

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



S. Mayfield, G. Ferguson, J. Carroll and J. Dent

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PO Box 120 Henley Beach SA 5022

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Fishery Assessment Report to PIRSA Fisheries and Aquaculture

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EXECUTIVE SUMMARY

This report provides an assessment of the *Haliotis rubra* and *H. laevigata* (hereafter referred to as blacklip and greenlip, respectively) stock status in the Central Zone (CZ) in 2013.

This assessment was informed by both the harvest strategy in the new Abalone Fishery Management Plan and the traditional weight-of-evidence assessment. Comparison between these has identified the need for the harvest strategy to be reviewed.

Data spanning four spatial scales were integrated in this assessment: CZ, fishing area (FA), mapcode (MC) and spatial assessment unit (SAU). Data from Cowell, a separately managed area, were excluded.

GREENLIP

The total allowable commercial catch (TACC) for greenlip has been 47.7 t (meat weight) since 1994. Greenlip comprises 85% of the combined abalone TACC (55.8 t *i.e.* greenlip and blacklip) in the CZ, which highlights the importance of this species to this fishery. Total catches are slightly higher (6%) than the mean catch prior to TACC implementation.

Tiparra Reef has been the most important SAU for greenlip in both the CZ and the South Australian Abalone Fishery since 1990. The weight-of-evidence assessment and harvest strategy both determined that the harvestable biomass of greenlip in this SAU has declined substantially. Notably, the catch harvested from this SAU in 2013 (9 t) was the lowest on record and 50% below the 18 t 'catch-cap'.

The combination of declining catches on Tiparra Reef and a stable TACC, has resulted in catch and effort having been re-distributed into other SAUs. In 2013, the catch harvested from SAUs other than Tiparra Reef was the highest on record. The recent decreases in catch rates and re-distribution of catches among mapcodes indicate that, with few exceptions, greenlip stocks across the CZ are declining.

As this evidence suggests that stock abundance is likely to decrease further at the current TACC, the CZ greenlip fishery has been classified as '**transitional-depleting**' under the national framework for reporting stock status (Flood *et al.* 2012).

Consequently, to prevent overfishing, additional management arrangements including reducing the TACC and a greater level of spatial management should be considered.

This outcome from the weight-of-evidence assessment strongly contrasted with that obtained from the application of the harvest strategy in the Management Plan which categorised CZ greenlip stock status as '**under-fished**'.

BLACKLIP

The blacklip abalone TACC was reduced by 40% from 14.1 t (1994–2004) to 8.1 t (2006–2013). Despite the lower catches over the past decade, much of the current data suggests that the blacklip stocks in the CZ have declined further from their weak position in the mid 2000s.

The strongest evidence of decline is the recent reductions in the catch-per-unit effort (CPUE) estimates observed across multiple spatial scales – CZ, key blacklip SAUs, FAs and mapcodes – to levels at, or among, the lowest on record. The proportion of fishing effort in 10-20 m water depth and proportion of the TACC harvested from the Western Kangaroo Island SAU have increased, which likely reflect diver responses to reductions in blacklip abundance in shallow water and other fishing grounds. The proportion of small (135-140 mm shell length) blacklip harvested has reduced substantially, indicating low levels of recruitment to the fishable stock.

The evidence suggests blacklip biomass is likely to decrease further at the current TACC. Consequently, as with greenlip, additional management arrangements including reducing the TACC and a greater level of spatial management should be considered to prevent overfishing.

Based on this evidence, the CZ blacklip fishery has been classified as '**transitional-depleting**' under the national framework for reporting stock status (Flood *et al.* 2012). This outcome from the weight-of-evidence assessment was in sharp contrast to that obtained from the application of the harvest strategy in the Management Plan which categorised the stock status of this fishery as '**sustainable**'.

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; Chick and Mayfield 2012) and stock status reports (Mayfield and Carlson 2005a, 2009). The report covers the period 1 January 1968 to 31 December 2013 and is part of the ongoing assessment program for the fishery undertaken by SARDI Aquatic Sciences. Similarly to recent CZ reports, data from Cowell, 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 laevis*; 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) evaluate spatial and temporal changes in the behaviour of the commercial divers in the CZ and their potential influence on catch rates for blacklip; (4) identify uncertainty associated with the assessment; (5) evaluate the new harvest strategy for the fishery; and (6) 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, catch-per-unit 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 the current knowledge; (2) compares the 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.

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 1-1. Summaries of the fishery can be found in Prince and Shepherd (1992), Zacharin (1997), Keesing and Baker (1998), Nobes *et al.* (2004) and Mayfield *et al.* (2011a). 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 a catch/effort reduction program related to the implementation of the marine park sanctuary zones (Ward *et al.* 2012).

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 85% and 15% of the total allowable commercial catch (TACC) in the CZ, respectively (Table 1-2). The greenlip TACC has remained at 47.7 t meat weight since 1994. In contrast, the TACC for blacklip has been reduced twice and by over 40% since 2004. This reduction occurred in two stages: from 14.1 t (1994 - 2004) to 9.9 t (2005) and 9.9 t to 8.1 t (2006). The blacklip TACC has remained at 8.1 t.yr⁻¹ since 2006.

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 current management arrangements in the CZ are summarised in Table 1-1 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.

To monitor catches and facilitate compliance with quota limits, fishers must complete a Catch and Disposal Record form immediately upon landing. A research logbook must also be 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 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. These analyses underpin assessments of 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 at Tiparra Reef, the key fishing area.

1.2.2. Recreational fishery

The total recreational catch of abalone in South Australia was estimated at 5,147 abalone from November 2007 to October 2008 (Jones 2009). Previous fishing surveys estimated a harvest of 17,780 abalone for the period May 2000 to April 2001 (Henry and Lyle 2003). These results indicate a substantial decline in the harvest of abalone by recreational fishers in South Australia. Jones (2009) provides species and zone-specific estimates of recreational catch within South Australia (CZ greenlip 18%; CZ blacklip 14%). Based on these estimates, the total recreational harvests of greenlip and blacklip in the CZ in 2009 were 0.1 t and 0.03 t meat weight, respectively. This represents 0.21% and 0.38% of the TACCs for these species in the CZ.

1.2.3. Illegal, unregulated and unreported catches

Accurate estimation of illegal, unregulated and unreported (IUU) catch is difficult, as many information reports cannot be validated. During 2013, Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture received 85 information reports. Weight data from 14 of these yielded a mean estimated illegal take of 31.85 kg.Information Report⁻¹. Applying this mean value to the 85 information reports

received, the estimated illegal catch of abalone in the CZ was about 2.7 t (meat weight), which equates to 4.8% of the TACC. This estimate excludes IUU take where a caution, expiation or brief has been compiled (PIRSA Fisheries and Aquaculture). It would be expected that PIRSA Fisheries and Aquaculture would not have been notified of all reports alleging that abalone theft had occurred within the CZ during 2013, so the actual extent of IUU take of abalone is likely to have been higher.

Table 1-1 Management milestones in the South Australian 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
1984	MLL for greenlip increased to 145 mm SL in the WZ
1985	WZ divided into Regions A and B Quota introduced to Region A in the WZ.
1989	Greenlip TACC reduced from 97.8 t to 69 t in Region A of the WZ
1990	Quota introduced to the CZ. TACCs set at 47.4 t and 13.7 t (meat weight) for greenlip and blacklip
1990	Quota introduced to the CZ.
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 <i>et al.</i> 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) – application of 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 increased to 135 mm SL in CZ

1.2.4. Economic importance

Econsearch provides an annual assessment of the economic performance of the SAAF (Paterson *et al.* 2013). Catch value (gross value of production) in the fishery increased rapidly between 1997/98 and 2000/01, but followed a declining trend in subsequent years that was associated with a decline in the ‘beach price’ of abalone linked to a rise in the value of the Australian dollar (Paterson *et al.* 2013). In spite of the decrease in product value, in 2011/12 the SAAF was estimated to contribute AU\$49.5 million to the South Australian economy and generate 316 full time jobs directly and indirectly.

Paid labour, which accounts for the largest share of total cash costs to the SAAF, decreased by 13% between 2010/11 and 2011/12 (Paterson *et al.* 2013). Other major costs include interest, management costs and fuel. The average cost of management per licence holder has remained relatively stable since 2004/05 and, in 2011/12, was \$70,102. In contrast, there was a large (29%) increase in fuel and interest costs between 2010/11 and 2011/12.

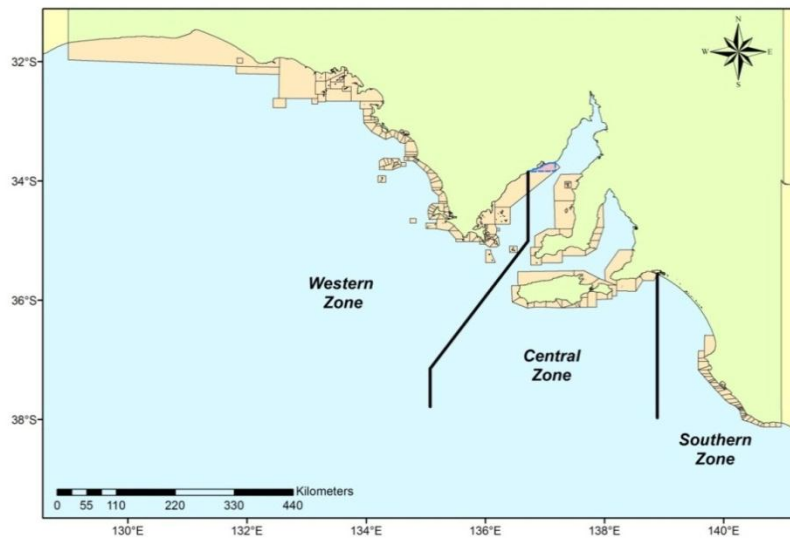


Figure 1-1 Fishing Zones and mapcodes of the South Australian Abalone Fishery

Table 1-2 TACC (tonnes, meat weight) for the CZ of the SAAF from 1990 to 2013. * indicates the MLL in 2013 was 135 mm SL.

Fishing season	Greenlip abalone SL ≥ 130 mm	Blacklip abalone SL ≥ 130 mm
1990–1993	47.4	13.7
1994–2004	47.7	14.1
2005	47.7	9.9
2006–2013	47.7*	8.1

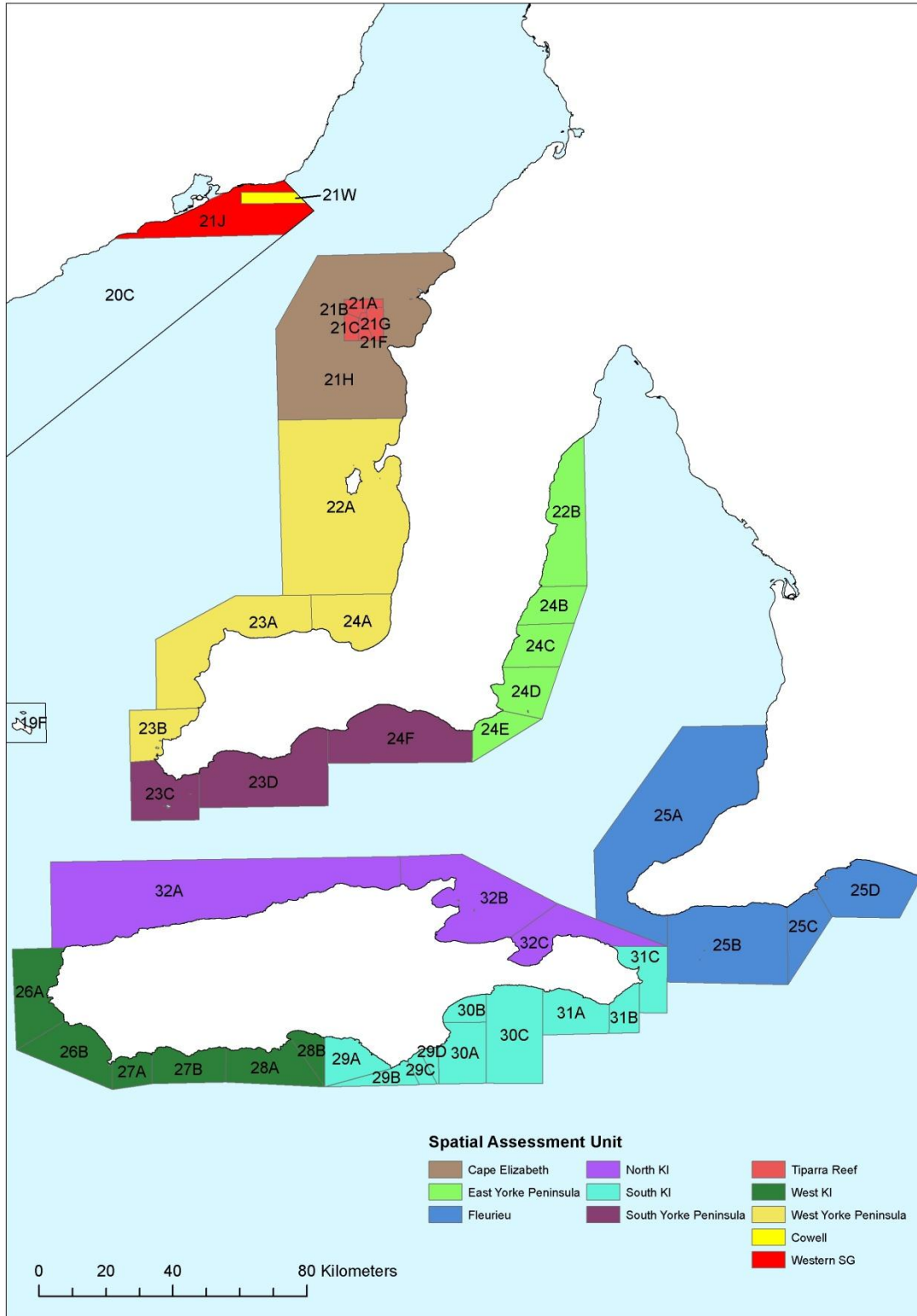


Figure 1-2 Spatial assessment units (SAUs; coloured blocks), fishing areas (numbered areas) and mapcodes (numbered and lettered areas) of the CZ of the South Australian Abalone Fishery.

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 ($\text{kg}\cdot\text{hr}^{-1}$), (2) size composition of the commercial catch, and (3) abundance of legal-sized and pre-recruit-sized abalone observed on fishery-independent surveys ($\text{number}\cdot\text{m}^{-2}$). Reference points were percentage changes in these measures between years and across five consecutive years which, when exceeded, triggered a series of management actions. These management actions included notification to the responsible Minister, an examination of the causes of the observed changes, consultation on the need for alternative management arrangements and provision of a report on the review to the Minister within a specified time period.

Following extensive review, Zacharin (1997) was superseded in 2004 by the second Management Plan for the fishery (Nobes *et al.* 2004). Although Nobes *et al.* (2004) had similar (1) management objectives and associated strategies for the fishery and (2) management actions following triggering of PIs, this second Management Plan identified 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.

The triggering of PIs was primarily determined from statistically significant differences in PI values (1) between years and (2) across five consecutive years. This approach had two key advantages (Chick *et al.* 2009). Firstly, the suite of PIs was broad, thereby encompassing almost all aspects of the fishery and, secondly, the complex population structures of abalone were captured by their spatial focus (Saunders and Mayfield 2008; Mayfield and Saunders 2008; Miller *et al.* 2009; Saunders *et al.* 2009a,b). However, a key disadvantage of this approach was the need to continually assess the fishery against a large number of PIs that, when triggered, seldom provided consistent inferences about stock status. This made management decisions difficult because quotas are determined for each species in each zone. This challenge was compounded by (1) inclusion of PIs that seldom informed stock status (*e.g.* mean daily effort) or were difficult to calculate (*e.g.* egg production); (2) the lack of target or limit reference points for PIs; and (3) not amalgamating the PIs across fishing grounds into a single index of stock status, which made management decisions difficult because quotas are determined for each species in each zone. In addition, Nobes *et al.* (2004) did not

provide clear decision rules to guide TACC changes among years. Chick *et al.* (2009) made several suggestions to overcome these difficulties that aided development of the Management Plan, including (1) amalgamating the PIs for the key fishing grounds into a single index of stock status; and (2) employing the 'traffic-light' or 'thermostat' approaches suggested by Shepherd and Rodda (2001) and Caddy (2002).

1.3.2. The current Management Plan

Coincident with a project funded by the Fisheries Research and Development Corporation (FRDC) on abalone fishery performance measures (FRDC 2007/020), the second Management Plan (Nobes *et al.* 2004) was reviewed and revised in 2010 and 2011. The aim of this review was to develop a formal, species-specific, spatially-explicit harvest strategy for the SAAF that (1) defines stock status; (2) delivers sustainability outcomes; (3) is cost effective; and (4) facilitates stakeholder engagement. The objectives underpinning this process were to (1) capture the spatial structure of abalone stocks; (2) target assessments (and research) to key fishing grounds; (3) use a broad range of PIs to measure fishery performance and determine stock status; (4) develop clear frameworks for data utilisation, integration, interpretation; and (5) provide a structured, documented process for determining TACCs using harvest-decision rules that incorporate a framework to guide integration with industry information. These aims and objectives were selected following an extensive review of the role of indicators, reference points and decision rules in fisheries management (Caddy 2002, 2004; Sainsbury 2008). This review identified that clear indicators, reference points and decision rules improve the understanding of stock status among stakeholders and providing increased certainty in management decisions.

The Management Plan (PIRSA 2012) endeavours to achieve these aims and objectives. For example, assessments are made at spatial scales that better reflect functional biological populations, termed SAUs. Research is focussed into those SAUs from which most of the catch is harvested (high importance) and as a result the risk that abalone stocks in these areas are over-fished is assessed using PIs that utilise both fishery-dependent and fishery-independent data. These PIs have clearly-documented data utilisation (Table 1-3) and interpretation (Figure 1-5) and were selected because they directly measure abundance and exploitation rate whilst remaining as independent as possible. In contrast, those areas from which limited catch has been harvested – low importance SAUs – are not assessed using PIs. Following the risk-of-overfishing assessment for each SAU, the assigned risks are catch-weighted and summed to determine the stock status for each species. These outcomes serve two purposes. First, the assigned risk-of-overfishing category for each

SAU is linked with explicit, bounded harvest-decision rules (Table 1-4) and industry-based information to determine the catch contribution from this SAU to the TACC in the subsequent year. Second, the stock status enables the TACC to be set for two years – concurrent with the biennial assessment program – providing that index does not change among years. Thus, the Management Plan (PIRSA 2012) incorporates a species-specific, spatially-explicit harvest strategy that combines (1) PIs and reference points with (2) harvest-decision rules to determine future catch contributions from each SAU. Catch contributions are then summed by species for each zone and used to adjust annual TACCs. This approach overcomes many of the deficiencies of previous plans including reduced subjectivity in interpretation of a complex array of spatially-explicit PIs and a structured process for determining TACCs.

There are two key components to the harvest strategy. These are (1) determining the risk that each SAU is over-fished 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 that, in turn, are determined by the risk-of-overfishing in each SAU. Determining the risk-of-overfishing and zonal stock status comprises five steps. Each of these is described in detail in the Management Plan and briefly below.

Step 1: Identify spatial assessment units

SAUs are the spatial scale at which monitoring and assessments are undertaken. Whilst they are intended to reflect distinct abalone populations (termed metapopulations; Morgan and Shepherd 2006; Mayfield and Saunders 2008; Miller *et al.* 2009) data limitations have required some SAUs to be larger than biologically desirable (*e.g.* WZ Region B) to allow minimum data requirements for their assessment. These SAUs are likely to encompass multiple abalone populations. To capture the known history of abalone catch, SAUs comprise single or multiple mapcodes, which are the spatial scale against which fishery-dependent data have been reported since 1979. SAUs are the same for greenlip and blacklip abalone in each zone. There are 11 SAUs identified for the CZ (Figure 1-2).

Step 2: Determine relative importance of each spatial assessment unit

The importance of each SAU for each species in each zone is based on the relative contribution to total (*i.e.* combined greenlip and blacklip) catch over the ten-year period ending with the year being assessed (*i.e.* the current year). Thus, for this assessment, importance was determined using data from 2004 to 2013. Three importance categories are defined – high, medium and low – based on the percentage contribution to total catch. SAUs from which, cumulatively, >50% of catch was harvested are deemed of high importance. Medium importance SAUs comprise those from which, cumulatively, the next 30% of catch was harvested. Thus, the total catch from those SAUs categorised as either high or medium importance will be >80% of the combined TACC. All remaining SAUs are classified as being of low importance. For the ten-year period ending 31 December 2013, there were two high and three medium importance SAUs (Figure 1-3).

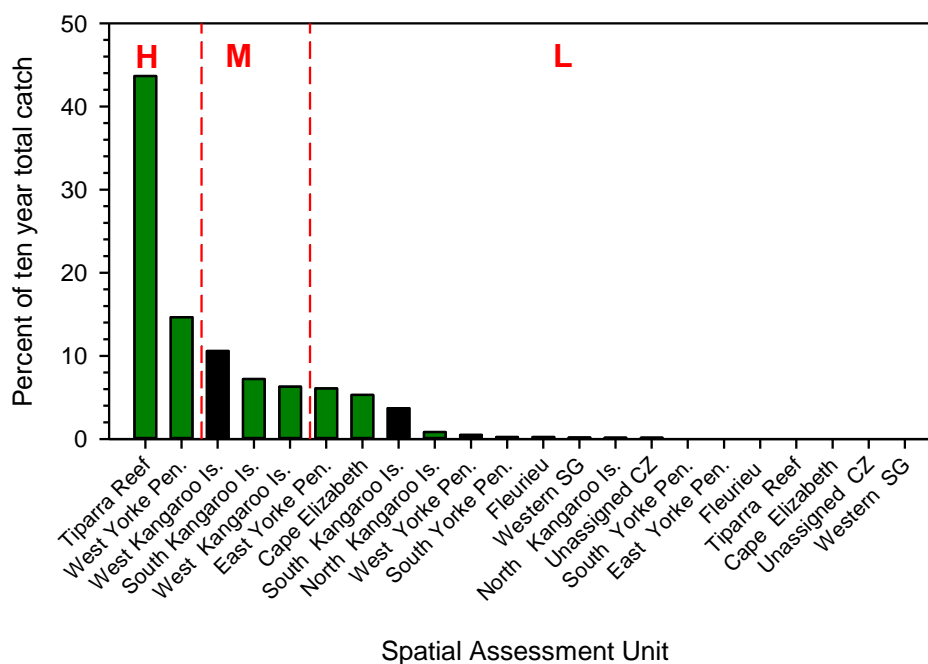


Figure 1-3 SAUs of the CZ Abalone Fishery, ranked in order of importance (High (H); Medium (M); and Low (L)) by percent of ten year (2004-2013) total catch for greenlip (green bars) and blacklip (black bars). SAU name abbreviations: Peninsula (Pen.); Island (Is.), Spencer Gulf (SG). Each SAU appears twice – once for greenlip and once for blacklip.

Step 3: Score performance indicators for each spatial assessment unit

Six PIs – three based on fishery-dependent and three based on fishery-independent data – are used to measure fishery performance (Table 1-3). All PIs are weighted equally. For those SAUs categorised as high, all six PIs are used to assess fishery performance; only the three fishery-dependent PIs are used for those SAUs categorised as medium importance. No assessment of the low importance SAUs is undertaken.

Where applicable, each PI for each species in each SAU is scored using a series of reference points. The reference points are derived from the 20-year time series (1990-2009) of data for each PI, termed the reference period. The exception is where <20 years of data are available, in which case the most recent years comprise the reference period. Four reference points are used for scoring (Figure 1-4): (1) upper limit reference point (ULRP) defined as the 3rd highest value during the reference period; (2) upper target reference point (UTRP) defined as the 6th highest value during the reference period; (3) lower target reference point (LTRP) defined as the 6th lowest value over the reference period; and (4) lower limit reference point (LLRP) which is defined as the 3rd lowest value during the reference period. Thus, 50% of values lie between the UTRP and LTRP, with 10% of values above and below the ULRT and LLRP, respectively.

The scoring system is symmetrical with assigned scores ranging from -2 to +2 (Figure 1-4). Each PI is scored on its current and recent performance. Current performance is scored on the current year value. Recent performance is scored on consecutive values of the PI above or below the UTRP-LTRP band for up to three previous years. The current and recent scores are summed to provide a single score for each PI. Thus, in combination, values of the PI from the last four years are considered in determining the score of each PI for each species in each SAU. Based on the example provided in Figure 1-4, the total score for that PI would be +3. This comprises +2 for current performance and +1 for recent performance (+1 for 2009). No score is assigned for 2008 as the value of the PI is inside the UTRP-LTRP band. Similarly, no score is assigned for 2007 because retrospective scoring ceases once the UTRP-LTRP band is entered or crossed. The principal exception to this scoring system is the assignment of a score of -1 to those high and medium SAUs for which commercial catch sampling data are not representative of, or available from, the fishery (see Burch *et al.* 2010).

Table 1-3 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)	$\text{CPUE}_{Wt} = \frac{\sum_{i=1}^n W_i \frac{C_{PSi}}{E_i}}{\sum_{i=1}^n W_i},$	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 ≥130 mm SL defined as legal-sized
Density _{pre-recruit}	Density of pre-recruit (<i>i.e.</i> 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 <130 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

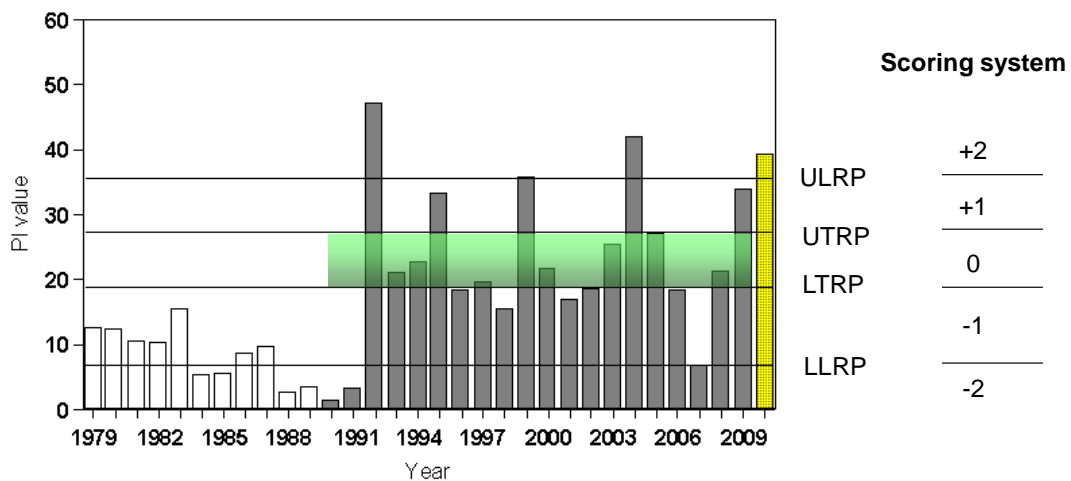


Figure 1-4 Schematic plot of a PI showing the reference period (grey bars) associated reference points, the year being assessed (yellow bar) and the scores applied to measure fishery performance. ULRP, UTRP, LTRP and LLRP refer to upper limit reference point upper trigger reference point, lower trigger reference point and lower limit reference point, respectively. The green shading indicates the middle 50% of values observed during the reference period.

Step 4: Determine risk-of-overfishing for each spatial assessment unit

Determining the risk that the stocks in each SAU are over-fished comprises two steps. First, the scores for each PI are summed to provide a single numeric value for that SAU. Second, the total score is used to assign that SAU to a risk-of-overfishing, colour-coded category using a probability distribution that describes the likelihood of obtaining that total score by chance. The probability distributions (Figure 1-5) were determined in two steps: (1) the probability of obtaining each score (range: -8 to +8) for each PI was determined analytically and (2) Monte-Carlo simulation ($n = 5000$) was used to obtain probabilities of scores for multiple (*i.e.* combined) PIs. This approach relies on the assumption that all outcomes are equally likely and that the PIs are independent from each other and between years. Simulations were undertaken separately for the high (*i.e.* six PIs; maximum range -48 to +48) and medium (*i.e.* three PIs; maximum range -24 to +24) importance SAUs. As with the scoring of the PIs, the categories defining the risk that the stocks in a SAU are over-fished are symmetrical with the boundaries between categories analogous to the reference points described in step 3 above. Importantly, the colour-coded categories are linked to explicit harvest-decision rules (Table 1-4) that are applied to the mean catch over the most recent (four-year) period from each SAU during the decision-making process.

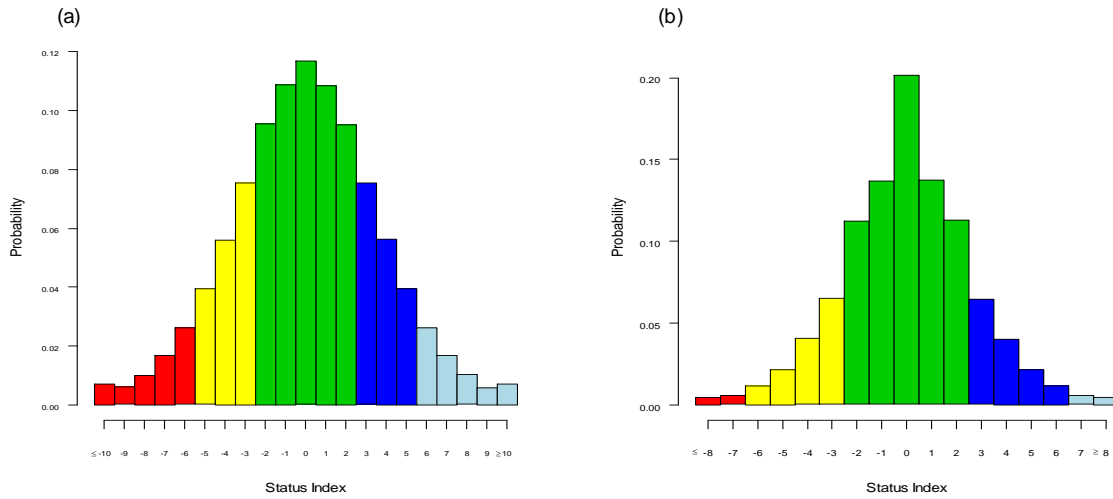


Figure 1-5 Histograms showing the probability distributions of obtaining total scores across (a) six PIs for SAUs of high importance and (b) three PIs for SAUs of medium importance. Distributions were generated by Monte Carlo simulations ($n = 5000$). Status index probabilities above and below ± 10 (high) and ± 8 (medium) were accumulated in these upper and lower bin classes, respectively, for each of the six and three PI distributions.

Table 1-4 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

Step 5: Determine zonal status

The status of each species in each zone is derived from a combination of the (1) risk-of-overfishing category for each SAU and (2) importance of that SAU, by catch, to the zone. This is undertaken in a four-stage process. First, numeric scores are assigned to each colour-coded, risk-of-overfishing, category. These scores are -2 (red), -1 (yellow), 0 (green), +1 (blue) and +2 (light-blue). Second, the proportional contribution to the combined catch from each high and medium SAU is determined, with catches from low importance SAUs ignored. Third, the risk-of-overfishing score (-2 to +2) for each SAU is multiplied by its proportional contribution to the combined catch. Finally, the products of these calculations are summed to provide a catch-weighted score for zone status that ranges between -2 and +2. Zone status scores fall into one of five categories. These are defined as depleted (score ≤ -1.5), over-fished (> -1.5 score ≤ -0.5), sustainably-fished ($> -0.5 >$ score ≤ 0.5), under-fished (> 0.5 score ≤ 1.5) and lightly-fished (score ≥ 1.5).

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 and 2009 (Mayfield and Ward 2003; Mayfield *et al.* 2004, 2005b, 2006, 2008a, 2010; Chick and Mayfield 2012).

For greenlip, the most recent stock assessment report for the CZ (Chick and Mayfield 2012) concluded that (1) Tiparra Reef has been the most important SAU for greenlip in the CZ, (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; (3) low catches from Tiparra Reef demonstrated that the 33 t.yr⁻¹ 'catch-cap' was too high to constrain catches, and (4) the combination of declining catches on Tiparra Reef and a stable TACC, had resulted in re-distribution of catch and effort into other SAUs, particularly West Kangaroo Island and South Kangaroo Island SAUs. For blacklip, weight of evidence and harvest strategy outcomes suggested that catches from West and South Kangaroo Island SAUs were sustainable.

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.* 2014), 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.* 2014).

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 1-5). 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 1-6 and Table 1-7). Fresh meat and bled-meat weights represent ~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 1-5). 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 1-9). Rates of natural mortality also vary temporally and spatially. Natural mortality rates (M) of greenlip at West Island were 0.26 year⁻¹. This was greater than that observed at Tiparra Reef ($M = 0.22$ year⁻¹; Table 1-10). 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).

Table 1-5 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 1-6 Relationship between shell length (mm) and shell weight (SW, g) for greenlip in the CZ. The equation is of the form $SW = aSL^b$.

Year	Site	a ($\times 10^{-5}$)	b	r	n	Reference
1997	Tiparra Reef – West Bottom	10.0	3.08	0.91	97	SARDI unpublished data
1997	Tiparra Reef	1.26	3.51	-	-	Shepherd and Baker (1998)
1997	West Island	1.7	3.41	-	-	Shepherd and Baker (1998)
2003	Tiparra Reef – West Bottom	2.0	3.35	0.99	82	SARDI unpublished data
2004	Tiparra Reef – Coal Ground	10.0	3.06	0.98	164	SARDI unpublished data
2004	Tiparra Reef – Mid West Bottom	3.0	3.28	0.97	99	SARDI unpublished data
2004	Tiparra Reef – West Bottom	3.0	3.29	0.99	204	SARDI unpublished data
2007	Tiparra Reef – Coal Ground	20.0	2.95	0.94	123	SARDI unpublished data
2007	Tiparra Reef – Mid West Bottom	9.2	3.06	0.97	129	SARDI unpublished data
2013	Tiparra Reef – Mid West/Coalground	18.0	2.97	0.72	147	SARDI unpublished data

Table 1-7 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	2×10^{-10}	5.01	-	-	SARDI unpublished data

Table 1-8 Mean growth rate ($\text{mm}\cdot\text{yr}^{-1}$) of greenlip tagged and recaptured in the CZ.

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

Table 1-9 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}) \pm SE	L_{∞} \pm SE	Reference
West Island	42-141	0.479 \pm 0.029	137.9 \pm 1.9	Shepherd and Hearn (1983)
Tiparra Reef	51-129	0.406 \pm 0.047	130.8 \pm 2.5	Shepherd and Hearn (1983)

Table 1-10 Natural mortality rates ($\text{M}\cdot\text{yr}^{-1}$) for adult (emergent) greenlip at two sites in the CZ.

Site	$M \pm SE$	Reference
West Island	0.26 \pm 0.06	Shepherd <i>et al.</i> (1982)
Tiparra Reef	0.22 \pm 0.10	Shepherd <i>et al.</i> (1982)

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. L_{50} was reached at 76.0 and 109.2 mm SL at West Island and Vennachar Point, respectively (Table 1-11). 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 1-12).

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 $0.34.\text{yr}^{-1}$ (West Island) while L_{∞} varied between 138.8 (West Island) and 142.6 mm SL (Tiparra Reef; Table 1-13).

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 1-14).

Table 1-11 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 1-12 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 1-13 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 1-14 Natural mortality rates ($M.\text{yr}^{-1}$) for adult (emergent) blacklip at two sites in the CZ.

Site	M	Reference
West Island	0.36 ± 0.28	Shepherd <i>et al.</i> (1982)
Tiparra Reef	0.21 ± 0.10	Shepherd <i>et al.</i> (1982)

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 2013, 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) fishing area (FA; *e.g.* FA 21); (3) mapcode (MC, *e.g.* MC 22A); and (4) spatial assessment unit (SAU; *e.g.* Tiparra Reef, West Yorke Peninsula, see Figure 1-2). 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 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 consist of (1) estimates of greenlip densities for individuals ≥ 130 mm SL, 90-130 mm SL (*i.e.* pre-recruits) and these two size categories combined; and (2) length-frequency distributions from fishery-independent surveys (Table 1-3).

Commercial catch and effort data have been collected since 1968 by fishers completing a research logbook for each fishing day. Data on the proportion of large abalone in the commercial catch were obtained from length-frequency data collected from January 2002 to June 2005, obtained by SARDI measuring samples provided by commercial fishers. Length-frequency data from July 2005 to December 2007 and from January 2008 to December 2013 were provided by the Abalone Industry Association of SA (AIASA) and Michael Tokley, representing the CZ licence holders, respectively, and supplemented by sampling on commercial vessels by SARDI. No catch-sampling data were provided for 2010 or 2011.

Catch (t, meat weight) was determined from all daily logbook returns. Effort was calculated from daily records where blacklip catch was zero because (1) effort is not

proportioned among species on each fishing day; (2) an average of >70% of fishing records from 1979 to 2011 report a blacklip catch of zero; (3) >80% of the greenlip catch is obtained on days when no blacklip are harvested; and (4) greenlip and blacklip are typically harvested from different fishing grounds. CPUE ($\text{kg}\cdot\text{hr}^{-1}$; meat weight) was calculated as the catch-weighted mean of daily CPUE (Burch *et al.* 2011; see Table 1-3), 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. The small proportion of records (<1%) where multiple daily dives were entered as separate days were ignored. Limited daily records (*i.e.* $n < 10$) prevented calculation of CPUE in some years at some spatial scales. The proportion of large greenlip (>155 mm SL) in the catch was determined from the catch-sampling data. Limited data (*i.e.* $n < 100$ SL measurements) prevented calculation of this metric in some years at some spatial scales.

Estimates of greenlip density were obtained from fishery-independent diver-surveys conducted by SARDI. Fishery-independent surveys at Tiparra Reef have been undertaken in most years since 1968 using the timed-swim method (relative abundance; Shepherd 1985). More recent surveys, from 2010 onwards, have also used the leaded-line method (absolute abundance; McGarvey *et al.* 2008) to improve the reliability and accuracy of estimates of greenlip density. In 2010 and 2012, surveys were conducted using both methods, but in 2011 and 2013 only the leaded-line method was used. Leaded-line survey locations have varied among years. Consequently, only data from those leaded lines surveyed in all four years are used in these analyses. Density estimates are provided for greenlip in three size categories for both methods. These are total greenlip and greenlip \geq and $<$ 130 mm SL (termed 'legal sized' and 'sub-legal-sized', respectively). The latter two categories reflect the MLL for greenlip in the CZ prior to 2013, with these categories retained in this assessment for historical continuity despite the MLL in 2013 being 135 mm SL. Estimates of greenlip density from timed-swims in 2011 and 2013, required for application of the harvest strategy, were obtained by applying the percentage change in density between years from the leaded-line surveys to the timed-swim estimates.

In 2013, GPS data that describe fishing location were used to identify the most important fishing grounds on Tiparra Reef. Based on these data, three strata were surveyed, encompassing areas of high (351,000 m^2 ; 21% of GPS points; $n = 15$ leaded lines), medium (906,000 m^2 , 30% of GPS points; $n = 16$ leaded lines) and low (1, 942,000 m^2 ; 26% of GPS points; $n = 21$ leaded lines) fishing intensity. The total area in which surveys were conducted was 3,199,244 m^2 , and encompassed 77% of GPS

points across this SAU. The leaded-line method was used to estimate the bleed-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). Simultaneously, greenlip were collected from Tiparra Reef and used to establish the SL to BMW relationship required to estimate harvestable biomass ($BMW = 5.65 \times 10^{-4} SL^{2.507}$).

As only a subset of the fishing grounds on Tiparra Reef were included in the harvestable biomass estimate, this estimate was 'scaled' to the Tiparra Reef SAU using three methods: (1) assuming the area surveyed represents the area from which 77% of the catch is harvested (based on the GPS data); (2) assuming the area surveyed represents the area from which 75% of the catch is harvested (mean estimate from commercial divers following their assessment of the survey design); and (3) determining the area containing a further 13% of GPS points (primarily excluding those likely to represent non-diving periods such as the vessel drifting during a diver's lunch break; *i.e.* total area encompassing 90% of 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 (2,763,590 m²) was estimated using a predicted survey density for this stratum that was based on the mean percentage difference in densities between strata 1 and 2 (29%) and strata 2 and 3 (80%; *i.e.* 55% below that in stratum 3).

The survey spanned the period from 11 September 2013 to 14 November 2013. The reported catch from Tiparra Reef at the mid-point of the survey (*i.e.* 15 October 2013) and the total catch from Tiparra Reef in 2013 were used with the scaled estimates of harvestable biomass to estimate the potential range of exploitation rates from this SAU in 2013. This approach required three key assumptions: natural mortality and recruitment were zero from 1 January to 15 October 2013 and the SL-meat weight relationship is time invariant. While it is reasonable to assume that recruitment would be offset by natural mortality and that the survey estimates of biomass would be under, rather than overestimated (Stobart *et al.* 2013b).

2.3. Results

2.3.1. Central Zone

Total catch has been stable at about 46.7 t.yr⁻¹ since 1994 (Figure 2-1). Prior to the implementation of a TACC (1990), the average annual catch was 44.3 t, which includes the maximum recorded catch of 84.3 t in 1989. Thus, current catches are about 6% greater than the annual average before implementation of a TACC. CPUE was 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. Since 2001, it has generally decreased and, in 2013, was 23 kg.hr⁻¹, the second lowest level since 1999. Total annual effort has generally increased since 2001 with rapid increases between 2009 and 2011. In 2011, total effort on greenlip was 359 days, the greatest number of days fished per year in 20 years. In 2013, total effort on greenlip was lower at 306 days.

Two key changes in the spatial distribution of catch are evident from 1990 following TACC implementation (Figure 2-1). Firstly, the proportion of catch harvested from Tiparra Reef (MCs 21A - G) increased substantially and peaked at 94% (44.9 t) in 2001. Secondly, following the imposition of a 'catch-cap' for FA 21 in 2005, catches from Tiparra Reef declined steadily, with a corresponding increase in catches from other areas of the CZ. In 2013, the catch from Tiparra Reef contributed 19% (9 t) to the total catch, the lowest proportion and the lowest catch since records began in 1979.

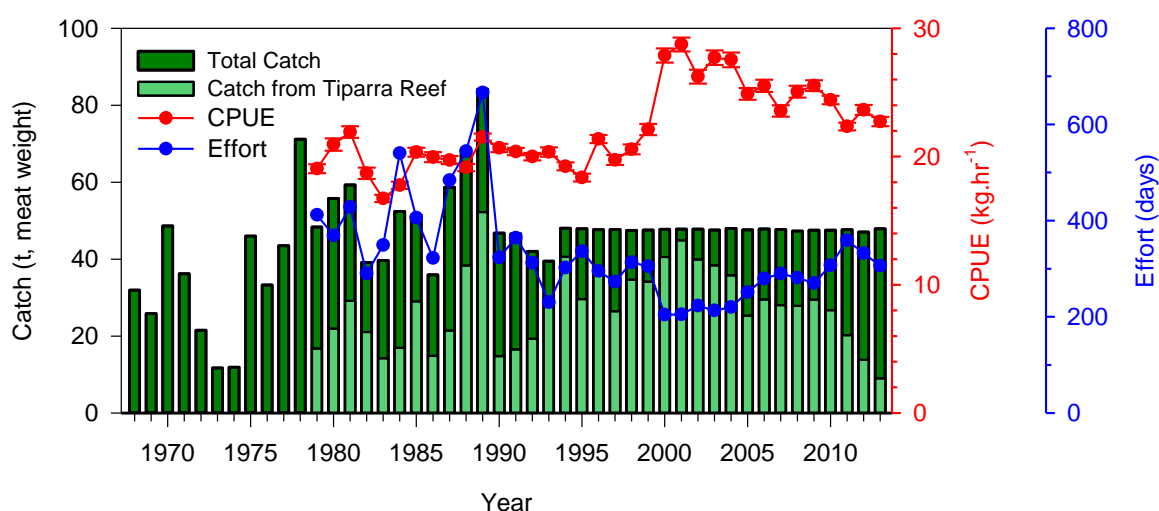


Figure 2-1 Total catch of greenlip for the CZ (t, meat weight; dark green) from 1968-2013. From 1979 to 2013, catch from Tiparra Reef (light green bars) is superimposed on total catch; these data were unavailable from 1968 to 1978. Total effort (days), and CPUE (kg.hr⁻¹, \pm SE) are shown by blue and red lines, respectively.

For areas other than Tiparra Reef, small amounts of catch have been harvested from a large number of mapcodes (Figure 2-2; 'Other'). However, several mapcodes have contributed substantial, but variable amounts among years. Historically, prior to the implementation of a TACC, substantial catches were obtained from MCs 24C and 24E (1980-1983) and MC 24A (1984-1988). From 1992 to 2004, when the proportion of the TACC harvested away from the Tiparra Reef SAU was low, most catches were obtained from MCs 24A and 21H. Since 2005, catches harvested away from Tiparra

Reef were first obtained from the West York Peninsula and then from the East York Peninsula SAUs. Thus, from 2005 to 2007 large catches were harvested from MCs 22A and 24A. Subsequently, from 2008 to 2010 the majority of the catch was harvested from MCs 24C-E. Across both periods (*i.e.* 2005 to 2013), catches from MC 21H have increased. In 2012 and 2013, a substantial proportion of the catch harvested away from Tiparra Reef was obtained from Hardwicke Bay (MC 24A).

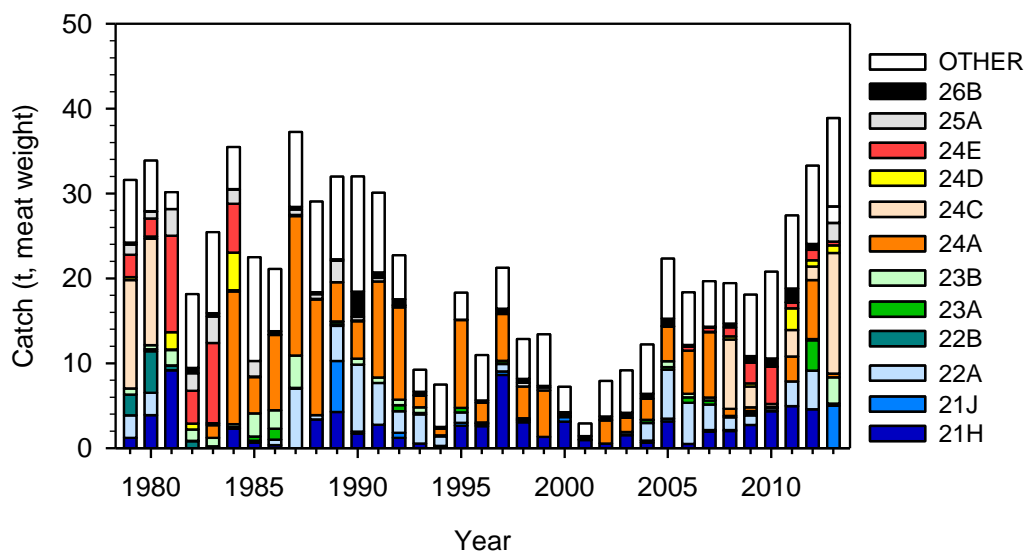


Figure 2-2 Annual catch of greenlip (t, meat weight) harvested from individual mapcodes 'away' from Tiparra Reef (colour coded to reflect SAU codes - Figure 1-2) from 1979 to 2013.

2.3.2. Fishing areas

2.3.2.1. Distribution of catch among fishing areas

Since 1992, an average of >85% of the greenlip TACC has been harvested from FA 21 (70%), FA 22 (3.5%) and FA 24 (12%; Figure 2-3) combined, indicating the importance of these areas to the fishery. Catches from the remaining FAs (FA 23 and 25–32) have been small (annual average <3%). The spatial distribution of the catch among FAs has changed substantially in the last 8-10 years. Notably, the proportion of the catch harvested from FA 21 has decreased to an historical low of 29% in 2013. Simultaneously, catches from FAs 22, 24 and 26-32 have increased. Catches from FA 24 increased from 10% to 37% of the total catch from 2010 to 2013, eclipsing FA 21 as the most important FA, by catch, in 2013. The contribution to the total catch from FAs located off Kangaroo Island (26-32) remained above 20% from 2010, the highest proportions since 1992. In 2013, these FAs contributed 25% to the total catch.

2.3.2.2. Temporal patterns of catch and CPUE in fishing areas

Substantial changes in catch have occurred among FAs through time, but particularly over the last 10 years (Figure 2-4). These patterns reflect a redistribution of the catch from FA 21 to other areas, including fishing grounds on the west and east coast of Yorke Peninsula and those off Kangaroo Island. For example, catch has increased over the last 8-10 years in FAs 24, 26, 27, 29, 30 and 31 and recent catches from FAs 24, 26, 27 and 29 are among the highest on record. In contrast, in FA 21, annual catches have generally decreased since 2001 and, in 2012 and 2013 were 18.4 t and 14.0 t, respectively. The 14.0 t catch in 2013 was the lowest since records began in 1979 and less than a third of the catch obtained from this FA in 2001 (contemporary maximum; 45.8 t). Pulses of fishing have occurred in FA 22, with peaks in catch recorded in 1980 (7.6 t), 1990 (7.8 t), 2005 (5.7 t) and 2012 (4.5 t).

Annual estimates of CPUE and the proportion of large greenlip in the commercial catch are highly variable among, and within, FAs (Figure 2-4). Current CPUEs in FAs 23, 24 and 29 are among the highest on record. In contrast, current estimates of CPUE in FAs 21, 26 and 27 are substantially lower than those observed in the late 2000's, but similar to those observed historically (*i.e.* 1979-2000). There was a high degree of spatial and inter-annual variability in the proportion of large greenlip in the commercial catch.

2.3.3. Spatial assessment units

2.3.3.1. Distribution of catch among SAUs

The distribution of catch among SAUs reflects the recent temporal shift in the proportional redistribution of catch from Tiparra Reef to other SAUs (Figure 2-5). Initially, catches from West Yorke Peninsula increased between 2005 and 2007. From 2008 to 2010, the contribution of catch from West Yorke Peninsula decreased, with catches from East Yorke Peninsula increasing in 2008 and 2009 and those from South and West Kangaroo Island subsequently rising from 2008 to 2013.

Over the last three years, catches from West Yorke Peninsula have again increased, and those from the South and West Kangaroo Island SAUs have been maintained. When compared to the early 2000s, this represents a more equitable distribution of catches among SAUs. Overall these temporal patterns in the distribution of catch have resulted in two high (Tiparra Reef and West Yorke Peninsula) and two medium-importance (South and West Kangaroo Island) SAUs for greenlip in the CZ in 2013.

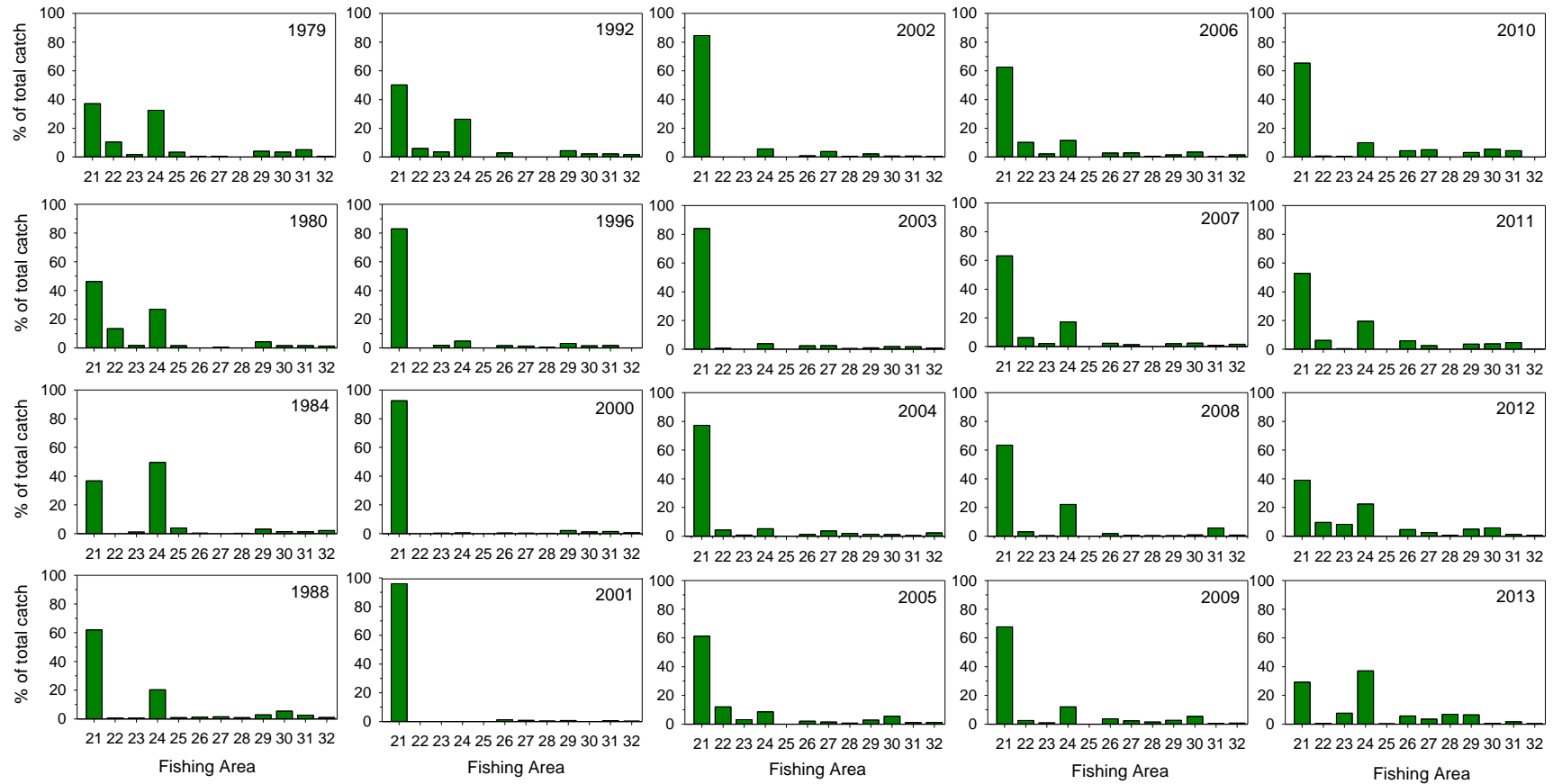


Figure 2-3 Spatial distribution of the greenlip catch (% of total catch) among each of the fishing areas in the CZ from 1979 to 2013.

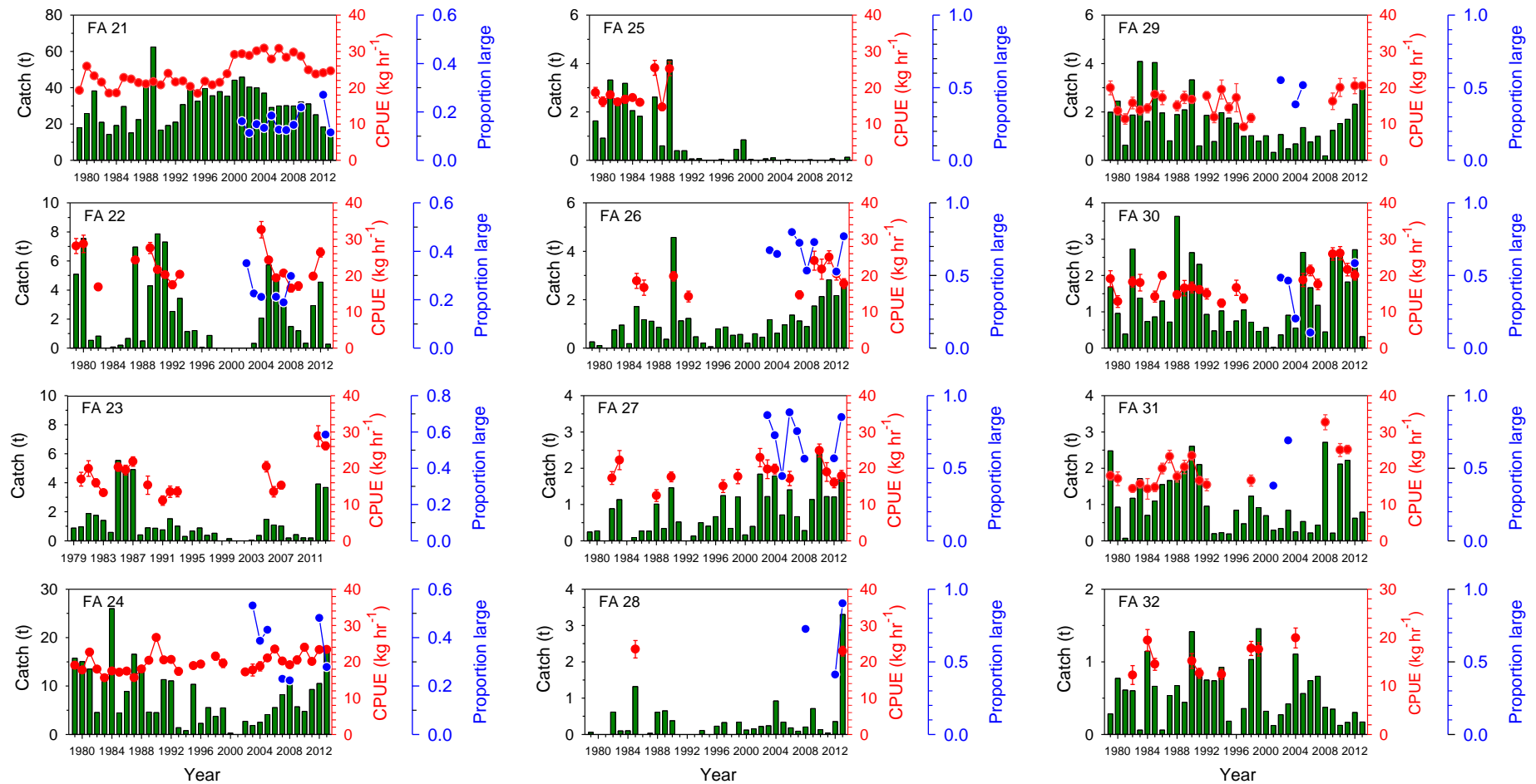


Figure 2-4 Catch (t, meat weight, green bars), CPUE ($\text{kg}\cdot\text{hr}^{-1}$, $\pm\text{SE}$, red lines) and the proportion of large (>155 mm, blue lines) greenlip in each of the fishing areas comprising the CZ from 1979 to 2013. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). Note different scales on the Y-axes for catch and CPUE.

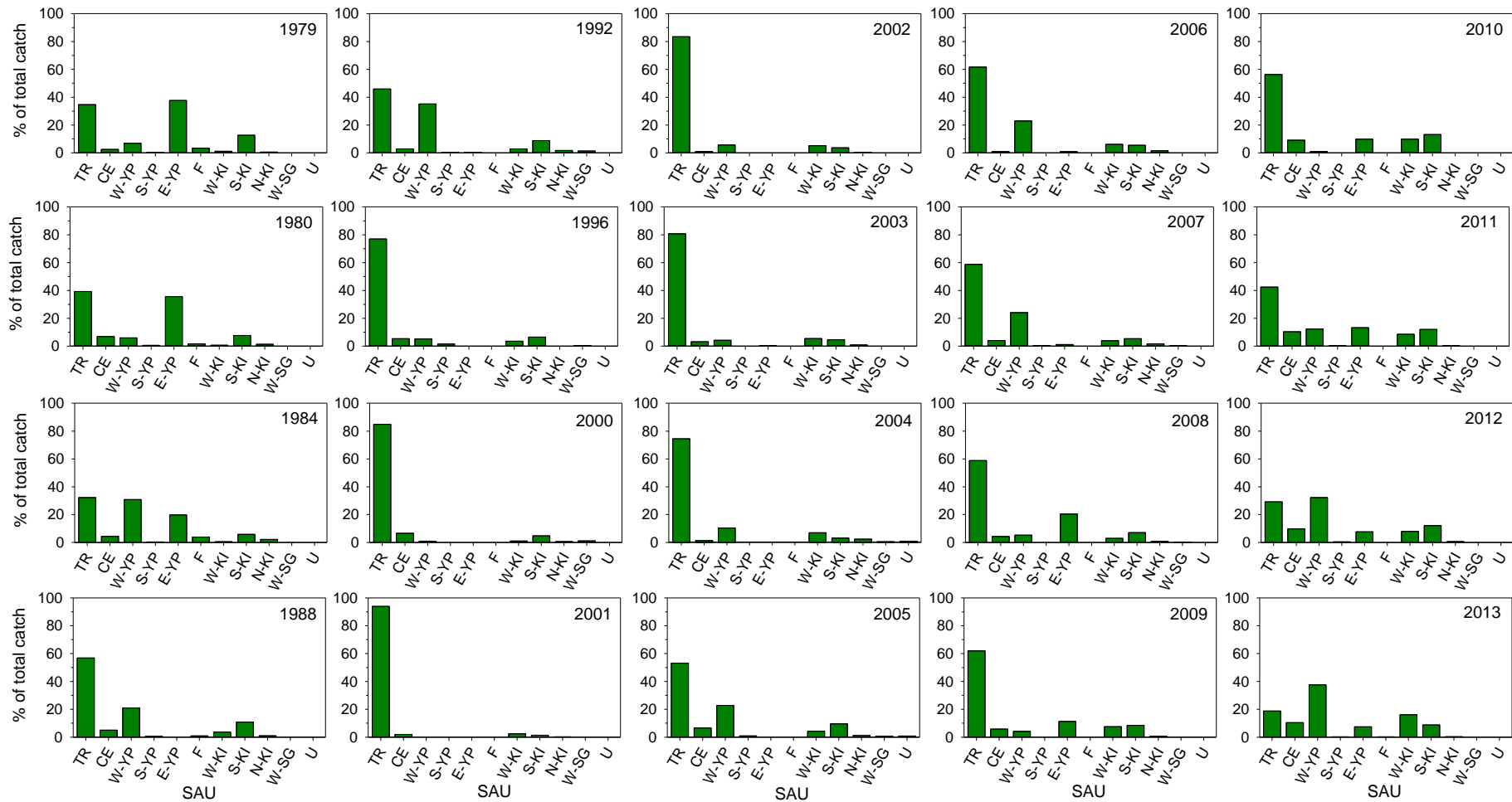


Figure 2-5 Spatial distribution of the greenlip catch (% of total catch, green bars) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ from 1979 to 2013.

2.3.3.2. Temporal patterns in SAUs of high importance

Tiparra Reef

Tiparra Reef has been the most important greenlip SAU in the CZ (61% of annual catch) and the SAAF (23%) since 1990. Total annual catches from Tiparra Reef increased steadily between 1979 (17 t) and 2001 (45 t), with large catches harvested in 1988 (38 t) and 1989 (52 t; Figure 2-6). Since 2001, catches have declined rapidly, particularly from 2009. In 2013, the catch from Tiparra Reef was 9.0 t, the lowest on record from this SAU. 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 2-6). CPUE decreased between 2009 (28.4 kg.hr⁻¹) and 2012 (23.4 kg.hr⁻¹). In 2013, CPUE was marginally higher (24.0 kg.hr⁻¹) than that in 2012. Although the 2013 estimate was about 13% below the previous 10 year average (2003-2012; 27.6 kg.hr⁻¹) and among the lowest since 1999, it remained above the 20-year average from 1979 to 1999. There was a substantial reduction in the proportion of large greenlip in the commercial catch between 2012 and 2013 (Figure 2-6).

Fishery-independent, timed-swim survey data of the density of total, legal and sub-legal size greenlip on Tiparra Reef indicate that total abundance was high in 1990 (0.76 greenlip.m⁻²) and 2005 (0.74 greenlip.m⁻²; Figure 2-7). The highest legal-size density was observed in 2005 (0.27 greenlip.m⁻²) and has decreased in subsequent survey periods (Figure 2-7). In 2012, the timed-swim estimate of legal-size density was 0.08 greenlip.m⁻², the lowest value for 10 years and more than 50% below that in 2005. Despite this decrease, the estimate of legal-size density remained above those observed in the early 1990s. The density of sub-legal-size greenlip was highest in 1990 and 1991, with a contemporary maximum in 2005 of 0.47 greenlip.m⁻² (Figure 2-7). In 2012, the timed-swim estimate of sub-legal-size density was 0.22 greenlip.m⁻², the lowest value on record.

Leaded-line surveys have been undertaken at Tiparra Reef from 2010 to 2013. Over this four-year period, total greenlip density has declined by 30% from 0.22 to 0.16 greenlip.m⁻² (Figure 2-7). This reflects reductions in the densities of both legal-sized (26%) and sub-legal-sized (33%) greenlip over this time period. In stratum 1 in 2013, the densities of legal-sized and mature greenlip (i.e. ≥ 100 mm SL) were 0.12 and 0.24 greenlip.m⁻².

Application of the 27% reduction in sub-legal-sized density between 2012 and 2013 to the 2012 estimate from the timed-swim surveys yields a value of 0.16 greenlip.m⁻², which would supersede the 2012 estimate as the lowest value recorded (Figure 2-7).

Similarly, the 11% reduction in the density of legal-sized greenlip results in a 2013 timed-swim density estimate of 0.07 greenlip.m⁻², the lowest value since 1994.

The 2013 leaded-line survey was used to estimate the harvestable biomass in this SAU. The stratified median estimate of legal-sized (*i.e.* ≥ 135 mm SL) biomass in the survey area in October 2013 was 23.2 t meat weight. There was a 90% probability that the biomass exceeded 19.2 t, and a 10% probability that it was greater than 27.6 t. The scaled, BMW estimates of the median harvestable biomass in the Tiparra Reef SAU were 30.1 t (Method 1), 30.9 t (Method 2) and 30.1 t (Method 3).

At the mid-point of the survey (*i.e.* 15 October 2013), the reported catch from Tiparra Reef was 6.7 t. Adding this value to the scaled median estimate of harvestable biomass suggests the harvestable biomass of greenlip on Tiparra Reef in January 2013 ranged between 36.8 t and 37.6 t. As the total catch harvested from Tiparra Reef in 2013 was 9.0 t, these estimates suggest that the exploitation rate at Tiparra Reef in 2013 was approximately 24%.

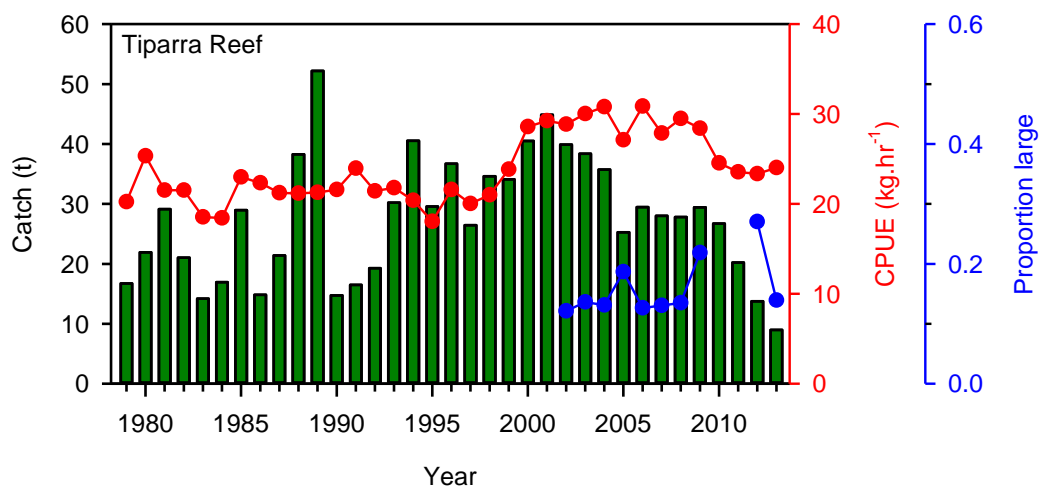


Figure 2-6 Tiparra Reef (high importance). Catch (t, meat weight; green bars), CPUE (kg.hr⁻¹, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2013. Gaps in the time series of the proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

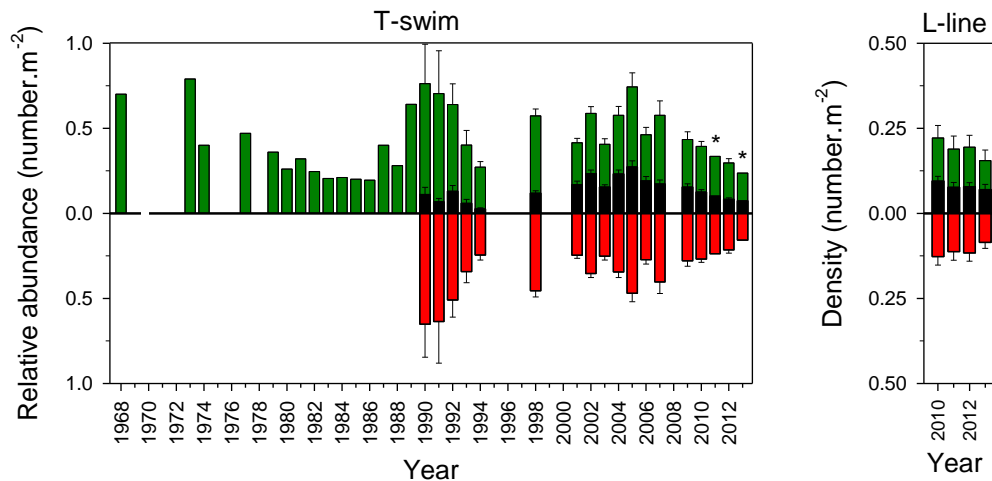


Figure 2-7 Tiparra Reef (high importance). Fishery-independent survey estimates of all greenlip (*i.e.* total number.m⁻²; green bars), and those greenlip ≥130 mm SL (black bars) and <130 mm SL (red bars) from 1968 to 2013 (timed-swims) and 2010 to 2013 (ledged-lines). Gaps in the time series indicate no surveys done. * indicates estimates of timed-swim densities derived from ledged-line densities. Y-axis scale varies between survey methods.

West Yorke Peninsula

Catches from the West Yorke Peninsula SAU appear cyclical (Figure 2-8). 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, had a lower peak (12 t in 2007), a lower average (11 t.yr⁻¹) and lasted a shorter time than the first. Following low catches from 2008 to 2010, the substantial catches from this SAU in 2012 (15.2 t) and 2013 (18.0 t) indicate the start of a third catch cycle that appears larger than that observed from 2004 to 2007. The large catches in 2012 and 2013, which are the largest since 1991, have been obtained at catch rates among the highest recorded for this SAU, with the CPUEs in these two years (26.7 and 25.5 kg.hr⁻¹, respectively) being substantially greater than the long-term mean CPUE for this SAU (19.8 kg.hr⁻¹). However, these high CPUEs may reflect re-distribution of catches among mapcodes (*e.g.* reduced catch from mapcode 22A, large increases in catch from mapcodes 23A and 24A; Appendix 1) to areas that have only been lightly-fished historically (*i.e.* mapcode 23A). Notably, there was a substantial reduction in the proportion of large greenlip in the commercial catch between 2012 and 2013 in this SAU (Figure 2-8), although current estimates remain above those observed in the mid 2000s.

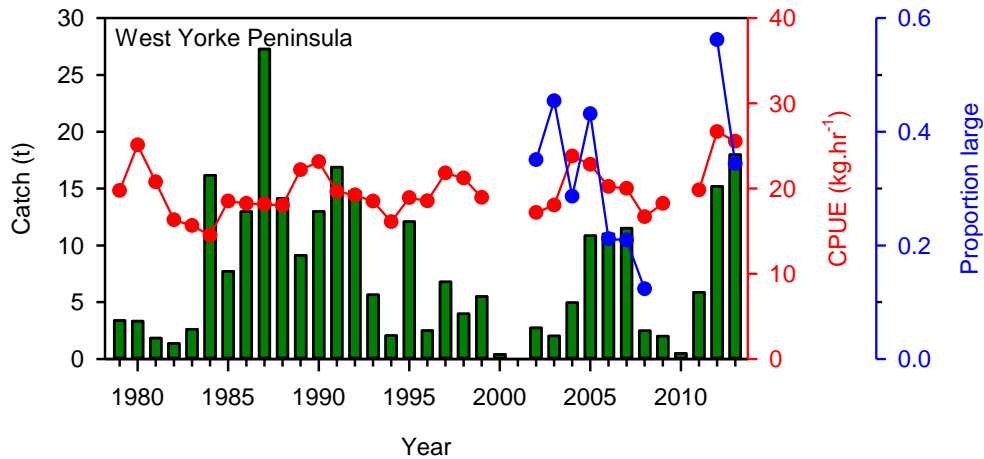


Figure 2-8 West Yorke Peninsula (high importance). Catch (t, meat weight, green bars), CPUE (kg.hr⁻¹, \pm SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2013. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

2.3.3.3. Temporal patterns in SAUs of medium importance

South Kangaroo Island

From 1979 to 1992, average annual catch from this SAU was ~ 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 2004, catches were relatively low, averaging approximately 2 t.yr⁻¹. Annual catches have increased substantially since 2004. Catches of about 6 t in 2010, 2011 and 2012 were the highest since 1990. In 2013, catch declined to 4 t. CPUE increased from the late 1990s, following the prolonged period of relatively low catch, reaching 28.1 kg.hr⁻¹ t in 2008, the highest value on record. Since then, it has gradually declined, reaching 18.8 kg.hr⁻¹ in 2013. This represents a decrease of more than 30% over five years, to the lowest value since 2007. These decreases in CPUE have occurred despite re-distribution of catches among mapcodes (e.g. reduced catch from mapcodes 30A, 30B and 30C, large increase in catch from mapcode 29C; Appendix 1) into areas from which catches in most previous years have been small (i.e. mapcode 29C). There were few data on the proportion of large greenlip in the commercial catch in this SAU.

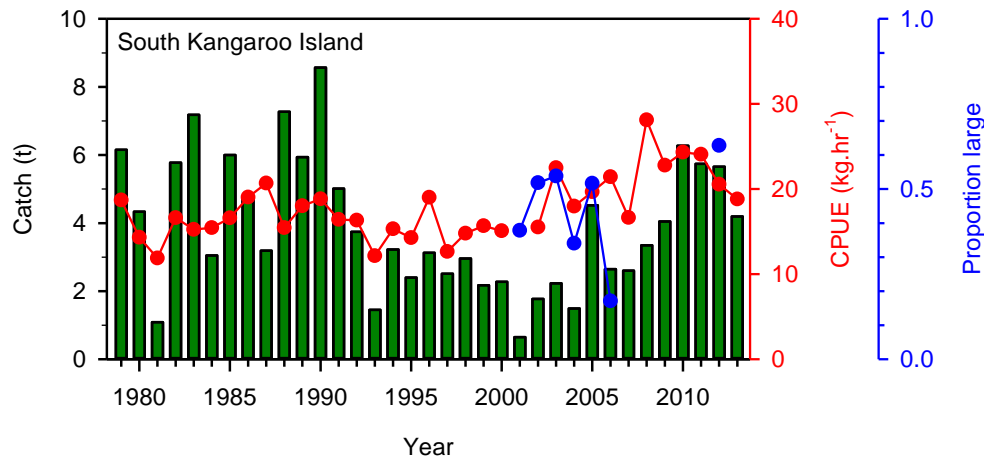


Figure 2-9 South Kangaroo Island (medium importance). Catch (t, meat weight, green bars), CPUE (kg.hr⁻¹, \pm SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2013. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

West Kangaroo Island

Prior to 2002, the average catch from this SAU was 1.6 t.yr⁻¹ (Figure 2-10). Catches over the last decade (2004-13) have been substantially higher, averaging 3.5 t.yr⁻¹. The catches from 2009 to 2012 were among the highest on record (range 3.6-4.7 t). In 2013, the catch of 7.7 t was the highest in the history of this SAU, and reflects substantial increases in catch from mapcodes 26B, 28A and 28B (Appendix 1). Before 2002, CPUE fluctuated substantially between years and often there were inadequate data (<10 fisher-days) to estimate it. Since 2002, inter-annual variability in CPUE has decreased. In 2010, the CPUE was 23.3 kg.hr⁻¹, the highest value since 1997. The CPUEs in 2012 and 2013 were approximately 15% lower, at about 20 kg.hr⁻¹. There was a high level of inter-annual variation in the proportion of large greenlip in the commercial catch in this SAU, impeding identification of any temporal trends (Figure 2-10).

2.3.3.4. Temporal patterns in SAUs of low importance

Catches and catch rates from low importance SAUs were variable among years (Figure 2-11). Among low importance SAUs, Cape Elizabeth and East Yorke Peninsula have made the highest contributions to total annual greenlip catches. For the Cape Elizabeth SAU, annual catches ranged from high catches of 9.2 t in 1981 and 8.6 t in 1997, to catches of less than 1 t.yr⁻¹ in several years. From 2010-13, annual catches were relatively stable at about 4.7 t.yr⁻¹ with 5.0 t taken in 2013. The CPUE in the Cape Elizabeth SAU generally increased between 1984 and 2005 (36.1 kg.hr⁻¹), the highest value for this SAU since 1981. This metric decreased rapidly between 2008 and 2011,

where after it has been relatively stable at about 25.4 kg.hr⁻¹. Large catches were obtained from the East Yorke Peninsula SAU between 1979 and 1984 (mean: 12.9 t.yr⁻¹) and moderate catches from 2008 to 2013 (5.5 t.yr⁻¹). Catches in this SAU from 1985 to 2007 were negligible. The low catch in 2013 (3.5 t) was obtained at one of the lowest catch rates on record (17.0 kg.hr⁻¹). There were few data for evaluating spatial or temporal trends in the proportion of large greenlip in the commercial catch across the low importance SAUs (Figure 2-11).

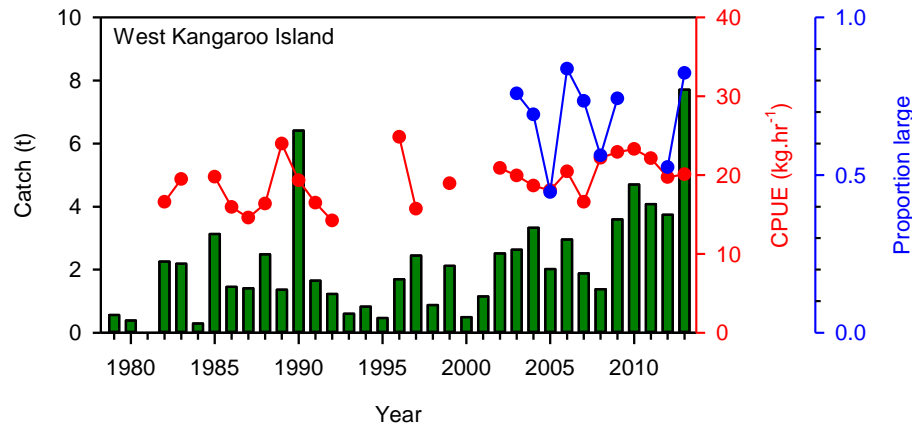


Figure 2-10 West Kangaroo Island (medium importance). Catch (t, meat weight, green bars), CPUE (kg.hr⁻¹, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2013. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

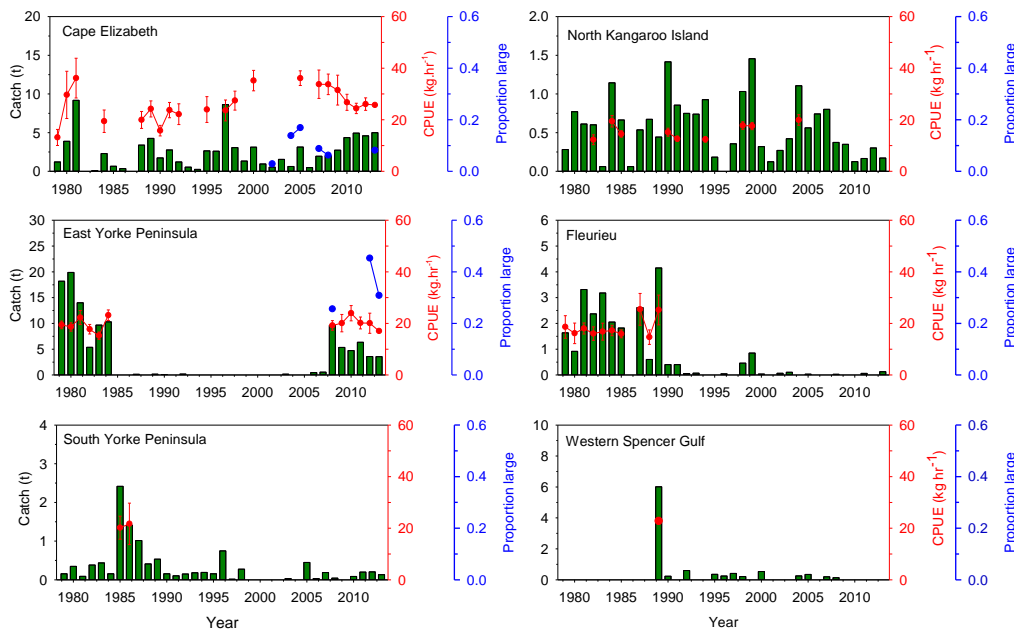


Figure 2-11 Low importance SAUs. Catch (t, meat weight, green bars), CPUE (kg.hr⁻¹, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2013. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

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

There were two high and two medium importance SAUs for greenlip (Figure 1-3; Table 2-1). It was possible to determine the risk of being overfished for all four of these SAUs (Table 2-1; Appendix 2). Summed PI scores ranged between -14 (Tiparra Reef) and +9 (West Kangaroo Island; Table 2-1). Tiparra Reef was assigned to a 'red', West Yorke Peninsula and West Kangaroo Island to a 'light blue' and South Kangaroo Island to a 'blue' risk-of-overfishing category (Table 2-1). The catch-weighted zonal score was 0.97. Under the harvest strategy, this score defines the status of the greenlip fishery in the CZ as '**under fished**' (Table 2-1).

Table 2-1 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. ND indicates no data.

Spatial assessment unit	%Contribution to mean total catch (CZ) over last 10 years (04-13)	Importance	%Contribution to catch from high & medium SAU in 2013	CPUE	%TACC	%Large	Pre-recruit density	Legal density	Mortality	Combined PI score	Risk of overfishing	Catch-weighted contribution to zonal score
Tiparra Reef	43.7	High	23.1	0	-8	0	-4	-2	ND	-14	-2	-0.46
West Yorke Peninsula	14.6	High	46.3	4	4	0	ND	ND	ND	8	2	0.93
South Kangaroo Island	7.2	Medium	10.8	0	7	-1	-	-	-	6	1	0.11
West Kangaroo Island	6.3	Medium	19.8	0	8	1	-	-	-	9	2	0.40
East Yorke Peninsula	6.1	Low	-	-	-	-	-	-	-	-	Not assessed	-
Cape Elizabeth	5.3	Low	-	-	-	-	-	-	-	-	Not assessed	-
North Kangaroo Island	0.8	Low	-	-	-	-	-	-	-	-	Not assessed	-
South Yorke Peninsula	0.2	Low	-	-	-	-	-	-	-	-	Not assessed	-
Western Spencer Gulf	0.2	Low	-	-	-	-	-	-	-	-	Not assessed	-
Fleurieu	0.0	Low	-	-	-	-	-	-	-	-	Not assessed	-
Unassigned Central Zone	0.1	Low	-	-	-	-	-	-	-	-	Not assessed	-
Sum	84.6		100.0									
											Zonal stock status	0.97

2.4. Discussion

Greenlip comprises 85% of the total abalone TACC (55.8 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 ground, has yielded both fishery-dependent and fishery-independent data for assessment. As the current harvest strategy (PIRSA 2012) rationalises resources to ensure they are distributed into assessments of SAUs that support the largest catches, fishery-independent surveys have been restricted to Tiparra Reef. Historically, fishery-independent surveys have been undertaken in the West Yorke Peninsula SAU at Port Victoria and Hardwicke Bay. As the West Yorke Peninsula SAU is now of high importance, these surveys will be resumed from 2015.

Total greenlip catches in the CZ have been consistent with the TACC since the implementation of this output control in 1990. Current catches are slightly higher (6%) than the long-term mean catch prior to TACC implementation. Since the TACC was implemented, there have been two 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 substantially from 1990 to 2001, reaching 44.9 t and accounting for 94% of the total greenlip harvest in the CZ. This was the second-highest catch from this SAU; the largest of 52.2 t was harvested in 1989. Second, from 2001, catches from the Tiparra Reef SAU have decreased substantially. In 2013, the catch from this SAU was 9.0 t. This value was the lowest recorded for this SAU, almost 75% smaller than the peak catches from 1998 to 2004 (38.3 t.yr⁻¹), and substantially (50%) below the 18-t 'catch-cap'. As the TACC has remained unchanged throughout this period, catches from several other SAUs have increased over the last decade, most notably in the South Kangaroo Island, West Kangaroo Island and Cape Elizabeth SAUs. There were also large increases in annual catch harvested from the West Yorke Peninsula SAU from 2005-07 and in 2012 and 2013. These patterns, which likely reflect changes in stock abundance, diver preferences, or a combination of these, were also evident among fishing areas and mapcodes.

The Tiparra Reef SAU has been the most important SAU for greenlip in both the CZ (61% of annual catch) and the SAAF (23%) since 1990, with these rankings retained despite the reduced catch harvested from this SAU since 2001. There is strong evidence that the abundance of greenlip on Tiparra Reef has decreased substantially over the past five years. This evidence includes (1) an 80% reduction in catch since 2001; (2) half the allocated 'catch cap' of 18 t not being harvested in 2013; (3) CPUE decreasing sharply between 2009 and 2010, with the subsequent mean CPUE from

2010 to 2013 being 18% below that from 2000 to 2009; (4) the proportion of large greenlip in the catch decreasing substantially between 2012 and 2013; (5) declining fishery-independent, timed-swim, survey estimates of legal and sub-legal sized greenlip since 2005, the former to the lowest level in a decade and the latter to the lowest value on record; and (6) fishery-independent, leaded-line survey estimates showing substantial reductions in greenlip density, particularly for the sub-legal-sized component, since their inception in 2010.

Our conclusion, from the weight of evidence available, that greenlip abundance has declined in the Tiparra Reef SAU is consistent with the outcome from applying the harvest strategy because the Tiparra Reef SAU was allocated to a 'red' risk-of-overfishing category. This category was assigned because the combined PI score was -14, one of the lowest on record for the SAAF (see Stobart *et al.* 2012, 2013a, 2014a,b). This score was strongly influenced by the contributions of the PIs for catch (-8), pre-recruit density (-4) and legal-sized density (-2). For the Tiparra Reef SAU, we note that the PI for catch is different to that used elsewhere in the CZ or the SAAF because the catch-cap makes scoring a PI based on catch as a percentage of the TACC inappropriate and inconsistent with the scoring system applied to the remaining PIs. However, if the PI was scored using catch as a percentage of the TACC, the score for this PI would also have been -8.

The 2013 leaded-line survey yielded estimates of harvestable biomass for the surveyed areas, which were scaled to provide estimates of harvestable biomass for the Tiparra Reef SAU. The three methods used to undertake the scaling resulted in harvestable biomass estimates of between 30.1 t and 30.9 t. As 6.7 t had been harvested by the mid-point of the survey, these estimates suggest that harvestable biomass in January 2013 was about 37 t, with a consequent exploitation rate at Tiparra Reef in 2013 of approximately 24%. This exploitation rate estimate in 2013 would be considered very high for long-lived, slow-growing species (Thorainsdóttir and Jacobsen 2005; Mayfield *et al.* 2008b,c) and for greenlip on Tiparra Reef in particular. This is for two reasons. First, the estimated mean density of mature greenlip in stratum 1 (the stratum with the highest mean densities) in 2013 was about 20% lower than the suggested densities below which fertilisation and recruitment levels are compromised (Babcock and Keesing 1999; Zhang 2008). Second, the most recent density estimates for sub-legal sized greenlip are at the lowest level on record, suggesting little recruitment to replenish legal-sized and/or spawning stocks. Notably, at Cowell, exploitation rates of 10% have previously resulted in a rapid decline in stock abundance (Mayfield *et al.* 2008b,c).

In response to the declining catches from the Tiparra Reef SAU and the stable TACC, total catches harvested outside the Tiparra Reef SAU have increased rapidly in recent years. In 2013, 81% of the TACC was harvested in the remaining SAUs. This was the highest percentage of the total catch on record and was the largest total greenlip catch from these combined areas on record. Most of that catch was harvested from the West Yorke Peninsula SAU and two of the three SAUs around Kangaroo Island (*i.e.* West and South Kangaroo Island). Catches from the Cape Elizabeth and East Yorke Peninsula SAUs have also increased, but to a lesser extent. For several of these SAUs, current catches are among (West Yorke Peninsula, South Kangaroo Island, Cape Elizabeth), or at (West Kangaroo Island), the highest levels recorded.

The recent large catches from the West Yorke Peninsula SAU have been obtained at catch rates that are among the highest observed in this SAU and similar to those recorded at Tiparra Reef. Harvesting substantial catches at a high CPUE suggests strong greenlip abundance in this SAU and was consistent with the outcome of the harvest strategy which allocated this SAU to a 'light-blue' risk-of-overfishing category. Application of the harvest-decision rules to this category permits an increase in the catch contribution to the TACC of up to 50% of the mean catch over the last four years (*i.e.* 2010-2013). However, given that the current catch from this SAU is among the highest on record and catches have recently been redistributed among the component mapcodes, any increase in the catch contribution to the TACC from this SAU should be carefully considered. Structured, defensible information from divers currently harvesting greenlip from these areas, in conjunction with other available data, may provide significant guidance in this regard.

Recent decreases in catch rates – in several cases to levels 25% below those observed in the Tiparra Reef and West Yorke Peninsula SAUs – indicate that current high catches in the West Kangaroo Island, South Kangaroo Island, Cape Elizabeth and East Yorke Peninsula SAUs are unlikely to be maintained. In addition, for some SAUs, there has also been a re-distribution of catches into mapcodes from which historically few greenlip have been harvested, which suggests a continued expansion from traditional to less-traditional fishing grounds to maintain catch. For the East Yorke Peninsula SAU, where the increased catch from 2008 was not sustained, this likely reflects limited resilience from the high greenlip mortality following *Perkinsus olseni* infection (Goggin and Lester 1995). The declines in catch and catch rate in this SAU suggest that the fishing grounds adjacent to Yorke Peninsula are currently unable to support catches similar to those harvested in the 1980s, despite the absence of fishing from 1985 to 2005.

Collectively, the (1) long-term decline in CPUE and increase in fishing effort across the CZ; (2) strong evidence that the abundance of greenlip on Tiparra Reef has decreased substantially over recent years, with catches from the Tiparra Reef SAU reduced to the lowest level on record; (3) recent decreases in catch rates in many SAUs where catches have increased over recent years; and (4) re-distribution of catches into mapcodes from which historically few greenlip have been harvested – indicative of spatial expansion to maintain catch – suggest that stock abundance is likely to decrease further at the current TACC. Based on this evidence, the CZ greenlip fishery has been classified as **'transitional depleting'** under the national framework for reporting stock status (Flood *et al.* 2012).

The weight-of-evidence assessment – **'transitional depleting'** – strongly contrasted with that obtained from the application of the harvest strategy in the Management Plan (**'under fished'**). The primary reason for this difference was the large contribution of the PI for catch to the combined PI score, which negated the low scores for CPUE in the South Kangaroo Island and West Kangaroo Island SAUs. This feature of the harvest strategy, where an increase in the risk-of-overfishing resulting from substantial decreases in relative abalone abundance can be offset by large positive scores from the remaining PIs has been previously identified as a key driver of the differences in stock status from the weight-of-evidence and harvest strategy assessments (Chick and Mayfield 2012; Stobart *et al.* 2012, 2013a, 2014a). Similar problems were evident for blacklip in this report (Section 3) and will need careful consideration when the harvest strategy is reviewed in 2015.

In summary, the current low catches and reduced abundance of greenlip on Tiparra Reef suggest that maintenance of the 47.7 t TACC for greenlip in the CZ is reliant on (1) the continuation of high catches from those SAUs which have now been supporting the TACC for several years; (2) increased catches from remaining the SAUs where catches have historically been higher than more recent yields; and/or (3) a combination of these. The productivity of stocks in those SAUs from which recent catches are elevated – including West Yorke Peninsula, Cape Elizabeth, West Kangaroo Island, South Kangaroo Island and East Yorke Peninsula – is poorly understood. However, recent reductions in catch and/or catch rate suggest a limited capacity to continue providing current levels of catch. Thus, additional management arrangements including a lower TACC, catch caps, spatially-variable MLLs and spatial closures should be considered from 2015 to prevent overfishing in key SAUs as abalone stocks reduced to low biomass levels require extended recovery times and likely subsequent lower productivity (Gorfine *et al.* 2008; Prince and Peeters 2010; Haddon *et al.* 2014).

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 2013 and an assessment of the current stock status. Data are presented at four spatial scales. These are: (1) the whole blacklip fishery (*i.e.* all areas of the CZ combined); (2) fishing area (*e.g.* FA 26); (3) mapcode (*e.g.* 26B); and (4) spatial assessment unit (SAU; *e.g.* West Kangaroo Island, see Figure 1-2). 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 the high and medium SAUs are overfished and (2) the zonal stock status for blacklip. 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 1-3). The fishery-dependent catch and effort data were also used to evaluate spatial and temporal changes in the behaviour of the commercial divers in the CZ, including changes in (1) fishing effort; (2) the proportions of greenlip and blacklip in daily and total catch; (3) depth profiles; and (4) length of fishing day.

Commercial catch and effort data have been collected since 1968 by fishers completing a research logbook for each fishing day. Data on the proportion of large abalone in the commercial catch were obtained from length-frequency data collected from January 2002 to June 2005, obtained by SARDI measuring samples provided by commercial fishers. Length-frequency data from July 2005 to December 2007 and from January 2008 to December 2013 were provided by the AIASA and Michael Tokley, representing the CZ licence holders, respectively, and supplemented by SARDI sampling on commercial vessels. No data were provided for 2010, 2011 or 2012.

Catch (t, meat weight) was determined from all logbook returns. Effort was calculated from daily records where blacklip catch was $\geq 50\%$ of the total catch because: (1) effort is not differentiated or apportioned among species on each fishing day; (2) few fishing records between 1979 and 2013 report a blacklip catch of zero; (3) an average of <13% of fishing records in each year report a blacklip catch on fishing days when no greenlip are harvested; and (4) using daily records where the blacklip catch is less than 50% of the total catch is inappropriate as blacklip were probably not being targeted on those days. The

small proportion of records (<0.5%) where multiple daily dives are entered as separate days were ignored.

CPUE (kg.hr⁻¹; meat weight) was calculated as the catch-weighted mean of daily CPUE (Burch *et al.* 2011; see Table 1-3), where 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 occurring as a result of spatial and temporal changes in diver behaviour, estimates of annual CPUE 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 3-1). In addition, for the CZ, annual CPUE estimates were also derived using those daily records where the proportion of blacklip in the total catch was at least 30% and where at least 50% and 85% of daily effort was in water less than 10 m depth (Figure 3-1). There were inadequate data to evaluate the potential impact on CPUE from changes to the timing of blacklip harvest within each year.

Visual and Pearson's correlation (r , range 0.75 – 0.98) comparisons among these CPUE estimation methods demonstrated high levels of consistency in temporal trend (after Burch *et al.* 2011). In addition, the percentage differences in mean CPUE between recent years (i.e. 2012 and 2013) and the decade prior (i.e. 2002 to 2011) were similar among CPUE estimation methods (Figure 3-1; panel A: 12.5 to 15.2%, panel B: 9.9 to 14.5%, and panel C: 12.7 to 15.2%). Consequently, all daily records (i.e. across all depths) where the proportion of blacklip in the total catch was at least 30% were confirmed as the most appropriate data to determine the CPUE on blacklip in the CZ (Burch *et al.* 2011; Chick and Mayfield 2012). 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 was determined from most of the available data; and (3) temporal patterns and the magnitude of changes in CPUE across data sets were similar. Despite this approach, limited daily records (i.e. $n < 10$) prevented the calculation of CPUE in some years at some spatial scales.

The proportion of large blacklip (>155 mm SL) in the catch was determined from the catch-sampling data. Limited data (i.e. $n < 100$ SL measurements) prevented calculation of this metric in most years at most spatial scales.

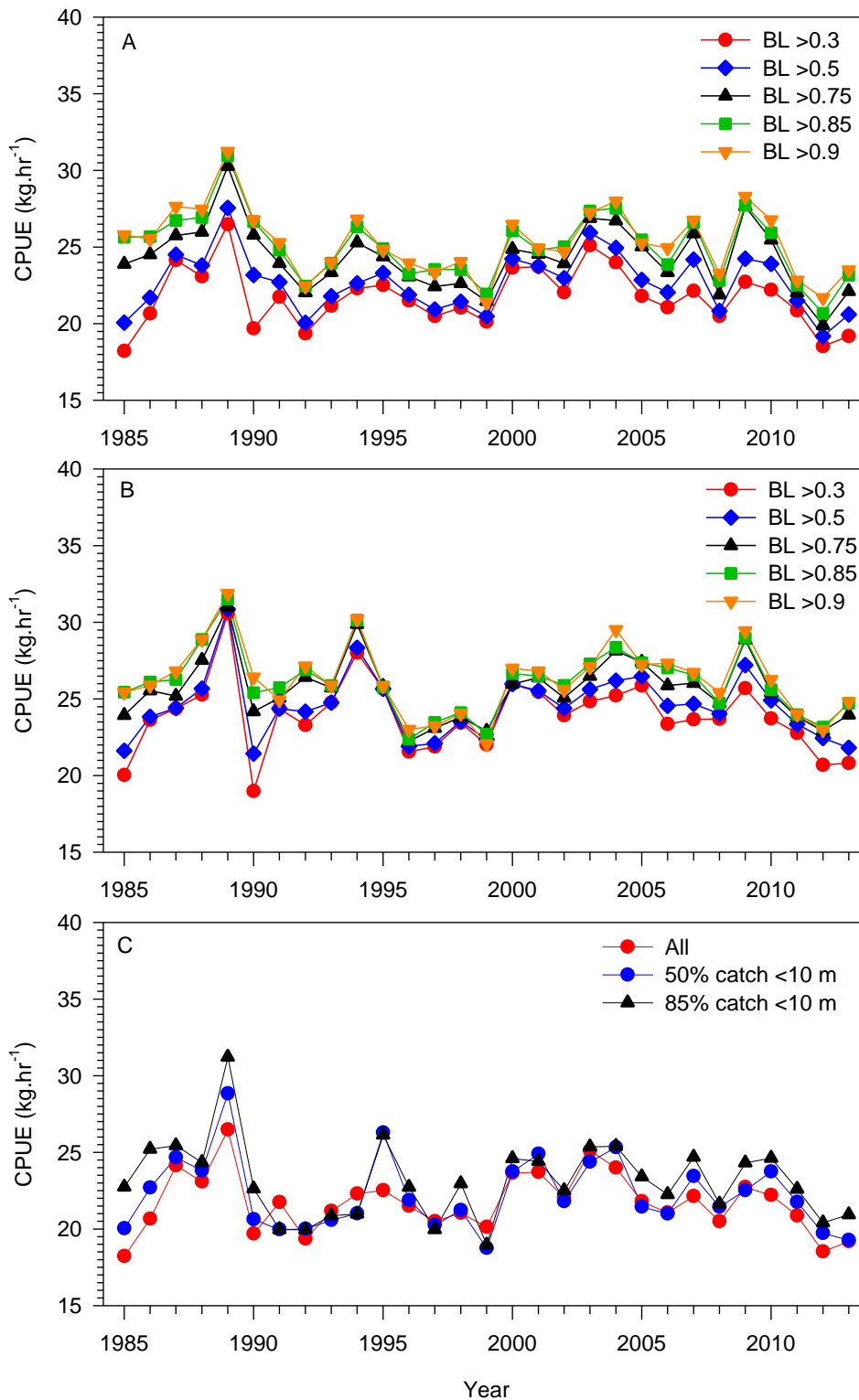


Figure 3-1 Blacklip CPUE (kg.hr⁻¹) from 1985 to 2013 estimated for a range of species composition (blacklip contribution to daily catch at least 30%, 50%, 75%, 85%, 90%) for (A) the Central Zone and (B) West Kangaroo Island. (C) Estimates of blacklip CPUE for the Central Zone, where blacklip comprised at least 30% of the daily catch for (i) all depths, (ii) days where at least 50% of fishing effort was in <10 m water depth and (iii) days where at least 85% of fishing effort was in <10 m water depth.

3.3. Results

3.3.1. Central Zone

3.3.1.1. Catch, effort and CPUE

Total catch of blacklip has been stable at $\sim 8 \text{ t.yr}^{-1}$ 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. Thus, current catches are at the lowest levels since 1984 and reflect the TACC. Prior to implementation of a TACC in 1990, total effort (days) varied substantially among years, ranging from 11 days in 1981 to 158 days in 1988. Since TACC implementation, the total number of days fished has declined, stabilising at $\sim 59 \text{ days.yr}^{-1}$ from 2006. The CPUE was relatively stable between 1990 and 2009 (range: $19.4 - 25.1 \text{ kg.hr}^{-1}$; average: 21.8 kg.hr^{-1}), where-after it has decreased. The 2012 (18.5 kg.hr^{-1}) and 2013 (19.2 kg.hr^{-1}) CPUE estimates were at least 12% below the average value from 1990 to 2009, 15% below the recent peak in 2009 (22.7 kg.hr^{-1}), 24% below the contemporary maximum in 2003 (25.1 kg.hr^{-1}) and among the lowest values on record. The CPUE estimate in 2012 was the lowest since 1985.

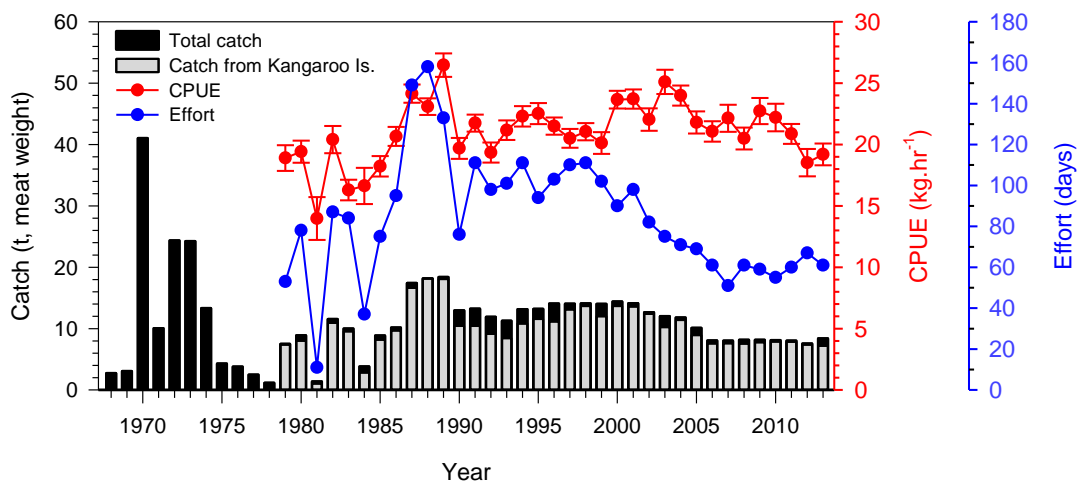


Figure 3-2 Total catch of blacklip for the CZ (t, meat weight, black bars) from 1968-2013. From 1979 to 2013, catch for Kangaroo Island (grey bars) is superimposed on total catch. Total effort (days), and CPUE (kg.hr^{-1} , $\pm \text{SE}$) are shown by blue and red lines, respectively.

3.3.1.2. Spatial and temporal distribution of catch and effort

Since 1979, most of the total blacklip catch (91%; range: 75-99%) has been harvested from Kangaroo Island (FAs 26-32; Figure 3-2). Over the last 10 years (2004-2013), 94% of the total catch has been taken from the fishing grounds surrounding Kangaroo Island (range: 86-98%). During this decade, there have been several changes in the spatial and

temporal distribution of catch and effort and the ratio of greenlip to blacklip in daily and annual catches. For example, the total abalone catch harvested from around Kangaroo Island has increased rapidly since 2008, reflecting the higher proportion of the greenlip TACC harvested from this region of the fishery (Section 2; Figure 3-3). Co-incident with the increased greenlip catch have been sharp rises in the total number of fishing days, the number of fishing days on which only greenlip were harvested and the proportion of fishing effort in water 10-20 m depth (Figure 3-3). There have also been changes in the ratios of greenlip and blacklip in the daily catch and daily fishing effort (Figure 3-4) and the timing of harvesting from the waters off Kangaroo Island within years (Figure 3-5). For example, the proportion of blacklip in the daily catch from the West and South Kangaroo Island SAUs has decreased substantially from 2001 and daily fishing effort has been increasing since 2010 (Figure 3-4). From 1991 to 2005, most of the catch from fishing grounds off Kangaroo Island was harvested during autumn and winter, but since 2006 catches have been concentrated during summer and spring (Figure 3-5).

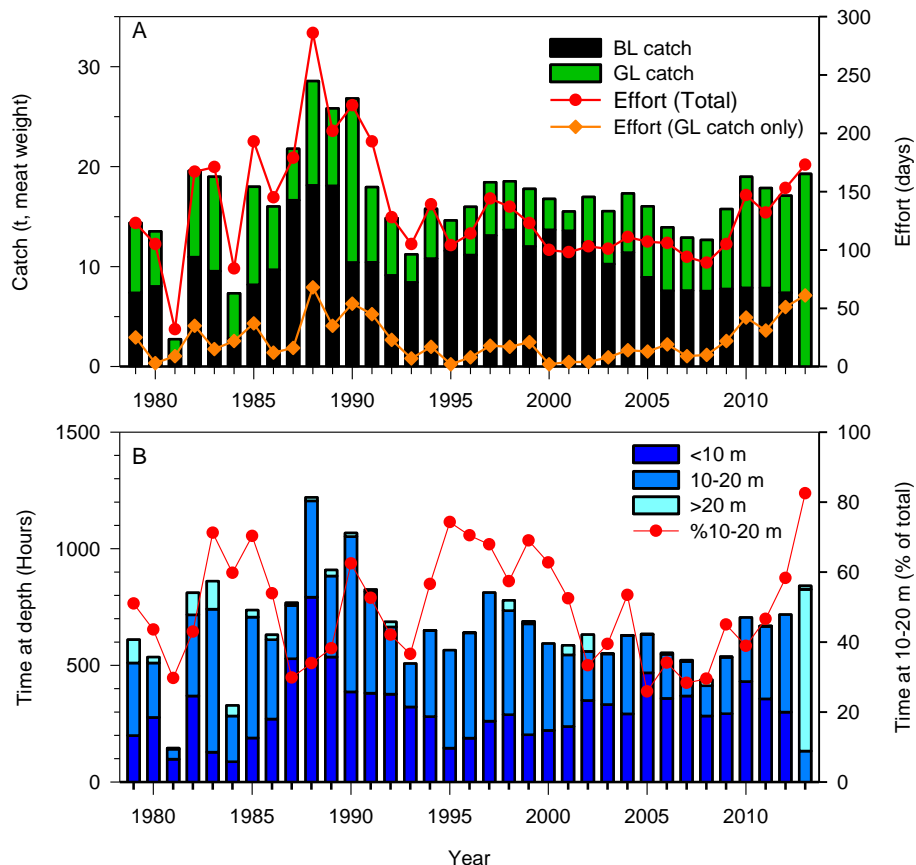


Figure 3-3 For the fishing grounds off Kangaroo Island: (A) Annual catches of blacklip and greenlip showing total annual effort (red circles) and effort when only greenlip were caught (orange diamonds); and (B) time at three depth ranges (blue bars) and the percentage of total time at 10-20 m (red circles).

Some of the spatial and temporal changes identified for all abalone fishing off Kangaroo Island were also evident for blacklip. For example, over recent years, blacklip catches have been re-distributed from autumn and winter to summer and spring (Figure 3-5). However, a high proportion of the blacklip catch harvested since 2006 (range: 51.7% to 78.5%; average: 61.2%) has been obtained on days when blacklip abalone comprised at least 85% of the total daily catch (Figure 3-6). In 2013, 81% of the total blacklip catch was obtained on fishing days where blacklip comprised at least 50% of the total catch. Also evident, is the rapid increase in the proportion of fishing effort at depths than greater 10 m since 2007 on those fishing days when blacklip comprised at least 85% of the daily catch (Figure 3-6). In 2013, 65% of fishing effort on these days was undertaken between 10 m and 20 m depth, the highest proportion since 1999 (73%).

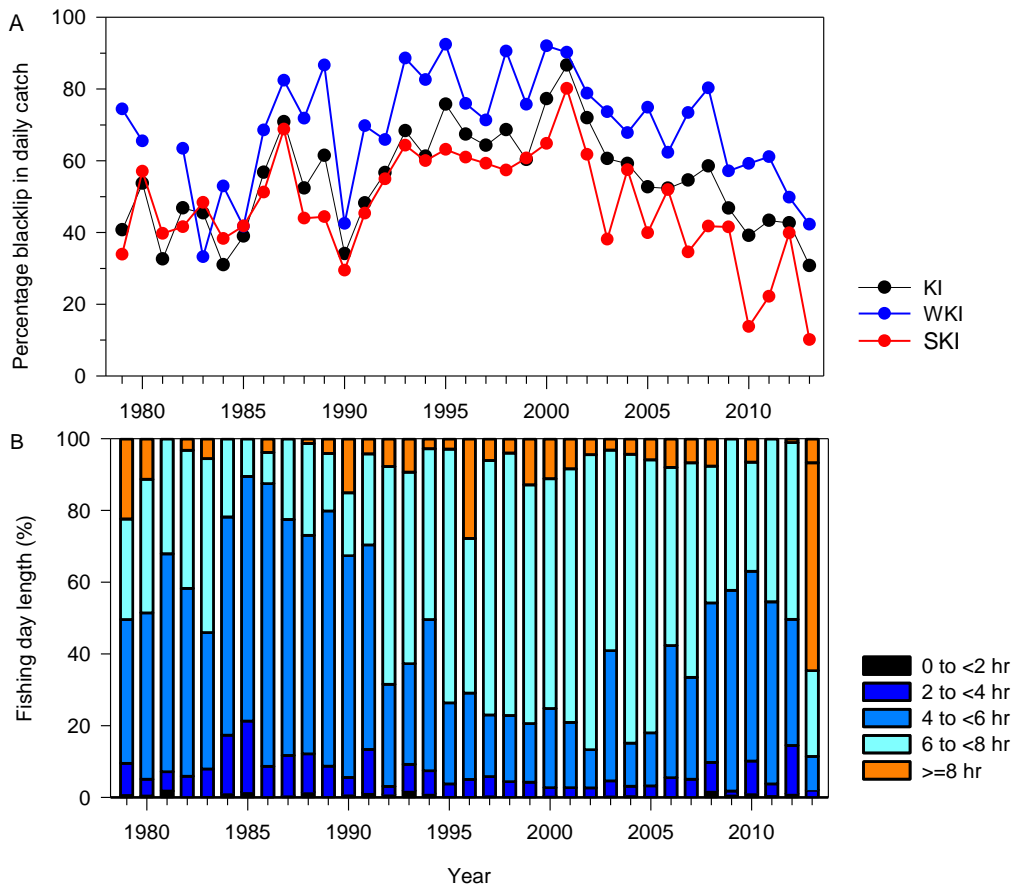


Figure 3-4 For the fishing grounds off Kangaroo Island (KI): (A) average daily proportion of blacklip in the total catch from KI and the West Kangaroo Island (WKI) and South Kangaroo Island (SKI) SAUs from 1979 to 2013; and (B) distribution of fishing day length among five day-length categories from 1979-2013.

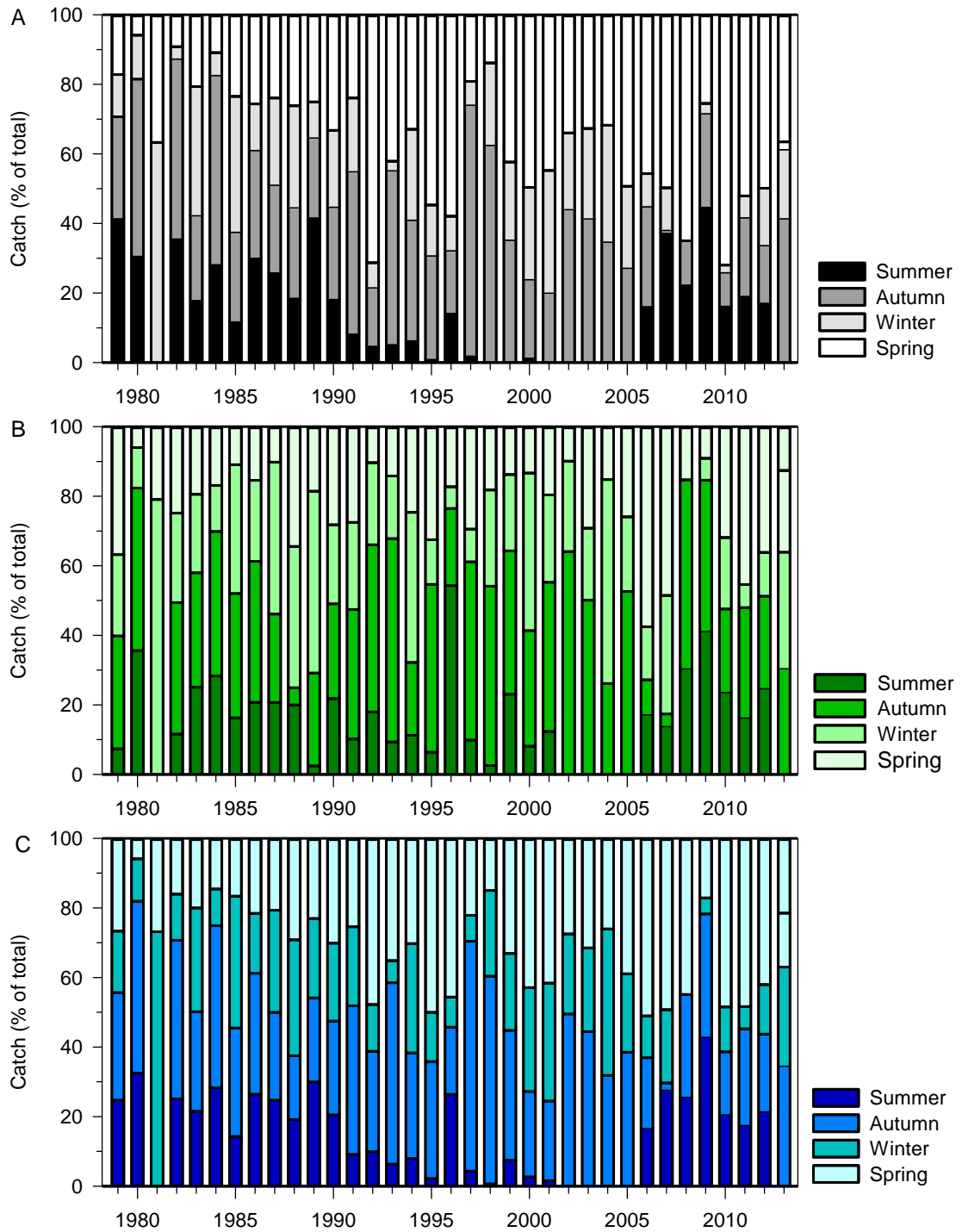


Figure 3-5 Seasonality of annual catches between 1979 and 2013 from fishing grounds off Kangaroo Island for (A) blacklip, (B) greenlip and (C) total catch. Summer: January-March; Autumn: April-June; Winter: July-September; and Spring: October-December.

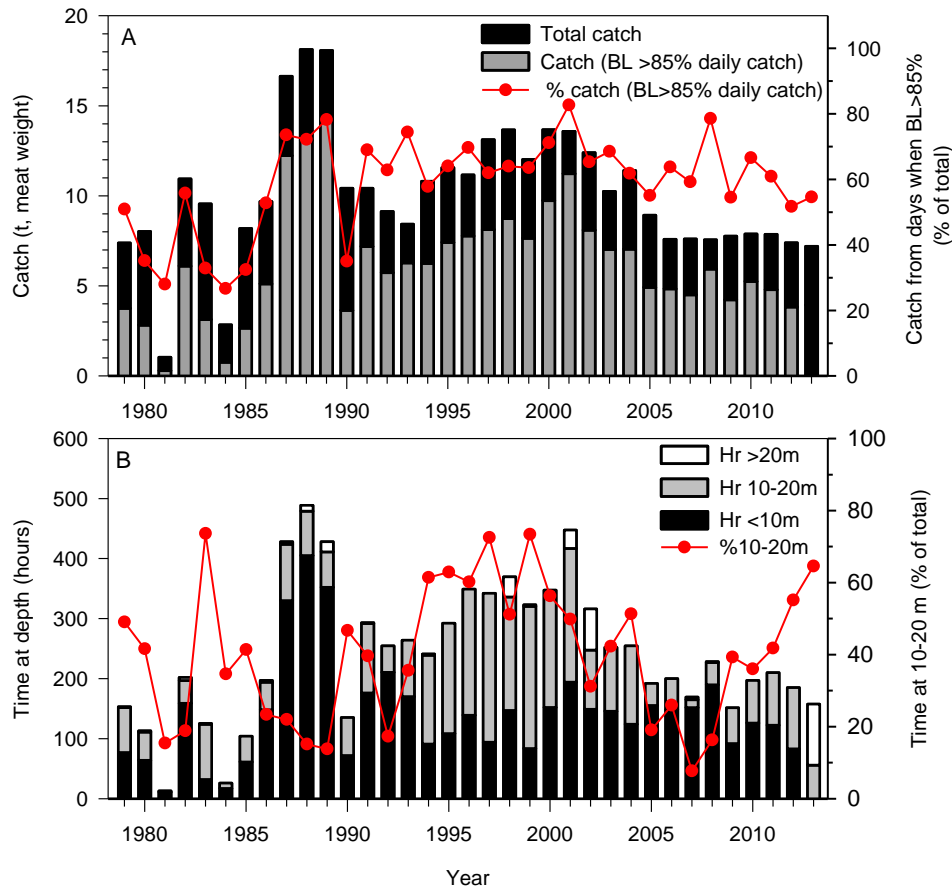


Figure 3-6 (A) Total annual catch of blacklip (black bars; t meat weight) from 1979 to 2013 with catches of blacklip when blacklip comprised at least 85% of the daily catch superimposed (grey bars). Red line shows the percentage of the total blacklip catch taken for days when blacklip comprised at least 85% of the daily catch. (B) Time spent at three depth ranges off Kangaroo Island (grey scale) and percentage of time at 10-20 m depth (red dots) for those days when the blacklip catch was at least 85% of daily catch.

3.3.2. Fishing areas

3.3.2.1. Distribution of catch among fishing areas

Over the history of the fishery, the spatial distribution of catch has changed substantially. Since 2001 (last 15 years) over 75% of the blacklip TACC has been harvested from FA 26 (36%), FA 27 (18%) and FA 29 (20%; Figure 3-7), demonstrating the importance of these FAs to this fishery. More recently, since 2007, the combined catch contribution from FA 26, FA 27 and FA 29 has exceeded 85% of the total blacklip catch per year, the highest percentage contributions in the history of the fishery. The proportion of the total blacklip catch harvested from FA 26 has increased steadily since 1979 (Figure 3-7). In 2013, it was 66% (5.6 t) and the highest on record. The remaining FAs (*i.e.* FAs 21-25, FA 28 and FAs 30-32) have contributed minimal blacklip catches since the 1980s.

3.3.2.2. *Temporal patterns of catch and CPUE in fishing areas*

Despite some short-term anomalies, catches from FA 26 have been relatively stable since the mid-1980s (Figure 3-8). In contrast, catches from FAs 23, 27, 29, 30 and 31 have, with rare exception, decreased over at least the last 15 years. Current catches from these areas are at (FAs 29 and 30), or are among (FA 23, 27 and 31), the lowest on record. Catches from remaining FAs have been small ($<2.5 \text{ t.yr}^{-1}$) and typically intermittent.

Estimates of CPUE in most FAs and for most years are not available due to limited data (Figure 3-8). The exceptions to this are FAs 26, FA 27 and FA 29. The CPUE in these three FAs has been declining over recent years and the most recent estimates of CPUE in these FAs are at (FA 27), or are among (FAs 26 and 29), the lowest on record.

3.3.3. Spatial assessment units

3.3.3.1. *Distribution of catch among spatial assessment units*

Since 1979, most of the catch has been harvested from two SAUs (West and South Kangaroo Island; Figure 3-9). These two SAUs have contributed an average of $>94\%$ (range 86% to 98%) of the total catch each year since 2006. The percentage of catch harvested from West Kangaroo Island has increased since 1991. In 2012, the contribution to the total catch from the West Kangaroo Island SAU was 79% and among the highest on record. Overall there was one medium-importance (West Kangaroo Island) SAU for blacklip in the CZ in 2013.

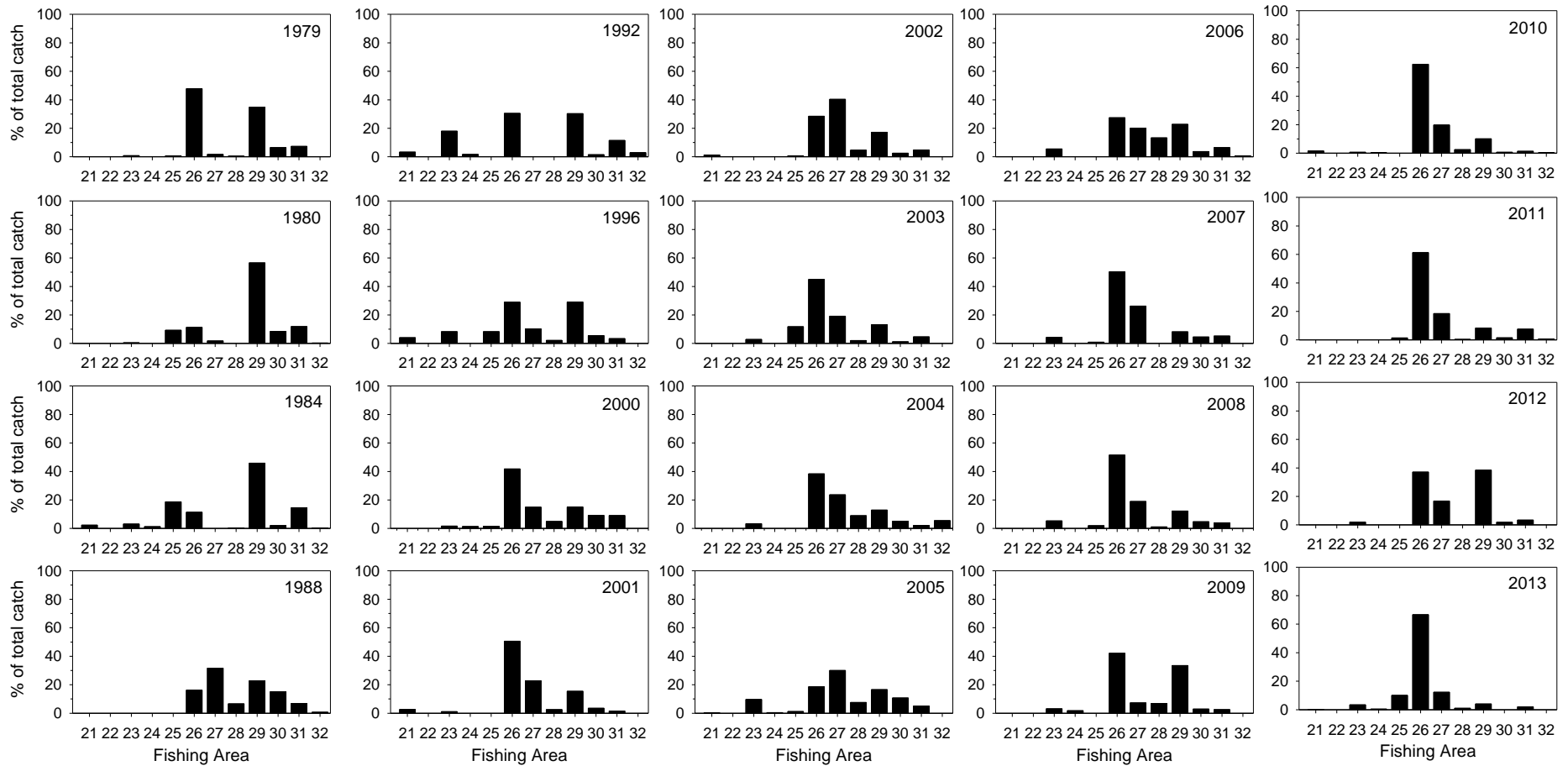


Figure 3-7 Spatial distribution of the blacklip catch (% of total catch) among fishing areas in the CZ from 1979 to 2013.

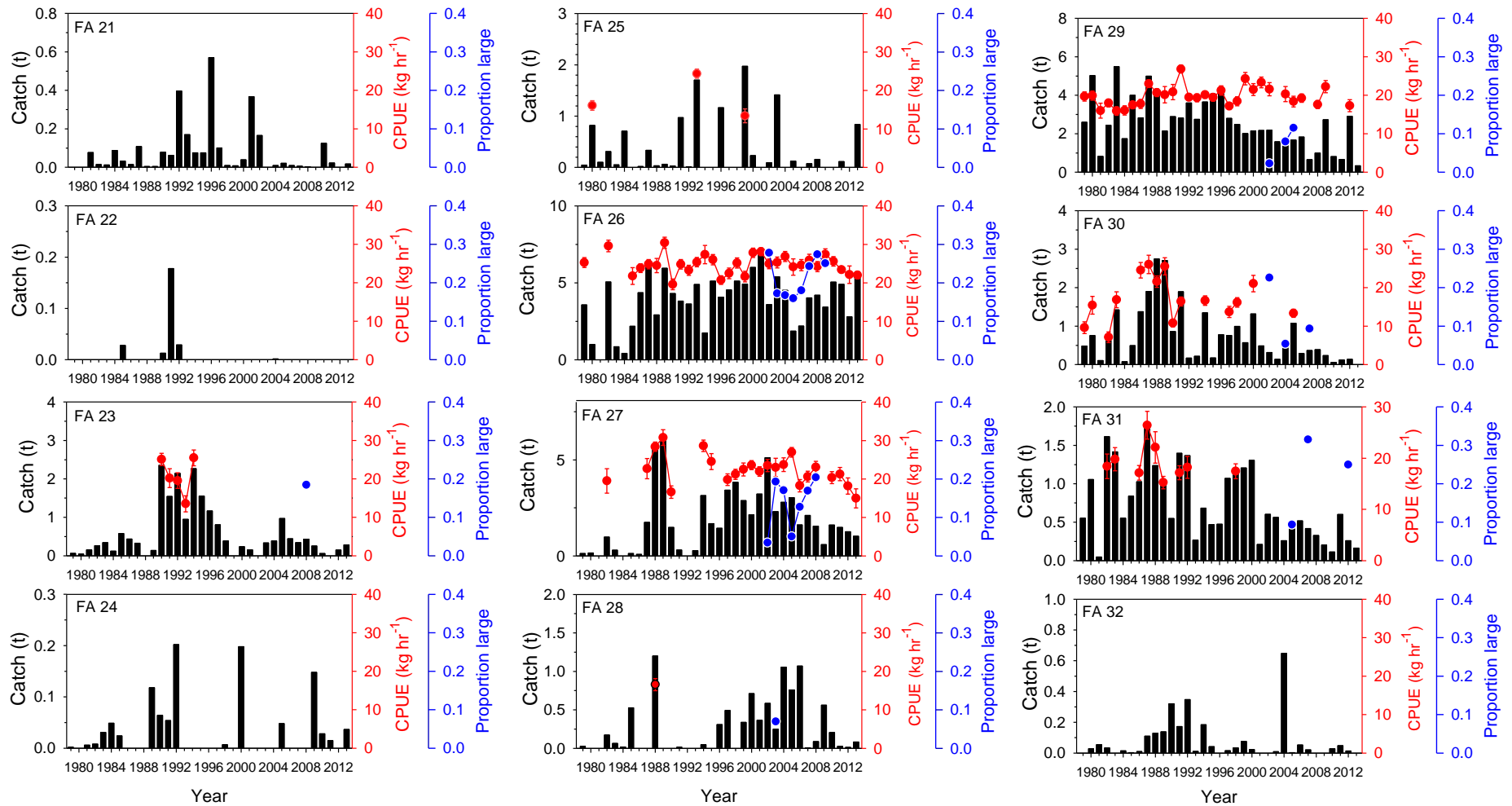


Figure 3-8 Catch (t, meat weight, black bars), CPUE ($\text{kg}\cdot\text{hr}^{-1}$, $\pm\text{SE}$, red lines) and the proportion of large (>155 mm, blue lines) blacklip in each of the fishing areas comprising the CZ from 1979 to 2013. Gaps in the time series of the CPUE and proportion large indicate insufficient data (<10 fisher days or <100 individuals, respectively). Note different scales on the Y-axes for catch and CPUE.

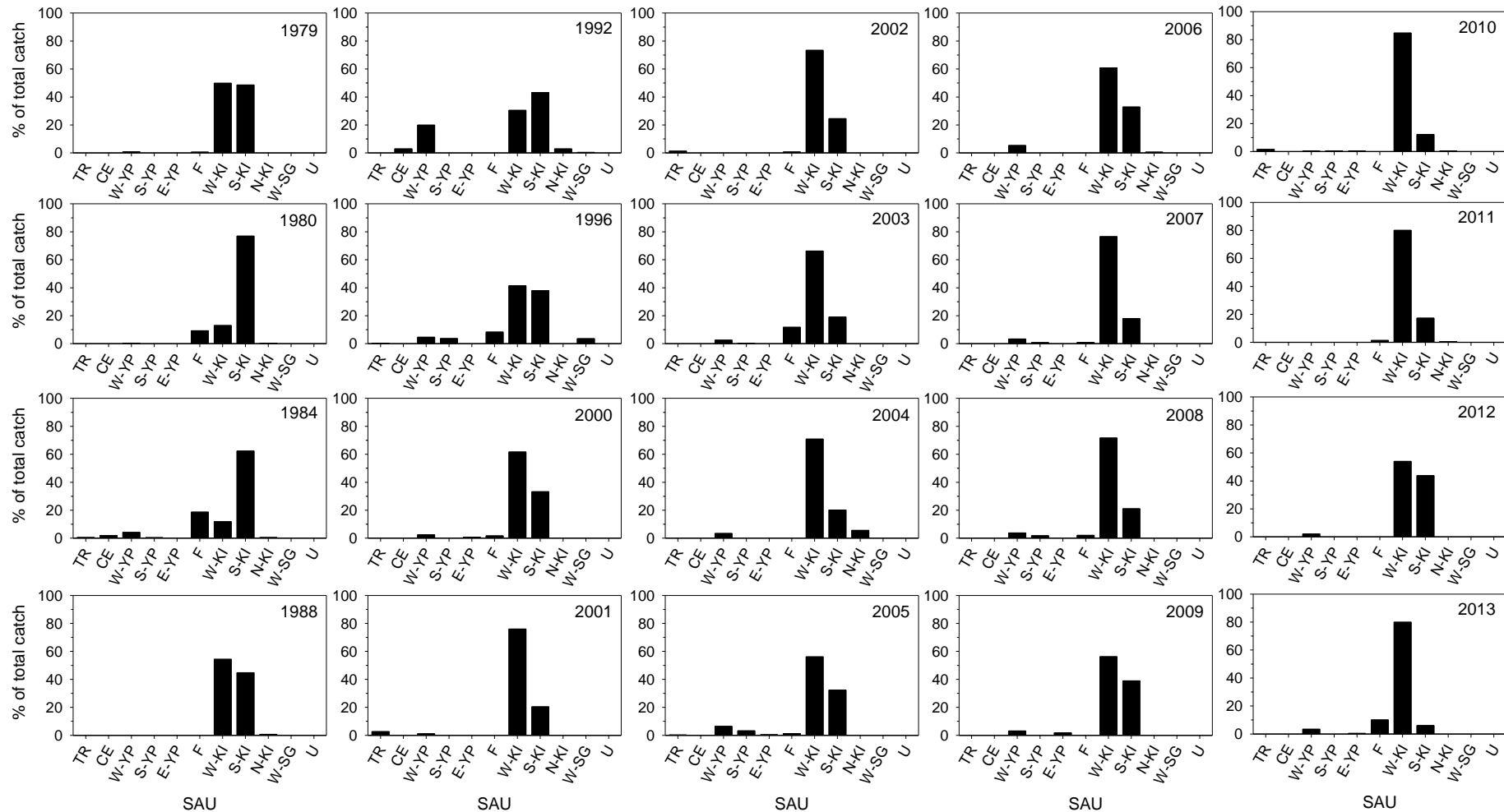


Figure 3-9 Spatial distribution of the blacklip catch (% of total catch) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ from 1979 to 2013.

3.3.3.2. Temporal patterns in SAUs of medium importance

West Kangaroo Island

West Kangaroo Island has contributed an average of 54% to the annual blacklip catch since 1979, 63% since 1994 (last 20 years) and 69% since 2004 (last 10 years). This reflects a steady increase in the percentage of catch harvested from this SAU since 1991, reaching approximately 80% in 2010, 2011 and 2013 (Figure 3-10). These values were the highest on record.

Catches have varied among years with peaks in 1989 (12.1 t) and 2001 (10.7 t; Figure 3-10). 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. Although catches have been substantially lower since 2005 (range: 4.6-6.9 t; average 5.6 t.yr⁻¹), reflecting TACC reductions, catches in 2010 (6.9 t), 2011 (6.4 t) and 2013 (6.7 t) were larger than the average catch taken since 2005.

The CPUE was relatively stable (mean: 24.1 kg.hr⁻¹) from 1990 to 2009, although there was some inter-annual variation through this period (range: 19.0-28.0 kg.hr⁻¹; Figure 3-10). However, since 2009, the CPUE has gradually declined, reaching 20.7 kg.hr⁻¹ and 20.8 kg.hr⁻¹ in 2012 and 2013, respectively, the lowest since 1990 and among the lowest on record. The CPUE in 2013 was also low despite the proportion of large blacklip in the catch being the highest on record (Figure 3-10). Similar patterns were observed in mapcode 26B which, by catch weight, is the most important mapcode for blacklip in the Western Kangaroo Island SAU (Appendix 1).

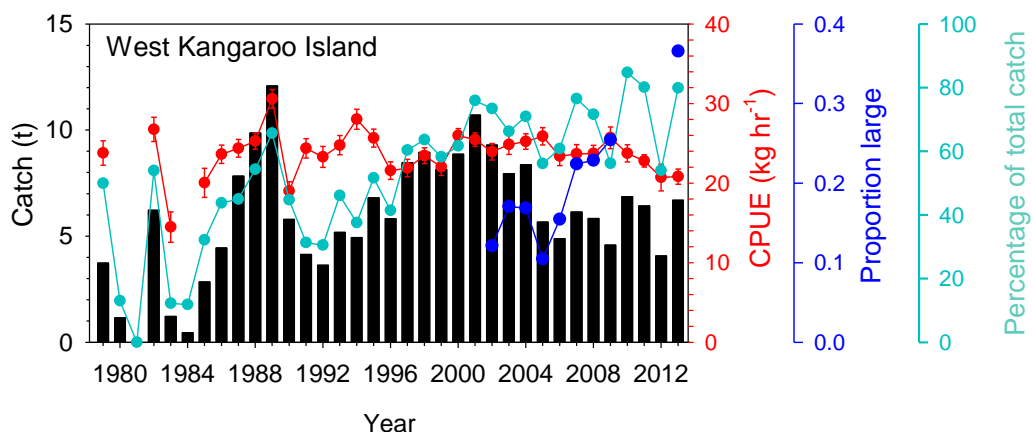


Figure 3-10 West Kangaroo Island (medium importance). Catch (t, meat weight, black bars), CPUE (kg.hr⁻¹, \pm SE, red line), the proportion of large blacklip (>155 mm, blue line) and the percentage of the total blacklip catch (light blue line) each year from 1979 to 2013. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

3.3.3.3. *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 are small and intermittent (Figure 3-11). 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 CPUE estimation 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 in 2013 was 0.5 t, the lowest on record. The CPUE was relatively stable from 1979 to 2001 (range: 15.0 - 24.5 kg.hr⁻¹). Since 2001, the CPUE has generally declined, but was high in 2003 and 2009. Current estimates of CPUE are among the lowest on record. The mean CPUE from 2010-2012 was 14.8 kg.hr⁻¹, 22% below the long-term mean from 1979 to 2001 (18.9 t.yr⁻¹). There were insufficient data to estimate CPUE in 2013.

3.3.4. 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 -1, a 'green' risk-of-overfishing category (Figure 1-3, Table 3-1, Appendix 2). The catch-weighted zonal score was 0. Under the harvest strategy, this score defines the status of the blacklip fishery in the CZ as '**sustainable**' (Table 3-1).

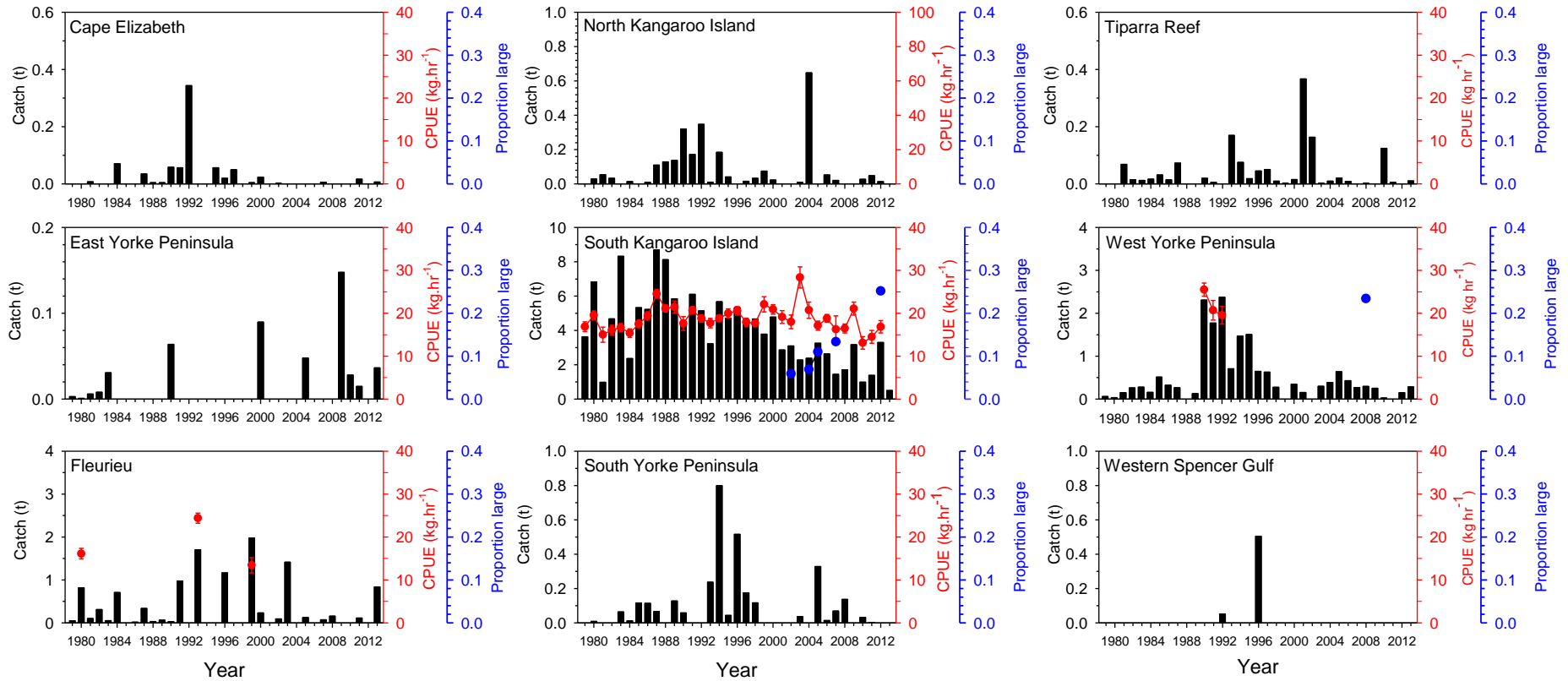


Figure 3-11 Catch (t, meat weight, black bars) and CPUE (kg.hr⁻¹, ±SE, red lines) of blacklip in each of the SAUs of low importance in the CZ blacklip fishery from 1979 to 2013. Gaps in the time series of the CPUE and proportion large indicate insufficient data (<10 fisher days or <100 individuals, respectively). 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.

Spatial assessment unit	%Contribution to mean total catch (CZ) over last 10 years (04-13)	Importance	%Contribution to catch from high & medium SAU in 2013	CPUE	%TACC	%Large	Combined PI score	Risk of overfishing	Catch-weighted contribution to zonal score
West Kangaroo Island	10.6	Medium	100.0	-5	2	2	-1	0	0.00
South Kangaroo Island	3.7	Low	-	-	-	-	-	Not assessed	-
West Yorke Peninsula	0.5	Low	-	-	-	-	-	Not assessed	-
Fleurieu	0.2	Low	-	-	-	-	-	Not assessed	-
North Kangaroo Island	0.1	Low	-	-	-	-	-	Not assessed	-
South Yorke Peninsula	0.1	Low	-	-	-	-	-	Not assessed	-
East 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	15.4		100.0						
								Zonal stock status	0.00

3.4. Discussion

Blacklip comprise 15% of the total abalone TACC (55.8 t *i.e.* blacklip and greenlip) in the CZ of the SAAF. The total catch in 2013 was 8.4 t, which was consistent with the TACC implemented from 2006. Current catches are the lowest since 1985, 40% below the mean catch from 1990 to 2006 and reflect the substantial reductions in the TACC across 2005 and 2006 that were implemented in response to declining stock status (Mayfield *et al.* 2004; Mayfield *et al.* 2005a,b). Most of the blacklip harvested in the CZ has been obtained from the fishing grounds off Kangaroo Island. Over the last decade, over 90% of the blacklip catch has been caught from this region of the fishery. In three of the last four years (2010, 2011 and 2013), at least 80% of the blacklip catch was harvested from the West Kangaroo Island SAU, mainly from mapcode 26B (60% of catch from West Kangaroo Island SAU and 47% of the blacklip TACC in 2013). While this highlights the importance of the blacklip stocks off Kangaroo Island and particularly those in the Western Kangaroo Island SAU to the harvesting of the blacklip TACC, their co-incidence with long-term declining catches and catch rates in the South Kangaroo Island SAU suggests there has been a spatial contraction of the fishery with the harvest of the current TACC seemingly reliant on blacklip stocks off the south-western corner of Kangaroo Island.

There have been several substantial changes in the spatial and temporal distribution of catch and effort among SAUs off Kangaroo Island during recent years. The total abalone catch harvested from stocks off Kangaroo Island has increased rapidly since 2008. This reflects the substantial increases in the proportion of the greenlip TACC harvested from these fishing grounds (Section 2) with concurrent rapid rises in the total number of fishing days, the number of fishing days on which only greenlip were harvested, the proportion of fishing effort in water 10-20 m depth and the ratio of greenlip to blacklip in the daily catches. There has also been a change to the timing of harvest, with a clear shift from taking abalone during autumn and winter to concentrating catches during summer and spring.

These rapid, recent changes in the spatial and temporal distribution of catch and effort from Kangaroo Island SAUs had the potential to bias current estimates of CPUE of blacklip in the CZ, relative to historical values. This required consideration because CPUE is the primary indicator of relative stock abundance for this fishery. Consequently, in this assessment, the spatial and temporal changes in fishing the Kangaroo Island blacklip stocks and their potential impact on catch rate were, where possible, evaluated for blacklip. Some of the spatial and temporal changes identified for all abalone fishing off Kangaroo Island were also evident for blacklip. These included a re-distribution of catches from autumn and winter to summer and spring and an increase in the proportion of fishing effort at depths greater than 10 m since 2007. However, over the period of these changes, a high proportion of the blacklip catch has continued to be harvested on days when blacklip abalone dominated the total daily catch (*i.e.*

at least 85%) and, on these days, the rapid increase in the proportion of fishing effort in water more than 10 m deep over recent years remained. In combination with the steady increase in fishing days off Kangaroo Island on which only greenlip are harvested, these data demonstrate that blacklip remain targeted off Kangaroo Island.

There was strong evidence that the spatial and temporal re-distribution of catch and effort off Kangaroo Island has not biased recent CPUE estimates, despite the potential for this to have occurred. This is because the temporal patterns in CPUE were similar across a diverse suite of estimation methods and was confirmed by the subsequent, highly-significant, Pearson's correlation tests. Methods used captured ranges of both blacklip proportions in the daily catch and the distribution of fishing effort among water depths, but a lack of data prevented an evaluation of the shift in fishing among seasons. The finding of high levels of consistency in temporal CPUE trends was similar to that demonstrated by Burch *et al.* (2011) and shows that recent CPUE estimates are unlikely to be biased by the recent changes in catch and effort distribution in fishing grounds off Kangaroo Island. Given the similarity among estimates of CPUE across the different methods used, and the generally few daily records for estimating CPUE on blacklip in the CZ, all daily records (*i.e.* across all depths) where the proportion of blacklip in the total catch was at least 30% were selected as the most suitable data. Consistent with Burch *et al.* (2011) and Chick and Mayfield (2012), these data were considered the most appropriate because (1) daily records where blacklip was less than 30% of the catch and likely not targeted on that fishing day were discarded and (2) it discarded the fewest number of daily records, thus ensuring CPUE was determined from as much of the available data as possible. Overall, we consider this method provides appropriate estimates of CPUE in this fishery and that these remain a strong indicator of relative stock abundance.

The recent reductions in the estimates of CPUE on blacklip, observed across multiple spatial scales, provide strong evidence that the abundance of legal-sized blacklip has decreased over the last few years despite the substantially lower TACC from 2006 and the voluntary increase in the MLL to 135 mm SL implemented by commercial fishers since 2001. For example, the 2012 and 2013 CPUE estimates for the CZ were more than 12% below the mean from 1990 to 2009, 15% below the recent peak in 2009, 24% below the contemporary maximum in 2003 and among the lowest values on record. The CPUE in the three most important FAs for blacklip in the CZ have all been declining over recent years and the most recent estimates are at, or are among, the lowest on record. Similarly, in the West Kangaroo Island SAU from which approximately 80% of the TACC was harvested in 2010, 2011 and 2013, the CPUE has gradually declined since 2009. The estimates of CPUE in this SAU in 2012 and 2013 are the lowest since 1990 and among the lowest on record. Similar patterns were also evident in mapcode 26B, the most important mapcode for blacklip catches in the CZ (47% of 2013 TACC). The increases in the proportion of fishing effort in water 10-20 m depth and the

proportion of the TACC harvested from the Western Kangaroo Island SAU provide further evidence of a reduction in harvestable biomass because it suggests that divers have moved from shallower to deeper water and from the South Kangaroo Island SAU (CPUE declining) to the Western Kangaroo Island SAU in response to reductions in blacklip abundance. In addition, while it may reflect the catch of larger blacklip at the greater diving depth, the large (and increasing) mean SL and more likely indicate a lack of evidence for recent recruitment to the fishanbe stock and suggest that stock abundance is likely to decrease further at the current TACC. Based on this evidence, the CZ blacklip fishery would be classified as '**transitional depleting**' under the national framework for reporting stock status (Flood *et al.* 2012).

This outcome from the weight-of-evidence assessment – '**transitional depleting**' – was in sharp contrast to that obtained from the application of the harvest strategy in the Management Plan which categorised the stock status of this fishery as '**sustainable**'. There were two primary reasons for this discrepancy. First, '**sustainable**' 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 is inherently biased towards that SAU and compromises the effectiveness of the current harvest strategy for the CZ. Consequently, the use of the harvest strategy to determine the zonal stock status of blacklip in the CZ is considered inappropriate. This situation is similar to that seen in the Southern Zone (Mayfield *et al.* 2013, 2014) where the harvest strategy is not used to assess greenlip stock status. Second, for the West Kangaroo Island SAU, the combined PI score of -1 was influenced by scores for percentage of the TACC (+2) and proportion of large blacklip in the catch (+2) which effectively negated the large negative score for CPUE (-5). This feature of the harvest strategy, where substantial decreases in relative abundance and, thus, an increase in the risk-of-overfishing, can be offset by large positive scores from remaining PIs 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) and will need careful consideration when the harvest strategy is reviewed in 2015.

Overall, most of the evidence indicates that the CZ blacklip stocks are in one of their weakest positions since at least 2001 and that stock abundance is likely to decrease further at the current TACC. Consequently, additional management arrangements including a lower TACC, catch caps, spatially-variable MLLs and spatial closures may need to be considered from 2015 to prevent overfishing in key SAUs, and subsequent likely extended recovery times (Gorfine *et al.* 2008; Prince and Peeters 2010; Haddon *et al.* 2014). Whilst it would be useful to confirm this assessment with fishery-independent data, 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.

4. GENERAL DISCUSSION

4.1. Information for assessment of the CZ abalone fishery

There was substantial information available for some areas to assess the abalone stocks in the CZ including (1) a well-documented history of the management of the fishery; (2) fine-scale catch and effort data; (3) long-term fishery-independent survey data for greenlip at Tiparra Reef; and (4) biological data. There are, however, several limitations to this assessment. First, decision rules are applied to all data series presented in this report (Table 1-3), with the exception of catch, with these decision rules 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; Chapter 3) 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. Similarly to Burch *et al.* (2011), we showed that previous decision rules were sufficiently robust for assessment of the stocks in the CZ, and confirmed that a catch-weighted mean of daily CPUE is the most appropriate to estimate CPUE as it (1) weights each daily record of catch and effort objectively; (2) removes the need to 'subset' the data subjectively; and (3) can be applied consistently to greenlip and blacklip abalone at multiple spatial scales across the fishery.

Second, the limited fishery-independent survey data for greenlip outside the Tiparra Reef SAU in FA 21, 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. Third, we were unable to use length-frequency data to determine temporal changes in the length structure and mean length of the commercial catch in this fishery through time in most SAUs, as undertaken in NSW (Andrew and Chen 1997) and Tasmania (Tarbath and Gardner 2011). This was because of (1) the limited degree to which the current data are representative of the fishery; (2) the near-absence of data from 2009 to 2012; and (3) the lack of data from some SAUs in 2013 (*e.g.* greenlip in the South Kangaroo Island SAU). The lack of robust, representative, commercial, length-frequency data increases the uncertainty in the assessment of stock status (Burch *et al.* 2010).

Fourth, 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 market demands for particular product types (*e.g.* larger or smaller

abalone – though this has not yet been documented for the CZ), 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). However, we note that CPUE can be strongly influenced by numerous factors, including changes in abalone abundance, diver behaviour and increasing fishing efficiency, and is often viewed as a biased index of changes in abalone abundance (Harrison 1983; Breen 1992; Prince and Shepherd 1992; Gorfine *et al.* 2002). This is 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. For example, the CPUE on greenlip in the Tiparra Reef SAU was stable from 2010 to 2013, during which the leaded-line survey estimate of greenlip ≥ 130 mm SL decreased by 26%. Lastly, the accuracy and precision of illegal catch estimates are unknown. This prevents accurate estimates of the total catch and hence impedes this assessment.

4.2. Current status of greenlip and blacklip in the CZ

There were several similarities in the assessment of greenlip and blacklip. First, current catch rates on both species at many of the spatial scales considered were low and/or declining. This was more obviously the case for blacklip than greenlip. Second, based on the weight-of-evidence, both stocks were classified as '**transitional depleting**' under the national framework for reporting stock status (Flood *et al.* 2012). Consequently, to prevent overfishing, additional management arrangements should be considered from 2015. These could include reducing the TACC and a greater level of spatial management potentially incorporating catch caps, spatially-variable MLLs and closures. This is particularly the case for greenlip in the Tiparra Reef SAU where the densities of mature individuals are 20% lower than the densities below which reduced fertilisation and recruitment levels are indicated, and for blacklip in both the West Kangaroo Island and South Kangaroo Island SAUs where current catch rates are historically low and declining.

Third, the stock status classifications from the weight-of-evidence assessments ('**transitional depleting**') contrasted with the outcome from the application of the harvest strategy in the Management Plan (greenlip: '**under fished**'; blacklip: '**sustainable**'). This is particularly the case for blacklip for which the use of the harvest strategy to determine the zonal stock status is considered inappropriate and suggests that the harvest strategy for the fishery needs to be reviewed. Fourth, the assessments of both species were

fundamentally dependent on fishery-dependent data, primarily catch and CPUE. The exception was the Tiparra Reef SAU for greenlip where long-term fishery-independent data were available, including estimates of harvestable biomass for 2013. Finally, 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 been recently re-distributed among mapcodes comprising SAUs, indicative of continued spatial expansion. In contrast, for blacklip, the proportion of the TACC harvested from the West Kangaroo Island SAU, FA 26 and mapcode 26B has increased substantially.

4.3. Harvest strategy for the CZ

Consistent with previous reports (*e.g.* Chick and Mayfield 2012; Stobart *et al.* 2012, 2013a, 2014a), there were several difficulties with implementing the harvest strategy that should be considered when it is reviewed in 2015. First, zonal stock status of blacklip was determined from a single medium-importance SAU, while stock status of greenlip was derived from four SAUs, two of high importance and two of medium importance. This limitation for blacklip arises because it comprises 15% 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 principle SAUs. However, there were no fishery-independent data for assessment of greenlip in the West Yorke Peninsula SAU, which was of high importance. Fishery-independent surveys of greenlip will now resume at Port Victoria and Hardwicke Bay in the West Yorke Peninsula SAU, and will yield these data for this SAU's assessment in 2016. 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 2013.

Second, there are few commercial catch sampling data for determining the proportion of large abalone harvested, which is one of the fishery-dependent PIs, particularly the period 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 many 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) substantially 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. One approach to supporting this requirement may be to impose a score of -2 for this PI if robust, representative, commercial, length-frequency data are unavailable. This would be a precautionary approach because the lack of these data increases the uncertainty in the assessment of stock status (Burch *et al.* 2010). 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 several issues 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 PI related to catch. 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 7, 0 and -1 were assigned for the catch, CPUE and proportion large PIs, respectively, for greenlip in the South Kangaroo Island SAU. This resulted in a combined score of 6 and a blue 'risk-of-overfishing' category. This 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 1-4) enables the catch contribution from this SAU to the TACC to be increased. However, the weight of available evidence does not suggest there is justification for such a change because the CPUE has declined substantially over recent years.

There are three possible solutions to this problem. Firstly, negative scores could be allocated when the proportion of the TACC harvested from a SAU exceeds the UTRP or ULRP. Secondly, supplementary decision rules could be used that prevent an increase in catch contribution to future TACCs when the score for CPUE is zero or negative. Third, the catch PI could be scored 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. Whilst this latter approach is more complicated, it probably provides the most defensible solution.

There were also problems applying the PI for catch in the Tiparra Reef SAU, which arose from the implementation of the catch-cap in FA 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 FA 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) 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 (1) evaluating the suitability and cost-effectiveness of the harvest strategy; (2) determining the suitability of data from GPS and depth loggers for assessment of stock status in the CZ (after Mundy 2012 and FRDC project 2011/201); (3) obtaining weight-grade data across the catch of both species from processors (after Mayfield 2010); and (4) establishing and validating an index of recruitment (*e.g.* FRDC project 2014/010). The first two of these are the most important. The harvest strategy requires review because of the discrepancies in stock status between the weight-of-evidence method and application of the current harvest strategy. The review should include testing the harvest strategy performance using a management strategy evaluation procedure and linking the harvest strategy more closely with the national fishery status reporting framework (Flood *et al.* 2012). Evaluating the use of the logger data is important because of the heavy reliance on fishery-dependent data (principally catch and CPUE) for assessing these stocks. Assessment of abalone stocks in the CZ would also benefit from (1) analysing catch rate data to standardise external influences (*e.g.* diver, dive location, month, loss of access); (2) improving estimates of the magnitude and trends in illegal catch; (3) assessing the direct and indirect effects of commercial harvest on the ecosystem, but these are of a lower priority; and (4) developing and implementing a process to formally include industry information into the application of the harvest-decision rules for determining TACCs.

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Appendix 1. Catches by mapcode for medium importance SAUs

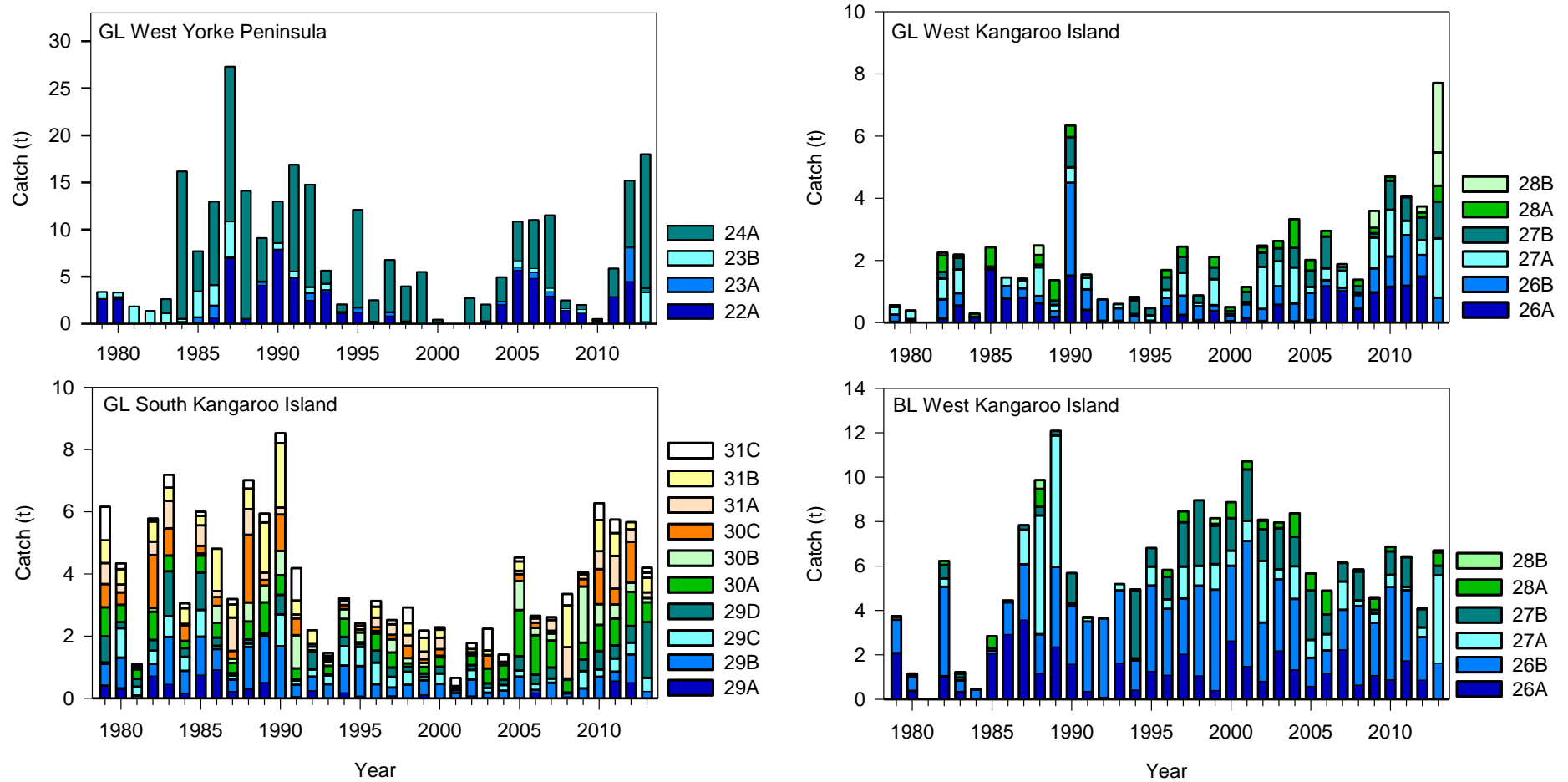


Figure A1.1 Distribution of annual catches (t, meat weight) among mapcodes from 1979 to 2013 for (i) greenlip in the West Yorke Peninsula, South Kangaroo Island and West Kangaroo Island SAUs and (ii) blacklip in the West Kangaroo Island SAU.

Appendix 2. Greenlip – Harvest strategy PI plots.

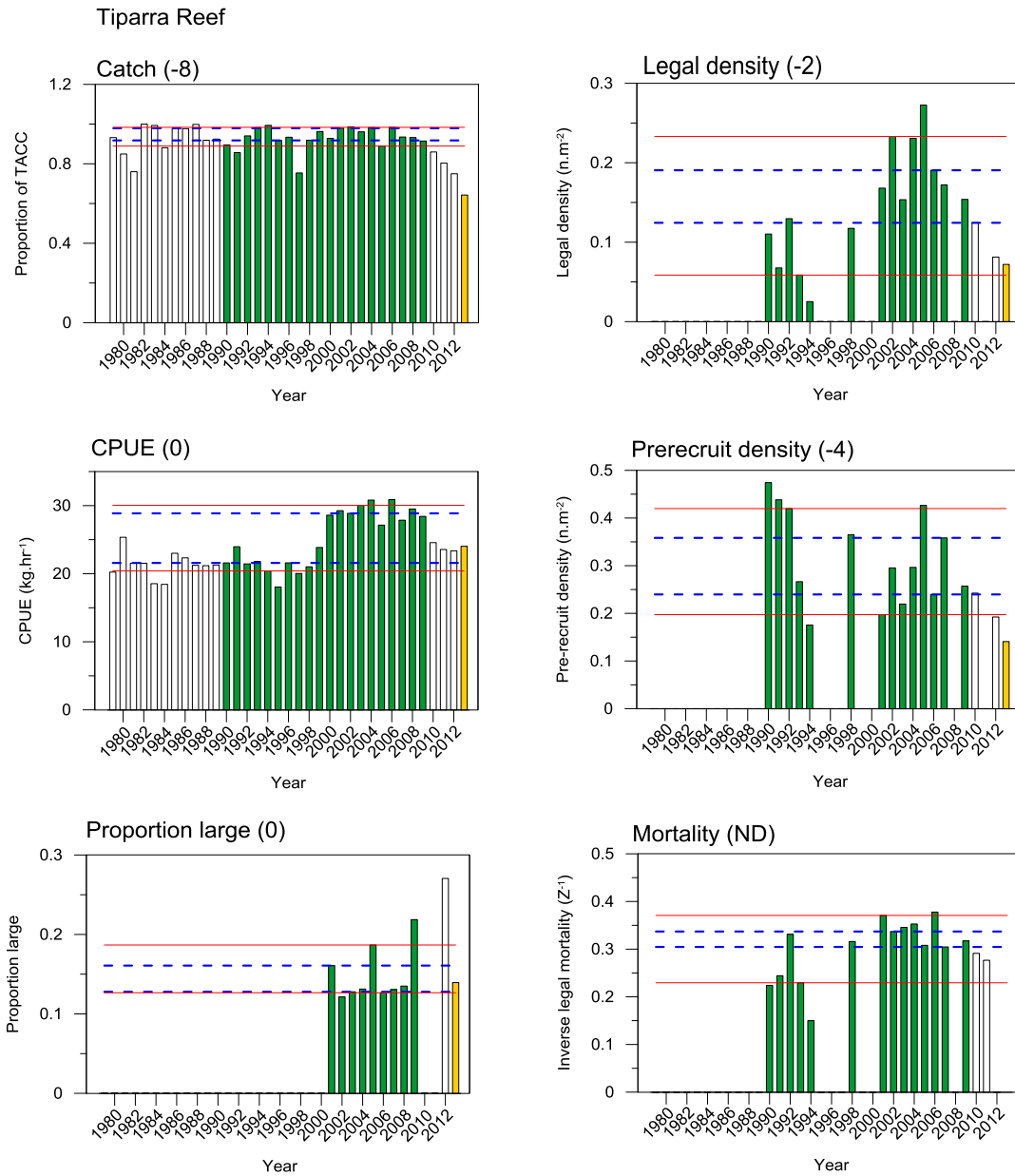


Figure A2.1 Tiparra Reef (high importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Green bars describe the data and time over which the reference points 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.

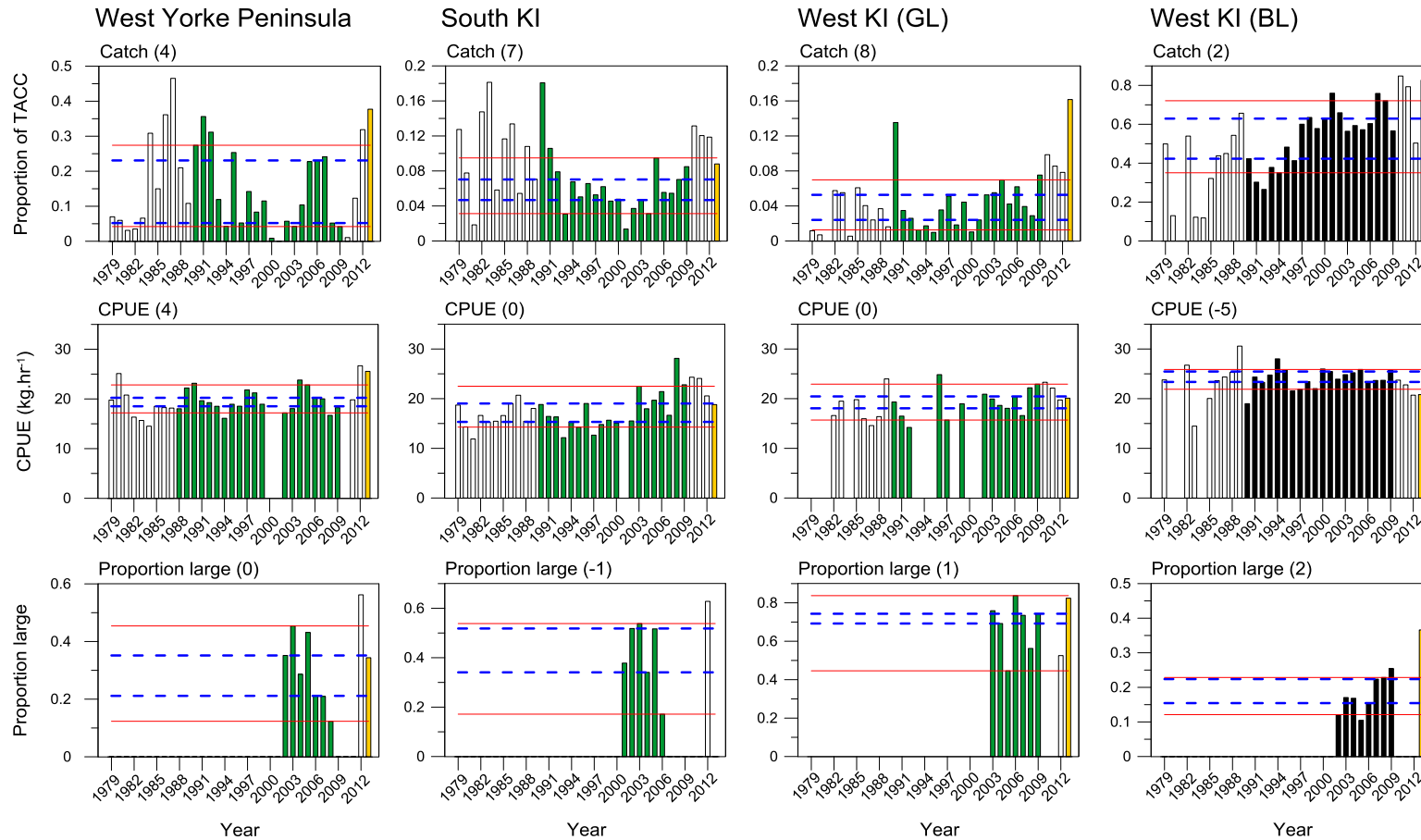


Figure A2.2 Greenlip: West Yorke Peninsula, South Kangaroo Island (KI) and West KI; Blacklip: West KI (medium importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference 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.