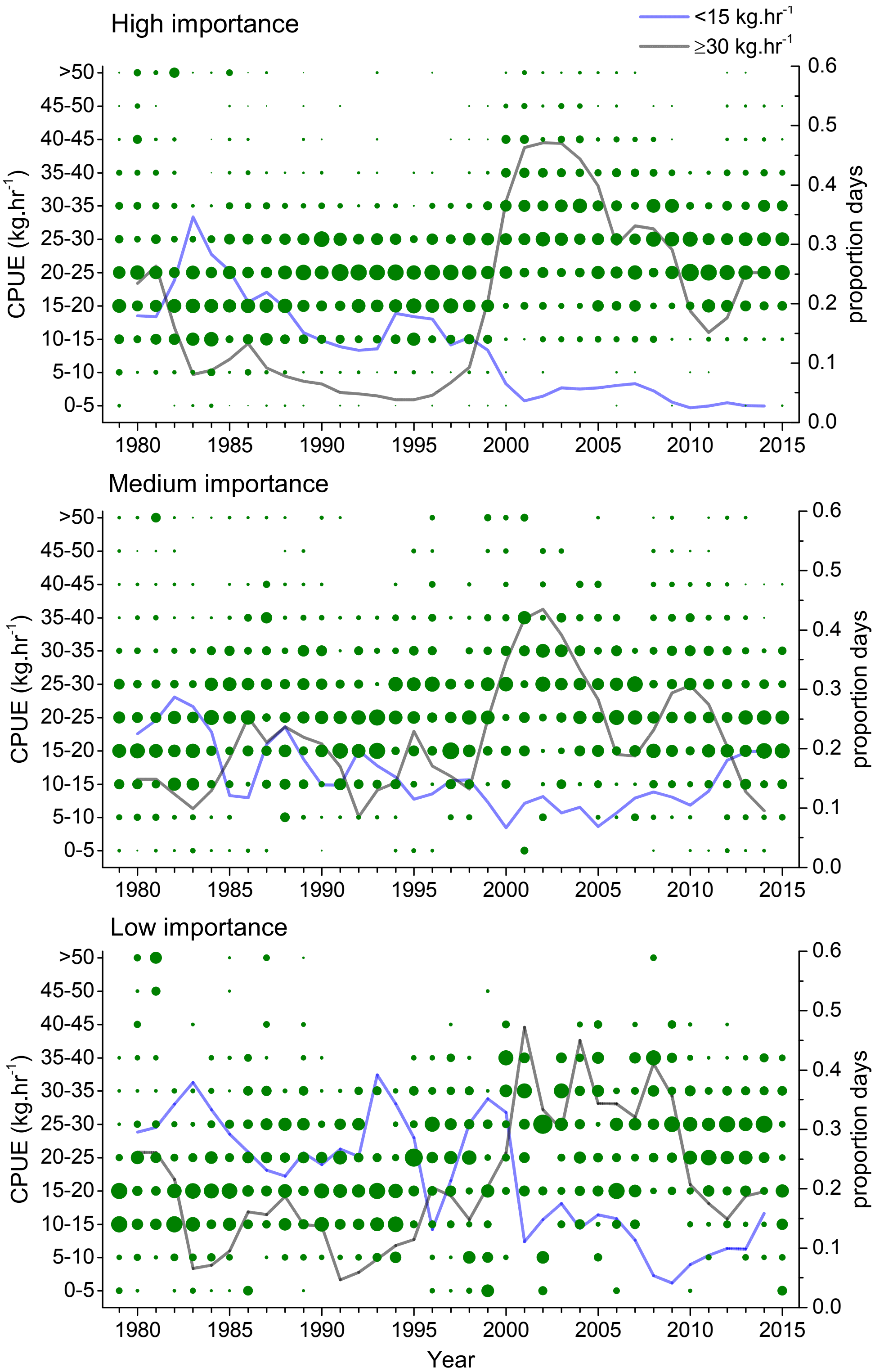

Figure A3-3 Bubble plots showing the distribution of unweighted daily CPUE (kg.hr^{-1}) with SAUs aggreagted by importance (high, medium and low) on days when greenlip were ≥30% of the total catch from 1979-2015. The trend line indicates the proportion of fishing days with catch rates <15 kg.hr^{-1} (blue line) and ≥30 kg.hr^{-1} (black line), which is smoothed by presenting as a three year average.

Appendix 4. Catches by mapcode

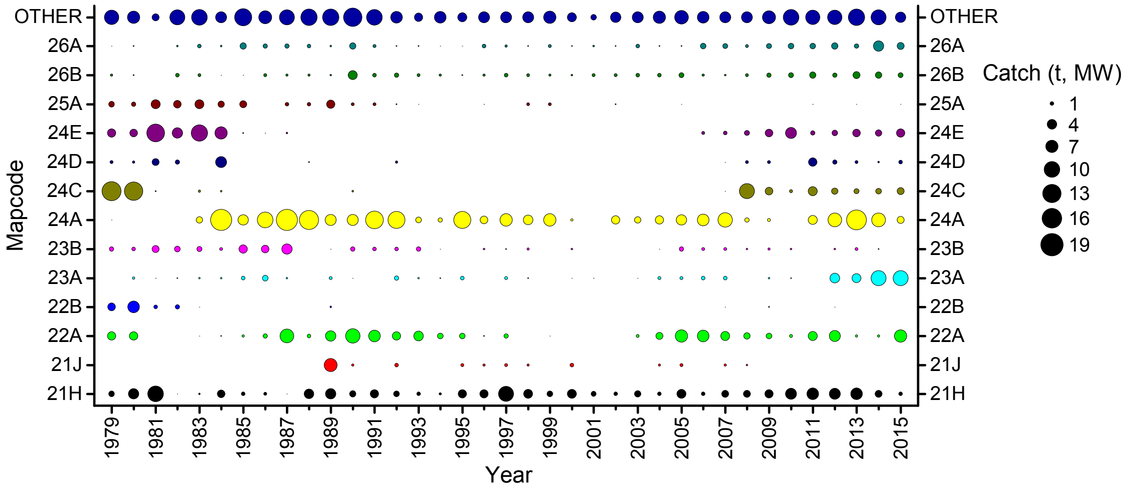

Figure A4-1 Annual catch of greenlip (t, meat weight) harvested from individual mapcodes 'away' from Tiparra Reef (refer SAU codes – Figure 1-2) from 1979 to 2015.

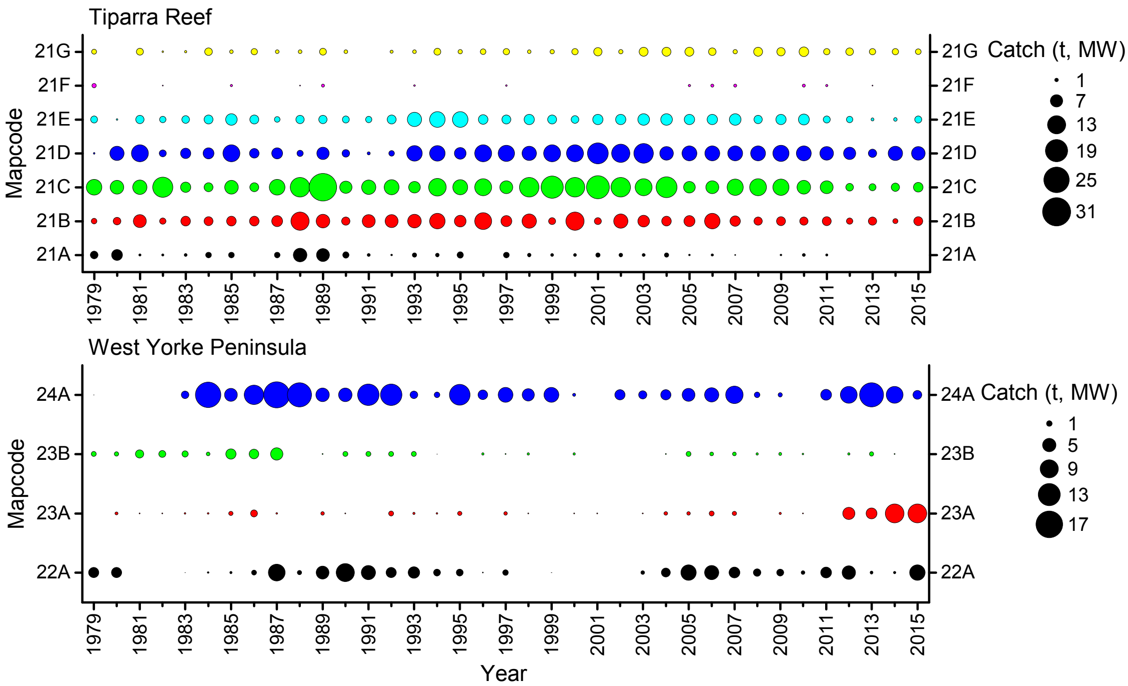

Figure A4-2 Distribution of annual catches (t, meat weight) among mapcodes 1979 to 2015 for greenlip in the Tiparra Reef and West Yorke Peninsula high importance SAUs.

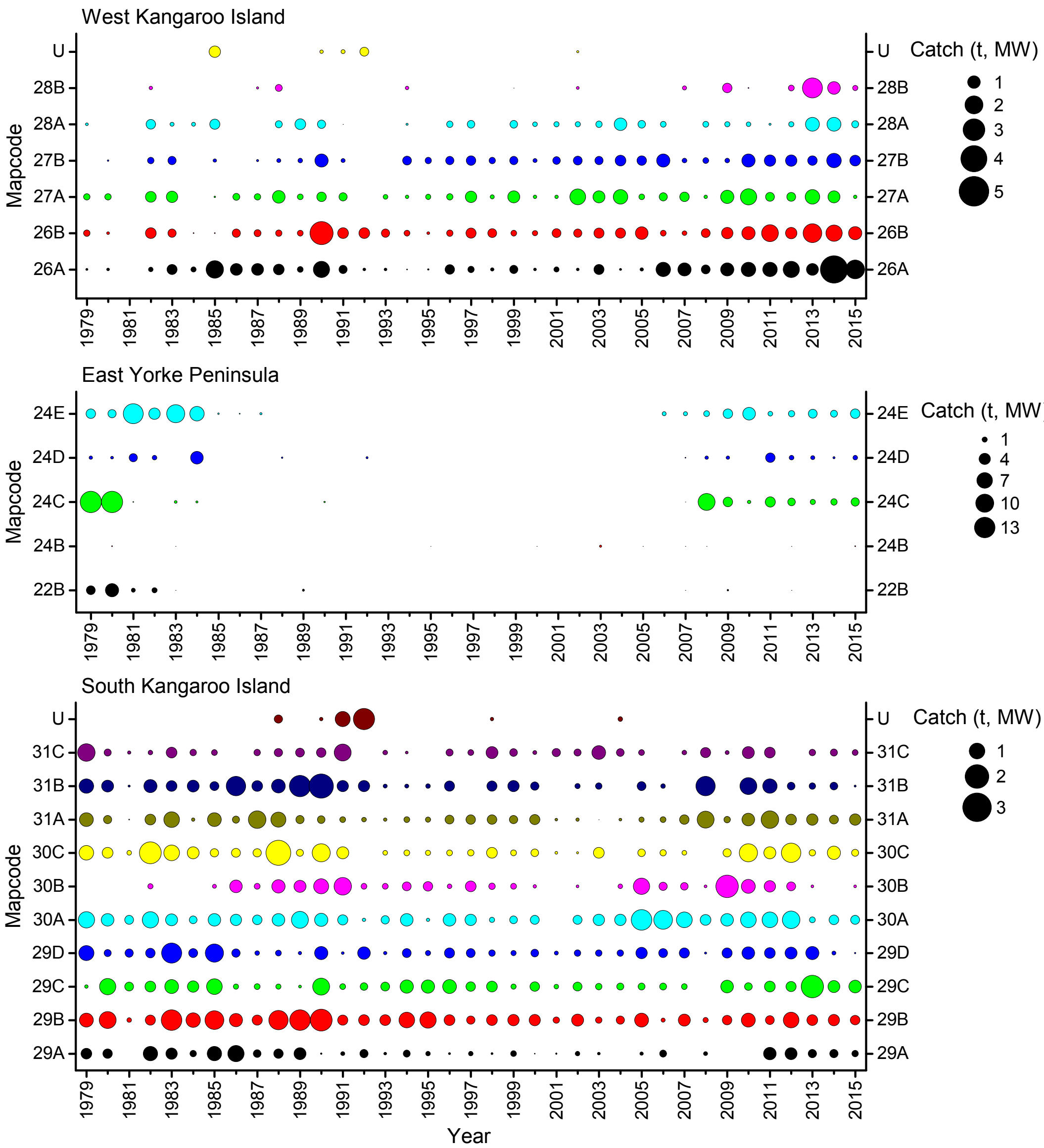

Figure A4-3 Distribution of annual catches (t, meat weight) among mapcodes from 1979 to 2015 for greenlip in the West Kangaroo Island, East Yorke Peninsula and South Kangaroo Island medium importance SAUs (U = unassigned catch).

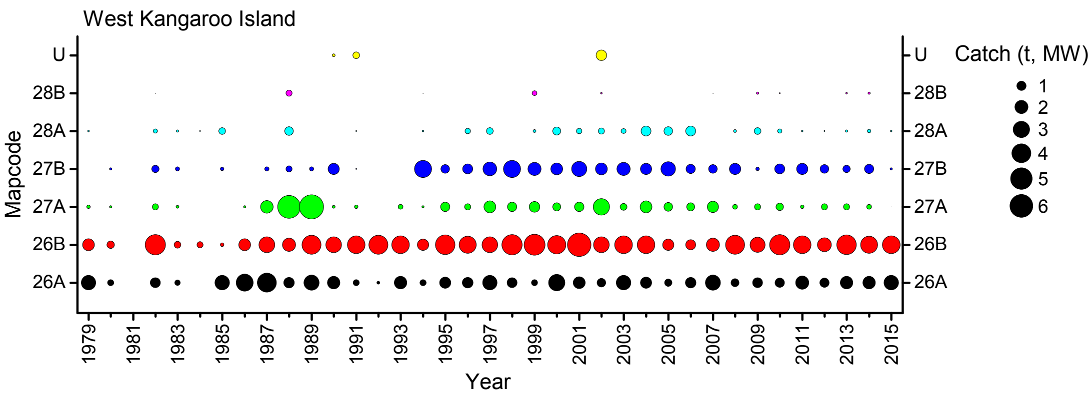

Figure A4-4 Distribution of annual catches (t, meat weight) among mapcodes from 1979 to 2015 for blacklip in the West Kangaroo Island medium importance SAU (U = unassigned catch).

Appendix 5. Harvest strategy PI plots

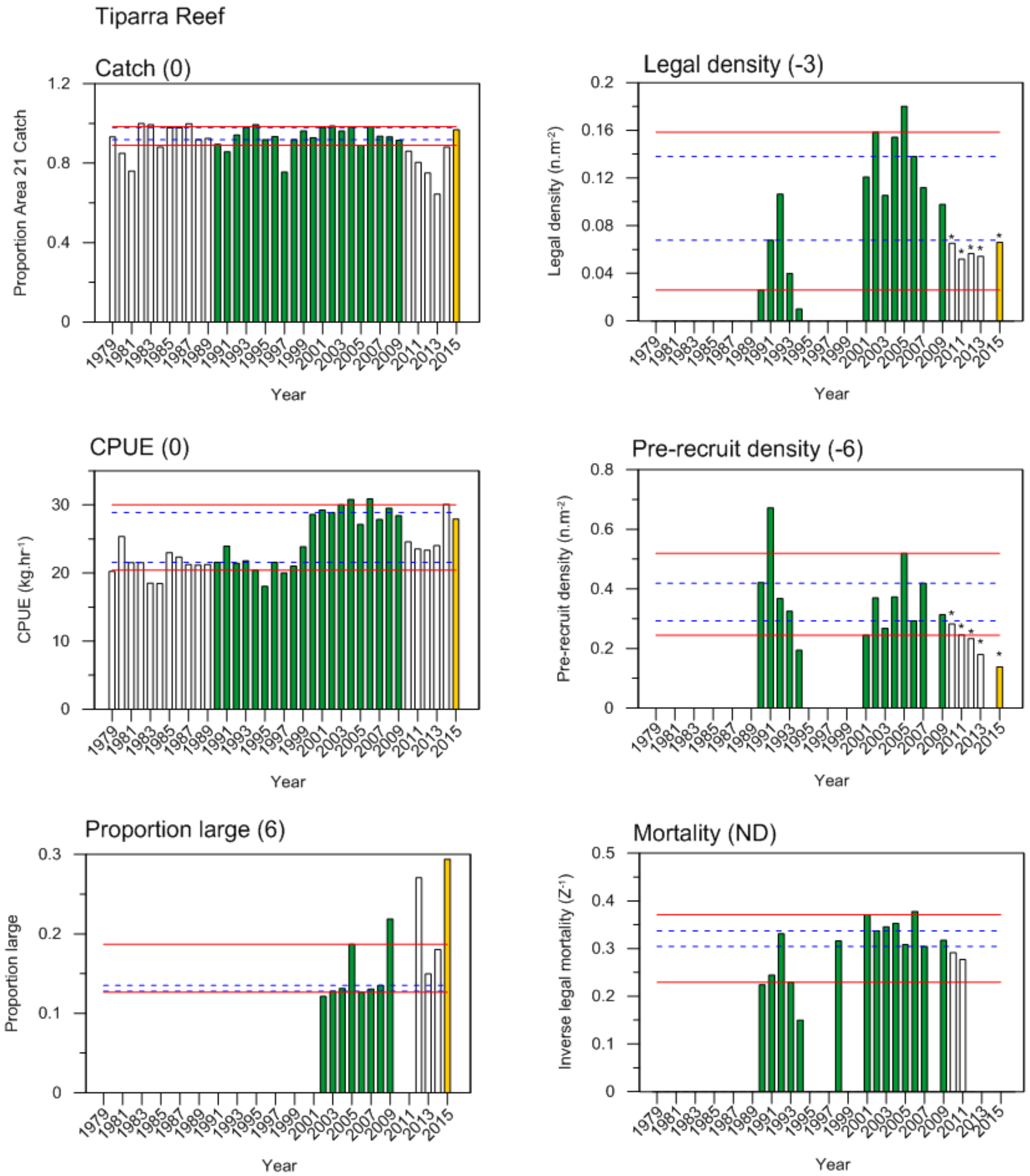

Figure A5-1 Tiparra Reef (high importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Green bars describe the data and time over which the reference points were calculated. Open bars describe measures of the PI outside of the reference period. Orange bars describe the data and year subject to assessment for each PI *i.e.* the score-year.

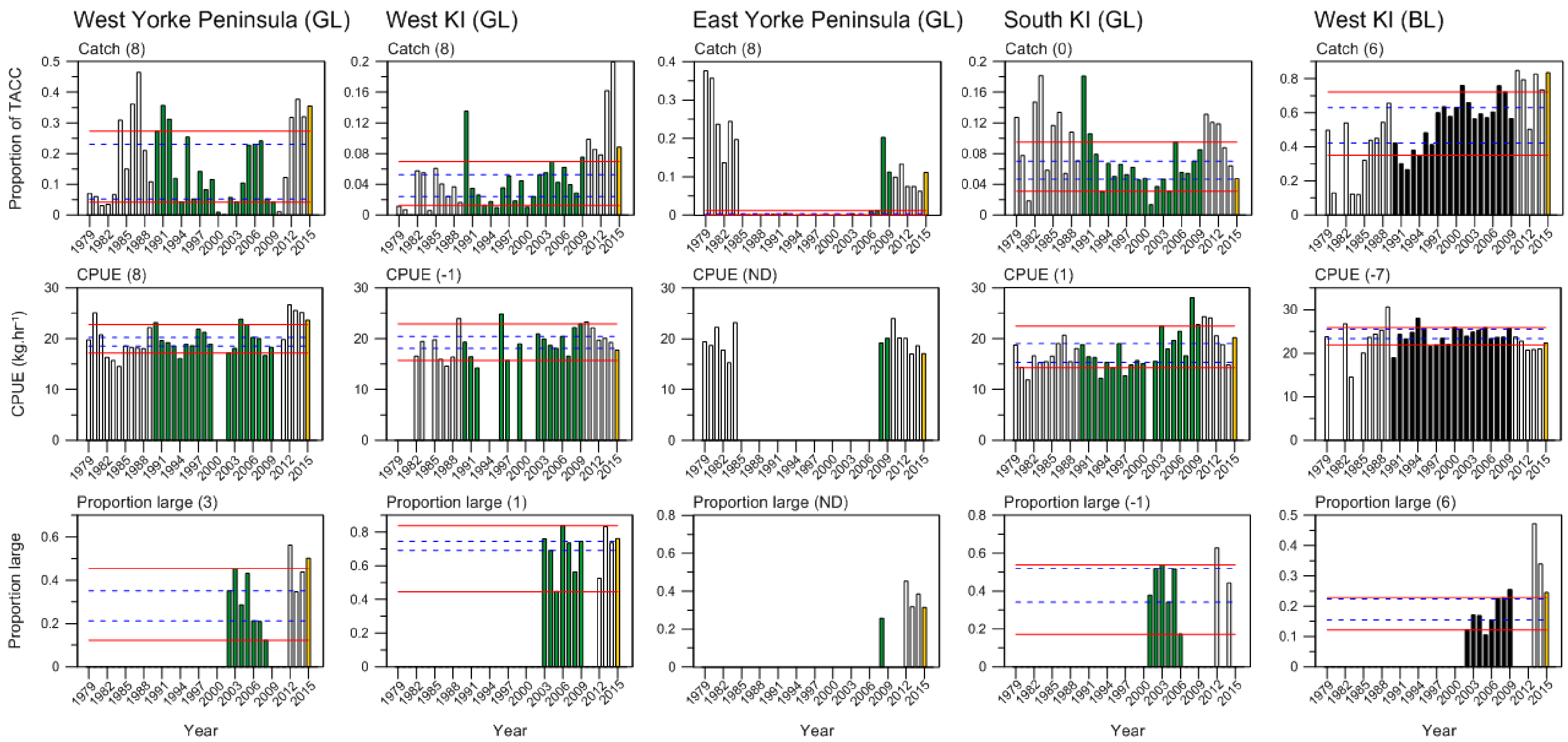

Figure A5-2 Greenlip: West Yorke Peninsula, West Kangaroo Island (KI), East Yorke Peninsula and South KI; Blacklip: West KI (medium importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Green/black bars describe the data and time over which the reference points were calculated. Open bars describe measures of the PI outside of the reference period. Orange bars describe the data and year subject to assessment for each PI *i.e.* the score-year.

Appendix 6. CPUE estimation rules for BL

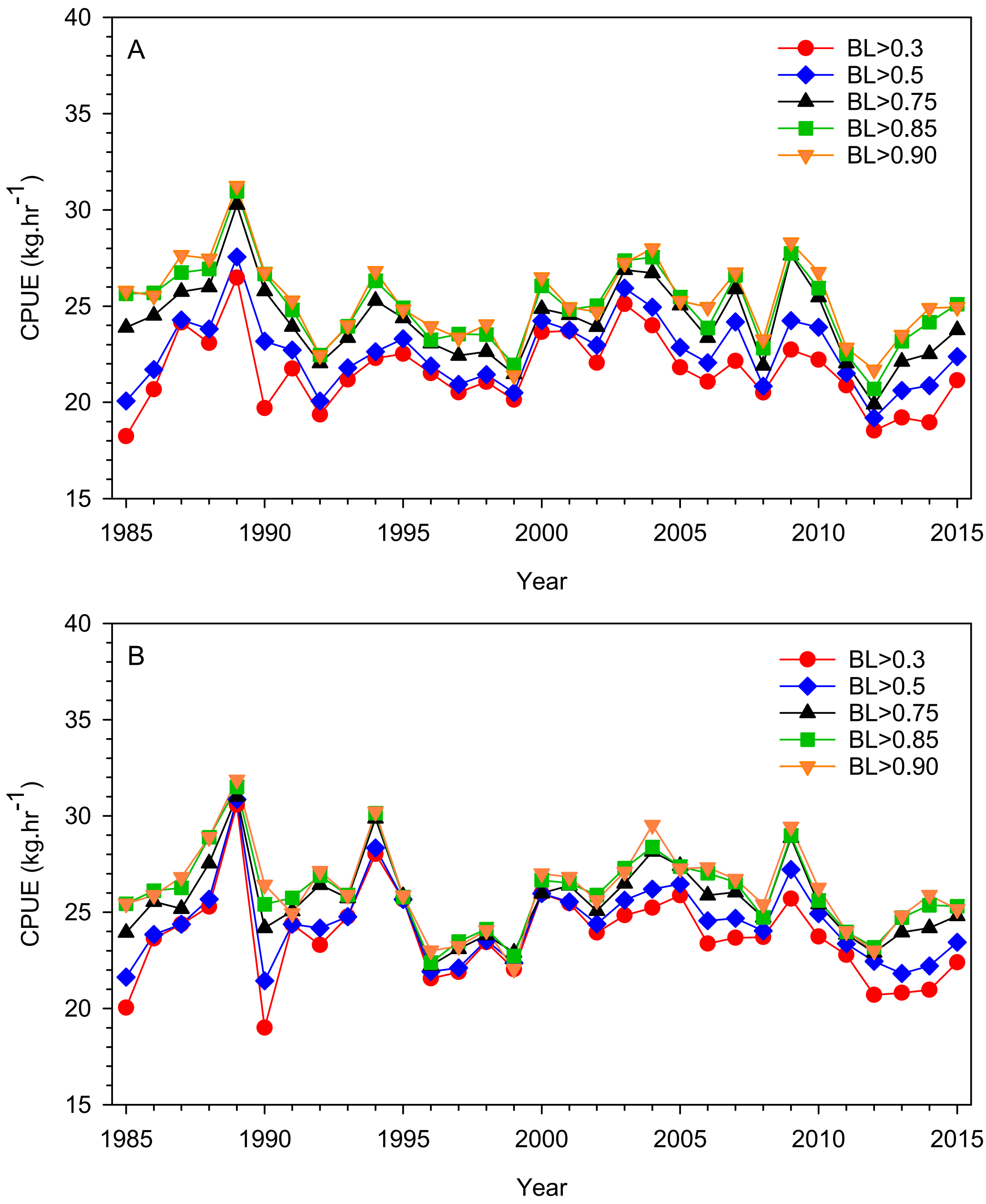

Figure A6-1 Blacklip CPUE (kg.hr^{-1}) from 1985 to 2015 estimated for a range of species composition (blacklip contribution to daily catch at least 30%, 50%, 75%, 85%, 90%) for (A) the Central Zone and (B) West Kangaroo Island.

Appendix 7. Running mean CPUE estimation rules

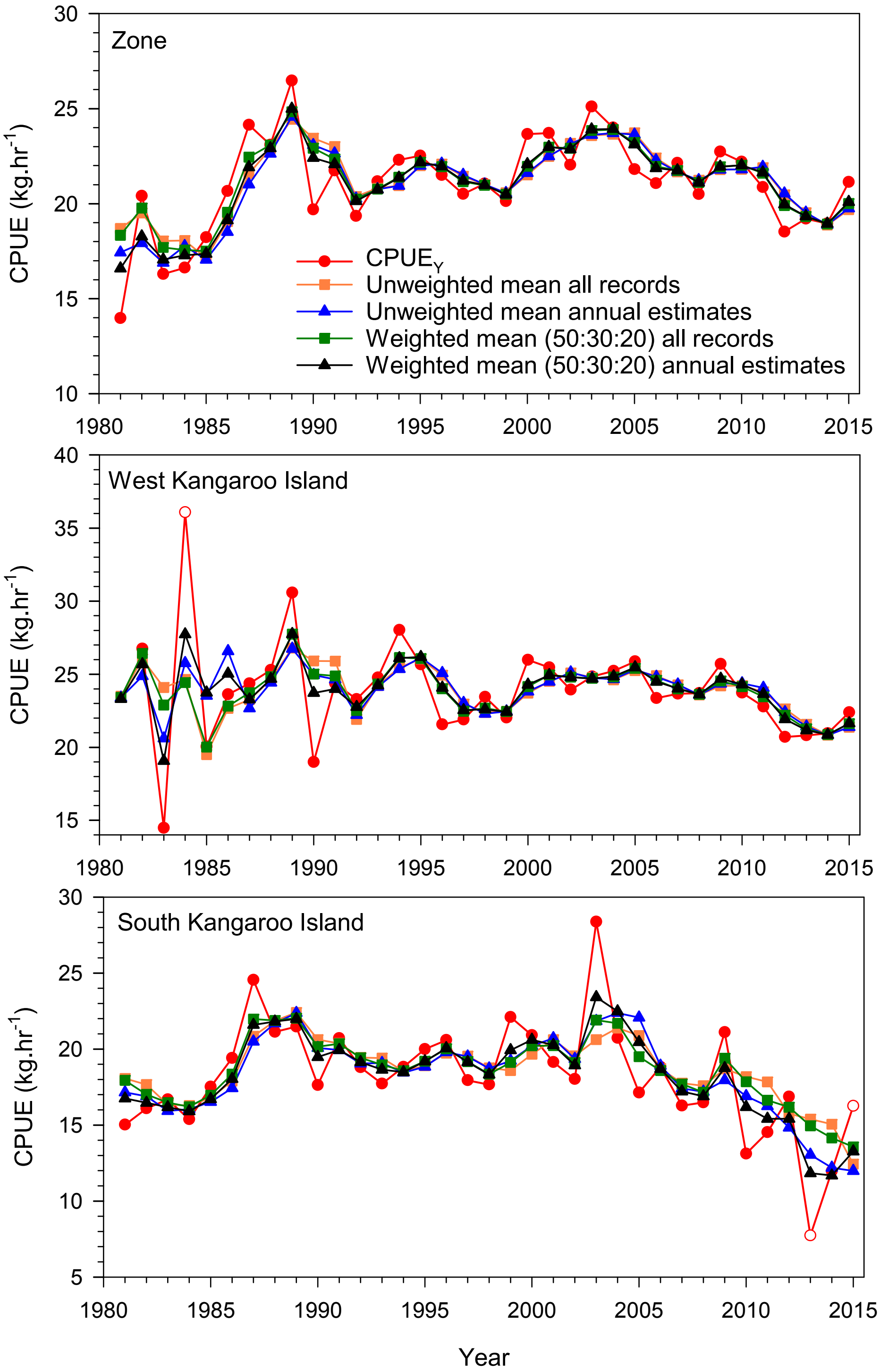

Figure A7-1 Blacklip $CPUE_Y$ ($kg.hr^{-1}$) and four different methods of determining the three-year running mean (unweighted mean of all daily records across the three years – orange squares; unweighted mean of the three annual mean estimates – blue triangles; weighted mean of all daily records across the three years – green squares; weighted mean of the three annual mean estimates – black triangles) from 1981 to 2015 for (A) the Central Zone, (B) West Kangaroo Island and (C) South Kangaroo Island. Open red symbols indicate years where no $CPUE_Y$ estimate was made due to <10 daily records.