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

R.C. Chick and S. Mayfield

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PO Box 120 Henley Beach SA 5022

September 2012

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

Government of South Australia

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EXECUTIVE SUMMARY

1. This report provides an assessment of the *Haliotis rubra* and *H. laevigata* (hereafter referred to as blacklip and greenlip, respectively) stocks in the Central Zone (CZ) in 2011.
2. 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 several potential improvements to the harvest strategy.
3. Data spanning four spatial scales were integrated in this assessment: CZ, fishing areas (FA), Map-codes (MC) and spatial assessment units (SAUs). Data from Cowell, a separately managed area, were explicitly excluded.

GREENLIP

4. The total allowable commercial catch (TACC) for greenlip has been 143.1 t (whole weight) since 1994. Greenlip comprises 85% of the combined abalone TACC (167.4 t *i.e.* greenlip and blacklip) in the CZ, which highlights the importance of this species to this fishery.
5. Total catches are slightly higher (6%) than the mean catch prior to TACC implementation and, over recent years, most of the catch has been harvested from Tiparra Reef.
6. Tiparra Reef has been the most important SAU for greenlip in both the CZ and the South Australian Abalone Fishery (SAAF) since 1990. The weight-of-evidence assessment and harvest strategy ('red' risk-of-overfishing category) both determined that the harvestable biomass of greenlip in this SAU has declined substantially. The low catches currently harvested from Tiparra Reef also demonstrate that the 100 $t.yr^{-1}$ 'catch-cap' is currently too high to constrain catches.
7. 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 2011, the catch harvested away from Tiparra Reef was the highest since 1992 and similar to that prior to a TACC.
8. Current high catch rates in the West Kangaroo Island and South Kangaroo Island SAUs suggest stocks in these areas could support small increases in catch. However, it appears unlikely that the fishing grounds adjacent to York Peninsula can support additional catches. This includes Cape Elizabeth, where CPUE is declining rapidly.
9. The harvest strategy categorised the stock status of the CZ greenlip fishery as over-fished and was consistent with the traditional weight-of-evidence assessment. Consequently, the TACC may need to be reduced from 2013 to prevent overfishing in key SAUs. A TACC reduction could be moderated by additional approaches including (1) greater spatial management and/or (2) a temporal closure to reduce the number of greenlip harvested.

BLACKLIP

10. The blacklip abalone TACC was reduced by 40% from 42.3 t (1994–2004) to 24.3 t (2006–2011). In 2011, >95% of the TACC was obtained from the West and South Kangaroo Island SAUs.
11. The weight-of-evidence assessment and harvest strategy outcome ('blue' risk-of-overfishing category) were consistent for the West Kangaroo Island SAU and suggest that current catches from this SAU are sustainable.
12. Data available to assess other SAUs were more limited. However, decreasing catches and CPUEs suggest that the biomass of legal-sized blacklip in the South Kangaroo Island SAU continue to decline.
13. The harvest strategy – based on the West Kangaroo Island SAU – which categorised the CZ blacklip fishery as under-fished was more optimistic than the conclusion from the weight-of-evidence assessment. Nevertheless, the current TACC appears sustainable.

1. GENERAL INTRODUCTION

1.1. Overview

This fishery assessment report for the Central Zone (CZ) of the South Australian Abalone Fishery (SAAF) updates previous fishery assessment (Mayfield *et al.* 2010) and stock status reports (Mayfield & Carlson 2009). The report covers the period 1 January 1968 to 31 December 2011 and is part of the SARDI Aquatic Sciences ongoing assessment program for the fishery. Similarly to recent CZ reports, data from Cowell, a separately managed area within the CZ (see Mayfield *et al.* 2008b), are explicitly excluded. This report differs substantially from previous reports in two ways: (1) data are presented at the scales of Spatial Assessment Units (SAUs) as defined in the Abalone Fishery Management Plan (PIRSA 2012), hereafter referred to as the new Management Plan and; (2) it provides a spatially-explicit, quantitative assessment of the status of the greenlip (*Haliotis laevigata*, hereafter referred to as greenlip) and blacklip abalone (*H. rubra*, hereafter referred to as blacklip) fisheries in the CZ. The aims of the report are to (1) determine and assess the current status of the greenlip and blacklip fisheries in the CZ; (2) determine the risk-of-overfishing in SAUs of 'high' and 'medium' importance; (3) identify uncertainty associated with the assessment; (4) evaluate the new harvest strategy for the fishery; and (5) 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 its history and 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 new 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 (>155 mm shell length) 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 overfished and the status of the greenlip and blacklip fisheries in the CZ, as outlined in the new Management Plan. Finally, 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 new 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 & Shepherd (1992), Zacharin (1997), Keesing & Baker (1998), Nobes *et al.* (2004) and Mayfield *et al.* (2011a).

The fishery 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 35 licence holders in the fishery.

In 1971 the South Australian Abalone Fishery (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 143.1 t since 1994. In contrast, the TACC for blacklip has been reduced twice and by about 40% since 2004. This reduction occurred in two stages: from 42.3 t (1994-2004) to 29.7 t (2005) and from 29.7 t to 24.3 t (2006-2012).

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, quota) 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.

To monitor catches and facilitate compliance with quota limits, fishers must complete a Catch and Disposal Record (CDR) form immediately upon landing. In addition, a research logbook must also be completed for each fishing day and submitted to the SARDI Aquatic Sciences at the end of each month. 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 Map-codes (map letters; see Figure 1.1 and Figure 1.2). Supplementary data fields (e.g. 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 the SARDI Aquatic Sciences for analyses of catch, effort, catch-per-unit-effort (CPUE) and proportion of large abalone data that underpin assessments of the fishery. These data are supplemented by fishery-independent surveys of abalone density and population structure in key fishing areas.

1.2.2. Recreational fishery

The total recreational abalone catch in South Australia was estimated at 5,147 abalone for the 12-month period 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 & 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 greenlip harvest in the CZ in 2009 was 0.30 t and that for blacklip was 0.09 t. This represents 0.21% and 0.38% of the TACCs for greenlip and blacklip in the CZ, respectively.

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. However, during 2011, PIRSA Fisheries and Aquaculture identified, through 12 information reports, that at least 383.1 kg (meat weight) and 2,947 individual abalone were taken illegally. In addition to this, 60 information reports were received. It would be expected that PIRSA Fisheries and Aquaculture would not have information on all abalone theft occurring in the CZ during 2011, so the actual extent of illegal take of abalone is likely to have been higher. By attributing 32 kg per information report the illegal catch of abalone in the CZ is estimated to be about 2.3 tonnes (meat weight). This estimate excludes illegal take where a caution, expiation or brief has been compiled (Deryck Donovan pers. com. – PIRSA Fisheries and Aquaculture).

Table 1.1 Management milestones in the South Australian Abalone Fishery (SAAF).

Date	Milestone
1964	Fishery started
1971	>100 licences; licences made non-transferable
	Fishery divided into three Zones (Western, Central and Southern)
	Minimum legal length (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 increased to 145 mm SL in the WZ
1985	Western Zone divided into Regions A and B
	Quota introduced to Region A in the WZ. TACC set at 293.3 t.
1989	TACC reduced from 293.3 t to 207 t in Region A of the WZ
1990	Quota introduced to the CZ. TACCs set at 142.2 t for greenlip and 41.1 t for blacklip
1993	Abolition of owner-operator regulation
1994	CZ Greenlip TACC increased from 142.2 t to 143.1 t
	CZ Blacklip TACC increased from 41.1 t to 42.3 t
1997	Management Plan implemented (Zacharin 1997)
2002	MLL - voluntarily increase in harvest length to 135 mm SL in the CZ
2004	Management Plan revised (Nobes et al. 2004)
	Fishery assessed against the Principles of Ecologically Sustainable Development
2005	CZ Greenlip catch capped at 90 t (shell weight) in FA 21 (Tiparra Reef & Cape Elizabeth)
	CZ Blacklip TACC reduced from 42.3 to 29.7 t (shell weight)
2006	CZ Blacklip TACC reduced from 29.7 to 24.3 t (shell weight)
2009	Catch-cap increased to 100 t (shell weight) in FA 21
	Catch capped at 5 t (shell weight) in Port Victoria (FA 22)
2010	Catch capped at 3 t (shell weight) in Hardwicke Bay (FA 24)
2011	Catch-caps removed from Port Victoria (FA 22) and Hardwicke Bay (FA 24)
	Management Plan revised (PIRSA 2012) – application of new harvest strategy

Table 1.2 TACC (tonnes, whole weight) for the CZ of the SAAF from 1990 to 2011.

Fishing season	Greenlip abalone SL > 130 mm	Blacklip abalone SL > 130 mm
1990–1993	142.2	41.1
1994–2004	143.1	42.3
2005	143.1	29.7
2006–2012	143.1	24.3

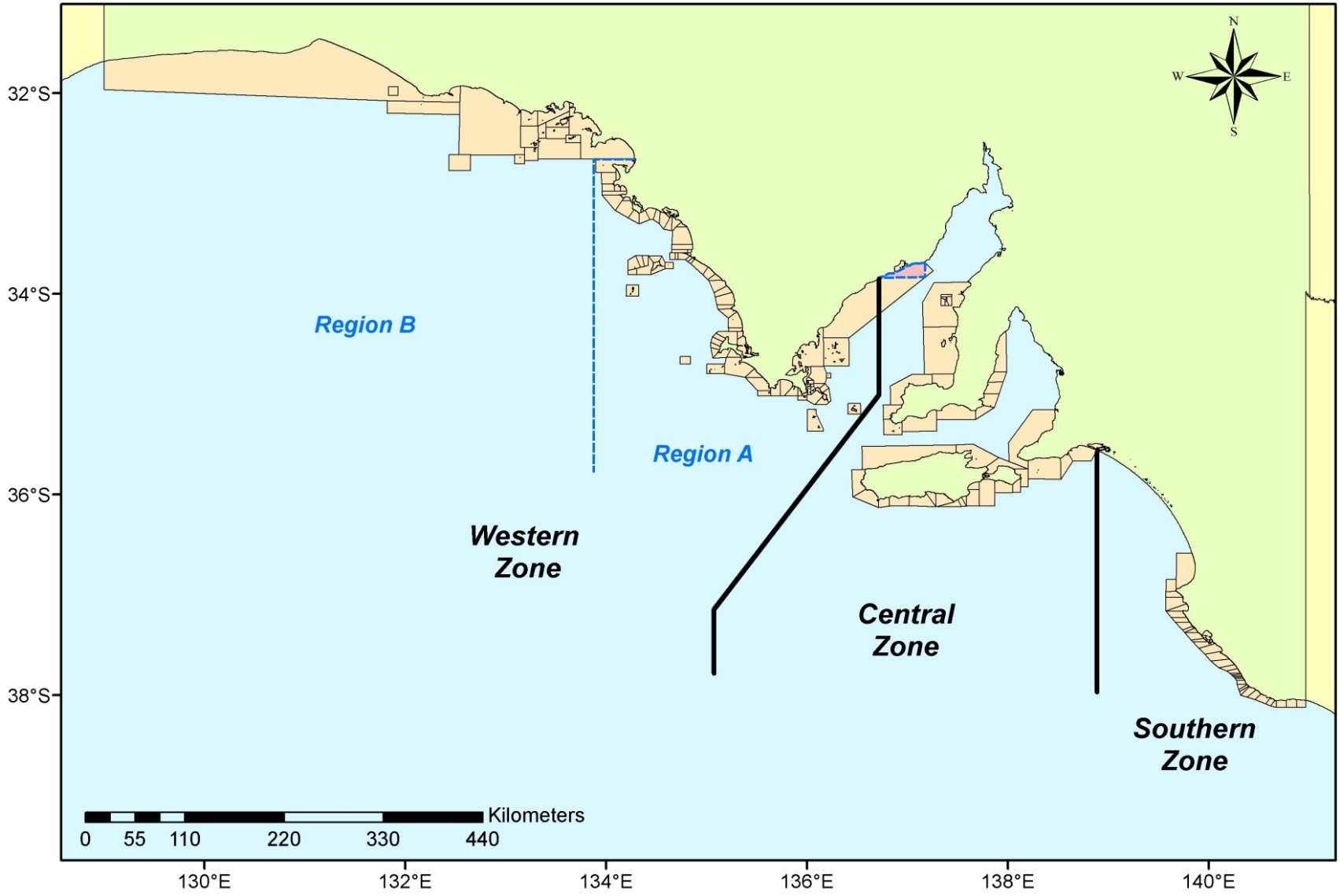

Figure 1.1 Fishing Zones, regions and map-codes of the South Australian Abalone Fishery.

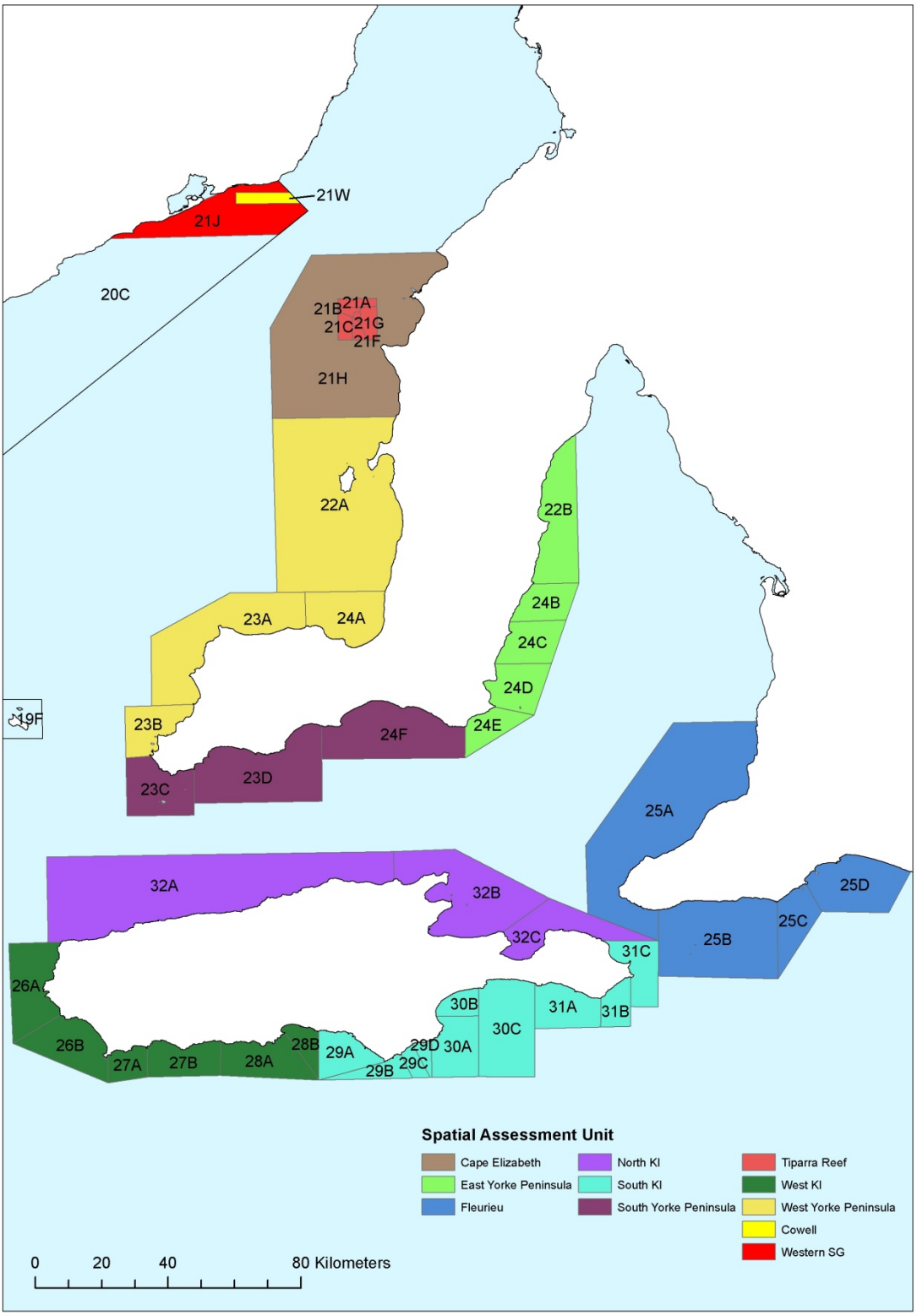

Figure 1.2 Spatial Assessment Units (SAUs; coloured blocks), Fishing Areas (numbered areas) and map-codes (numbered and lettered areas) of the CZ of the South Australian Abalone Fishery.

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 (PI) and reference points. The key PI were (1) catch rate ($kg.hr^{-1}$), (2) size composition of the commercial catch, and (3) the abundance of legal-sized and pre-recruit-sized abalone observed on fishery-independent surveys. 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 of 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 by the second Management Plan for the fishery in 2004 (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 sufficiently broad, thereby encompassing almost all aspects of the fishery and, secondly, the complex population structures of abalone were captured by their spatial focus (Saunders & Mayfield 2008, Miller *et al.* 2009, Saunders *et al.* 2009a, 2009b). 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 PI 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 new 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 Caddy (2002) and Shepherd and Rodda (2001) .

1.3.2. The new Management Plan

Coincident with an FRDC-funded project focussed 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 incorporated a framework to guide integration with industry information. This aim and these objectives were selected because, following extensive review of the use of indicators, reference points and decision rules in fisheries management (Caddy 2002, 2004, Sainsbury 2008), these systems have a demonstrated record of improving the understanding of stock status among stakeholders and providing increased certainty in management decisions.

The new Management Plan (PIRSA 2012) endeavours to achieve these objectives. For example, assessments are made at scales that better reflect functional biological populations, termed Spatial Assessment Units (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 new 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 the overall status (depleted, over-fished, sustainably-fished, under-fished or lightly-fished) of each species in each zone; and (2) 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 new 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 (Morgan & Shepherd 2006, Mayfield & 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 ensure known catch history, SAUs comprise single or multiple map-codes, which is 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 2002 to 2011. 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 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 2011, there was 1 high and four medium importance SAUs (Figure 1.3), each of which is assessed in this report.

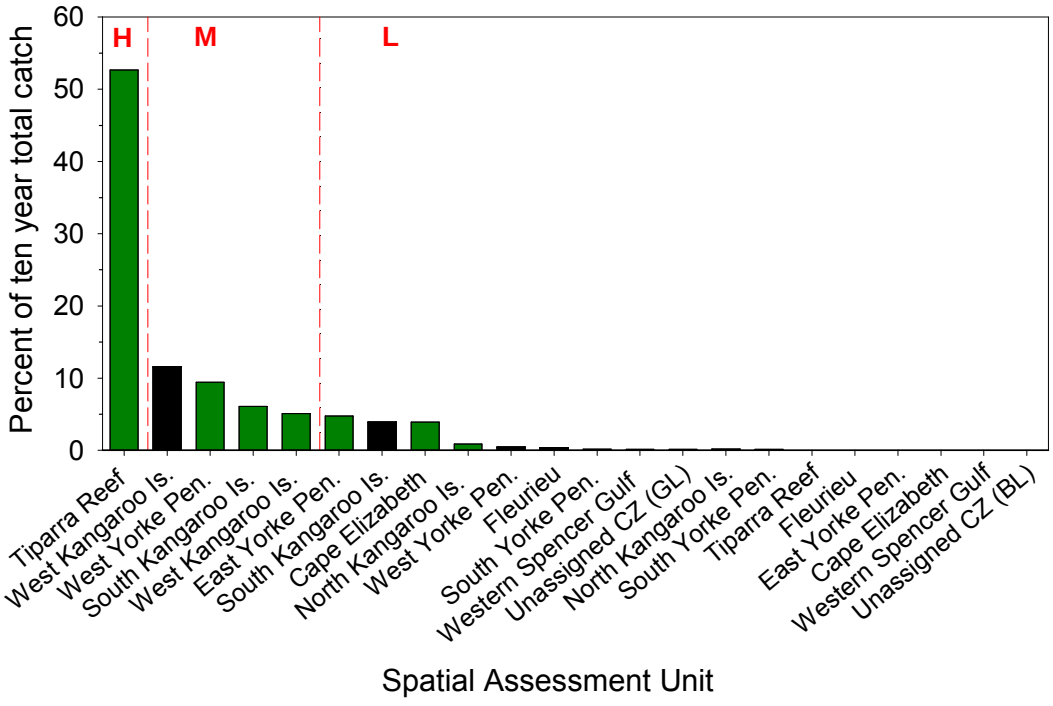

Figure 1.3 SAUs of the CZ Abalone Fishery, ranked in order of importance (High (H); Medium (M); and Low (L)) by percent of ten year (2002-2011) total catch for greenlip (green bars) and blacklip (black bars). SAU name abbreviations: Peninsula (Pen.); Island (Is.).

Step 3: Score performance indicators for each spatial assessment unit

Six PI – 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 (i.e. top 10%) during the reference period; (2) upper target reference point (UTRP) defined as the 6th highest value (i.e. top 25%) during the reference period; (3) lower target reference point (LTRP) defined as the 6th lowest value (i.e. bottom 25%) over the reference period; and (4) lower limit reference point (LLRP) which is defined as the 3rd lowest value (i.e. bottom 10%) during the reference period.

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). However, as the harvest strategy is new, this penalty score applies to assessments from 2013 onwards; absence of these data for this PI in this assessment was scored a zero.

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 Blacklip & greenlip >155 mm SL defined as large
CPUE	Commercial catch-per-unit effort ($kg.hr^{-1}$)	$CPUE_{Wt} = \frac{\sum_{i=1}^{n} w_i \frac{C_{PSi}}{E_i}}{\sum_{i=1}^{n} w_i},$	All records where: total catch was >900 kg; CPUE (total catch/total effort) was >150kg/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
$\text{Density}_{\text{legal}}$	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 & blacklip ≥130 mm SL defined as legal-sized
$\text{Density}_{\text{pre-recruit}}$	Density of pre-recruit (i.e. those that will exceed MLL within ~2 yr) abalone on surveys	$\text{Density}_{\text{Pre-recruit}} = \frac{\sum \text{Pre-recruit counted}}{\text{Total area surveyed}}$	>90% of survey completed Greenlip & 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

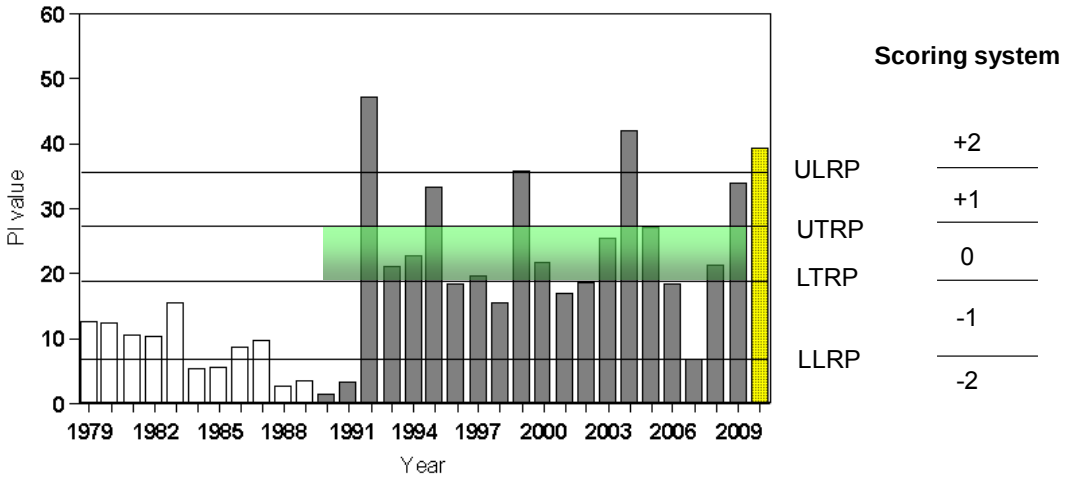

Figure 1.4 Schematic showing the reference period (grey bars) associated reference points, the year being assessed (yellow bar) and the scores applied to measure fishery performance. ULRP, UTRP, LTRP and LLRP refer to upper limit reference point upper trigger reference point, lower trigger reference 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 which 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) PI. 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 PI; maximum range -48 to +48) and medium (i.e. three PI; 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.

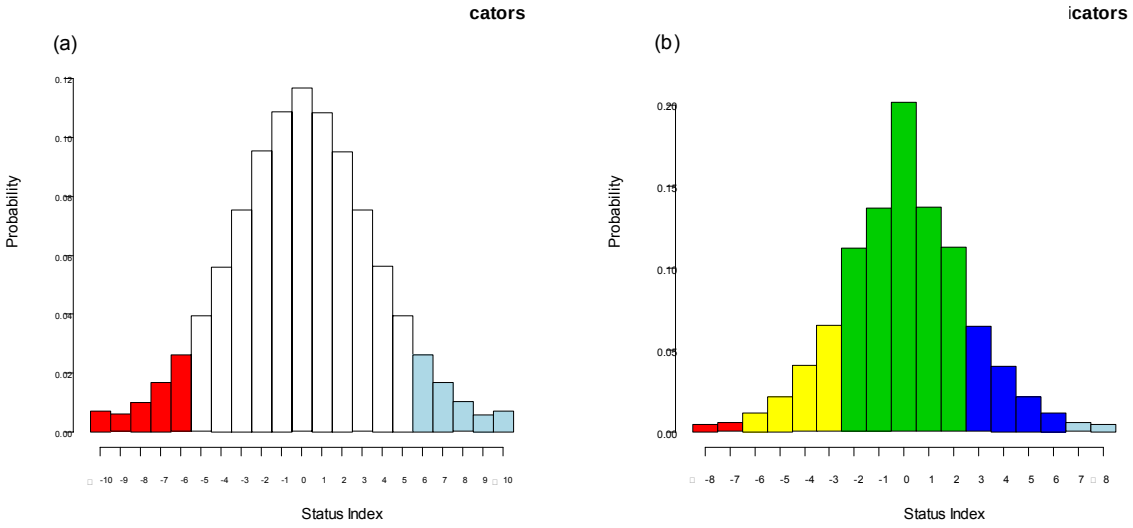

Figure 1.5 Histograms showing the probability distributions of obtaining total scores across (a) six PIs for SAUs of high importance and (b) three PIs for SAUs of medium importance. Distributions were generated by Monte Carlo simulations (*n* = 5000). Probabilities above and below ±10 (High) and ±8 (Medium) were accummulated in these upper and lower bin classes, respectively, for each of the six and three PI distributions.

Table 1.4 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 (see Tables 2.1 & 3.1). 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, Shepherd *et al.* 1999, Rodda *et al.* 2000). 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 & 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 & Ward 2003, Mayfield *et al.* 2004, Mayfield *et al.* 2005a, Mayfield *et al.* 2006, Mayfield *et al.* 2008a, 2010).

The most recent stock assessment report for the CZ (Mayfield *et al.* 2010) concluded that (1) catches of 90-100 t.yr^{-1} from FA 21 were sustainable; (2) the catch-cap in FA 21 (100 t.yr^{-1}) and stable TACC had increased fishing pressure elsewhere, with the capacity of other FA to sustainably support the TACC being poorly understood; and (3) despite several encouraging signals in recent data, the blacklip stocks remained in a weak condition and required ongoing precautionary management.

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 world-wide 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 & Murray 1992, Elliott *et al.* 2000, Hancock 2000, Temby *et al.* 2007, Miller *et al.* 2009), demonstrating limited dispersal among 'metapopulations' (Fleming 1997, Miller *et al.* 2009).

Abalone have separate sexes. Spawning is generally seasonal and synchronised. Fertilisation success is strongly influenced by adult density (Babcock & 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). 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 & 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 & 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 & Hearn 1983), although alternative (Bardos 2005) and more complex models are being used (Haddon *et al.* 2008). Recently settled abalone prefer encrusting coralline algae (Shepherd & Turner 1985, Shepherd & Daume 1996) that provide an important source of food, and protection from predation (Shepherd & Cannon 1988).

Through their ontogeny the diet shifts from crustose coralline algae (individuals 5-10 mm SL) to drift algae (Shepherd & 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 polycheates also erode the shells and spire (Shepherd 1973).

1.5.1. Biology of greenlip in the Central Zone

Greenlip are contiguous throughout southern Australia, with their distributions 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 & Brown 1993, Morgan & Shepherd 2006).

The length at sexual maturity of greenlip can vary significantly among areas. Fifty percent of individuals were sexually mature (L_{50}) between 75 and 87 mm SL (Tiparra Reef; Table 1.5). Greenlip spawned synchronously between October and March at both West Island and Tiparra Reef (Shepherd & Laws 1974; SARDI unpublished). These data match the pattern of larval settlement onto artificial collectors (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 length, whole weight, meat weight, bled meat weight and fecundity for greenlip from Tiparra Reef and West Island are well established (Table 1.6 & 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 in space and through time; sub-adult growth rates in the CZ ranged between 15.4 and 20.9 $mm.yr^{-1}$ (Table 1.8). 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 vary spatially and temporally. 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); individuals between 1 and 4 years of age had natural mortality rates of 0.23-0.4 year^{-1} (Shepherd & Baker 1998).

Table 1.5 Length at 50% maturity (mm, shell length) for greenlip in the CZ.

Year	Site	Length at 50% maturity (mm)	CI (95%)	Reference
1964	West Island	87	-	Shepherd & Laws (1974)
1969	Tiparra Reef	75	-	Shepherd & 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 (SL, mm) and shell weight (SW, g) for greenlip in the CZ. The equation is of the form $SW = aSL^b$.

Year	Site	a (x 10^{-5})	b	r	n	Reference
1997	Tiparra Reef – West Bottom	10	3.08	0.91	97	SARDI unpublished data
1997	Tiparra Reef	1.26	3.51	-	-	Shepherd & Baker (1998)
1997	West Island	1.7	3.41	-	-	Shepherd & Baker (1998)
2003	Tiparra Reef – West Bottom	2	3.35	0.99	82	SARDI unpublished data
2004	Tiparra Reef – Coal Ground	10	3.06	0.98	164	SARDI unpublished data
2004	Tiparra Reef – Mid West Bottom	3	3.28	0.97	99	SARDI unpublished data
2004	Tiparra Reef – West Bottom	3	3.29	0.99	204	SARDI unpublished data
2007	Tiparra Reef – Coal Ground	20	2.95	0.94	123	SARDI unpublished data
2007	Tiparra Reef – Mid West Bottom	9	3.06	0.97	129	SARDI unpublished data

Table 1.7 Relationship between fecundity (F, millions of eggs) and shell weight (SW, g) and between fecundity and shell length (SL, 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 & Baker (1998)
1986	West Island	-	-	-0.36	0.015	Shepherd & Baker (1998)
2004	Tiparra Reef – Coal Ground	0.4271	3.09	-	-	SARDI unpublished data
2004	Tiparra Reef – Mid West Bottom	0.0007	4.26	-	-	SARDI unpublished data
2007	Tiparra Reef – Mid West Bottom	2 x 10^{-10}	5.01	-	-	SARDI unpublished data

Table 1.8 Growth rate (mm.yr^{-1}) of greenlip tagged and recaptured in the CZ.

Site	Length range	Growth rate ± SE	Reference
West Island	42-141	20.3±0.4	Shepherd (1988)
Tiparra Reef	51-129	20.9±0.7	Shepherd & Triantafillos (1997)
Tiparra Reef	46-157	15.4±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 ($.yr^{-1}$)±SE	L_∞±SE	Reference
West Island	42-141	0.479±0.029	137.9±1.9	Shepherd & Hearn (1983)
Tiparra Reef	51-129	0.406±0.047	130.8±2.5	Shepherd & Hearn (1983)

Table 1.10 Natural mortality rates ($M.yr^{-1}$) for adult (emergent) greenlip at two sites in the CZ.

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

1.5.2. Biology of blacklip in the Central Zone

Blacklip are contiguous throughout southern Australia between Coffs Harbour (New South Wales) and Rottnest Island (Western Australia). They commonly occur in shallow water (0-30 m) along rocky coastlines. Blacklip have a fine-scale population structure (Brown 1991) with significant genetic differentiation occurring at very small spatial scales (Shepherd & 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 & Laws 1974). The annual spawning cycle may be driven by seasonal fluctuations in water temperature (Shepherd & Laws 1974). Relationships between shell length and fecundity for blacklip on 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 through time and space. Emergent blacklip growth is non linear and can be represented by the von Bertalanffy growth model. Model parameter k ranged from 0.32 (Tiparra Reef) to 0.34 $.yr^{-1}$ (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 Length at 50% maturity (mm, shell length) for blacklip in the CZ. The equation is of the form f(x) = (1+exp((L50-x)/ δ))-1.

Year	Site	Length at 50% maturity (mm)	CI (95%)	Reference
1964	West Island	76	-	Shepherd & Laws (1974)
1969	Tiparra Reef	93	-	Shepherd & 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 (SL, 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 & Hearn (1983)
Tiparra Reef	73-140	0.32±0.063	142.6±4.3	Shepherd & Hearn (1983)

Table 1.14 Natural mortality rates ($M.yr^{-1}$) for adult (emergent) blacklip at two sites in the CZ.

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

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 2011 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 Areas (FA; e.g. FA 21); (3) Map-codes (MC, e.g. MC 22A); and (4) spatial assessment units (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 new Management Plan for the fishery (PIRSA 2012), which determines the: (1) 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, whole weight), catch-per-unit-effort (CPUE, $kg.hr^{-1}$) and the proportion of large (>155 mm SL) greenlip in the commercial catch. Fishery-independent data consist of estimates of all, legal (≥130 mm SL), and pre-recruit (90-130 mm SL) greenlip densities and 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 2009 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. These data are presented for completeness but, given that the most recent data are from 2009 and the poor understanding of the degree to which the data in most years are representative of the fishery, they are not considered in the analysis or discussion of resource status. Estimates of greenlip density were obtained from fishery-independent diver-surveys conducted by SARDI.

Catch was determined from logbook returns. For historical comparison, mean values of the proportion of the greenlip TACC harvested from each SAU for the ten year period between 2002 and 2011 ($C_{02\text{-}11}$) is provided. 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. The small proportion of records (<1%) where multiple daily dives are entered as separate days were ignored. CPUE ($kg.hr^{-1}$) was calculated as the catch-weighted mean of daily CPUE (Burch *et al.* 2011), 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. Limited daily records (*i.e. n* <10) prevented calculation of CPUE in some years at some spatial scales.

Fishery-independent surveys at Tiparra Reef have been undertaken in most years since 1968 using the timed-swim method (Shepherd 1985). More recent surveys, from 2010 onwards, have used both the timed-swim and leaded-line methods (McGarvey *et al.* 2008) to improve the reliability and accuracy of estimates of greenlip density. No data are available to distinguish the density of legal and sub-legal (including pre-recruit) greenlip from total density estimates from surveys done prior to 1990.

2.3. **Results**

2.3.1. Central Zone

Total catch has been stable at about 140 $t.yr^{-1}$ since 1994 (Figure 2.1). Prior to the implementation of a TACC (1990), the average annual catch was 133 t, which includes the maximum recorded catch of 253 t in 1989. Thus, current catches are about 6% greater than the annual average before implementation of a TACC. CPUE was stable from 1990 to 1999 (average: 61 $kg.hr^{-1}$). In 2000, it increased to 84 $kg.hr^{-1}$ and was at the highest recorded level of 86 $kg.hr^{-1}$ in 2001. Since 2001, it has generally decreased and, in 2011, was 66.9 $kg.hr^{-1}$, the lowest level since 1999. Total annual effort has generally increased since 2001 with rapid increases since 2009. In 2011, total effort on greenlip was 356 days, the greatest number of days fished per year in 20 years.

Two key changes in the spatial distribution of catch are evident from 1979 (Figure 2.1). Firstly, in response to the TACC implementation in 1990, the proportion of catch harvested from Tiparra Reef (MCs 21A - G) increased substantially and peaked at 94% (135 t) in 2001. Secondly, following the imposition of a 'catch-cap' in FA 21 in 2005, the

proportion of catch harvested away from Tiparra Reef increased steadily. In 2011, catches taken away from Tiparra Reef contributed 58% (82 t) to the total catch, the highest proportion since 1992 and similar to the magnitude of the catch taken prior to the implementation a TACC (1979 to 1989; mean: 86 t.yr^{-1}).

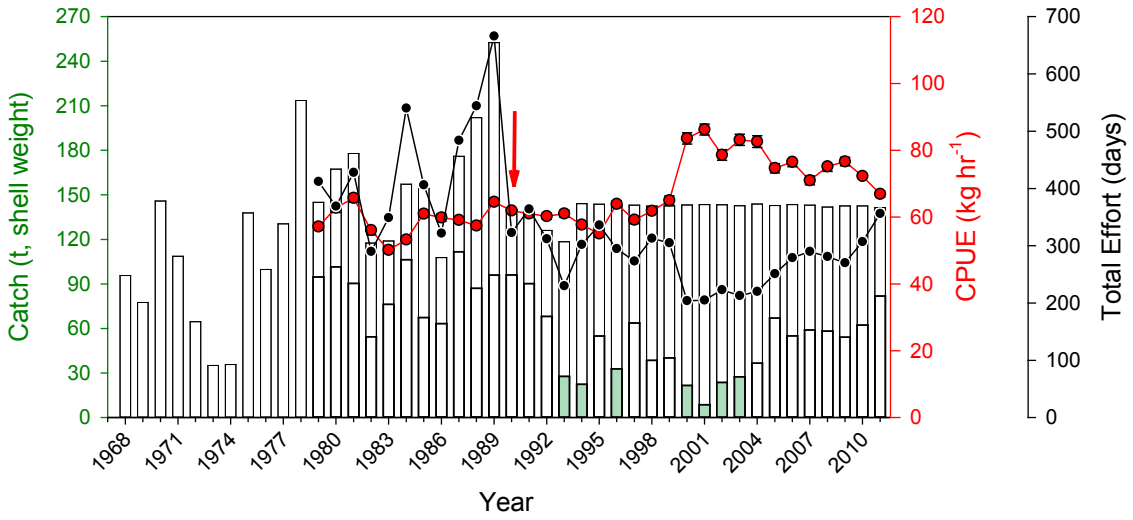

Figure 2.1 Total catch of greenlip for the CZ (t, shell weight; dark green bars) and that 'away' from Tiparra Reef (light green bars, from 1979) from 1968 to 2011. Total effort (days), and CPUE (kg.hr^{-1}, ±SE) are shown by the black and red lines, respectively. Red arrow indicates implementation of TACC.

Away from Tiparra Reef, small amounts of catch have been harvested from a large number of map-codes (Figure 2.2; 'Other'). However, several map-codes 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 (1980-1984) and MC 24A (1985-1988). From 1992 to 2004, when the proportion of the TACC harvested away from Tiparra Reef was low, most catches were obtained from MCs 24A and 21H. Since 2005, catches harvested away from Tiparra Reef were first obtained from West York Peninsula and then from East York Peninsula. 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 2010), catches from MC 21H have increased whilst CPUE has simultaneously decreased (Appendix 1 - Figure A1.5, Cape Elizabeth).

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 (73%), FA 22 (3.5%) and FA 24 (10%; 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 and, in 2011, was 53%. This was the lowest proportion from this FA since 1992. In compensation, catches from FA 22, 24 and 26-32 have increased. The latter, all off Kangaroo Island, contributed ~20% of the total catch in 2010 and 2011, the highest proportions since 1992.

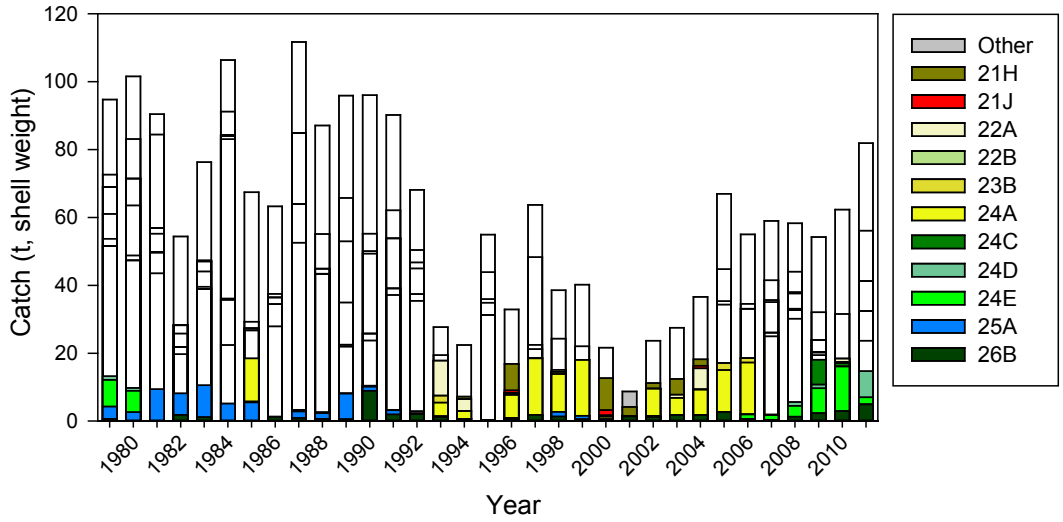

Figure 2.2 Annual catch harvested 'away' from Tiparra Reef, showing individual map-codes (colour coded to reflect SAU codes - Figure 1.2) that have contributed >5% to total annual catch in any one year from 1979 to 2011.

2.3.2.2. *Temporal patterns of catch and CPUE in key Fishing Areas*

Substantial changes in catch have occurred within 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, initially the west and east coast of Yorke Peninsula and more recently those off Kangaroo Island. For example, catch has increased over the last 8-10 years in FA 24, 26, 27, 29, 30 and 31 and recent catches from FA 26, 27, 29 and 30 are among the highest on record. In contrast, in FA 21, annual catches have generally decreased since 2001 and, in 2011, it was 74 t, the lowest level since 1993 and ~25 t below the 'catch-cap'. Pulses of fishing have occurred in FA 22, with peaks in catch recorded in 1980 (23 t), 1990 (24 t), 2005 (17 t) and 2011 (9 t). Notably, through time, successive peaks are lower and fishing periods shorter.

Changes in CPUE (kg.hr^{-1}) among, and within, FAs have also been substantial over the last 10 years (Figure 2.4). Current CPUEs in FAs off Kangaroo Island (FAs 26, 27, 29, 30 and 31) are among the highest on record (range: 60-75 kg.hr^{-1}). In contrast, CPUE in FA 21 has decreased substantially since 2009 and, in 2011, was 71 kg.hr^{-1}. Whilst this is the lowest value since 1999, it remained about 10% above the long-term average from 1990 to 2000 (64 kg.hr^{-1}). These patterns in FA 21 suggest a substantial decline in legal biomass over recent years, to levels similar to those prior to 2000.

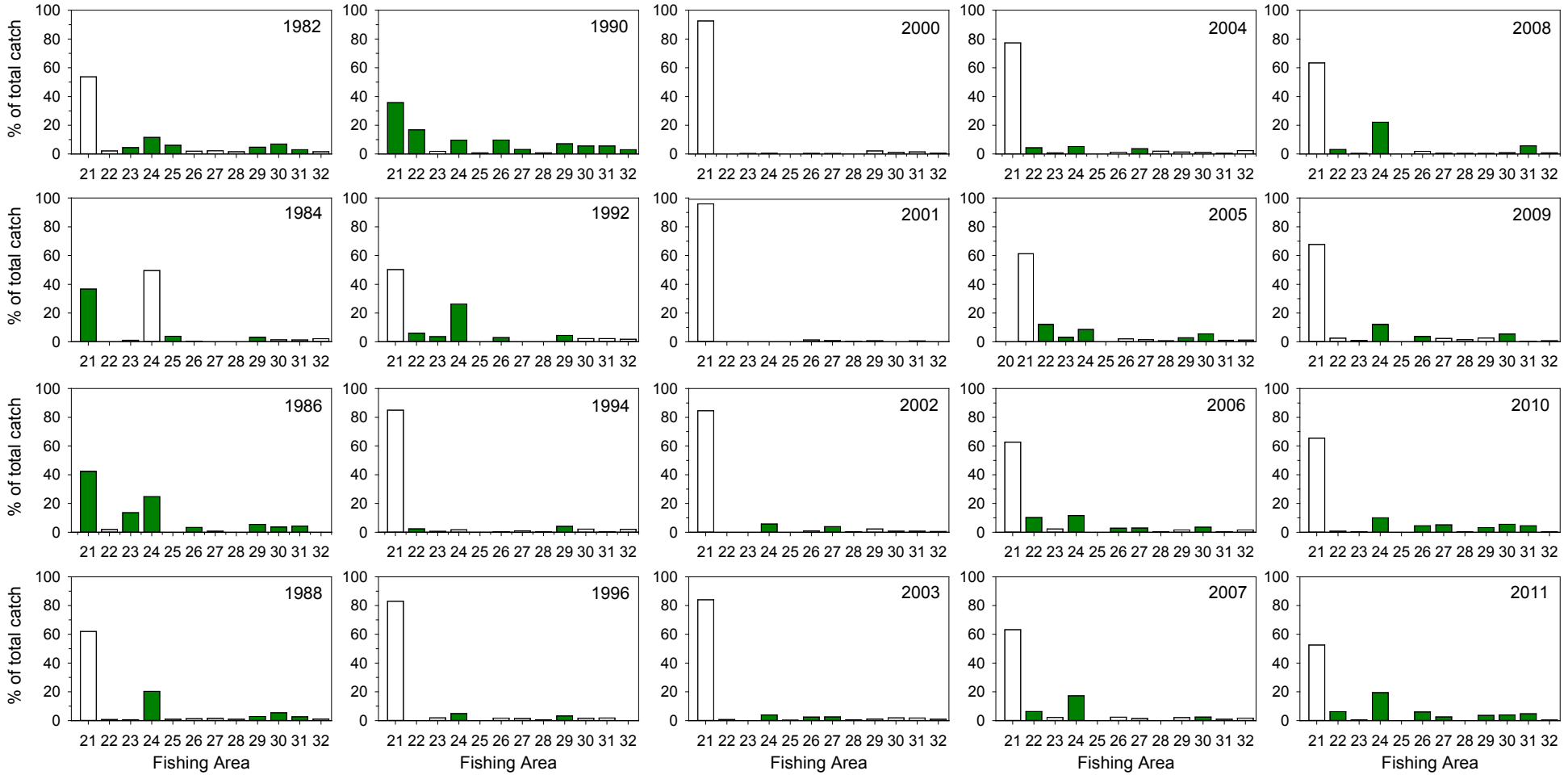

Figure 2.3 Spatial distribution of the greenlip catch (% of total catch) among each of the fishing areas in the CZ in alternate years from 1982 to 1996 and annually from 2000 to 2011.

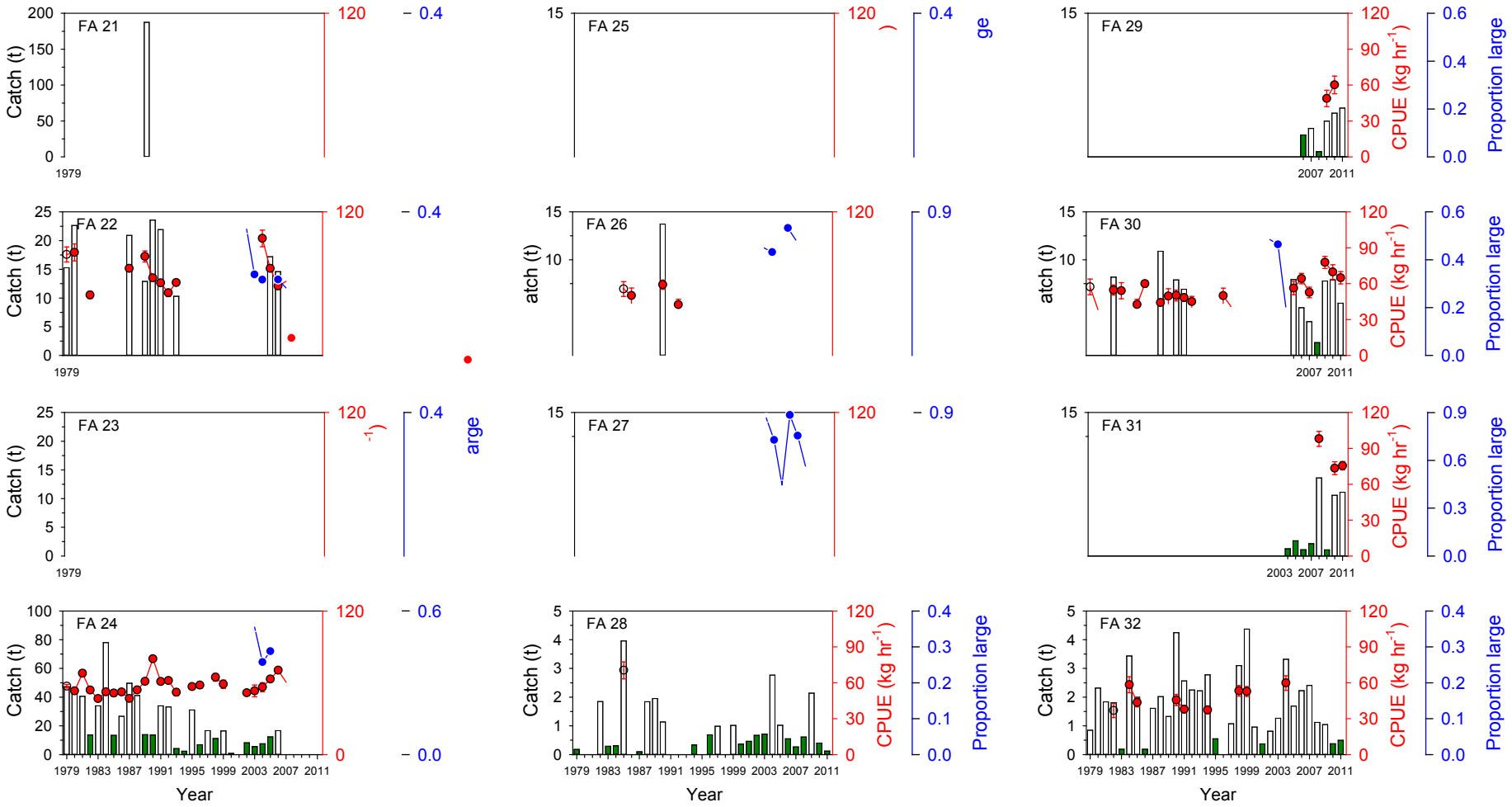

Figure 2.4 Catch (t, shell weight, green bars), CPUE (kg.hr^{-1}, ±SE, red lines) and the proportion of large (>155 mm, blue lines) greenlip in each of the fishing areas comprising the CZ from 1979 to 2011. Gaps in the time series of the CPUE and Proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). Note different scales on the Y-axis for catch (t).

2.3.3. Spatial Assessment Units

2.3.3.1. *Distribution of catch among SAU*

The distribution of catch among SAUs reflects the temporal shift in the proportional redistribution of catch from Tiparra Reef (Figure 2.5). Initially, as a consequence of the 'catch-cap' implemented from 2005, catches from West Yorke Peninsula increased between 2005 and 2007. From 2008, the contribution from West Yorke Peninsula decreased, with catches from East Yorke Peninsula dominating in 2008 and 2009. The continued redistribution of catch away from Tiparra Reef is evident through the increasing proportion of the greenlip catch harvested from West and South Kangaroo Island and Cape Elizabeth in the last 2-3 years (Figure 2.5). Increased catches have not been observed in either the South Yorke Peninsula or Fleurieu SAUs, despite these areas yielding substantial catches in the 1980s (Appendix 1 - Figure A1.5)

2.3.3.2. *Temporal patterns in SAUs of high importance*

Tiparra Reef ($C_{02\text{-}11}$ - 63%; Rank 1)

Tiparra Reef has been the most important greenlip SAU in the CZ (65% of annual catch) and the SAAF (38%) since 1990. Total annual catches from Tiparra Reef increased steadily between 1979 (50 t) and 2001 (135 t), with large catches harvested in 1988 (115 t) and 1989 (157 t). Since 2001, catches have declined rapidly to 60 t in 2011, the lowest catch from Tiparra Reef since 1992 and substantially lower than the 'catch-cap' (Figure 2.6). From 2000 to 2009, CPUE was relatively stable (87 $kg.hr^{-1}$) and >20% above the long-term average from 1979 to 1999 (64 $kg.hr^{-1}$; Figure 2.6). CPUE decreased between 2009 (85 $kg.hr^{-1}$) and 2011 (70 $kg.hr^{-1}$). Thus, the CPUE in 2011 was ~18% below the previous 10 year average (2001-2010; 86 $kg.hr^{-1}$) and at the lowest level since 1999. However, it remained above the 20-year average from 1979 to 1999.

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). Data from 1990 show that the density of sub-legal-size greenlip has been substantially greater (range: 1.4 to 9.8 times) than that of legal-size individuals, and that sub-legal-size density has dominated the difference in total density through time (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 2010, the timed-swim estimate of legal-size density was 0.12 $greenlip.m^{-2}$, the lowest value for 10 years and >50%

below that in 2005. Despite this decrease, the estimate of legal-size density remained above those observed in the early 1990s. However, leaded-line surveys show that the density of legal-size greenlip in 2011 (0.07 greenlip.m^{-2}) was ~25% lower than that in 2010 (0.09 greenlip.m^{-2}). When this level of decline was applied to the 2010 timed-swim survey estimates, it yielded a value of 0.09 legal-sized greenlip.m^{-2}. This was 65% below the 2005 estimate and among the lowest on record. However, it remained ~15% above the mean level observed during the early 1990s.

The density of sub-legal-size greenlip peaked in 2005 (0.47 greenlip.m^{-2}; Figure 2.7). In 2010, the timed-swim estimate of sub-legal-size density was 0.27 greenlip.m^{-2}. This was below the average (0.32 greenlip.m^{-2}) but within the range from 2001 (0.25-0.47 greenlip.m^{-2}). Sub-legal-size density from leaded-line surveys done in 2011 was 0.13 greenlip.m^{-2}, ~15% below that observed in 2010 (0.15 greenlip.m^{-2}). There was no long-term trend evident in estimates of sub-legal-size density.

The general absence of weak length classes in data from fishery-independent surveys suggests that population structures on Tiparra Reef have remained reasonably stable through time and that recruitment has been relatively consistent among years (Figure 2.8). However, the proportion of large greenlip (>150 mm SL) measured in 2011 (0.8%) was the lowest since 1994, confirming substantial declines in legal-size greenlip in recent years.

2.3.3.3. *Temporal patterns in SAUs of medium importance*

West Yorke Peninsula ($C_{02\text{-}11}$ - 11%; Rank 2)

The annual catch from West Yorke Peninsula appears cyclical and declining, with prolonged periods of relatively high and low catches (Figure 2.9). For example, catches from 1984 to 1992 averaged 44 t.yr^{-1} (range 23-82 t.yr^{-1}), whereas between 1996 and 2003 the average catch was 9 t.yr^{-1}. The 2nd period of increased catch, between 2005 and 2007, had a lower peak (35 t in 2007), a lower average (33 t.yr^{-1}) and lasted a shorter time than the first. The increased catch between 2010 and 2011 may indicate the start of a new period of high catch. Since 1992 CPUE has remained relatively stable and ranged from ~50-70 kg.hr^{-1}.

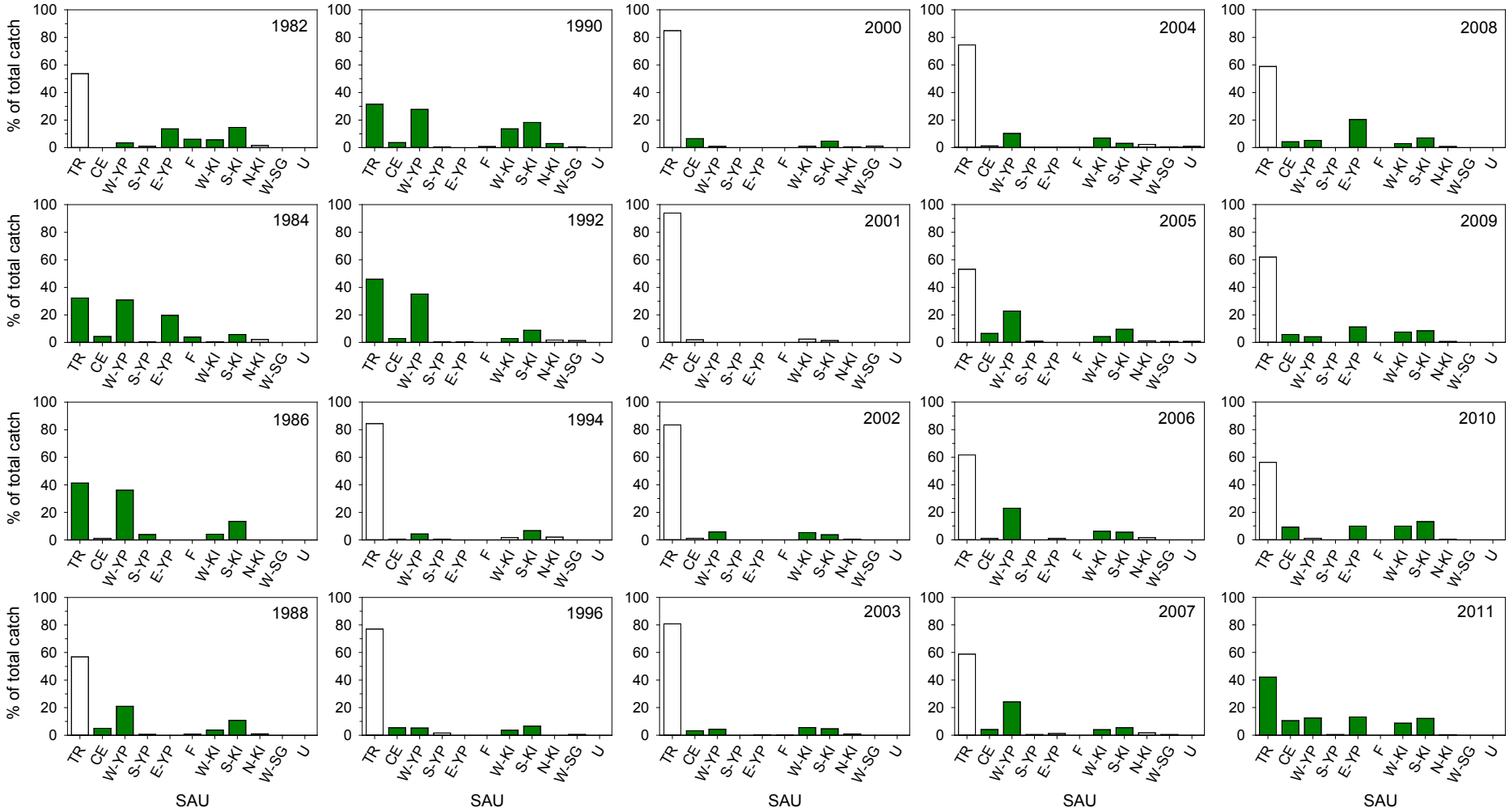

Figure 2.5 Spatial distribution of the greenlip catch (% of total catch, green bars) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; E-KI: East Kangaroo Island; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ in alternate years from 1982 to 1996 and annually from 2000 to 2011.

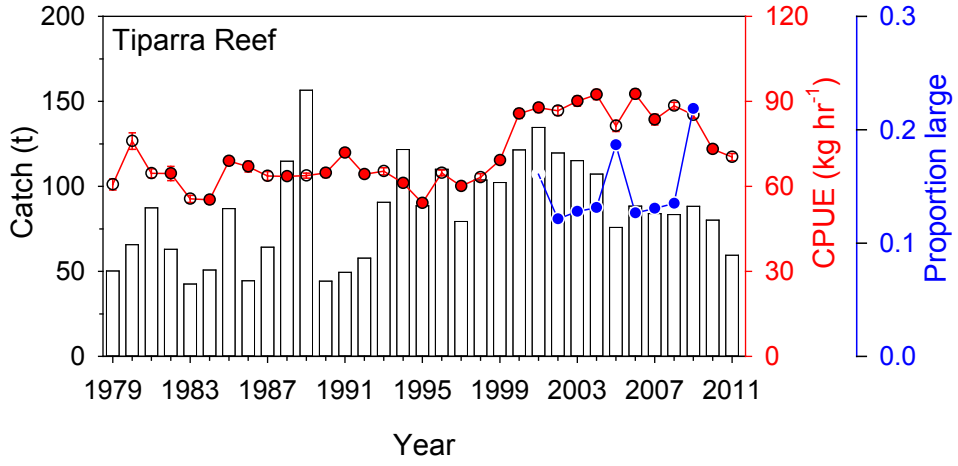

Figure 2.6 Tiparra Reef (high importance). Catch (t, shell weight, green bars), CPUE (kg.hr^{-1}, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2011. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

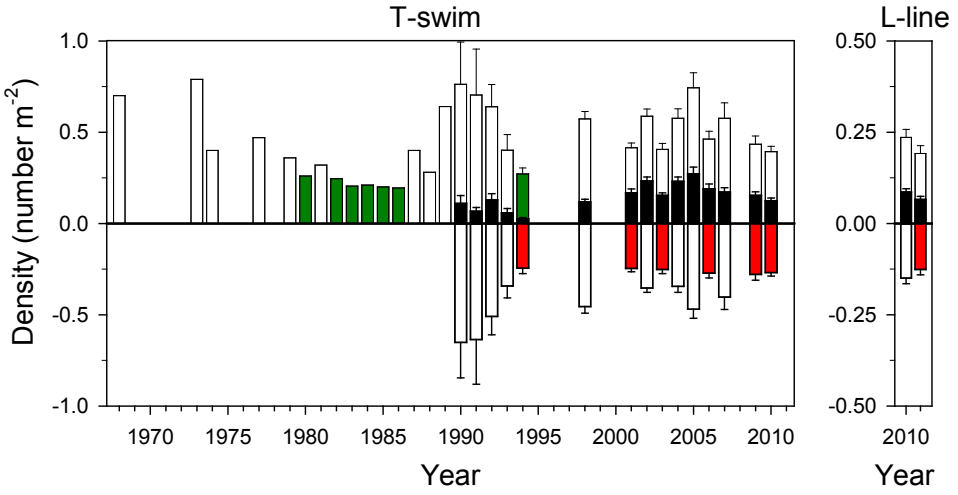

Figure 2.7 Tiparra Reef (high importance). Fishery-independent survey densities of total (number m^{-2}, green bars), legal (≥130 mm, black bars) and sub-legal (<130 mm, red bars) greenlip from 1968 to 2010 (timed-swims) and 2010 to 2011 (leaded-lines). Gaps in the time series indicate no surveys done. Note both survey methods done in 2010 and Y-axis scale varies between survey methods.

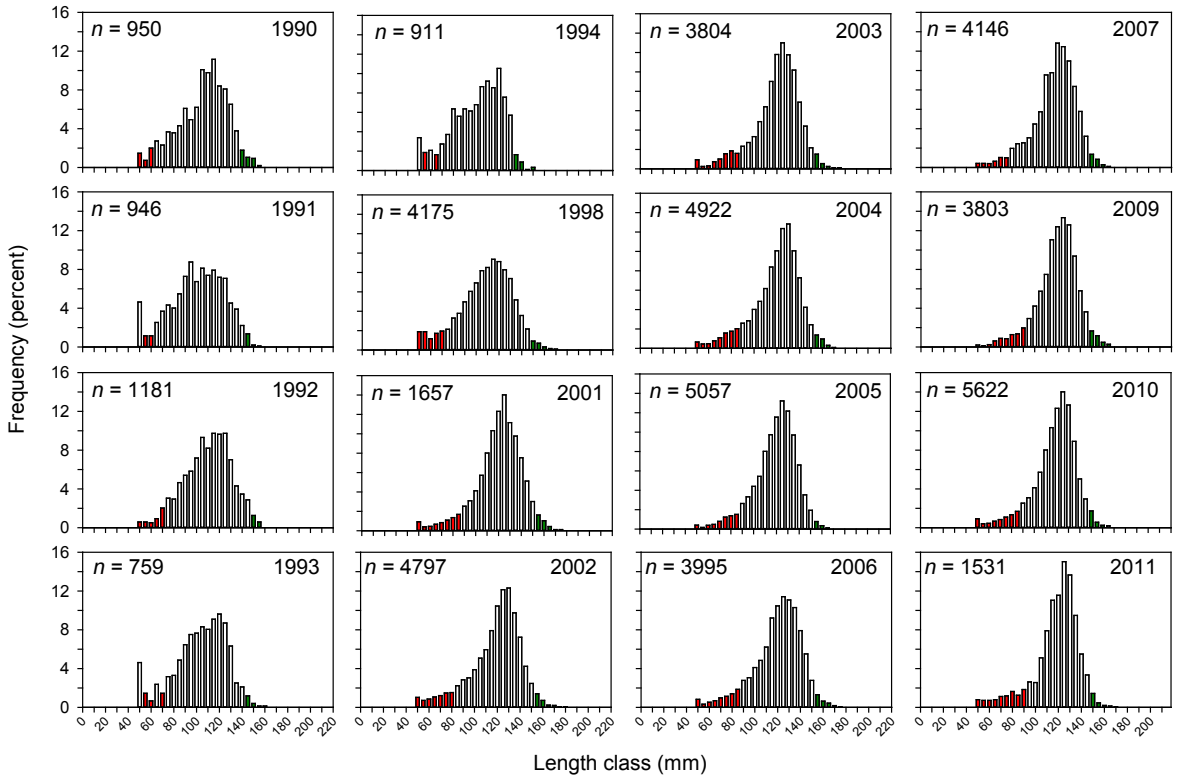

Figure 2.8 Tiparra Reef (high importance). Length frequency distributions of legal-size (green bars) and sub-legal-size (red bars) greenlip at Tiparra Reef observed on fishery-independent surveys from 1990 to 2011. Bin classes are 5 mm. Bin classes below 50 mm were pooled.

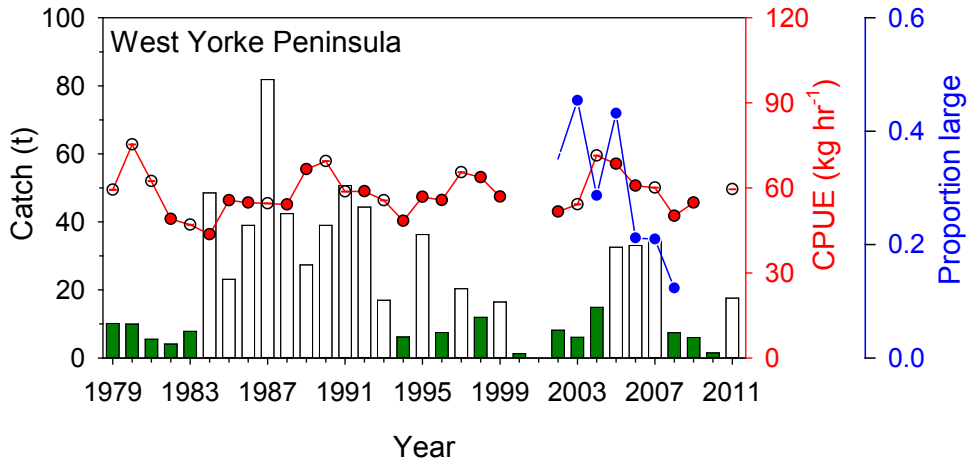

Figure 2.9 West Yorke Peninsula (medium importance). Catch (t, shell weight, green bars), CPUE (kg.hr^{-1}, ± SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2011. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

South Kangaroo Island ($C_{02\text{-}11}$ - 7%; Rank 3)

From 1979 to 1992, average annual catch from this SAU was ~15 t.yr^{-1} and during this time generally increased, fluctuating by up to 15 t between years over a 2-3 year cycle. The highest catch was 26 t in 1990 (Figure 2.8). From 1993 to 2004, catches were relatively low, averaging ~6.5 t.yr^{-1}. Annual catches have increased substantially since 2004. In 2010 and 2011, they were 19 t and 17 t, respectively, and the highest since 1990. CPUE has increased from the late 1990s, following the prolonged period of relatively low catch. Thus, current CPUEs are among the highest on record.

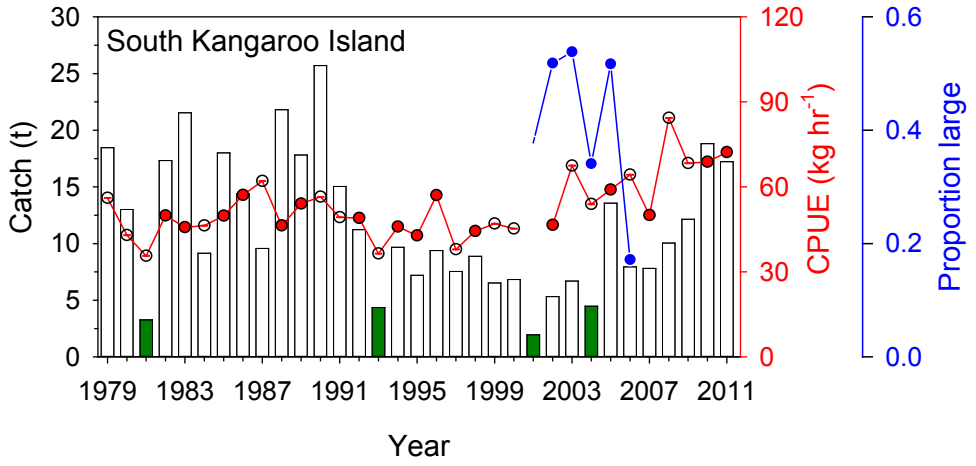

Figure 2.10 South Kangaroo Island (medium importance). Catch (t, shell weight, green bars), CPUE (kg.hr^{-1}, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2011. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

West Kangaroo Island ($C_{02\text{-}11}$ - 6%; Rank 4)

Prior to 2002, the average catch from this SAU was 4.6 t.yr^{-1} (Figure 2.11). Catches over the last decade have been substantially higher, averaging 8.7 t.yr^{-1}. Thus, current catches are among the highest on record. 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 been lower and it has increased, with CPUE over the last four years (2008 to 2011) among the highest levels in the history of this SAU.

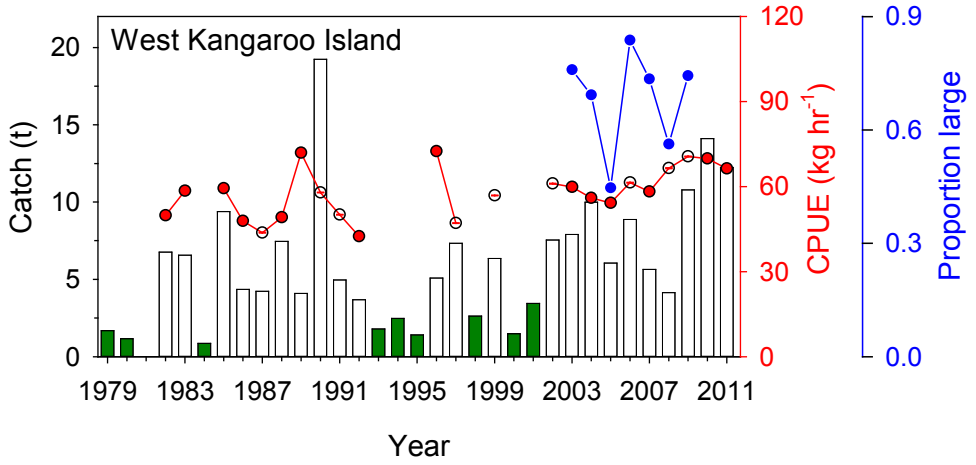

Figure 2.11 West Kangaroo Island (medium importance). Catch (t, shell weight, green bars), CPUE (kg.hr^{-1}, ±SE, red line) and the proportion of large greenlip (>155 mm, blue line) from 1979 to 2011. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

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

This section of the report provides the outcome of applying the harvest strategy, as described in the new Management Plan (PIRSA 2012), to determine the (1) risk that greenlip stocks in the high and medium SAUs are over-fished and (2) the zonal stock status for greenlip. There was one high and three 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 1).

Summed PI scores ranged between -8 (Tiparra Reef) and +13 (South KI; Table 2.1). Tiparra Reef was assigned to a 'red', West Yorke Peninsula to a 'green' and both South and West KI to a 'light-blue' risk-of-overfishing category (Table 2.1). The catch-weighted zonal score was -0.56. This indicates that the status of the greenlip fishery in the CZ is over-fished (Table 2.1).

Table 2.1 Outcome from application of the harvest strategy described in the new Management Plan against the greenlip 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 (02-11)	Importance	%Contribution to catch from high & medium SAU in 2011	CPUE	%TACC	%Large	Pre-recruit density	Legal density	Mortality	Scientific assessment score	Risk of overfishing	Catch-weighted contribution to zonal score
Tiparra Reef	52.7	High	55.8	0	-5	0	-1	0	-2	-8	-2	-1.11
West Yorke Peninsula	9.4	Medium	16.5	0	0	0	-	-	-	0	0	0.00
South KI	6.1	Medium	16.2	8	5	0	-	-	-	13	2	0.32
West KI	5.1	Medium	11.5	4	6	0	-	-	-	10	2	0.23
East Yorke Peninsula	4.8	Low		-	-	-	-	-	-	-	Not assessed	
Cape Elizabeth	3.9	Low		-	-	-	-	-	-	-	Not assessed	
North KI	0.9	Low		-	-	-	-	-	-	-	Not assessed	
South Yorke Peninsula	0.2	Low		-	-	-	-	-	-	-	Not assessed	
Western SG	NA	Low		-	-	-	-	-	-	-	Not assessed	
Fleurieu	NA	Low		-	-	-	-	-	-	-	Not assessed	
Unassigned CZ	NA	Low		-	-	-	-	-	-	-	Not assessed	
Sum	**83.3**		**100.0**									
											Zonal stock status	**-0.56**

2.4. **Discussion**

Greenlip comprises 85% of the combined abalone TACC (167.4 t *i.e.* greenlip and blacklip) in the CZ, which highlights the importance of this species to this fishery. The importance of this species in the CZ, as well as accessibility of the principal fishing ground, has culminated in both fishery-dependent and fishery-independent data being available for assessment of this species in this Zone. However, the current harvest strategy, outlined in the new Management Plan (PIRSA 2012), rationalises resources to ensure they are distributed into assessments of the most important SAUs, by catch, in the CZ of the SAAF. On this basis, there is one high (Tiparra Reef) and three medium-importance (West York Peninsula, South Kangaroo Island, West Kangaroo Island) SAUs for greenlip in the CZ. Thus, fishery-independent surveys are restricted to high-importance SAUs, notably Tiparra Reef. Nevertheless, the harvest strategy encompassed these four SAUs, which ensured that its application to greenlip was more robust than that for blacklip, which was based on fishery-dependent data from a single SAU.

Total greenlip catches in the CZ, whilst consistent with the TACC, are slightly higher (6%) than the long-term, mean catch prior to implementation of a TACC from 1990. In recent years, the catch has been obtained at a high catch rate. CPUE increased between 1999 and 2000 and has subsequently remained above that observed during the first decade following the TACC introduction. The CPUE has, however, gradually declined over this 11-year period and, consequently, it was at the lowest level since 2001 in 2011. The recent, 13% decrease in CPUE between 2009 and 2011 reflects a rapid increase in fishing effort over the same time period, to the highest level in 20 years, in combination with a stable TACC.

There have been two substantial changes in the spatial distribution of the greenlip catch among the available fishing areas and SAUs comprising the CZ abalone fishery since 1980. First, following implementation of the TACC in 1990, catches from FA 21 increased substantially. In 2001, the catch from FA 21 was 138 t, and accounted for 96% of the total greenlip harvest in the CZ. This was the second-highest catch from this FA but the highest percentage contribution to total catch. Second, from 2005 when the catch from FA 21 was capped, catches from FA 21 have decreased substantially. In 2011, the catch from FA 21 was 74 t, the lowest since 1993 and 25% below the 100-t 'catch-cap'. Thus, the current 100 $t.yr^{-1}$ 'catch-cap' is too high to constrain catches from this FA. As the TACC has remained unchanged throughout this period, catches from several other FAs have increased over the last six years, with substantial increases observed in FA 24, 26, 30 and 31. The greatest rates of increasing catch were evident

for those FAs off Kangaroo Island (i.e. FA 26, 30 and 31). Similar patterns were evident among SAUs. For example, the proportion of the TACC harvested from the Tiparra Reef SAU has decreased from 94% (135 t) in 2001 to 42% (60 t) in 2011, whilst that from both the South and West Kangaroo Island SAUs has increased. These patterns likely reflect changes in stock abundance, diver preferences, or a combination of these.

The Tiparra Reef SAU, has been the most important SAU for greenlip in both the CZ (65% of annual catch) and the SAAF (38%) since 1990, with this rank retained despite the ~60% decrease in catch harvested from this SAU since 2001. Initially, declines in catch reflected the catch-cap that was established to limit catches from this important fishing ground. Subsequently, annual catches declined from 2009, such that 60 t was harvested from this SAU in 2011, the lowest since 1992. The decreases in catch over the last two years were coincident with a ~20% decrease in CPUE over the same time period. In combination, these patterns indicate that the abundance of legal-sized greenlip in the Tiparra Reef SAU has reduced substantially since 2009. This assertion was supported by density estimates of legal-sized greenlip from fishery-independent surveys, which have decreased by ~50% from 2005 to 2010. In addition, leaded-line surveys measured a ~25% reduction in the density of legal-sized greenlip between 2010 and 2011, suggesting that an overall decrease of ~65% has occurred since 2005. While these differences demonstrate that the rate of change in survey density exceeds that of CPUE, suggesting the latter measure is hyperstable (Officer *et al.* 2001, Dowling *et al.* 2004), both measures in 2011 remained above the long-term, 20-year average, from 1979 to 1999.

Our conclusion, from the weight of evidence available, that the abundance of legal-sized greenlip has declined in the Tiparra Reef SAU was consistent with the outcome from applying the harvest strategy to determining the risk that the greenlip stocks in this SAU are over-fished. This is because the harvest strategy determined a 'red' risk-of-overfishing category for the Tiparra Reef SAU. This category was assigned because the combined PI score was -8, which was derived from scores of -5 (catch from Tiparra Reef as a percentage of the catch from FA 21), 0 (CPUE), 0 (proportion of large blacklip in the commercial catch), 0 (density of legal-sized greenlip), -1 (density of pre-recruit-sized greenlip) and -2 (mortality). Notably, this score was heavily influenced by the contribution of the PI for catch which, for the Tiparra Reef SAU, is different to that used elsewhere in the CZ or the SAAF. This PI was amended 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, we note that

if the PI was scored using catch as a percentage of the TACC, the score for this PI would have been lower than -5.

Application of the harvest-decision rules to a 'red' risk-of-overfishing category specifies a minimum 30% reduction in the catch contribution from this SAU to the TACC, based on the mean catch over the last four years (i.e. 2008-2011). The implementation of a 30% reduction would result in the catch contribution from the Tiparra Reef SAU to the greenlip TACC for the CZ reducing by 23.4 t to 55 t. This implies that 88.1 t would need to be harvested elsewhere in the CZ to enable the TACC to remain unchanged at 143.1 t.

Total catches harvested outside the Tiparra Reef SAU were ~90 $t.yr^{-1}$ over the 12-year period between 1979 and 1991. Following introduction of the TACC from 1990, catches reduced rapidly to ~30 $t.yr^{-1}$ but, since 2001, have increased substantially, reaching 82 t in 2011. This was the highest catch harvested ‘away from Tiparra Reef’ since 1992, and was within 10% of the mean catch harvested from these areas prior to TACC implementation. However, assessing the sustainability of these catches is challenging because data are more limited and analyses depend solely on catch, the spatial distribution of catch and CPUE.

Several map-codes have contributed substantial, but variable amounts to the ‘away from Tiparra Reef’ catch among years with ostensibly inverse patterns prior to the implementation of a TACC (1979-1990) and following establishment of a catch-cap in FA 21 (2005-2011). From 1980-1984 and 2008 to 2011, a substantial proportion of the ‘away’ catch was obtained from MCs 24C, 24D and 24E (i.e. the East Yorke Peninsula SAU), whereas much of the catch was harvested from map-codes 22A and 24A (i.e. West Yorke Peninsula) between 1985 and 1990 and 2005 and 2007. Despite the low catches harvested from Eastern York Peninsula from 1985 to 2007 and from Western York Peninsula between 1996 and 2004, that would have reduced fishing pressure on stocks in these SAUs, annual catches harvested from these areas post-2005 were substantially lower and maintained for a shorter duration when compared with those observed prior to 1990. For the Eastern Yorke Peninsula SAU, this may reflect limited recovery from high greenlip mortality following *Perkinsus olseni* infection (Goggin & Lester 1995). These patterns suggest that the fishing grounds adjacent to Yorke Peninsula are currently unable to support catches similar to those harvested historically. This is also apparent for the Cape Elizabeth SAU where increasing catches from 2007 have been coincident with a substantial decrease in CPUE.

In contrast, much of the evidence from SAUs off Kangaroo Island suggests that these areas could support additional catches. This is because current levels of catch and

CPUE are among the highest on record for the West Kangaroo Island and South Kangaroo Island SAUs. Our assessment, across all available evidence was consistent with the outcome of the harvest strategy which placed both these SAUs into a 'light-blue' risk-of-overfishing category. Application of the harvest-decision rules to this category permits increases in the catch contribution from these SAUs to the TACC of up to 50% of the mean catch over the last four years (i.e. 2008-2011). However, given that current catches from these SAUs are among the highest on record, any increase in their catch contribution to the TACC 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. In addition, and based on catch history, it is also possible that the Fleurieu and South Yorke Peninsula SAUs could contribute additional catch.

In summary, there is evidence that the abundance of legal-sized greenlip in the Tiparra Reef SAU has reduced substantially since 2001, to levels similar to those observed during the 1990s. This was confirmed by the harvest strategy which placed this SAU into a 'red' risk-of-overfishing category. Application of the harvest-decision rules, would result in the catch contribution from this SAU to the greenlip TACC in the CZ being reduced. Similarly, the catch contribution from the Cape Elizabeth SAU, where CPUE is declining rapidly, may also need to be decreased. In contrast, stocks in the West Kangaroo Island and South Kangaroo Island SAUs were placed into a 'light-blue' risk-of-overfishing category, which is consistent with our assessment that these areas could support small increases in catch. The capacity of stocks in the remaining SAUs – including West York Peninsula and East York Peninsula, which have historically yielded substantial catches – is not known with a high level of confidence. However, it appears unlikely that the fishing grounds adjacent to York Peninsula can support additional catch. In combination, the traditional assessment was consistent with the outcome of the harvest strategy which categorised the CZ greenlip stocks as over-fished. Consequently, the TACC may need to be reduced from 2013 to prevent overfishing in key SAUs. However, it may be possible to moderate a TACC reduction through additional approaches such as (1) elevated spatial management, with appropriate MLLs and 'catch-caps' to reduce the exploitation rate in key mapcodes/SAUs; and/or (2) a temporal closure from November to February (inclusive) when the bled meat weight to total weight ratio is lowest, resulting in fewer greenlip being harvested for a given TACC (Stobart *et al.* in review).

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 2011 and an assessment of the current stock status. Data are presented at three spatial scales. These are: (1) the whole blacklip fishery (i.e. all areas of the CZ combined); (2) Fishing Areas (e.g. FA 26); and; (3) individual spatial assessment units (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 new Management Plan for the fishery (PIRSA 2012), which determines the (1) 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 uses fishery-dependent data including catch (t, whole weight), catch-per-unit-effort (CPUE, $kg.hr^{-1}$) and the proportion of large (>155 mm SL) blacklip in the commercial catch. 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 from January 2002 to June 2005 were obtained by SARDI measuring samples provided by commercial fishers. Length-frequency data from July 2005 to December 2007 and from January 2008 to December 2009 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. These data are presented for completeness but, given the most recent data are for 2009 and the representivity of data is poorly understood, they are not considered in the analysis or discussion of resource status.

Catch was determined from logbook returns. Effort was calculated from daily records where blacklip catch was ≥50% of the total catch because: 1) effort is not differentiated or proportioned among species on each fishing day; (2) few fishing records between 1979 and 2011 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 ($kg.hr^{-1}$) was calculated as the catch-weighted mean of daily CPUE (Burch *et al.* 2011), 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. Limited daily records (*i.e. n* <10) prevented calculation of CPUE in some years at some spatial scales.

3.3. **Results**

3.3.1. Central Zone

Total catch has been stable at ~24 t.yr^{-1} since the TACC was reduced in 2006 (Figure 3.1). Decreases in annual catch from 2001 to 2006 reflect the TACC not being harvested (2002 to 2004) and sequential reductions in the TACC from 42.3 t in 2004 to 29.9 t in 2005 and 24.3 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 ~60 days.yr^{-1} from 2006. Since 1990, CPUE has been relatively stable (range: 59-75 kg.hr^{-1}; average: 66 kg.hr^{-1}). However, in 2011, it was 62 kg.hr^{-1} and among the lowest values since the TACC was introduced, despite the recent, relatively low, levels of catch.

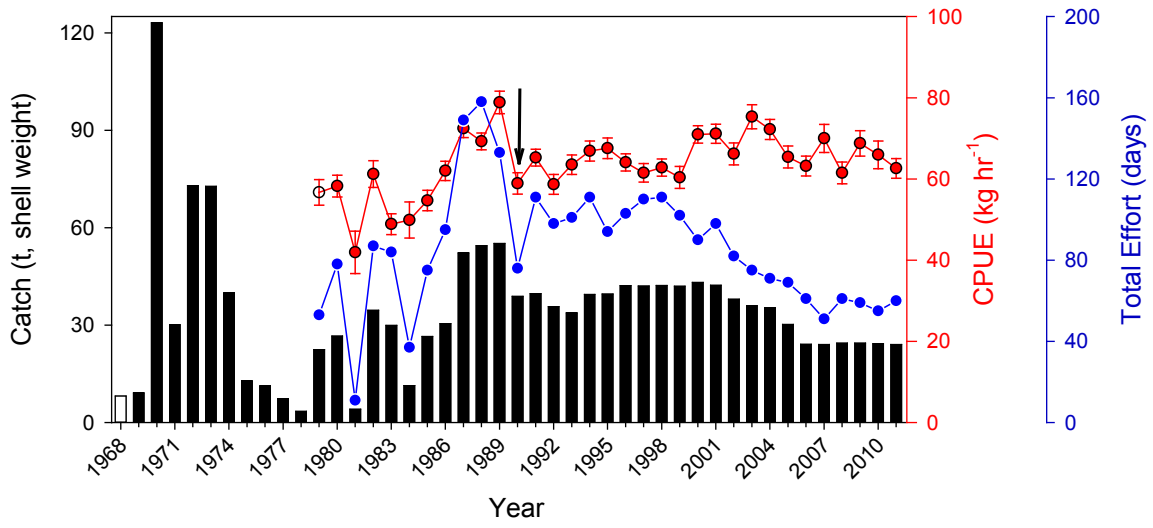

Figure 3.1 Catch (t, shell weight; black bars) of blacklip in the CZ from 1968 to 2011. Total effort (days), and CPUE (kg.hr^{-1}, ±SE) are shown by the blue and red lines, respectively. Black arrow indicates implementation of TACC.

3.3.2. Fishing Areas

3.3.2.1. *Distribution of catch among Fishing Areas*

Since 1992 (last 20 years) an average of >75% of the blacklip TACC has been harvested from FA 26 (39%), FA 27 (19%) and FA 29 (19%; Figure 3.2), demonstrating the importance of these FAs to this fishery. Remaining FAs (FA 21-25, FA 28 and FA 30-32) have each contributed <6% to annual catches over the same period. Over the history of the fishery, the spatial distribution of catch has changed substantially. From the 1980s to the early 2000s, catches were more evenly distributed among FAs when compared to the

period since the introduction of the current TACC (2006), when the distribution of catch among FAs has reduced substantially. Thus, current catches are obtained from few FAs. Notably, since 2007, the combined catch contribution from FA 26, FA 27 and FA 29 has exceeded 80% of the total blacklip catch per year, the highest percentage contributions in the history of the fishery.

3.3.2.2. *Temporal patterns of catch and CPUE in key Fishing Areas*

Catches among all FAs have fluctuated substantially over short periods of time (Figure 3.3). For example, in FA 26, annual catch decreased 8 t between 2004 (13.6 t) and 2005 (5.6 t) and in FA 29, increased 5 t between 2006 (3 t) and 2007 (8 t). Despite some short-term anomalies, catches from FA 26 have been relatively stable. In contrast, catches from FA 27, FA 29, FA 30 and FA 31 have decreased over at least the last 15 years and current catches are among the lowest on record. Recent declines in catch from these areas have been exacerbated since the current TACC was introduced, whilst catches from FA 26 have increased. Catches from remaining FAs have been small (<8 $t.yr^{-1}$) and frequently intermittent.

Estimates of CPUE in most FAs and for most years are not available due to limited data (Figure 3.3). The exceptions to this are FA 26, FA 27 and FA 29, where CPUE has remained relatively stable. However, current values are low in a recent historical context.

3.3.3. Spatial Assessment Units

3.3.3.1. *Distribution of catch among SAU*

The distribution of catch among SAUs through time highlights that most of the catch is harvested from two SAUs i.e. West and South Kangaroo Island (Figure 3.4 and Appendix 2 - Figure A2.2). These two SAUs have contributed an average of >95% (range 93% to 98%) of the total catch each year since 2006. The percentage of catch harvested from West Kangaroo Island has increased since 2006. In 2010 and 2011, catches from this SAU contributed 85% and 80% of the annual catch, respectively, the highest levels in the history of the fishery (Figure 3.4).

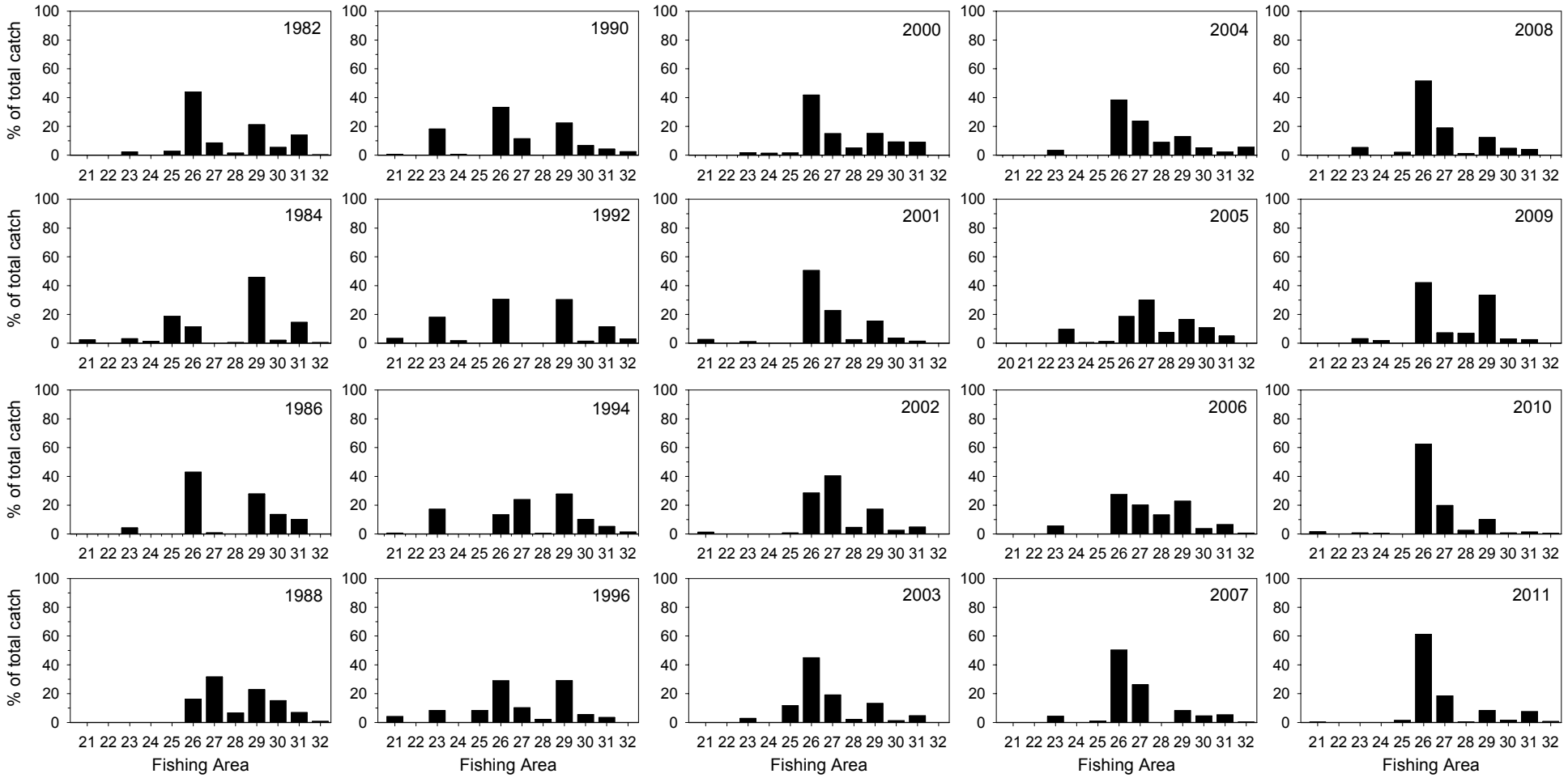

Figure 3.2 Spatial distribution of the blacklip catch (% of total catch) among each of the fishing areas in the CZ in alternate years from 1982 to 1996 and annually from 2000 to 2011.

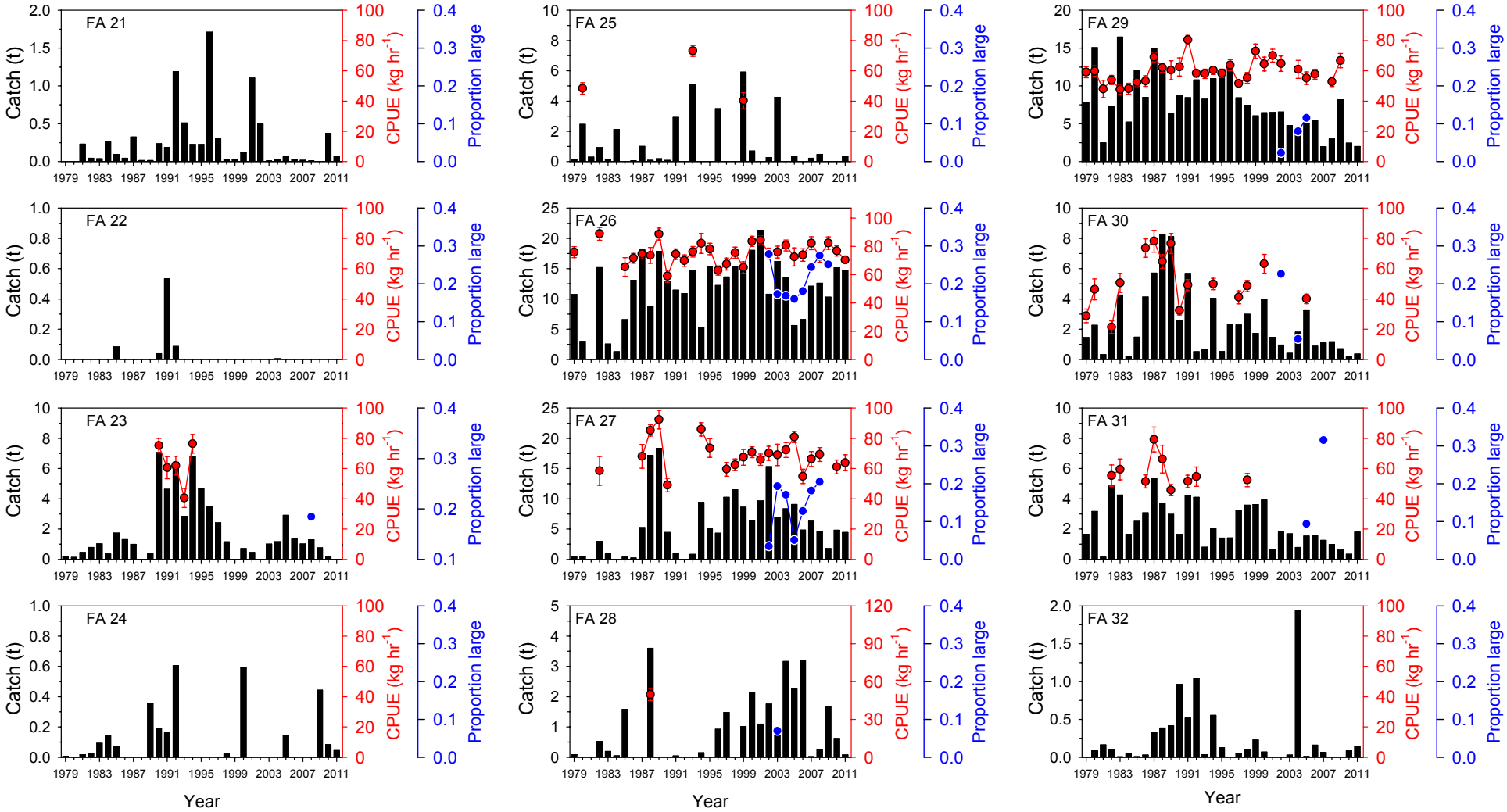

Figure 3.3 Catch (t, shell weight, black bars), CPUE (kg.hr^{-1}, ±SE, red lines) and the proportion of large (>155 mm, blue lines) blacklip in each of the fishing areas comprising the CZ from 1979 to 2011. Gaps in the time series of the CPUE and Proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively). Note different scales on the Y-axis for catch (t).

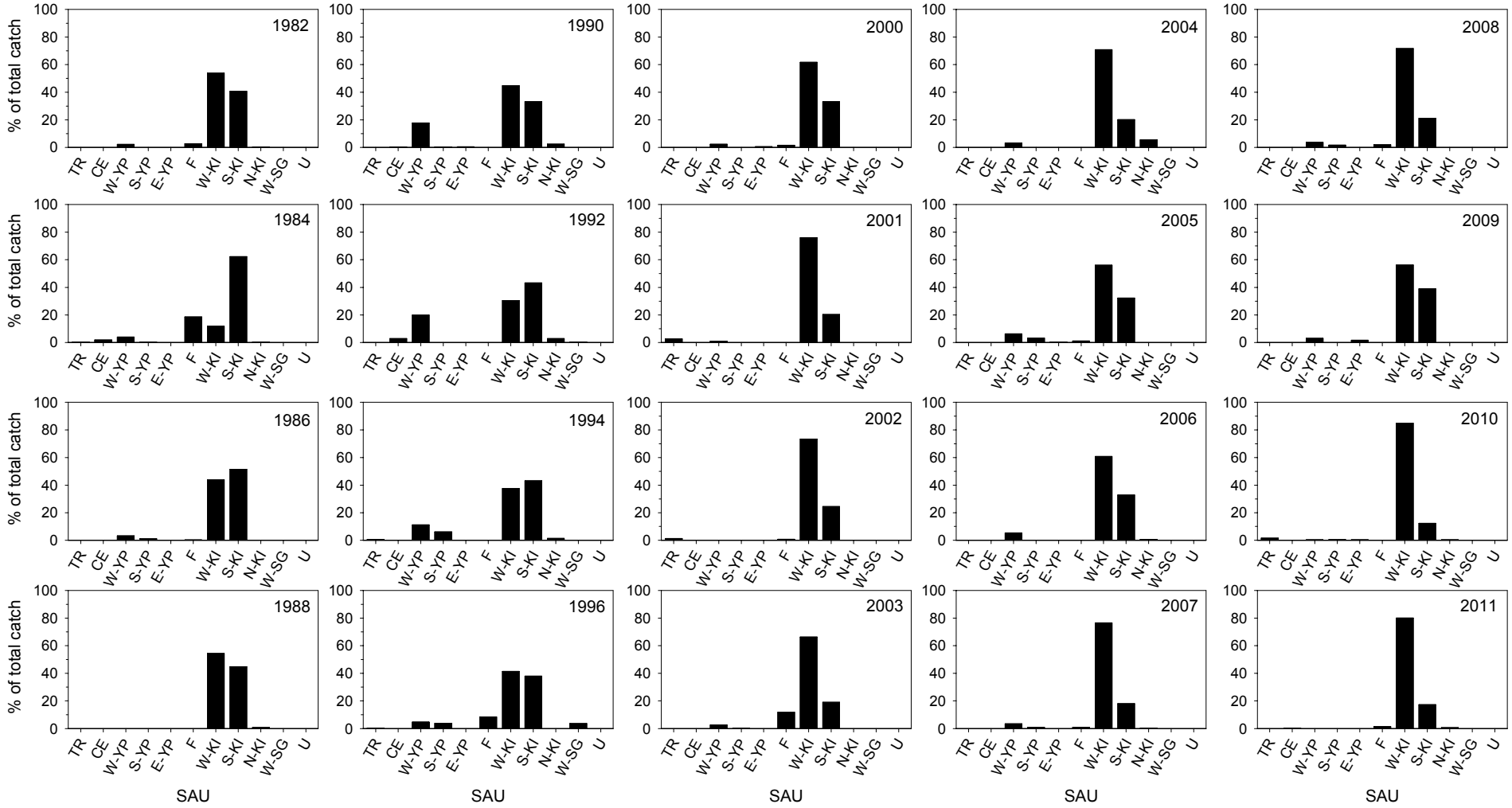

Figure 3.4 Spatial distribution of the blacklip catch (% of total catch) among each of the SAUs (TR: Tiparra Reef; CE: Cape Elizabeth; W-YP: West Yorke Peninsula; S-YP: South Yorke Peninsula; E-YP: East Yorke Peninsula; F: Fleurieu; E-KI: East Kangaroo Island; S-KI: South Kangaroo Island; W-KI: West Kangaroo Island; W-SG: West Spencer Gulf; U: Unassigned CZ) in the CZ in alternate years from 1982 to 1996 and annually from 2000 to 2011.

3.3.3.2. *West Kangaroo Island ($C_{02\text{-}11}$ - 70%; Rank 1)*

West Kangaroo Island has contributed an average of 51% to the annual blacklip catch since 1979, 61% since 1992 (last 20 years) and 70% since 2002 (last 10 years). It is the only SAU of medium importance for blacklip in the CZ. Catches have varied among years with peaks in 1989 (36.3 t) and 2001 (32.1 t; Figure 3.5). Catches increased between 1990 and 1997, then remained relatively stable at an average of 26.5 t between 1997 and 2004. Since 2005, catches have been substantially lower (range: 13.6-20.6 t; average 17.3 $t.yr^{-1}$). In 2010 (21 t) and 2011 (19 t), catches from this SAU were at the highest levels since 2006, equating to >80% of the total blacklip catch in the CZ (Figure 3.5).

Since 1992 (20 years), CPUE has remained relatively stable at an average of 73.0 $kg.hr^{-1}$ (range: 65-84 $kg.hr^{-1}$) and, since 2000, has varied by <10 $kg.hr^{-1}$. However, in 2011, CPUE was 68.3 $kg.hr^{-1}$, the lowest level since 1999.

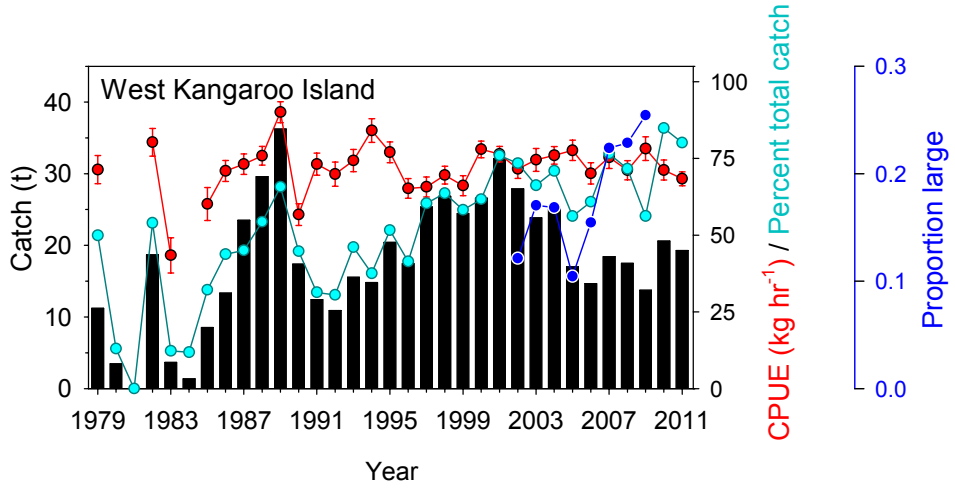

Figure 3.5 West Kangaroo Island (medium importance). Catch (t, shell weight, black bars), CPUE ($kg.hr^{-1}$, ±SE, red line), the proportion of large blacklip (>155 mm, dark blue line) and the percentage of the total blacklip catch (light blue line) each year from 1979 to 2011. Gaps in the time series of the CPUE and proportion large data indicate insufficient data (<10 fisher days or <100 individuals, respectively).

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

This section of the report provides the outcome of applying the harvest strategy, as described in the new Management Plan (PIRSA 2012), to determine the (1) risk that blacklip stocks in the high and medium SAUs are over-fished; and (2) the zonal stock status for blacklip. There was one medium importance SAU for blacklip, West Kangaroo Island, for which the summed PI score was +3, a 'blue' risk-of-overfishing category (Figure 1.3, Table 3.1, Appendix 2). The catch-weighted zonal score was 1.0. This indicates that the status of the blacklip fishery in the CZ is under-fished (Table 3.1).

Table 3.1 Outcome from application of the harvest strategy described in the new 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 (02-11)	Importance	%Contribution to catch from high & medium SAU in 2011	CPUE	%TACC	%Large	Scientific assessment score	Risk of overfishing	Catch-weighted contribution to zonal score
West KI	11.6	Medium	100.0	-1.0	4.0	0.0	3	1	1.00
South KI	3.9	Low		-	-	-	-	Not assessed	
West Yorke Peninsula	0.5	Low		-	-	-	-	Not assessed	
Fleurieu	NA	Low		-	-	-	-	Not assessed	
North KI	0.1	Low		-	-	-	-	Not assessed	
South Yorke Peninsula	0.1	Low		-	-	-	-	Not assessed	
Tiparra Reef	0.1	Low		-	-	-	-	Not assessed	
East Yorke Peninsula	0.0	Low		-	-	-	-	Not assessed	
Cape Elizabeth	0.0	Low		-	-	-	-	Not assessed	
Western SG	NA	Low		-	-	-	-	Not assessed	
Unassigned CZ	NA	Low		-	-	-	-	Not assessed	
Sum	**16.7**		**100.0**						
								Zonal stock status	**1.00**

3.4. **Discussion**

Blacklip comprise 15% of the total abalone TACC (167.4 t *i.e.* blacklip and greenlip) in the CZ of the SAAF. The total catch in 2011 was 24.1 t, which was consistent with the 24.3 t TACC implemented from 2006, and at the lowest level since 1985. The current low catches reflect the 40% reduction in the TACC across 2005 and 2006 that was implemented in response to declining stock status (Mayfield *et al.* 2004, Mayfield *et al.* 2005a), and is also reflected in the stabilisation of effort at the low level of ~60 days.yr^{-1}. In combination, the low catches and hence lower importance of SAUs together with the inaccessibility of the key fishing grounds restrict assessments of the status of blacklip in the CZ to the interpretation of fishery-dependent data, principally catch and CPUE. This is unlikely to change in the foreseeable future because the current harvest strategy, outlined in the new Management Plan (PIRSA 2012), rationalises resources to ensure they are distributed into assessments of the most important SAUs, by catch, in the CZ of the SAAF. Consequently, application of the harvest strategy to determine the risk that blacklip stocks are over-fished was limited to one SAU of medium importance (West Kangaroo Island). This compromises the utility of the harvest strategy in the new Management Plan (PIRSA 2012).

The last stock assessment report (Mayfield *et al.* 2010) concluded that there were some data showing that declines in blacklip stocks, reported in previous assessments though the mid 2000s (Mayfield *et al.* 2004, Mayfield *et al.* 2005a, Mayfield *et al.* 2005b), may have abated. These data included increases in catch and CPUE in FA 26 and, to a lesser extent, in FA 29. However, they noted that the positive signals were not widespread; for example, data from FA 27 indicated stocks continued to decline (Mayfield *et al.* 2010). Much of the data presented in this assessment report suggests that the blacklip stocks in the CZ have not recovered from their weak position in the mid 2000s, despite relatively low catches over the past six years, a consequence of reduced TACCs. Notably, (1) CPUE across the CZ and in FA 26 and two SAUs (West Kangaroo Island and South Kangaroo Island) were among the lowest since the late 1990s; and (2) catches from FA 27, 29, 30 and 31 and, consequently, the South Kangaroo Island SAU have declined substantially.

From 1980 through to the early 2000s, the spatial distribution of the catch among the available fishing areas was relatively stable, with most of the catch harvested from FA 26, FA 27 and FA 29, demonstrating the importance of these FAs to this fishery. However, this has changed substantially since 2006 as the proportion of the catch harvested from FA 26 has increased from 19% to 61%. In compensation, catches have decreased in almost all other FA, especially FA 27 and 29. Similar patterns were evident among SAUs. In 2011, catches from the West Kangaroo Island SAU represented >80% of the total blacklip catch. Consequently, the proportion of the catch harvested from all remaining SAUs has declined substantially. Whilst interpretation of these changes is complicated by the (1) substantial reduction in the TACC;

and (2) the reasons underpinning these patterns (e.g. diver preferences, changes in stock abundance or a combination of these), they nevertheless highlight the importance of FA 26 and the West Kangaroo Island SAU to the blacklip fishery in the CZ.

Annual catches from FA 26 and the West Kangaroo Island SAU have increased in recent years. However, they remain below levels observed through the late 1990s and early 2000s, when the TACC was substantially greater. CPUE has remained relatively stable in both these areas over the past decade, with no evidence of any long-term trend. Despite this, in both cases in 2011, CPUEs were the lowest since 1999. In combination, these data suggest that the magnitude of current catches from FA 26 (15 t) and the West Kangaroo Island SAU (19 t) are sustainable. This conclusion was consistent with the outcome from applying the harvest strategy which was a 'blue' risk-of-overfishing category for the West Kangaroo Island SAU, determined from a combined PI score of +3 which, in turn, was derived from scores of +4, -1 and 0 for catch as a percentage of the TACC, CPUE and the proportion of large blacklip in the commercial catch, respectively. Application of the harvest-decision rules to a 'blue' risk-of-overfishing category permit increases in the catch contribution from this SAU to the TACC of up to 30% of the mean catch over the last four years (i.e. 2008-2011). However, any increase should consider the (1) absence of an increase in CPUE since the TACC reduction in 2006; and (2) relatively low current level of CPUE in this SAU.

Assessment of stock status in the remaining FAs and SAUs was complicated by limited data. This problem arose because catches from FA 23, 27, 29, 30 and 31 and from the South Kangaroo Island and West York Peninsula SAUs are among, or at, the lowest levels in their history. Consequently, there were typically inadequate data to calculate CPUE. The exception was the South Kangaroo Island SAU, where the CPUEs in 2010 and 2011 were among the lowest on record. Whilst data were more limited in FAs 27 and 29, low CPUEs and catches have generally coincided during recent years. These combinations of low catches and catch rates do not provide any evidence that stock rebuilding has occurred since the TACC was substantially reduced six years ago. In contrast, they suggest that the biomass of legal-sized blacklip in these historically-important fishing grounds has continued to decline, resulting in the increased catch from the West Kangaroo Island SAU.

In conclusion, contrasts in patterns of catch and CPUE throughout key areas of the fishery suggest stocks are stable (FA 26, West Kangaroo Island) or in decline (FA 27, 29, 30, South Kangaroo Island). This was inconsistent with the harvest strategy which, based on a single SAU of medium importance, categorised the CZ blacklip fishery as under-fished.

4. GENERAL DISCUSSION

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. In addition, this fishery assessment report for the CZ is the first to provide a quantitative measure of fishery status, based on an integrated suite of performance indicators within a risk-analysis framework, in accordance with the new Management Plan (PIRSA 2012).

There are, however, several limitations to this assessment. First, the accuracy and precision of estimates of illegal catch are unknown and difficult to estimate. This prevents accurate estimates of the total catch and hence impedes this assessment. Second, the limited fishery-independent survey data for greenlip outside 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, decision rules are applied to all data series presented in this report (Table 1.3) 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 greenlip (Burch *et al.* 2011) excluded records where (1) the percentage of greenlip in the catch was <30%; (2) daily effort was <3 hrs and >8 hrs; and (3) total catch/total effort was >150 $kg.hr^{-1}$. This approach was adopted because both blacklip and greenlip can be harvested, but effort is not required to be apportioned among the species, within a fishing day and followed a comprehensive examination of the current, previous and a range of alternate decision rules to generate CPUE (Burch *et al.* 2011). Although Burch *et al.* (2011) showed that previous decision rules were sufficiently robust for assessment of the stocks in Region A of the WZ SAAF (see Stobart *et al.* 2011), they recommended that a catch-weighted mean of daily CPUE would be more appropriate to estimate CPUE as it (1) weights each daily 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. Fourth, 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, as undertaken in NSW (Andrew & Chen 1997) and Tasmania (Tarbath & Gardner 2011). This was because of (1) the limited degree to which the current data are representative of the fishery; and (2) the absence of data from 2009. The lack of robust, representative, commercial, length-frequency data increases the uncertainty in the assessment of stock status (Burch *et al.* 2010).

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 move among stocks for reasons other than changes in abundance including market demands for particular product types (e.g. larger or smaller abalone), access to launching sites and/or to maintain or increase expected catch rates. CPUE is a key performance indicator used to assess stock status, based on the assumption that changes in CPUE reflect changes in the abundance of the fishable stock (Tarbath & Gardner 2011). We note 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 & Shepherd 1992, Gorfine *et al.* 2002). For example, catch rates may remain high (or increase) as a result of (1) improvements in 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. However, decreases in CPUE in abalone fisheries can be considered a reliable indicator of declines in abalone abundance, particularly where effort is consistently applied (Tarbath & Gardner 2011).

4.1. **Current status of greenlip and blacklip in the CZ**

There were several similarities in the assessment of greenlip and blacklip. First, the majority of the catch of both species has been obtained from a single SAU. For greenlip, this was the Tiparra Reef SAU whilst for blacklip, it was the West Kangaroo Island SAU. Second, 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. Finally, no data were available on the length structure of the commercial catch for either species from 2009. One substantial difference between the species was the number of SAUs on which stock status was based, and their current status. For greenlip, the zonal stock status of over-fished was derived from four SAUs, one of high and three of medium importance. In contrast, the blacklip zonal stock status of under-fished was determined from a single SAU of medium importance.

4.1.1. Greenlip

Greenlip comprises 85% of the combined abalone TACC 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 and, over recent years, most of the catch has been harvested from the Tiparra Reef SAU. This SAU has been the most important for greenlip in both the CZ and the SAAF since 1990. However, recent data, including substantial declines in catch, CPUE and density of legal-sized greenlip observed on fishery

independent surveys, indicate the harvestable biomass of greenlip in this important SAU has declined. This conclusion was consistent with the 'red' risk-of-overfishing category for this SAU. The low catches currently harvested from the Tiparra Reef SAU also demonstrate that the 100 $t.yr^{-1}$ 'catch-cap' is too high to constrain catches.

As the TACC has remained stable, and catches from Tiparra Reef have declined in recent years, catches from other SAUs have increased. The catch harvested outside the Tiparra Reef SAU in 2011 was similar to those prior to the introduction of the TACC. Stocks in the West Kangaroo Island and South Kangaroo Island SAUs were placed into a 'light-blue' risk-of-overfishing category, suggesting that they could support small increases in catch. Similarly, the Fleurieu and South Yorke Peninsula SAUs may support small contributions to future catches. However, it appears unlikely that the fishing grounds adjacent to York Peninsula can support additional catch. This includes the Cape Elizabeth SAU, where CPUE is declining rapidly. In conjunction with the zonal stock status of ‘over-fished’, these patterns suggest that the greenlip TACC in the CZ may need to be decreased from 2013 to reduce the risk of overfishing the stocks in key SAUs.

4.1.2. Blacklip

Blacklip comprise 15% of the total abalone TACC in the CZ. Current low catches reflect the reductions in the TACC from 2005. Despite the low catches over the past six years, much of the current data suggests that the blacklip stocks in the CZ have not recovered from their weak position in the mid 2000s. Since 2006, the proportion of the catch harvested from the West Kangaroo Island SAU has increased substantially, highlighting the rising importance of this SAU. As the CPUE has remained relatively stable, despite small increases in catch over the last six years, current catches appear sustainable. This evaluation was consistent with the 'blue' risk-of-overfishing category for this SAU. Data to assess other SAUs were more limited. However, decreasing catches and CPUEs suggest that the biomass of legal-sized blacklip in the South Kangaroo Island SAU may have continued to decline. This conclusion was inconsistent with the harvest strategy – based on the West Kangaroo Island SAU only – which categorised the CZ blacklip fishery as under-fished.

4.2. **Harvest strategy for the CZ**

There were several difficulties with implementation of the harvest strategy in the CZ. First, stock status of blacklip was determined from a single medium-importance SAU, and that for greenlip was derived from four SAUs, one of high importance and three 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. For greenlip, this difficulty was less pronounced and application of the harvest strategy to

determine stock status was more representative of principle SAUs. One potential solution for this would be to change the criterion by which SAUs are assigned importance to increase the number of medium–importance SAUs formally considered by the harvest strategy. This would ensure that the determination of stock status was based on data that were more representative of the fishery. However, data limitations may also increase the number of SAUs assessed as uncertain.

Second, there are limited commercial-catch-sampling data for determining the proportion of large abalone harvested, which is one of the fishery-dependent PIs. Although this is currently addressed by designating a minimum sample size (Table 1.3), there is a high probability that these data poorly represent both the catch and the fishery. Appropriate sampling – five abalone from every catch-bag, for each species from SAUs of designated high and medium importance – with a minimum 70% participation rate by fishers is required to provide adequate estimates for this PI (Burch *et al.* 2010). If future sampling conforms to this protocol it will (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. An additional problem with this PI is that values may be 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. As these changes could also influence CPUE, one option to resolve this problem is the use of evidence from other sources (e.g. divers, processors) to aid interpretation of these PI scores.

Third, there are several problems associated with the PI related to catch. For example, to avoid TACC changes driving positive or negative scores for catch, the PI for catch was selected as the proportion of the TACC harvested from that SAU. 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. This is because 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. In this assessment, scores of 4 and -1 were assigned for the catch and CPUE PIs, respectively, for blacklip in the West Kangaroo Island SAU, which resulted in a combined score of 3 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.

There are several 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 negative. Finally, 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 six-year 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, it may be more appropriate to replace the PI-based assessment of this SAU with (1) a population model or (2) survey estimates of absolute harvestable biomass (e.g. Mayfield *et al.* 2008b, Mayfield *et al.* 2011b) from which a total allowable catch for this area could be set directly.

Despite these problems, application of the harvest strategy to CZ greenlip stocks in this report was consistent with the ‘weight-of-evidence’ assessment process used in previous reports (Mayfield & Carlson 2009, Mayfield *et al.* 2010). Thus, the (1) 'red' (Tiparra Reef), 'green' (West York Peninsula) and 'light-blue' (South Kangaroo Island, West Kangaroo Island) risk-of-overfishing categories assigned across these four SAUs; and (2) catch-weighted assessment of greenlip stock status in the CZ as over-fished, are considered appropriate. In contrast, for blacklip, the ‘blue’ risk-of-overfishing category for the West Kangaroo Island SAU was more optimistic than our weight-of-evidence analyses of the data would suggest. Consequently, as this was the only SAU contributing to the zonal stock status of blacklip in the CZ, this designation – under-fished – also appeared positively biased and should be considered with caution.

4.3. **Future research needs**

Assessment of abalone in the CZ would benefit from (1) analysing external influences (e.g. diver, dive location, month, loss of access) on catch rate data through standardisation; (2) improved estimates of the magnitude and trends in illegal catch and; (3) assessment of the direct and indirect effects of commercial harvest on the ecosystem.

Transitioning from the timed-swim to the leaded-line survey method will improve the accuracy and precision of survey estimates across Tiparra Reef (McGarvey *et al.* 2008). However, cessation of the long-term timed-swim surveys requires establishment of a predictive relationship between the survey estimates of both methods. This is necessary to ensure that the valuable, long time series of survey data from timed swims can be retrospectively calibrated against the leaded-line method. Once completed, these relationships should be evaluated and any improvements in survey design or efficiency identified.

Future determination of stock status in the CZ abalone fishery may also be strengthened by identification and testing of a process to formally include industry information into the application of the harvest-decision rules for determining TACCs. This is because (1) changes in the value of PIs through time may not be directly related to stock status and their interpretation can be informed by credible, structured information (e.g. market demand, weather patterns, changing diver demography); and (2) abalone divers directly observe abalone stocks through their harvesting process. The latter is different to nearly all other fisheries where fishers typically use fishing methods (e.g. traps, nets, lines) that do not readily facilitate direct observations on the distribution, abundance and population structure of the target species.

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Appendix 1. Greenlip – Harvest strategy PI plots and scores and low importance SAU fishery dependent data.

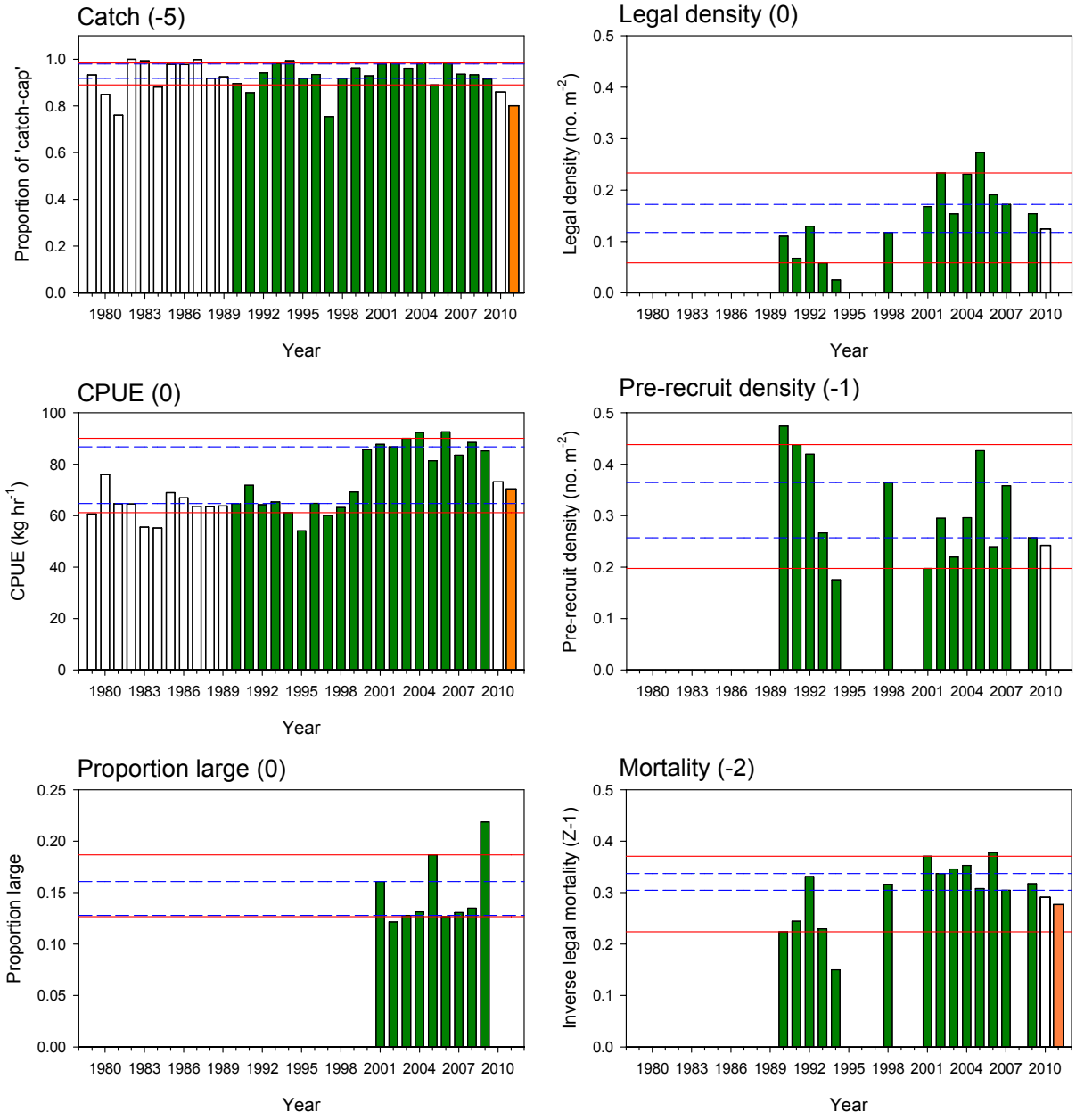

Figure A1.1 Tiparra Reef (high importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Green bars describe the data and time over which the reference points 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.

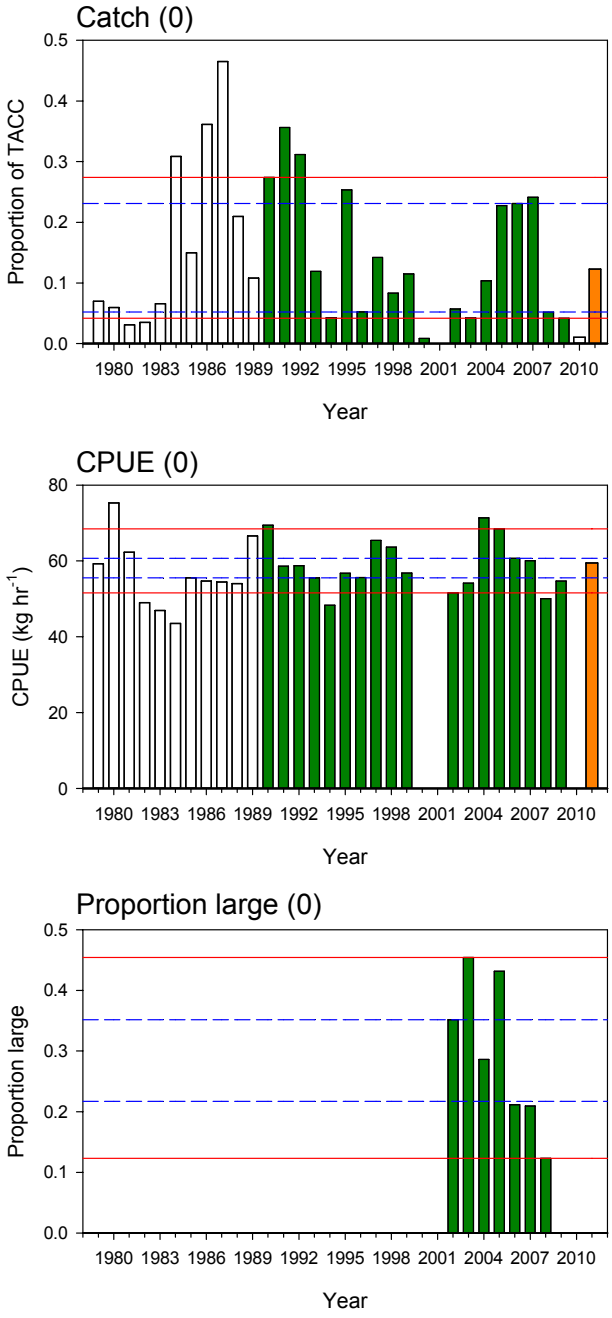

Figure A1.2 West Yorke Peninsula (medium importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Green bars describe the data and time over which the reference 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.

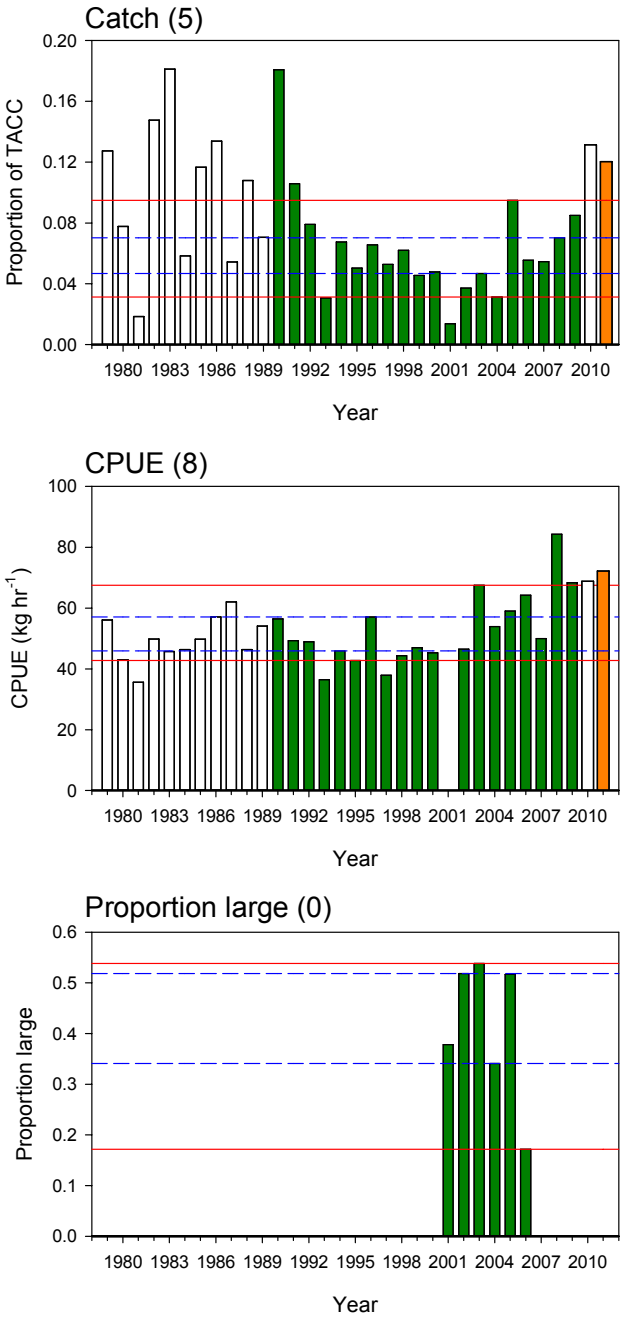

Figure A1.3 South Kangaroo Island (medium importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Green bars describe the data and time over which the reference 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.

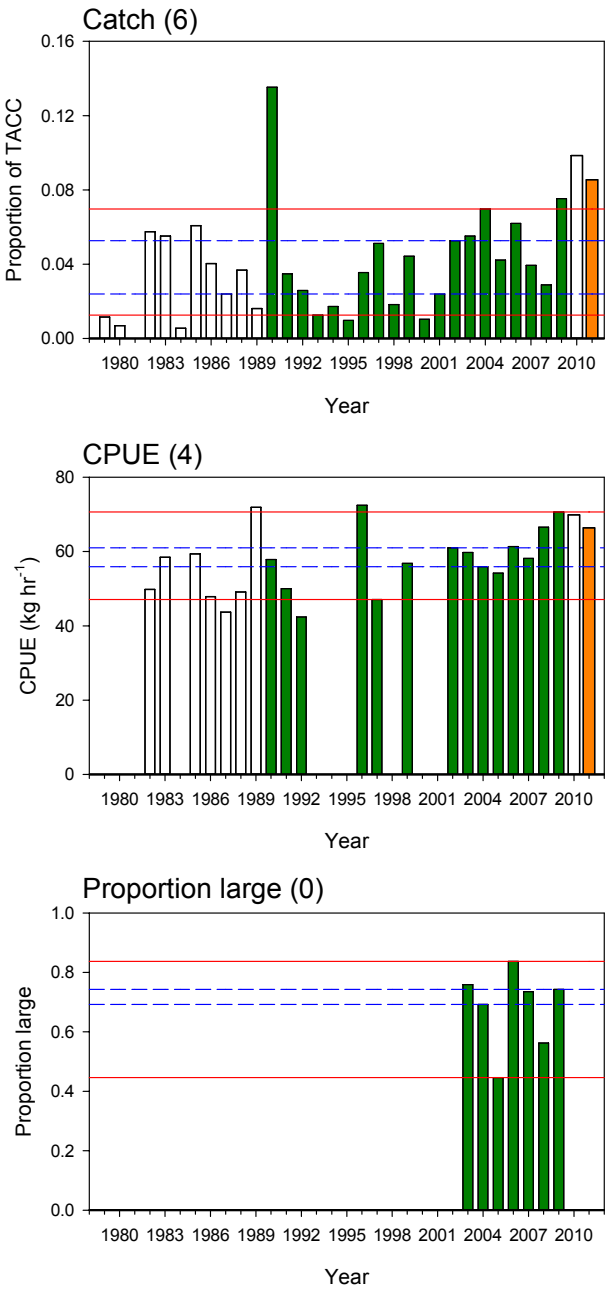

Figure A1.4 West Kangaroo Island (medium importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Green bars describe the data and time over which the reference 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.

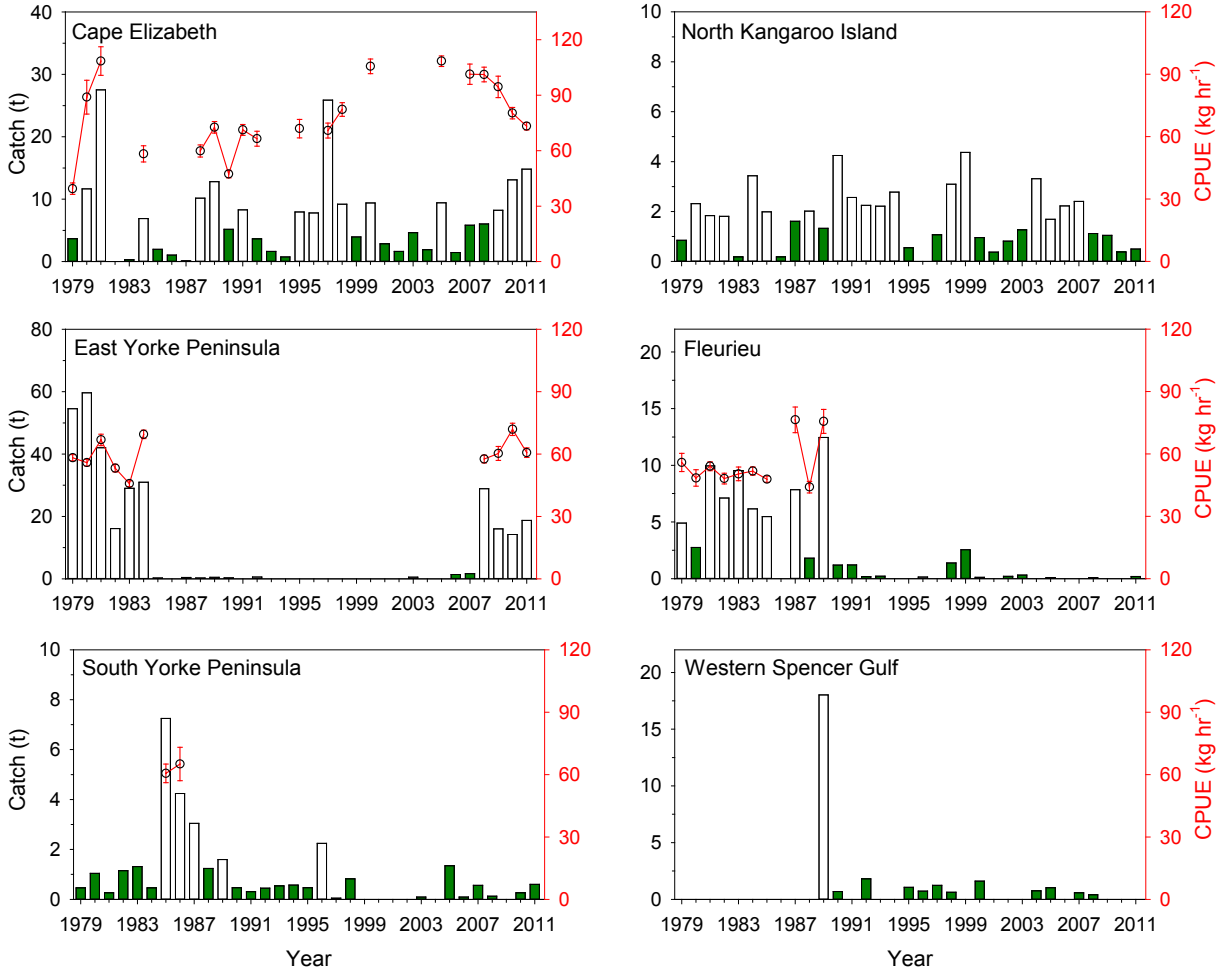

Figure A1.5 Catch (t, shell weight, green bars) and CPUE (kg.hr^{-1}, ±SE, red lines) of greenlip in each of the SAUs of low importance in the CZ greenlip fishery from 1979 to 2011. Gaps in the time series of the CPUE indicate insufficient data (<10 fisher days) Note different scales on the Y-axis for catch (t)..

Appendix 2. Blacklip – Harvest strategy PI plots and scores and low importance SAU fishery dependent data.

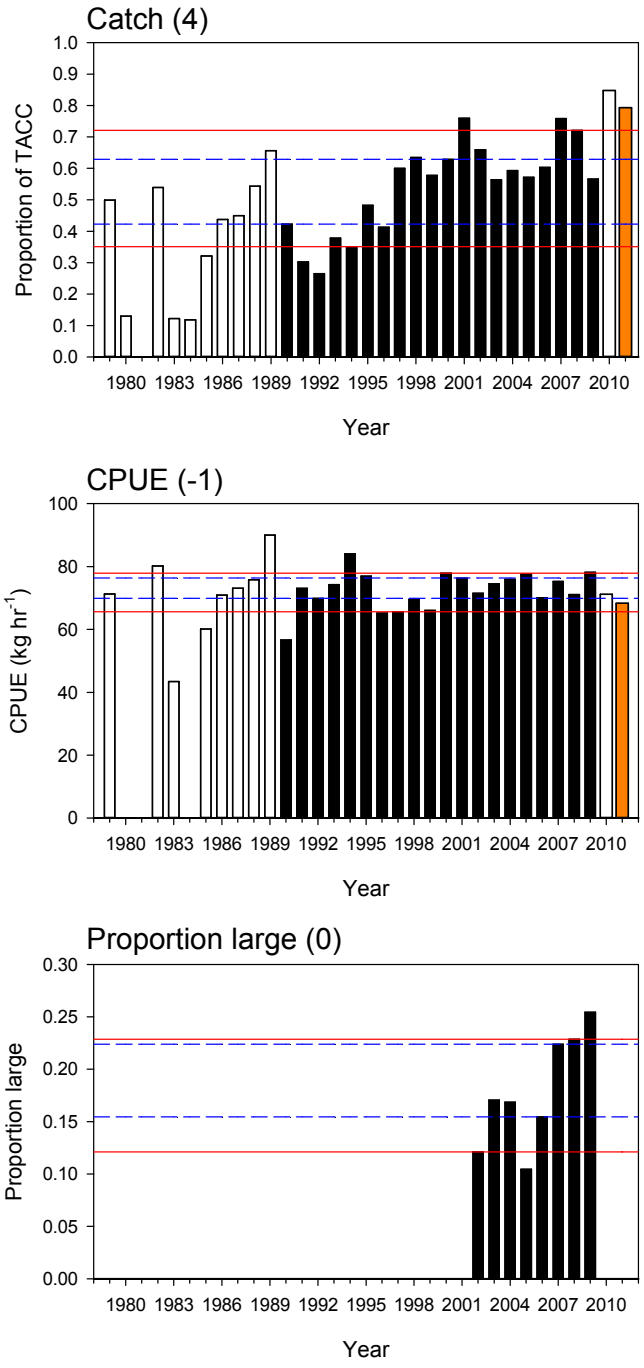

Figure A2.1 West Kangaroo Island (medium importance). Performance indicators (and scores from the harvest strategy to determine the risk of being overfished) and upper and lower target (red lines) and limit (blue dashed lines) reference points. Black bars describe the data and time over which the reference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

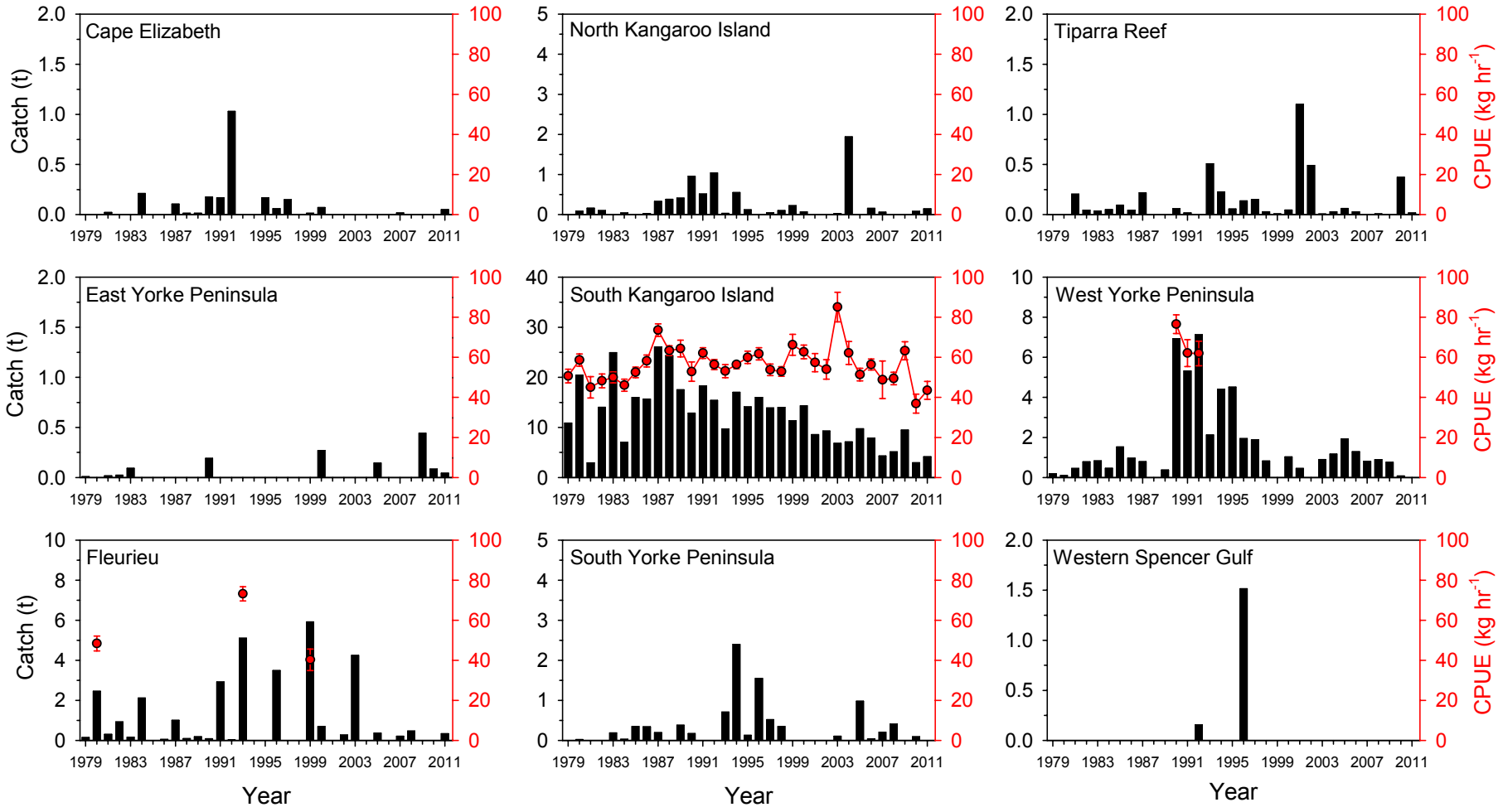

Figure A2.2 Catch (t, shell weight, black bars) and CPUE (kg.hr^{-1}, ±SE, red lines) of blacklip in each of the SAUs of low importance in the CZ blacklip fishery from 1979 to 2011. Gaps in the time series of CPUE indicate insufficient data (<10 fisher days). Note different scales on the Y-axis for catch (t).