Fisheries

Assessment of the Central Zone Abalone (*Haliotis laevigata* & *H. rubra*) Fishery in 2021

O. Burnell and S. Mayfield

SARDI Publication No. F2007/000611-12
SARDI Research Report Series No. 1201

SARDI Aquatic and Livestock Sciences
PO Box 120 Henley Beach SA 5022

November 2023

Report to PIRSA Fisheries and Aquaculture

Government of South Australia
Department of Primary Industries and Regions

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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This publication may be cited as:
Burnell, O. and Mayfield, S. (2023). Assessment of the Central Zone Abalone (*Haliotis laevigata* & *H. rubra*) Fishery in 2021. Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic and Livestock Sciences), Adelaide. SARDI Publication No. F2007/000611-12. SARDI Research Report Series No. 1201. 63pp.

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Date: 17 November 2023

Distribution: PIRSA Fisheries and Aquaculture, SARDI Aquatic and Livestock Sciences, Parliamentary Library, State Library and National Library

Circulation: OFFICIAL

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

Funds for this research were provided by Primary Industries and Regions South Australia (PIRSA), obtained through licence fees. SARDI Aquatic Sciences provided substantial in-kind support. The Central Zone Abalone Licence holders, fishers, and Mr Michael Tokley provided length measurements of abalone in the commercial catch. We thank the SA Abalone Fishery (Central Zone) licence holders and divers for their contribution to our understanding of the data presented in this report. We are grateful to SARDI staff, past and present, in particular David Delaine, Sam Hamood-Smith, Dr Ben Stobart, Andrew Hogg, Damien Matthews, Doug Graske, and Dr Sasi Nayar for field support. We would also like to thank members of the Fisheries Information Services Team, for support with data entry and management, and Dave Delaine and Sam Hamood-Smith for data entry of the commercial shells. Thanks to Craig Mundy from IMAS at The University of Tasmania for setting-up the data logger program in the Central Zone. This report was formally reviewed by Dr Annabel Jones (PIRSA Fisheries and Aquaculture), Dr Adrian Linnane and Dr Ben Stobart (SARDI), and Dr Mike Steer, Research Director, SARDI Aquatic and Livestock Sciences. It was formally approved for release by A/Prof Qifeng Ye, Program Leader (Inland Waters & Catchment Ecology) – SARDI Aquatic and Livestock Sciences.

EXECUTIVE SUMMARY

This report assesses the status of Greenlip Abalone (*Haliotis laevigata*, hereafter referred to as greenlip) and Blacklip Abalone (*H. rubra*; hereafter referred to as blacklip) in the Central Zone (CZ) of the South Australian Abalone Fishery (SAAF) in 2021. The stock status and recommended catch for greenlip was determined using the Harvest Strategy (HS) from the Abalone Management Plan (PIRSA 2021). The HS applies two key indicators, catch-per-unit-effort (CPUE) and abalone legal density from fishery independent surveys (FIS), to generate proxies for biomass and fishing mortality. The HS has been designed to deliver outcomes consistent with the national fishery status reporting framework (NFSRF; Piddock *et al.* 2021). The HS was not applied to blacklip in 2021 because the time series of the biomass and fishing mortality proxies was interrupted by the closure of the fishery in 2018 and subsequent low levels of catch and effort from 2019-2021, with recent data incomparable with those underpinning the HS, including the 1990-2000 reference period.

GREENLIP

Prior to 2020, the CZ greenlip fishery had a long-term, stable catch, consistent with the Total Allowable Commercial Catch (TACC), for over 25 years. By 2021, total greenlip catch had declined to 24.9 t (i.e., 54% of the 46.0 t TACC). This reflects a voluntary under-catch of the 2020 and 2021 TACCs by industry. In the two Spatial Assessment Units (SAUs) that have historically supported >70% of the catch, Tiparra Reef and West Yorke Peninsula, the combined catch has declined by 55% over the last two years (from 37.6 t to 16.9 t).

Following record high CPUEs in the early 2000s, since 2001 catch-rate has declined from 31 kg.hr^{-1} to 19.2 kg.hr^{-1} and is now among the lowest levels observed since the TACC was introduced in 1990. Among the six SAUs identified in the HS, two had CPUE values above or within the target range (i.e., Tiparra Reef & East Yorke Peninsula), whereas the remaining four SAUs had values below the target range (i.e., West Yorke Peninsula, South Kangaroo Island West Kangaroo Island and the combined data-limited SAUs). Abalone legal density from the FIS was within or below the target range from the HS for Tiparra Reef (5 out of 10) and West Yorke Peninsula (4.6 out of 10), respectively. Nonetheless, biomass from these SAUs has declined by 27% (Tiparra Reef) and 40% (West Yorke Peninsula) since recent peaks in 2017. There was also low sub-legal greenlip density at three out of four FIS sites (i.e., Tiparra Reef, Corny Point and Port Victoria) in 2021, when compared with the available historical estimates. Spatial data from the GPS loggers in the key SAUs (Tiparra Reef and West Yorke Peninsula) indicate divers are covering a greater area to harvest greenlip, providing further evidence of low and/or declining greenlip stock status.

Application of the HS in 2021 resulted in a **zone score (i.e., biomass proxy) of 4.4 out of 10** that, in combination with the **zone trend score (i.e., fishing mortality proxy) of 4.9 out of 10** (reflecting a decreasing trend), define the stock status for greenlip in the CZ in 2021 as **'depleting'**, which is consistent with recent classifications in 2019 and 2020. This means that biomass is declining and that the current level of fishing mortality (i.e., catch) is moving the stock in the direction of becoming recruitment impaired. The zone score of 4.4 in 2021 translates to a recommended zonal catch of 40.1 t for 2023.

BLACKLIP

The annual catch of approximately 1 t from 2019 to 2021 is 90% below average catches from 1979 to 2017. The low level of blacklip catch, combined with mixed-species fishing, means that blacklip CPUE estimates from 2019 differ substantially from, and cannot be directly compared with, CPUE estimates prior to 2018. Thus, from 2019, the limited data available were inadequate to measure the impact of the 2018 fishery closure and subsequent low levels of fishing. The fishery was classified as depleted using a weight-of evidence approach in 2017 (Burnell et al. 2018), which was consistent with retrospective application of the HS (Burnell et al. 2021). As there are no recent data that can be used to inform any potential change in stock status, blacklip in 2021 remains classified as 'depleted'. In the table below, stock status classifications for blacklip in 2019 and 2020 have been updated to be consistent with the approach taken in this report to assign stock status for 2021.

Key statistics for the CZ fishery from 2013 to 2021, including total allowable commercial catch (TACC), total commercial catch (TCC), catch per unit effort (CPUE), zone score, zone trend score and stock status from the weight of evidence using the national fishery status reporting framework (NFSRF) or Harvest Strategy. Tmw = tonnes meat weight, kg.hr^{-1} = kilograms per hour. *Indicates years when stock status was determined using the weight of evidence approach from the NFSRF (Piddocke et al. 2021). The 2019 and 2020 stock statuses for BL from Burnell et al. (2020, 2021) have been updated.

Season	TACC (t)	TCC (t)	CPUE (kg.hr^{-1})	Zone Score	Zone Trend Score	Stock Status
Greenlip						
2013	47.7	47.9	23.5	5.8	5.0	Depleting*
2014	47.7	47.5	24.3	6.8	6.0	Depleting*
2015	46.0	45.7	23.4	6.3	5.5	Depleting*
2016	46.0	46.0	23.7	6.1	5.0	Depleting*
2017	46.0	46.1	22.8	5.3	4.1	Sustainable*
2018	46.0	45.7	22.2	5.0	4.3	Sustainable*
2019	46.0	46.0	20.9	4.4	4.0	Depleting
2020	46.0	28.1	19.8	4.4	4.5	Depleting
2021	46.0	24.9	19.2	4.4	4.9	Depleting
Blacklip						
2013	8.1	8.4	24.0	3.9	5.0	Depleting*
2014	8.1	7.5	23.7	3.9	5.0	Depleting*
2015	6.4	6.4	24.6	4.4	5.0	Depleting*
2016	6.4	6.2	20.9	1.5	2.7	Depleting*
2017	6.4	5.8	18.3	0.6	0.1	Depleted*
2018	0.0	0.0	NA			Depleted*
2019	6.4	1.0	NA			Depleted*
2020	6.4	1.2	18.9			Depleted*
2021	1.2	1.2	NA			Depleted*

Keywords: Blacklip abalone, *Haliotis rubra*, Greenlip abalone, *Haliotis laevigata*, Stock assessment, Harvest strategy, South Australia.

1. GENERAL INTRODUCTION

1.1. Overview

This document provides a fishery assessment report for Greenlip Abalone (*Haliotis laevigata*, hereafter referred to as greenlip) and Blacklip Abalone (*H. rubra*; hereafter referred to as blacklip) in the Central Zone (CZ) of the South Australian Abalone Fishery (SAAF; Figures 1-1, 1-2) in 2021. These reports form part of the South Australian Research and Development Institutes' ongoing assessment program for the CZ, and updates previous stock assessment and status reports for both species (see Burnell *et al.* 2020; Burnell *et al.* 2021). This report (1) assesses the status of the greenlip resource using the Harvest Strategy (HS); (2) presents and analyses the data available for the fishery; (3) identifies the uncertainty associated with the assessment; and (4) identifies future research needs.

In this report, stock status for greenlip was determined using the (HS), which has been designed to deliver stock status outcomes consistent with the national fishery status reporting framework (NFSRF; Piddocke *et al.* 2021, Table 1-1). The HS used in this report is part of the Management Plan for the South Australian Commercial Abalone Fisheries (PIRSA 2021). The Management Plan specifies annual application of the HS to determine stock status and guides setting of the Total Allowable Commercial Catch (TACC). The HS assesses the abalone resource at the Spatial Assessment Unit (SAU) scale (Figure 1-3), followed by catch-weighted aggregation of SAU scores to provide a zone score, trend in zone score, recommended zone catch, and stock status. The HS was not used to assess the status of the blacklip resource because the blacklip CPUE estimates from 2019 differ substantially from, and cannot be directly compared with, CPUE estimates prior to 2018 thereby rendering them inappropriate for use in application of the HS. This approach supersedes that in Burnell and Mayfield (2021).

1.2. History and description of the fishery

1.2.1 Commercial fishery

A review of the management history of the SAAF since its inception in 1964 is provided by Mayfield *et al.* (2012). Major management milestones are listed in Table 1-2. The CZ of the SAAF includes all coastal waters of South Australia between 136°30'E and 139°E (Figure 1-2). The current management arrangements for the CZ are listed in Table 1-3. Total Allowable Commercial Catches (TACCs) were introduced for blacklip and greenlip in 1990. Since 1997, the fishery has operated under formal management plans (Zacharin 1997; Nobes *et al.* 2004; PIRSA 2012; PIRSA 2021). The current plan describes management through a regime of input (e.g., limited entry) and output (e.g., minimum legal length (MLL), TACC) controls.

There are six licences in the CZ, for which the fishing season extends from 1 January to 31 December each year. In 2021, greenlip comprised 97% of the CZ TACC (i.e., 46.0 t), and blacklip only 3% (i.e., 1.2 t). Key changes to the management arrangements for the fishery since the most recent stock assessment (Burnell *et al.* 2020) include: introduction of the new Management Plan and HS in 2021; reduction of the blacklip TACC from 6.4 t to 1.2 t in 2021 (noting an industry-managed agreement was already in place to limit catches to 1.2 t); removal of the legislated catch-cap at Tiparra Reef, with a voluntary industry-led initiative to manage catch limits and seasonal harvesting from Tiparra Reef; reduction of the greenlip TACC from 46.0 t to 36.0 t in 2022; voluntary industry-led initiative to under-catch the TACC in 2021 and 2022 and reduction of the blacklip TACC from 1.2 t in 2021 to 0 t in 2022.

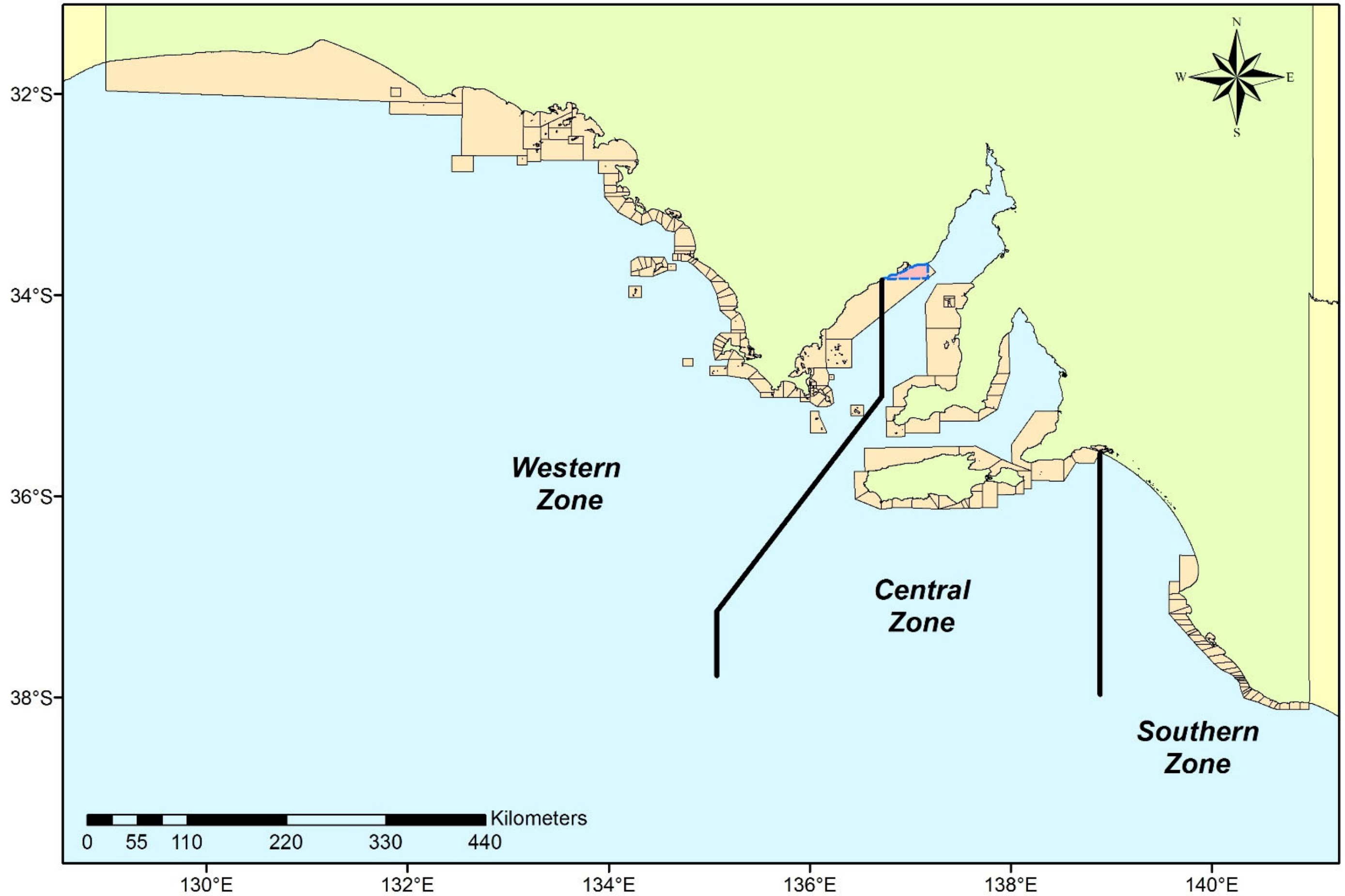

Figure 1-1 Fishing Zones and mapcodes of the South Australian Abalone Fishery.

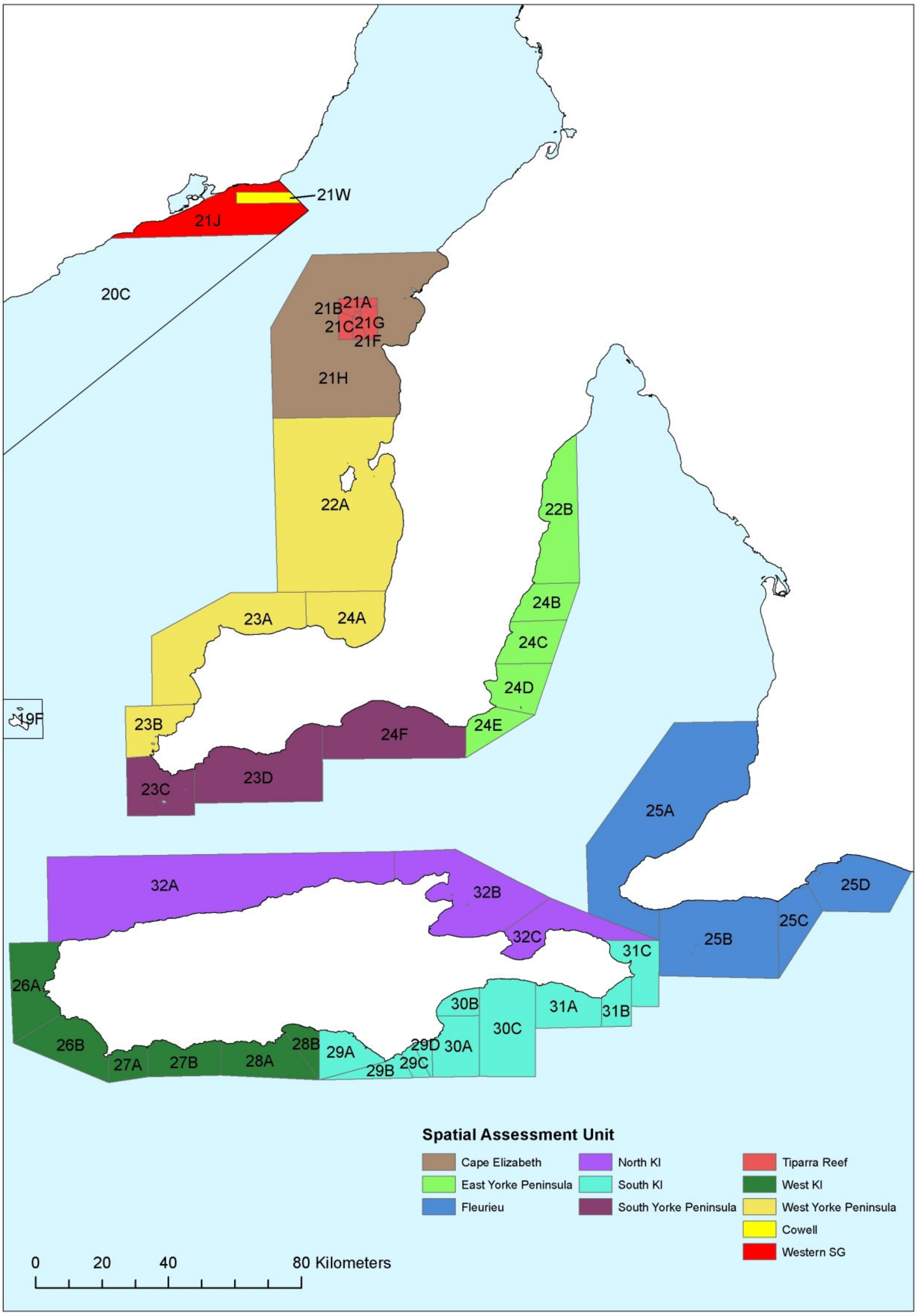

Figure 1-2 Spatial assessment units (SAUs; coloured blocks), fishing areas (numbered areas) and mapcodes (numbered and lettered areas) of the CZ of the South Australian Abalone Fishery.

Table 1-1 Terminology for the status of key Australian fish stocks (from Piddocke *et al.* 2021).

	Stock status	Description	Potential implications for management of the stock
	Sustainable	Biomass (or biomass proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e., recruitment is not impaired) and for which fishing mortality (or proxy) is adequately controlled to avoid the stock becoming recruitment impaired	Appropriate management is in place
	Depleting	Biomass (or proxy) is not yet depleted and recruitment is not yet impaired, but fishing mortality (or proxy) is too high (overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired	Management is needed to reduce fishing mortality and ensure that the biomass does not become depleted
	Recovering	Biomass (or proxy) is depleted and recruitment is impaired, but management measures are in place to promote stock recovery, and recovery is occurring	Appropriate management is in place, and there is evidence that the biomass is recovering
	Depleted	Biomass (or proxy) has been reduced through catch and/or non-fishing effects, such that recruitment is impaired. Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect
	Undefined	Not enough information exists to determine stock status	Data required to assess stock status are needed
	Negligible	Catches are so low as to be considered negligible and inadequate information exists to determine stock status	Assessment will not be conducted unless catches and information increase

1.2.2 Recreational and traditional fishing

The most recent estimate of the recreational catch of abalone estimate for South Australia was 282 blacklip and 4,651 greenlip for the 12-month period from late 2013 to 2014 (Giri and Hall 2015). This equates to 2.04 t meat weight, a 13% decrease since the previous survey from late 2007 to 2008 (Jones 2009). Based on the zone-specific estimates of Jones (2009), the total recreational harvests of greenlip and blacklip in the CZ in 2013/14 were estimated to be approximately 1,579 abalone (32% of state-wide catch), the majority of which are likely to have been greenlip (Giri and Hall 2015). Estimates of the levels of traditional fishing are currently unknown.

Table 1-2 Management milestones in the South Australian Central Zone abalone fishery.

Date	Milestone
1964	Fishery started
1971	>100 licences; licences made non-transferable
	Fishery divided into three Zones (Western, Central and Southern)
	MLL set at 130 mm shell length (SL) for all species
1976	Number of licences in CZ capped at six
1978	Change in spatial reporting of catch and effort data
1980	Licences became transferable
1990	Quota introduced to the CZ.
	TACCs set at 47.4 t and 13.7 t (meat weight) for greenlip and blacklip
1993	Abolition of owner-operator regulation
1994	Greenlip TACC increased from 47.4 t to 47.7 t (meat weight)
	Blacklip TACC increased from 13.7 t to 14.1 t (meat weight)
1997	Management Plan implemented (Zacharin 1997)
2002	Voluntarily increase in harvest length to 135 mm SL
2004	Management Plan revised (Nobes *et al.* 2004)
	Fishery assessed against the Principles of Ecologically Sustainable Development
2005	Greenlip catch capped at 30 t (meat weight) in FA 21 (Tiparra Reef and Cape Elizabeth)
	Blacklip TACC reduced from 14.1 to 9.9 t (meat weight)
2006	Blacklip TACC reduced from 9.9 to 8.1 t (meat weight)
2009	Catch-cap increased to 33.3 t (meat weight) in FA 21 (Tiparra Reef and Cape Elizabeth)
2010	Catch-cap of 1.6 and 1 t in Port Victoria (22A) and Hardwicke Bay (24A), respectively
2011	Catch-caps removed from Port Victoria (22A) and Hardwicke Bay (24A)
2012	Management Plan revised (PIRSA 2012) – new harvest strategy
2013	Catch-cap in FA 21 amended to 18 t (meat weight) from the Tiparra Reef SAU
	Tiparra Reef closed in January, February and December
	Use of GPS and depth loggers mandated in CZ
	MLL for greenlip legislated at 135 mm SL in CZ
2015	Greenlip TACC reduced from 47.7 to 46.0 t (meat weight) due to marine park sanctuaries
	Blacklip TACC reduced from 8.1 to 6.4 t (meat weight) due to marine parks sanctuaries
2018	Blacklip fishery voluntarily closed by industry; TACC reduced from 6.4 t to 0 t (meat weight)
2019	Blacklip TACC reinstated at 6.4 t (meat weight)
	Catch-cap in Tiparra Reef SAU increased to 19.2 t (meat weight)
2020	Tiparra Reef seasonal closure replaced with a voluntary Industry managed closure
2021	Blacklip TACC reduced from 6.4 to 1.2 t
	Management Plan revised (PIRSA 2021) – new harvest strategy
	Tiparra Reef catch-cap replaced with voluntary Industry managed limits
2022	Greenlip TACC reduced from 46.0 to 36.0 t, Blacklip TACC reduced from 1.2 to 0 t

Table 1-3 Summary of the current management arrangements for the Central Zone abalone fishery.

Management strategy	**Summarised Central Zone management arrangements in 2022**
Licence holders	6
Total allowable commercial catch	Greenlip = 36 t, Blacklip = 0.0 t
Target species	*Haliotis rubra* (blacklip), *H. laevigata* (greenlip)
Minimum legal length	Blacklip 130 mm shell length (SL), Greenlip 135 mm SL
Quota year	1 January to 31 December
Quota transferability	Yes
Other species permitted	*H. roei* (roei), *H. scalaris*, *H. cyclobates* when SL ≥130 mm
Method of capture	By hand – dive fishery

1.3. Biology of abalone

The biology of blacklip and greenlip in the CZ is described and documented in previous stock assessment reports (e.g., Mayfield *et al.* 2014; Burnell *et al.* 2016; see Appendix 1). Briefly, blacklip and greenlip are contiguous throughout southern Australia but have different overall distributions. Blacklip range from Coffs Harbour (New South Wales) to Rottnest Island (Western Australia), while greenlip range from Flinders Island (Tasmania) to Cape Naturaliste (Western Australia). Typically, these two species occupy different habitats, with blacklip mostly inhabiting crevices and caves or the bottom of steep rock faces of topographically complex rocky reefs (1 to 30 m depth) and greenlip tending to inhabit the edge of reefs and boulders near sand or seagrass (5 to >50 m depth).

Blacklip have a broad-scale population structure (Brown 1991), although significant genetic differentiation can occur between sites less than 15 km apart (Shepherd and Brown 1993; Temby *et al.* 2007; Miller *et al.* 2009), suggesting limited dispersal among 'metapopulations' (Fleming 1997; Miller *et al.* 2009). In contrast, for greenlip dispersal appears to be more widespread which is reflected in population genetics where 'metapopulations' occur at distances of up to 135 km (Miller *et al.* 2014). The relatively limited dispersal of abalone has implications for the recovery of depleted stocks and contrasts with many other marine organisms, whose widespread dispersal capacity makes them more resilient to localised depletion.

2. METHODS

2.1. Information sources for the assessment

This report provides spatial and temporal analysis of the fishery-dependent (FD) and fishery-independent (FI) data in the CZ from 1 January 1968 to 31 December 2021. Fishery-dependent data comprised catch (t, meat weight), CPUE (kg meat weight per hour; $kg.hr^{-1}$), shell length (SL) data from the commercial catch expressed as abalone mean length, and logger data (i.e., fishing location via GPS logger; fishing effort and depth via depth logger; following Mundy 2012; Mundy *et al.* 2018). Fishery-independent data were available for greenlip only and consisted of (1) estimates of density for legal-sized (≥135 mm SL) and sub-legal-sized abalone (<135 mm SL); (2) population length-frequency distributions; and (3) estimates of harvestable biomass derived by integrating reef area, density, length-frequency, and the relationship between shell length and bled meat weight. Data are presented at three (i.e., blacklip) or four (i.e., greenlip) spatial scales. These are (1) the zone (i.e., whole fishery); (2) spatial assessment unit (SAUs); (3) pooled data limited SAUs; and (4) mapcodes for the West Yorke Peninsula SAU. Similar to recent CZ reports, data from Cowell, historically a separately managed area within the CZ (see Mayfield *et al.* 2008a,b), are explicitly excluded.

2.2. Fishery-dependent data

2.2.1 Catch, effort and CPUE

Commercial catch and effort data have been collected since 1968 by fishers completing a research logbook for each fishing day.

Catch (t, meat weight) was determined from all daily logbook returns. Multi-dimensional scaling (MDS) is used to examine temporal changes in the spatial distribution of greenlip catch among the SAUs.

Catch-per-unit-effort ($kg.hr^{-1}$) was estimated as the mean of daily CPUE weighted by the proportion of the target species in the catch. Due to the mixed nature of catches, effort was split pro-rata based on the proportion of each species in the daily catch. The equation and decisions rules used to estimate CPUE are shown in Appendix 2. Estimates of CPUE (mean ± se) are not made where <10 fishing events are available at the relevant scale (i.e., zone, SAU, mapcode) in a given year. Catch rate estimates throughout the report with no standard error shown, represent running mean CPUE, estimated when there are ≥10 fishing events available across three years (with a minimum of 1 fishing event each year), which are required under the HS (PIRSA 2021). The low level of blacklip catch combined with mixed-species fishing means that blacklip CPUE estimates from 2019 differ substantially from, and cannot be directly compared with, CPUE estimates prior to 2018. However, estimates from 2019-2021 are included for completeness.

2.2.2 Mean length of abalone in the commercial catch

The mean length of abalone (≥135 mm SL) in annual catches was determined from the commercial catch-sampling data of abalone length.

2.2.3 GPS and depth logger data

Since 2013, the use of Global Positioning System (GPS) and depth loggers has been mandated in the CZ. During fishing operations, the GPS data logger (SciElex) records the position of the dive vessel, while the depth logger (Sensus Ultra, Reefnet), which is attached to the diver (or dive cage), records the duration and depth profile of each dive. Detailed methods for the integration and application of these two data sets are provided in Burnell *et al.* (2018).

In this report the logger data were used to generate five potential fishery performance indicators (PIs), at the SAU spatial scale for greenlip and the zonal scale for blacklip, using methods established in Tasmania (Mundy 2012; Mundy and Jones 2017), variants of which have also been applied elsewhere, including Western Zone Victoria and NSW (e.g., WADA 2016; Abalone Council of NSW 2017). These were (1) kilograms of catch per hectare, $kg.ha^{-1}$, (2) linear meters swum by the diver per hour, $lm.hr^{-1}$, (3) maximum dive distance, $distance.dive^{-1}$, (4) effort in hours across five different depth bands (0-5, >5-10, >10-15, >15-20, >20 m); and (5) the number of dives per day, $drops.day^{-1}$. The first three metrics are calculated from the Kernel Density (KUD_{90}), which represents the spatial footprint of the 90% isopleth derived from the GPS data for each dive event.

Data used for the calculation of the potential PIs were limited to days when the target species constituted ≥85% of the catch, to account for key differences in the spatial characteristics of greenlip and blacklip fishing (see Burnell *et al.* 2018). Data were also filtered to remove likely erroneous values, where effort recorded on the data logger was either less than half of more than double effort reported in the logbook.

2.3. Fishery-independent data

Estimates of greenlip density were obtained from FIS conducted by SARDI. For this assessment, data were available from two SAUs: Tiparra Reef; and West Yorke Peninsula (Figure 1-2). For both SAUs, temporal changes in greenlip density, length-count distributions from leaded-lines and estimates of harvestable biomass are provided. Length-frequency distributions, weighted by abalone density are also provided for greenlip at Tiparra Reef.

Density - Tiparra Reef

Surveys at Tiparra Reef have been undertaken in most years since 1968 using the timed-swim method (relative abundance; Shepherd 1985). Prior to 2002, the location and number of timed-swims used to estimate relative abundance varied among years. From 2002 onward, the number of timed-swims was increased, and greater consistency was introduced to the survey locations, subsequently increasing the reliability of density estimates. More recent surveys, from 2010 onwards, have used the leaded-line method (absolute abundance; McGarvey *et al.* 2008) to further improve the reliability and accuracy of estimates of greenlip density. In 2010 and 2012, surveys were conducted using both methods to enable calibration. Leaded-line survey locations have also varied among years. The number of sites surveyed increased from 31 in 2012 to 55 in 2013, following provision of detailed fishing location data. Consequently, density estimates from two leaded-line data series (2010-2019; n = 31 and 2013-2019; n = 55, Appendix 4) are presented. Density estimates are provided as legal-sized and sub-legal-sized greenlip per meter squared.

Greenlip densities from timed-swims between 2010 and 2019, required for application of the HS, were estimated in a two-stage process. First, the mean proportional density difference for each greenlip size class between the “paired” 2010 and 2012 leaded-line and timed-swim surveys was determined. These values were then applied to the density estimates from the leaded-line surveys to “scale” these to projected densities for the timed-swims (see below), where D_{TS} = Density timed-swim and D_{LL} = Density lead-line:

$$D_{TS} = D_{LL} \times (\frac{\left(\frac{D_{TS\_2010}}{D_{LL\_2010}}\right) + \left(\frac{D_{TS\_2012}}{D_{LL\_2012}}\right)}{2})$$

Density - West Yorke Peninsula

Leaded-line surveys are undertaken at three locations in the West Yorke Peninsula SAU (i.e., Hardwicke Bay, Port Victoria, and Corny Point). An expanded survey design was established in 2015, which was informed by GPS data of fishing events. Greenlip density data from leaded-lines were also available from Hardwicke Bay and Port Victoria in some years between 2006 and 2011, where historical sites (i.e., pre-GPS) were maintained due to overlap with the GPS logger data.

Harvestable Biomass

Harvestable biomass has been estimated for the Tiparra Reef and West Yorke Peninsula SAUs biennially since 2013 and 2015, respectively. Harvestable biomass estimates integrate (1) densities from the leaded-line surveys; (2) length-weight relationships of greenlip; and (3) reef area estimates from the GPS data. Estimates are reported for the (1) survey area; and

(2) scaled to the entire SAU, including adjustment to pre-season levels in each SAU using year-to-date catch. Total annual catch is then used to estimate the potential range of exploitation rates for each SAU and mapcodes for West Yorke Peninsula. Detailed methods for estimating harvestable biomass are provided in Appendix 3.

2.4. Harvest Strategy and stock status determination

The HS from the Management Plan was used to assign stock status for greenlip (PIRSA 2021). In the HS, each SAU is designated as surveyed (i.e., FIS undertaken), unsurveyed (i.e., no FIS undertaken) or data-limited (PIRSA 2021). The data-limited SAUs are pooled for estimation of CPUE and scoring in the HS (PIRSA 2021). The HS was not applied to blacklip. The low level of blacklip catch, combined with mixed-species fishing, means that blacklip CPUE estimates from 2019 differ substantially from, and cannot be directly compared with, CPUE estimates prior to 2018 – including those from the 1990 to 2000 reference period that underpins the HS – and are inappropriate for use in application of the HS (see also section 10.11 in PIRSA 2021). This approach supersedes that in Burnell and Mayfield (2021).

The HS is based on two Performance Indicators (PIs), CPUE and legal-sized abalone density from the FIS. Performance Indicator scores for each SAU range from 0 to 10, based on comparison with a historical reference period. For the CPUE PI the reference period is from 1990 to 2000, except for East Yorke Peninsula (2008 to 2016), due to the absence of fishing between 1990 and 2000 in this SAU. The FIS reference period varies by SAU and is dependent on the number of years surveys have been undertaken. A minimum of four years of surveys are required for a score function to be applied and the reference period requires at least 10 surveys before it becomes fixed (similar to the CPUE reference period). There are two surveyed SAUs for greenlip in the CZ. When FIS scores are available, combined SAU scores reflect equal weighting (i.e., 50:50) of the CPUE and FIS PIs. The upper and lower limit reference points and the target range are indicated on relevant plots for CPUE and legal density (see Results). Scores for each SAU are then weighted based on the last 12 years of catch, and summed to a zone score, which represents the biomass proxy from the NFSRF. The slope from the last four zone scores is used to generate a proxy for fishing mortality (i.e., zone trend score). Stock status is detemined based on the the combination of the zone score and the zone trend score, shown in Table 2-1.

The zone score (i.e., biomass proxy) translates directly to a recommended zonal catch, via a function applied to the target catch level (see PIRSA 2021). The target catch for the CZ greenlip and blacklip fisheries are 46.0 t and 9 t, respectively. For zone scores between 5 and 7, the recommended zonal catch is equal to the target catch (i.e., no adjustment). For zone scores between 7 and 10, there is a linear increase from 1.0 (i.e., no adjustment) to a maximum of 1.3 (30% above the target catch). Consequently, the theoretical maximum recommendable zonal greenlip catch for a score of 10 is 59.8 t (46 t x 1.3 = 59.8 t). For a zone score between 5 and 1, the adjustment decreases linearly from 1.0 (i.e., no adjustment) to 0.1 (90% below the target catch). Consequently, the recommended zonal greenlip catch for a score of 1 is 4.6 t (46.0 t x 0.1 = 4.6 t). For zone scores <1 the recommended catch is zero.

Table 2-1. Potential stock status outcomes from the Harvest Strategy

Status	Zone Score	Zone Trend Score
Sustainable	≥5	
Sustainable	<5	≥5
Depleting	<5 & ≥1	<5
Recovering	<1	≥5
Depleted	<1	<5

2.5. Quality Assurance

Quality assurance systems form an integral part of stock assessments undertaken by SARDI (Vainickis 2010). These systems are designed to ensure high quality project planning, data collection and storage, analyses, interpretation of results and report writing. Details of the five individual components are provided in Appendix 5.

3. RESULTS

3.1. Greenlip

3.1.1 Central Zone

Total greenlip catches were consistent with the TACC from 1994 to 2019 (Figure 3-1a). A small decline in TACC from 47.7 t to 46.0 t occurred in 2015, following the introduction of marine park sanctuary zones. In 2020, catches fell to 28.1 t, before declining again in 2021 to 24.9 t, reflecting a voluntary initiative by industry since 2020 to under-catch the TACC. Catch-per-unit-effort was relatively stable from 1985 to 1999 (average: 21 $kg.hr^{-1}$), before increasing to the highest recorded value of 31 $kg.hr^{-1}$ by 2001. After 2001, a decreasing trend was evident for the next decade, before stabilising at approximately 24 $kg.hr^{-1}$ between 2011 and 2016. Subsequently, CPUE has declined consistently each fishing season, reaching 19.2 $kg.hr^{-1}$ in 2021, which is the lowest estimate since 1995, and among the lowest on record. The 2021 value for the combined trend of relative catch and CPUE was the lowest value on record, reflecting the relatively low catch and catch rate in 2021 (Figure 3.1b).

3.1.2 Spatial assessment units

3.1.2.1 Distribution of catch among SAUs

Changes in the spatial distribution of catch are evident throughout the history of the fishery (Figure 3-1c). Greenlip catches were primarily harvested from two SAUs, Tiparra Reef and West Yorke Peninsula (Figure 3-1c). After TACC implementation in 1990, catches harvested from the Tiparra Reef SAU increased substantially, peaking in 2001 at 44.9 t (94% of catch). Catches declined following the introduction of a 'catch-cap' for Tiparra Reef in 2005, with corresponding increases in catch from the other SAUs, particularly West Yorke Peninsula. In 2021, catches from Tiparra Reef were the lowest on record (i.e., since 1979), while those from West Yorke Peninsula were the lowest since 2011. Catches from East Yorke Peninsula and the data limited SAUs remain low, while those from South and West KI have varied among recent years.

The MDS ordination identified eight clusters of fishing years with a similar spatial distribution of greenlip catches among SAUs between 1979 and 2021 (Figure 3-2). The length and direction of the vectors highlight that Tiparra Reef, East Yorke Peninsula and West Yorke Peninsula have the greatest bearing on the MDS. The spatial distribution of greenlip in recent seasons (marked as grey crosses) is characterised by higher relative catches from West Yorke Peninsula, South and West KI, and lower relative catches from Tiparra Reef and Cape Elizabeth.

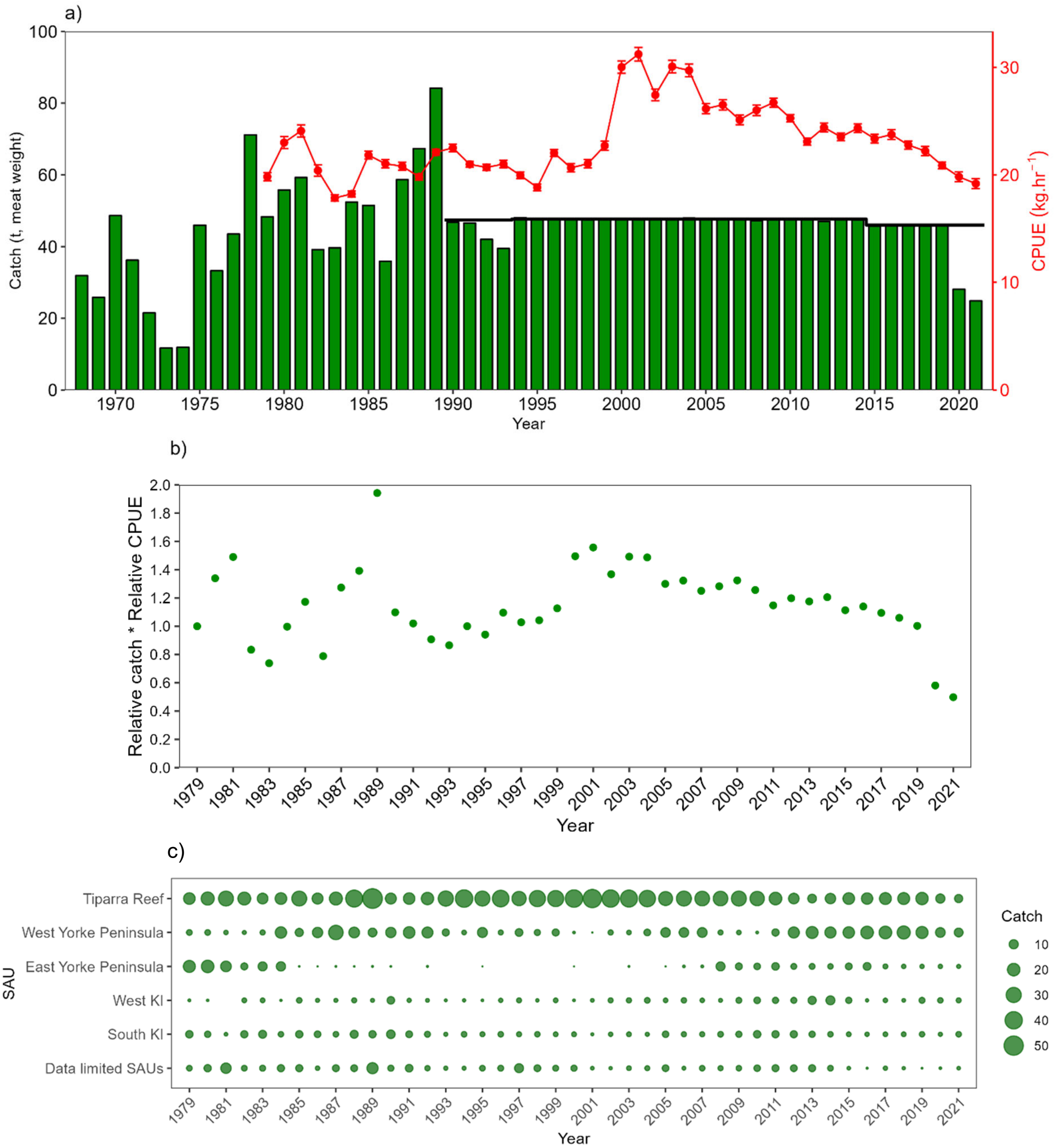

Figure 3-1 Zonal catch, CPUE, Catch * CPUE and the distribution of catch among SAUs available from 1968 to 2021 a) Total catch (green bars, tonnes), CPUE (red line) and TACC (black line) of greenlip in the CZ 1968-2021. b) Combined trend of relative catch and relative CPUE from from 1979 to 2021. c) Bubble plot showing the spatial distribution of the greenlip catch (green symbols) among each of the SAUs in the CZ from 1979 to 2021 (data limited SAUs from the HS are combined).

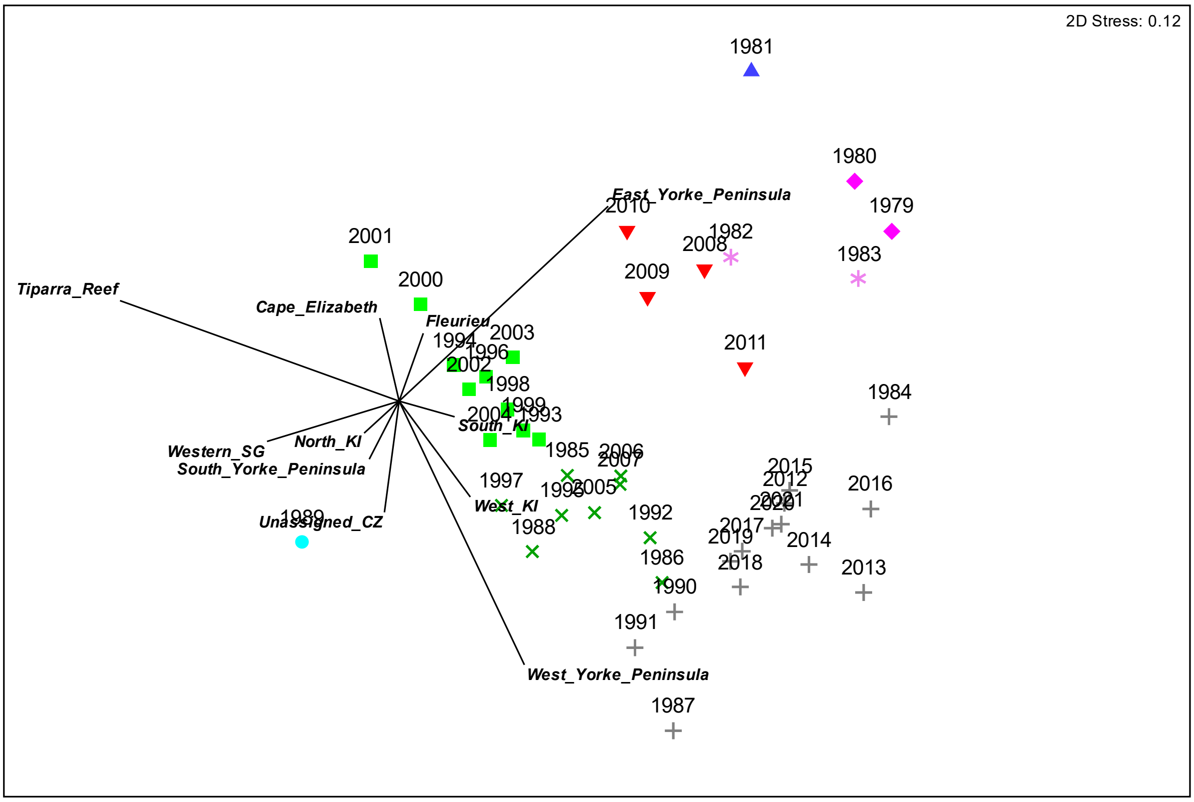

Figure 3-2 Multi-dimensional scaling (MDS) plot for SAUs showing similarity among seasons based on the spatial distribution of annual greenlip catch from the Central Zone from 1979 to 2021. Coloured symbols indicate different spatial distributions (SIMPROF; α = 0.05). Vector length and direction show the influence of each individual SAU on the MDS.

3.1.2.2 Temporal patterns in surveyed SAUs

Tiparra Reef

Fishery-dependent data: Tiparra Reef has been the most important SAU for greenlip in the CZ since TACC implementation (Figure 3-1c). Total annual catches from Tiparra Reef increased steadily from 1979 (17 t) to 2001 (45 t), with the largest historical catch recorded in 1989 (52 t). After 2001, catches declined rapidly to <10 t in 2013. Thereafter, catches increased to 19 t by 2019 (consistent with the then catch-cap), before declining during each of the past two seasons, to reach the lowest catch on record (8 t) in 2021.

Catch-per-unit-effort was relatively stable at a high level between 2000 and 2009 (mean 30.1 kg.hr^{-1}), and consistently exceeded the upper limit reference point (Figure 3-3a). In 2010, CPUE declined, and remained at approximately 24 kg.hr^{-1} until 2013. In 2014, CPUE increased to over 30.0 kg.hr^{-1}, but has generally declined thereafter, reaching 21.0 kg.hr^{-1} in 2021, resulting in a CPUE score of **5.0 out of 10** (Table 3-1).

The mean length of greenlip in the commercial catch has varied over time (Figure 3-3b). Mean lengths were low from 2004 to 2006 and again from 2013 to 2014 (145 to 147 mm), while the highest values were recorded in 2007 and 2009 (152 to 155 mm). Since 2017, the mean length has been stable between 149 and 150 mm.

Fishery-independent data: The density of legal-sized abalone on Tiparra Reef was highest during the early to mid-2000s, reaching a peak of 0.18 greenlip.m^{-2} in 2005, before declining steadily to a contemporary low of 0.05 greenlip.m^{-2} in 2011 (Figure 3-3c). After a period of stability from 2011 to 2013, legal-sized density estimates increased, reaching 0.09 greenlip.m^{-2} in 2019, before declining by 20% to reach 0.08 greenlip.m^{-2} in 2021. The density of greenlip remained within the target scoring range, resulting in a score of **5 out of 10** (Table 3-1).

The density of sub-legal-sized greenlip peaked in the early 1990s (0.91 greenlip.m^{-2}; Figure 3-3e) and again during the mid-2000s (0.56 greenlip.m^{-2}). After 2005, estimates of sub-legal density declined consistently, falling to the lowest value on record in 2015 (0.14 greenlip.m^{-2}). Since 2015, sub-legal density has generally increased, reaching 0.23 greenlip.m^{-2} in 2021, representing a 60% increase from 2015 levels. Sub-legal-sized greenlip density remains relatively low compared with surveys during the 1990s and 2000s.

Estimates of density for consistent lead-lines are shown in Figures 3-3d and 3-3f (see Appendix 4 for densities from the expanded survey of 55 sites which commenced in 2013). The temporal trend between these 31 consistent lead lines and those described above for the timed-swims are identical because the timed-swim estimates are scaled directly from these 31 leaded-line estimates.

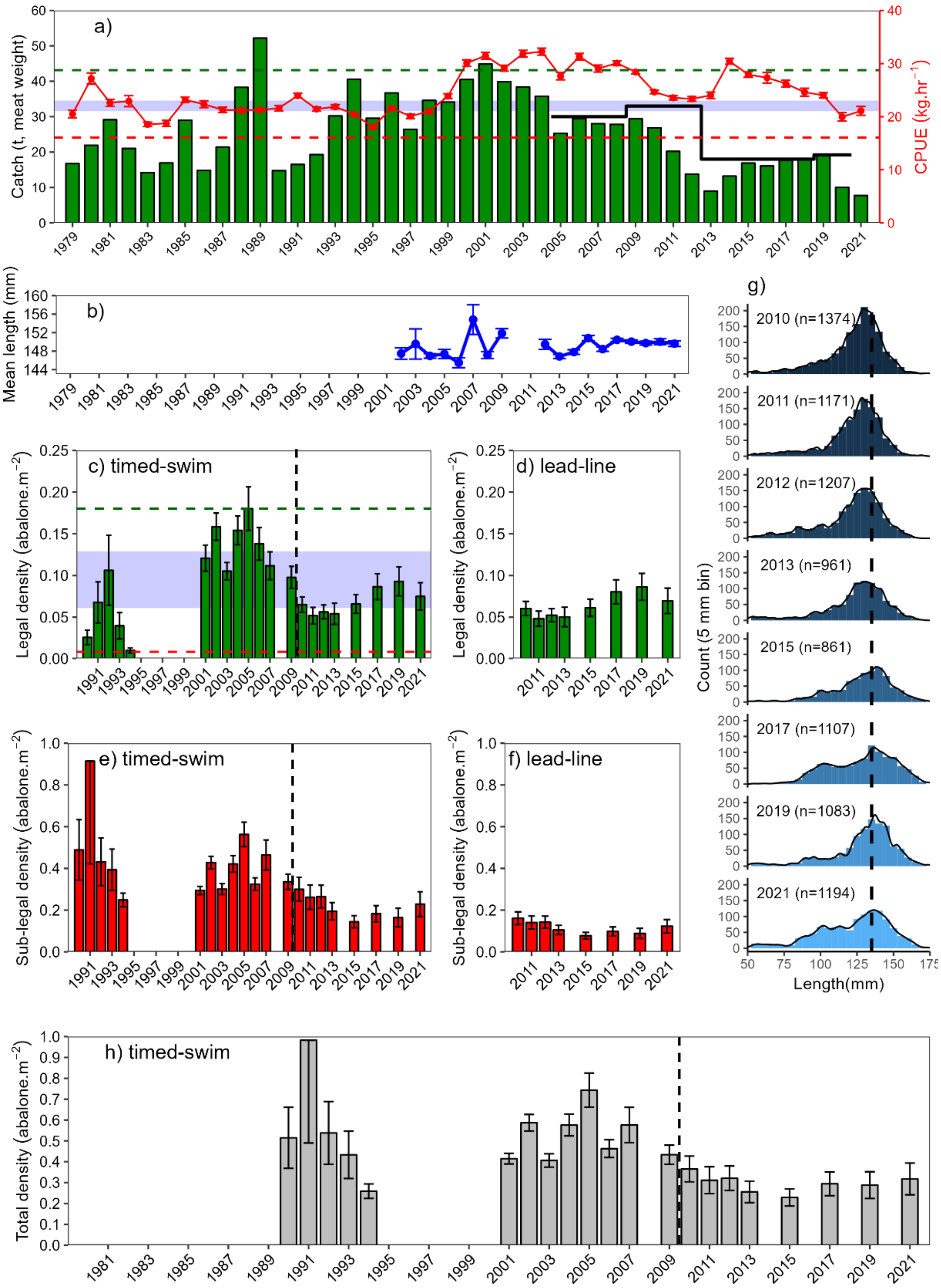

Figure 3-3 Tiparra Reef SAU data available from 1979 to 2021. a) Catch (green bars, tonnes), CPUE (red solid line), historic catch-cap (black line), b) mean length (blue line), c & d) legal density of greenlip (i.e., ≥135 mm green bars) from timed-swim and lead-line surveys, e & f) sub-legal density of greenlip (i.e., <135 mm SL, red bars) from timed-swim and lead-line surveys, g) Length counts, h) estimated total density of greenlip from timed-swim surveys. Gaps in the time series indicate no data. Scoring from the harvest strategy is shown for panels a) and c): Target Range (score of 5, blue shading), upper limit (score of 10, green dashed line), lower limit (score of 0, red dashed line). Timed-swim estimates from 2010 onward in panels c), e) and h) indicated by the dashed black line have been scaled from lead-line data.

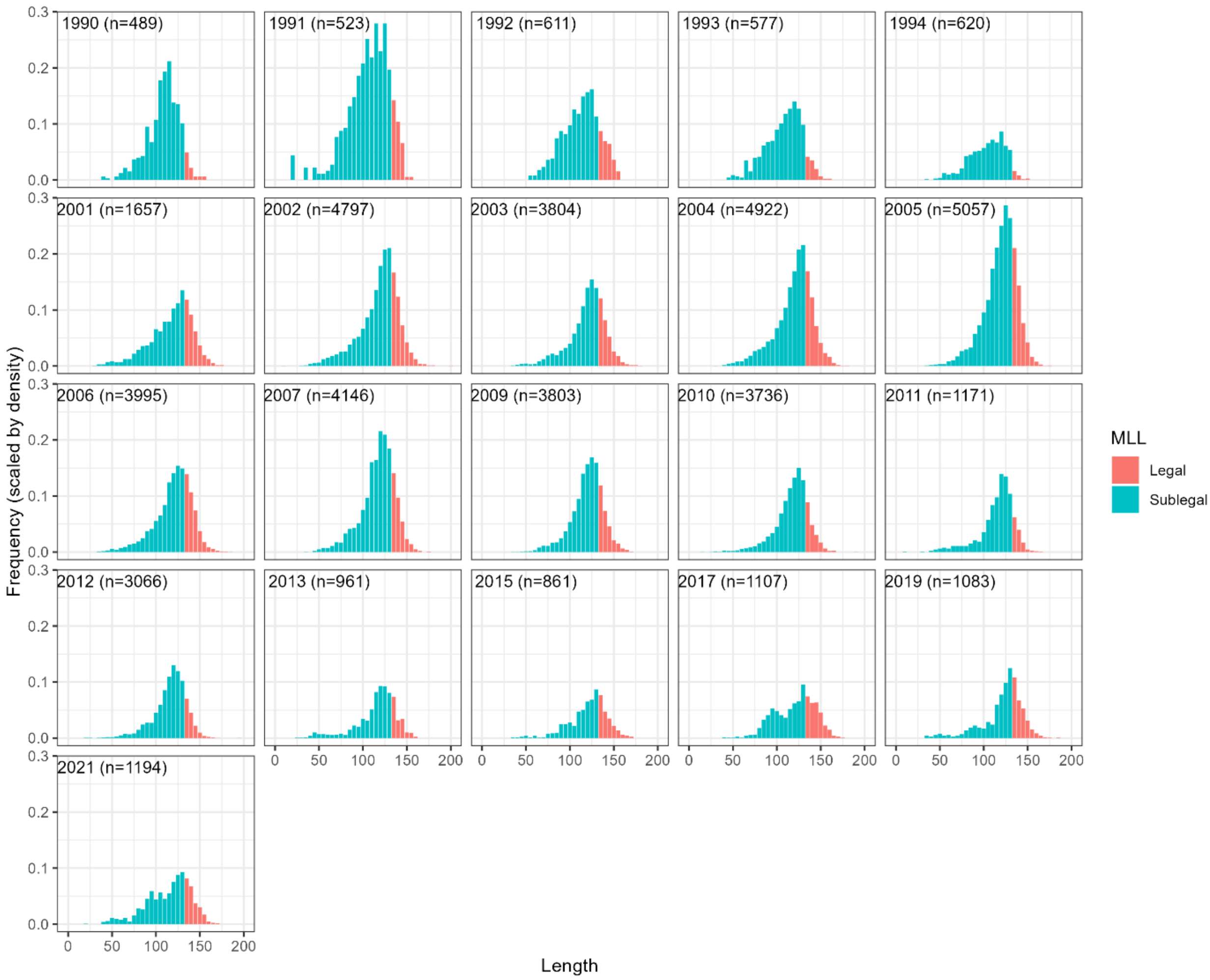

Figure 3-4 Length frequency in the Tiparra Reef SAU from 1979 to 2021 scaled by total greenlip density. n = the number of abalone counted during the fishery independent survey.

Length-count distributions for the 31 consistent lead-lines surveyed between 2010 and 2021 are shown in Figure 3-3g (see Appendix 4 for length distributions from the expanded survey of 55 sites which commenced in 2013). These distributions reflect the generally greater number of legal-size greenlip recorded on surveys since 2010. The presence of fewer sub-legal sized greenlip is evident since 2013, however, in 2021 there were high numbers of sub-legal-sized greenlip in the 85-115 mm SL size range, reflected in the bimodal distribution. The length-frequency distributions scaled by density (Figure 3-4), show the change abundance and size distribution of greenlip abalone on Tiparra Reef since timed-swims commenced in 1990.

The stratified, median estimate of legal-sized-greenlip harvestable biomass in the survey area in October 2021 was 30.6 t bled-meat weight (BMW; Figure 3-5). The successive decrease in biomass since 2017, reflects fewer large greenlip encountered and the overall reduction in legal density recorded in the expanded survey design (Appendix 4). When scaled to the

Tiparra Reef SAU and adjusted for year-to-date catch, the harvestable biomass estimates for January 2021 were between 46.9 t and 82.9 t (Figure 3.5, Appendix 3), with the largest scaled harvestable biomass estimate from method 5. The estimate from method 5 was substantially higher than estimates from the other four methods, with this difference driven by the much larger estimate for the area of stratum 4 obtained from method 5. These estimates suggest that the harvest fraction (HF) at Tiparra Reef was between 9 and 17% in 2021, which was the lowest HF since biomass surveys commenced in 2013 (Appendix 3).

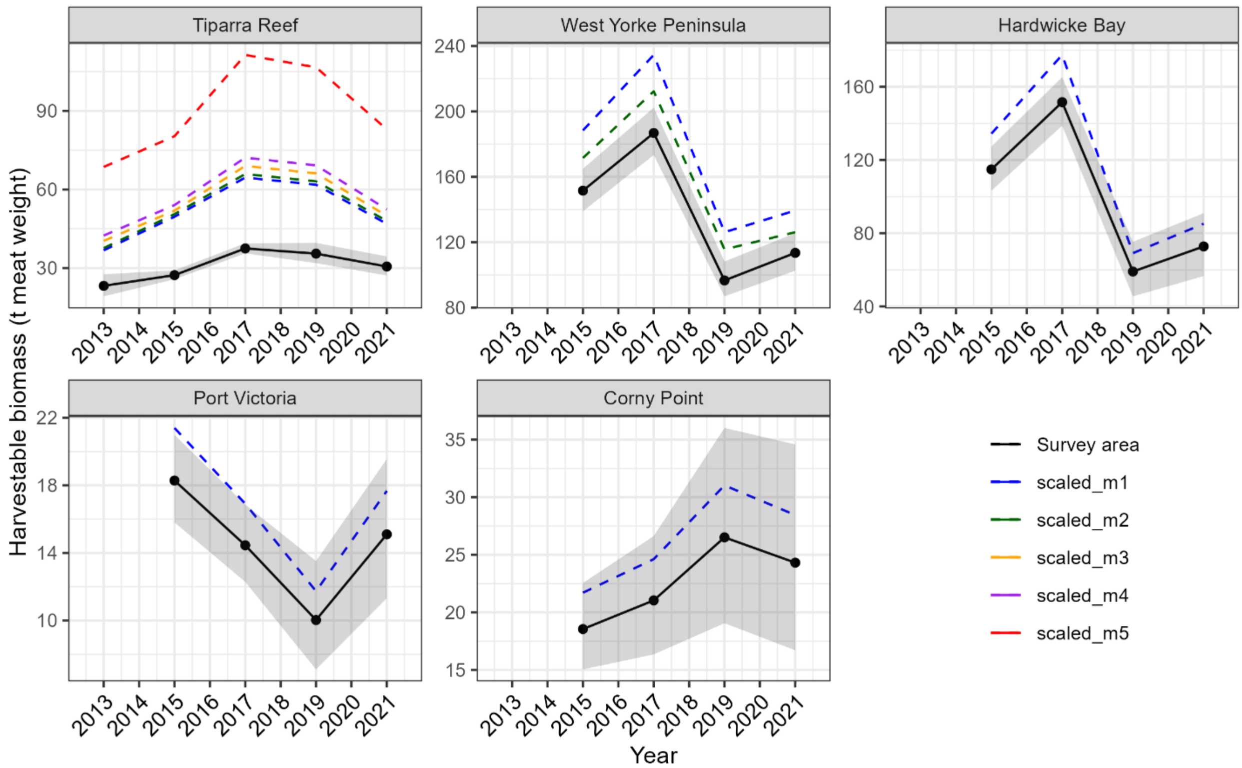

Figure 3-5 Harvestable biomass from Tiparra Reef and West Yorke Peninsula from 2013 to 2021, including estimates from the three indepdent fishing areas (i.e., Hardwicke Bay, Port Victoria & Corny Point) within West Yorke Peninsula (median ± 10%,90% quantiles, black line ± grey shading). Coloured dashed lines show estimates scaled to SAU and mapcodes and adjusted for year-to-date catch.

West Yorke Peninsula

Fishery-dependent data: Catches from the West Yorke Peninsula SAU (Figure 3-6a) show three periods of sustained higher catches (i.e., 1984-1992, 2005-2007, 2012-2021), interspersed among periods of lower catches (i.e., 1979-1983, 2000-2004, 2008-2011). Catches have declined from a contemporary peak of 22 t in 2018 to 9 t in 2021.

Catch-per-unit-effort was among the highest level on record in 2012. Subsequently, CPUE steadily declined until 2018, before falling sharply in 2019 to 18.4 $kg.hr^{-1}$. Thereafter, CPUE has been relatively stable, with the 2021 estimate of 19.0 $kg.hr^{-1}$ equating to a CPUE score of **4.6 out of 10** (Table 3-1).

The mean length of greenlip in the commercial catch has varied substantially through time (Figure 3-65b). Estimates generally declined throughout the 2000s, albeit with notable inter-annual variability. In 2012, the mean length estimate was the highest ever recorded, but has subsequently declined, albeit with notable interannual variability.

Fishery-independent data: The FIS for West Yorke Peninsula are a combination of data from three different locations, Figures 3-6c,d). The density of legal-sized abalone was highest during 2017 (0.041 $greenlip.m^{-2}$), before declining by 40% in 2019 (0.025 $greenlip.m^{-2}$). The number of legal-sized greenlip increased by 17% in 2021 (0.029 $greenlip.m^{-2}$). The density of greenlip was marginally below the target scoring range, resulting in a score of **4.6 out of 10** (Table 3-1).

The density of sub-legal-sized greenlip from the FIS has been stable averaging 0.036 $greenlip.m^{-2}$ since surveys commenced.

West Yorke Peninsula Mapcodes

Fishery-dependent data: Catches from the three mapcodes within this SAU have varied substantially throughout the history of the fishery (Figures 3-7a, 3-8a, 3-9a). Prior to 2012, catch had largely been harvested from Hardwicke Bay (Figure 3-7a) and Port Victoria (Figure 3-8a), whereas catches from Corny Point (Figure 3-9a) were negligible (average 0.2 t yr^{-1}). Since 2012, Corny Point has yielded an average catch of 5.2 t yr^{-1}.

In Hardwicke Bay, CPUE was stable and among the highest level recorded from 2012 to 2018 (21.6 to 25.6 $kg.hr^{-1}$), but by 2020 had declined to the lowest level on record (14.5 $kg.hr^{-1}$), before recovering to 17.9 $kg.hr^{-1}$ in 2021. In Port Victoria, estimates of CPUE are unavailable in many years due to low numbers (<10) or no fishing records. The last available estimate in the Port Victoria mapcode was 29.4 $kg.hr^{-1}$ in 2020, which was among highest on record. At Corny Point, CPUE declined by >40% from 32.7 to 18.5 $kg.hr^{-1}$ between 2012 and 2019, before stabilising and increasing to 21.1 $kg.hr^{-1}$ in 2021.

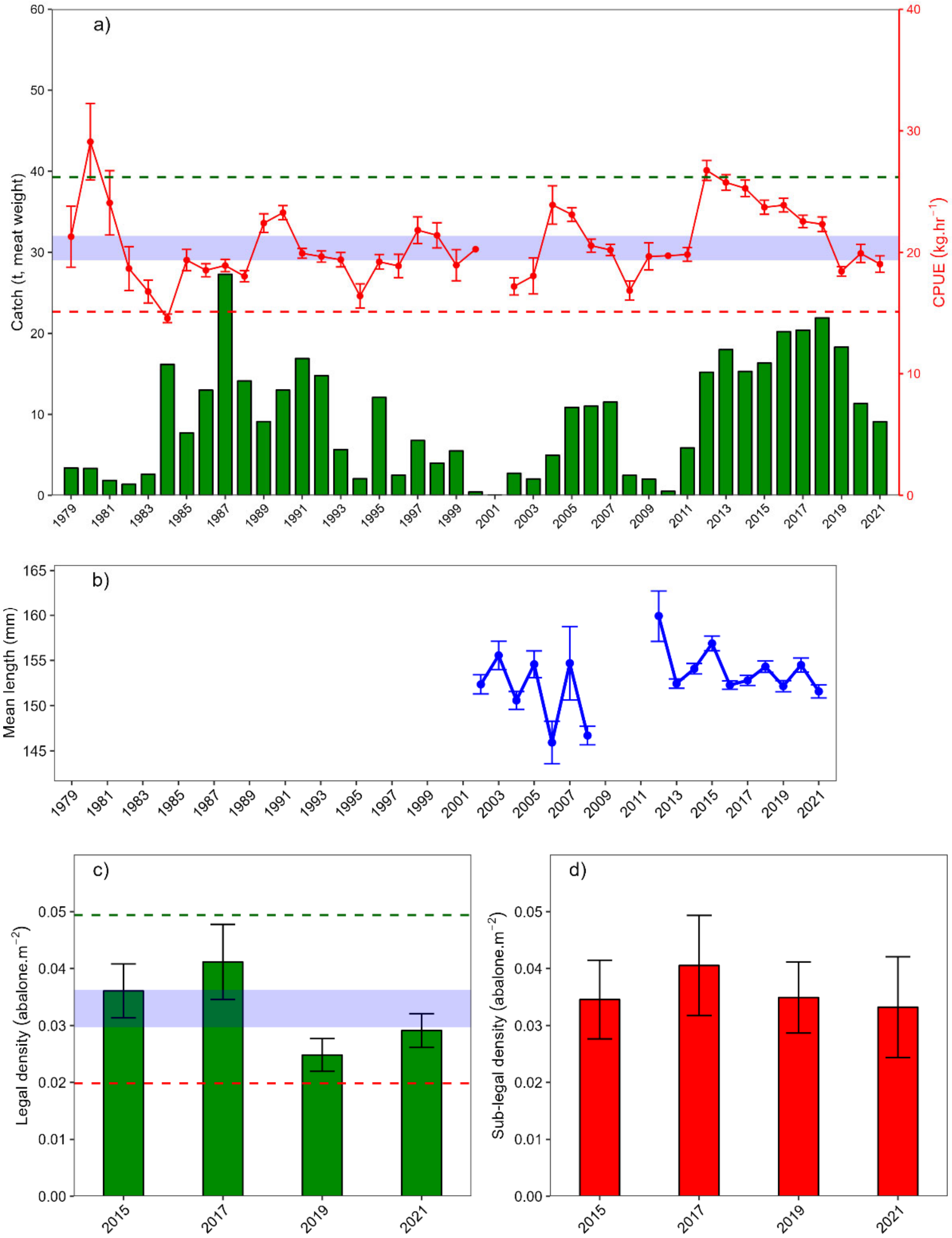

Figure 3-6 West Yorke Peninsula SAU data availble from 1979 to 2021. a) Catch (green bars, tonnes), CPUE (red line). b) mean length (blue line). c) legal density of greenlip (i.e., ≥135 mm green bars) from lead-line surveys. d) sub-legal density of greenlip (i.e., <135 mm SL, red bars) from lead-line surveys. Gaps in all time series indicate no data. Scoring from the HS is shown for panels a) and c): Target Range (score of 5, blue shading), upper limit (score of 10, green dashed line), lower limit (score of 0, red dashed line).

Fishery-independent data: At Hardwicke Bay, six consistent sites have been sampled intermittently since 2006 (Figure 3-7b & 3-7d). At these sites, the highest densities of legal- and sub-legal-sized greenlip were recorded between 2006 and 2010. Subsequently, the densities of legal- and sub-legal-sized greenlip have generally declined to levels among the lowest on record in 2021. In the expanded survey design with 26 consistent sites (Figure 3-7c & 3-6e), densities were higher than those recorded from the six consistent sites. The density of legal-sized greenlip peaked in 2017 (0.063 greenlip.m^{-2}), followed by a ~60% decline (0.063 to 0.026 greenlip.m^{-2}) in 2019, before stabilising at 0.032 greenlip.m^{-2} in 2021. In contrast, the density of sub-legal-sized greenlip has been stable among recent surveys. The length distribution showed a substantial cohort of sub-legal sized greenlip around 70 to 110 mm SL in 2015, which likely translated to higher legal density in 2017 (Figure 3-7f). The 2019 and 2021 distributions reflect fewer legal-sized greenlip recorded in the survey.

At Port Victoria, 11 consistent leaded-lines have been sampled intermittently since 2007 (Figure 3-8b,d). In 2021, the density of legal-sized greenlip increased by ~70% (0.037 greenlip.m^{-2}) and was the second highest density estimate on record. The density of sub-legal-sized greenlip was generally stable between 2007 and 2019 (range 0.012 to 0.017 greenlip.m^{-2}), before declining by ~55% in 2021 (0.009 greenlip.m^{-2}), which was the lowest level on record. The length distribution in 2021 reflects more legal-sized greenlip and fewer sub-legal-sized greenlip recorded during the survey (Figure 3-8f).

At Corny Point, leaded-line surveys commenced in 2015 (Figure 3-9b,c). The density of legal-sized greenlip has been stable among years. In contrast, the density of sub-legal-sized has declined by ~60% since 2015 (0.017 to 0.007 greenlip.m^{-2}). The length distribution reflects the declining number of sub-legal-sized greenlip recorded during the survey (Figure 3-9d).

West Yorke Peninsula Biomass

The stratified median estimate of legal-sized-greenlip harvestable biomass in October 2021 in the survey area was 112.2 t (i.e., 72.8 t, 15.1 t and 24.3 t BMW for Hardwicke Bay, Port Victoria, and Corny Point, respectively; Figure 3-5). When scaled to the West Yorke Peninsula SAU, and adjusted for year-to-date catch, the harvestable biomass estimates for January 2021 were between 126.2 and 139.4 t (Figure 3-5, Appendix 3).

The 2021 estimate reflects a 17% increase since 2019 but remains 26 to 40% below median estimates from 2015 and 2017, respectively. This overall decline in estimated biomass primarily reflects fewer legal-size-greenlip recorded in the FIS at Hardwicke Bay. The estimated biomass at Corny Point has increased since 2015, reflecting a greater number large greenlip in the FIS, while legal density has remained stable. As the total catch harvested from West Yorke Peninsula in 2021 was 8.8 t, the HF was approximately 7%, reflecting the lowest HF since biomass surveys began in 2015. The spatially explicit HFs for the three mapcodes were 6%, 6% and 8% for Hardwicke Bay, Port Victoria, and Corny Point, respectively (Appendix 3, Table A3-3).

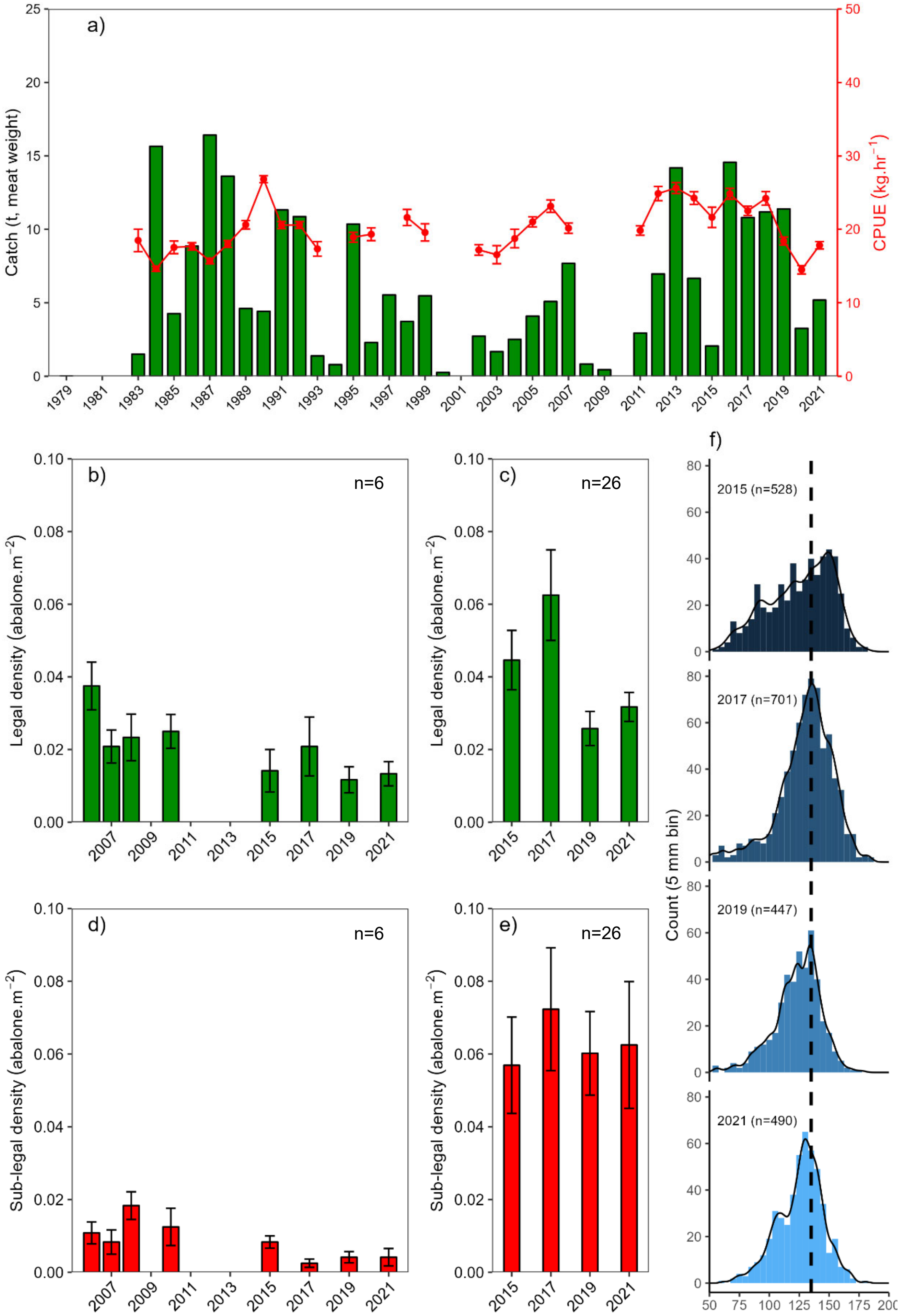

Figure 3-7 Fishery-depedent and fishery-independent data from mapcode 24A (Hardwicke Bay) from 1979 to 2021. a) Catch (green bars, tonnes) and CPUE (red line), b & c) Legal density of greenlip (i.e., ≥135 mm green bars) from historical and expanded survey design, d & e) Sub-legal density (i.e., <135 mm red bars) from historical and expanded survey design, f) Length-count distributions of greenlip from the expanded survey design. Gaps in all time series indicate no data.

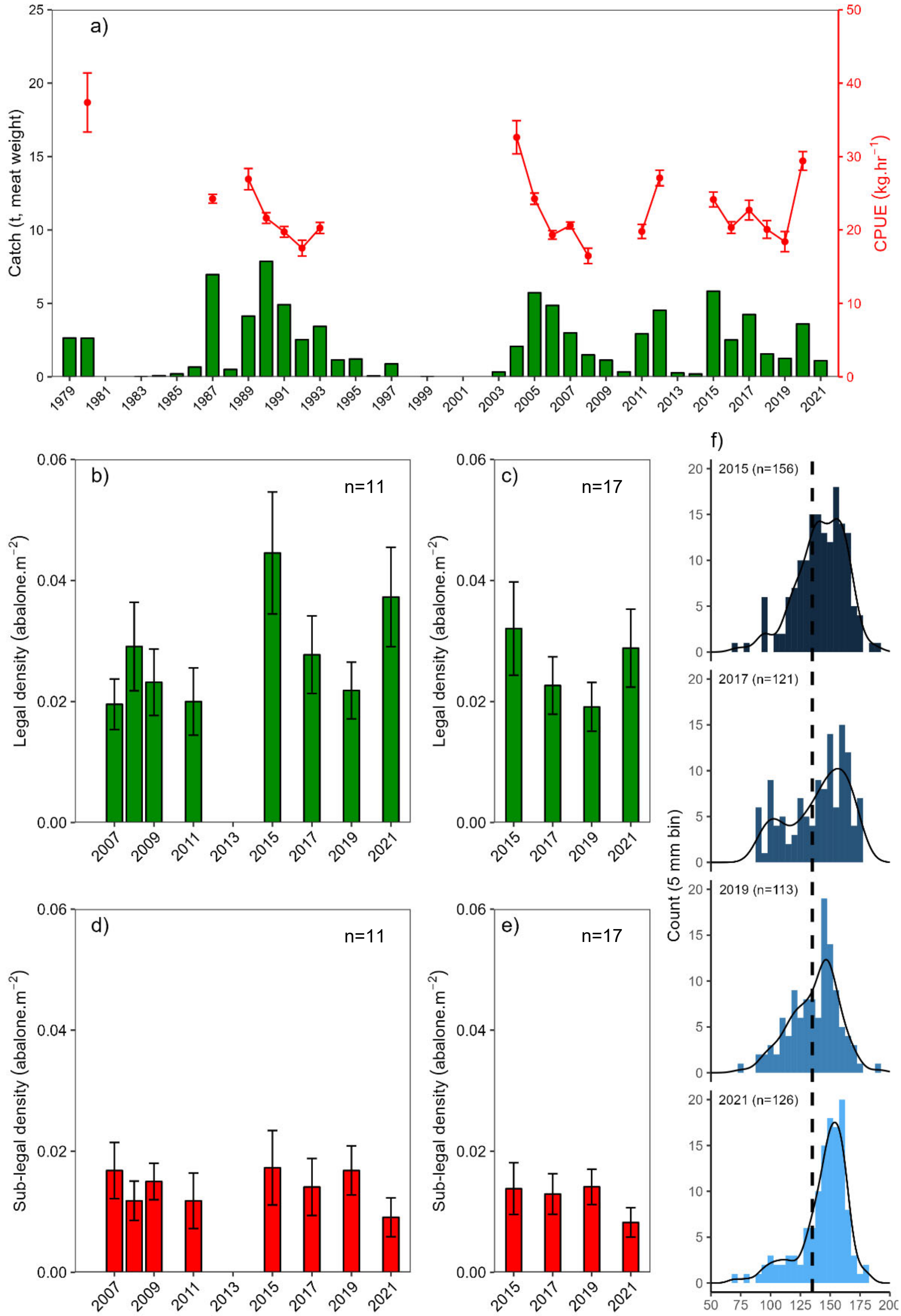

Figure 3-8 Fishery-depedent and fishery-independent data from mapcode 22A (Port Victoria) from 1979 to 2021. a) Catch (green bars, tonnes) and CPUE (red line), b & c) Legal density of greenlip (i.e., ≥135 mm green bars) from historical and expanded survey design, d & e) Sub-legal density (i.e., <135 mm red bars) from historical and expanded survey design, f) Length-count distributions of greenlip from the expanded survey design. Gaps in all time series indicate no data.

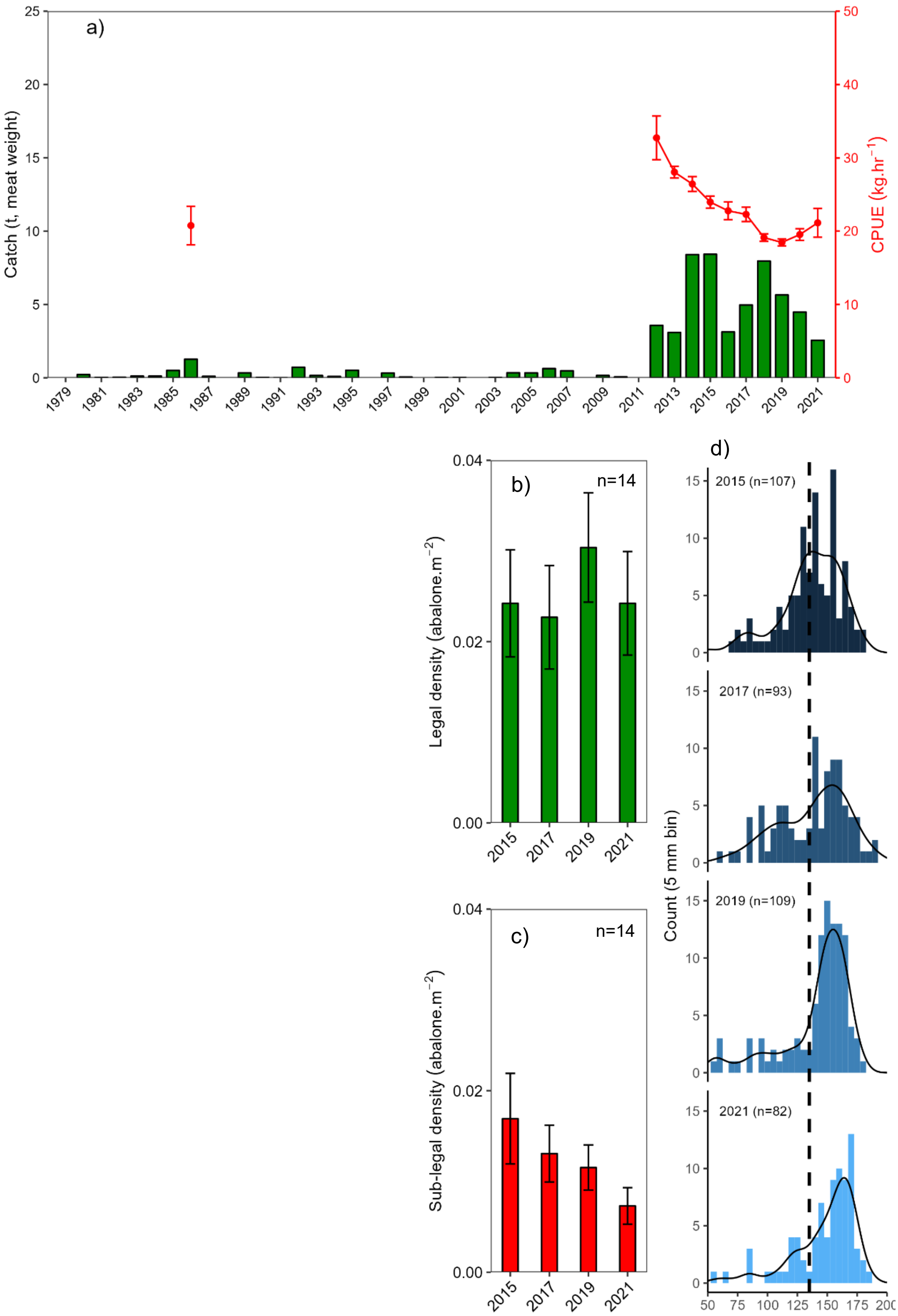

Figure 3-9 Fishery-depedent and fishery-independent data from mapcode 23A (Corny Point) from 1979 to 2021. a) Catch (green bars, tonnes) and CPUE (red line), b) Legal density of greenlip (i.e., ≥135 mm green bars) from the fishery independent surveys, c) Sub-legal density (i.e., <135 mm red bars) from the fishery independent surveys, d) Length-count distributions of greenlip from the expanded survey design. Gaps in all time series indicate no data.

3.1.2.3 Temporal patterns in unsurveyed SAUs

East Yorke Peninsula

Large catches were obtained from the East Yorke Peninsula SAU between 1979 and 1984 (average 12.9 t.yr^{-1}). This was followed by >20 years of negligible catches from 1985 to 2007 (Figure 3-10a). In 2008, significant catches recommenced in this SAU, when 9.6 t was harvested. Catches averaged 5.0 t.yr^{-1} from 2008 to 2016, but have declined to <2 t.yr^{-1} since 2017, with just 1.4 t harvested in 2021. Following an initial peak in CPUE at 24.1 kg.hr^{-1} 2010, catch rates decline to a contemporary low of 15.2 kg.hr^{-1} in 2017. Since 2017, CPUE has increased by 56%, reaching 23.7 kg.hr in 2021, which was among the highest on record and equated to a CPUE score of **9.0 out of 10** (Table 3-1). The mean length of greenlip harvested from this SAU declined from 156 mm in 2012 to 149 mm 2018, before increasing to average ~156 mm since 2019 (Figure 3-10b).

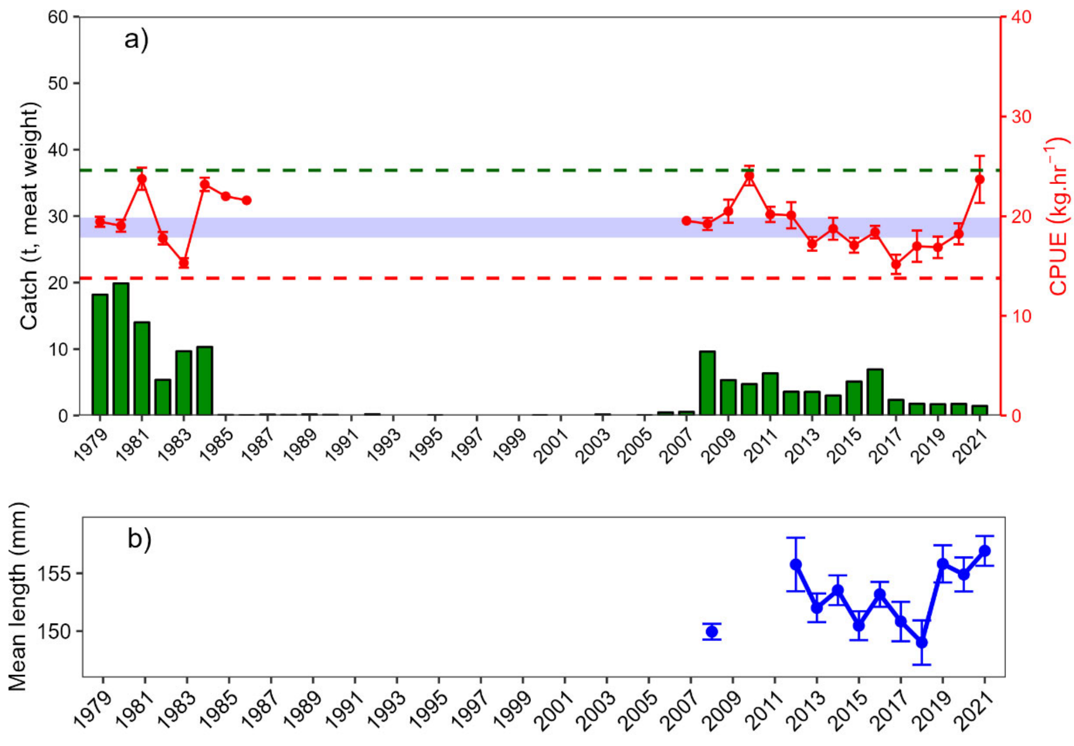

Figure 3-10 East Yorke Peninsula SAU data available from 1979 to 2021. a) Catch (green bars, tonnes), CPUE (red line), CPUE Target Range (score of 5, blue shading), CPUE upper limit (score of 10, green dashed line), and CPUE lower limit (score of 0, red dashed line). b) mean length (blue line). Gaps in all time series indicate no data.

West Kangaroo Island

The average catch from West KI before 2002 was 1.6 t.yr^{-1} (Figure 3-11a). After 2002, catches generally increased, reaching a peak of 9.5 t in 2014, before declining to <1t in 2016. Since 2016, catches have fluctuated between 1 and 4 t, including 2.4 t harvested in 2021. Catch-per-unit-effort fluctuated substantially among years prior to 2002. Thereafter, inter-annual variability in CPUE has decreased. In 2009, the CPUE estimate of 32.4 kg.hr^{-1}, was among the highest value on record, before steadily declining to average 17 kg.hr^{-1} between 2016 and 2018, which were among the lowest values on record. From 2019 and 2020, CPUE recovered averaging ~20.5 kg.hr^{-1}, but declined to 16.7 kg.hr^{-1} in 2021, which equated to a CPUE score of **0.5 out of 10** (Table 3-1). Historically, there has been high inter-annual variation in the mean length of greenlip in the commercial catch in this SAU (Fig. 3-11b).

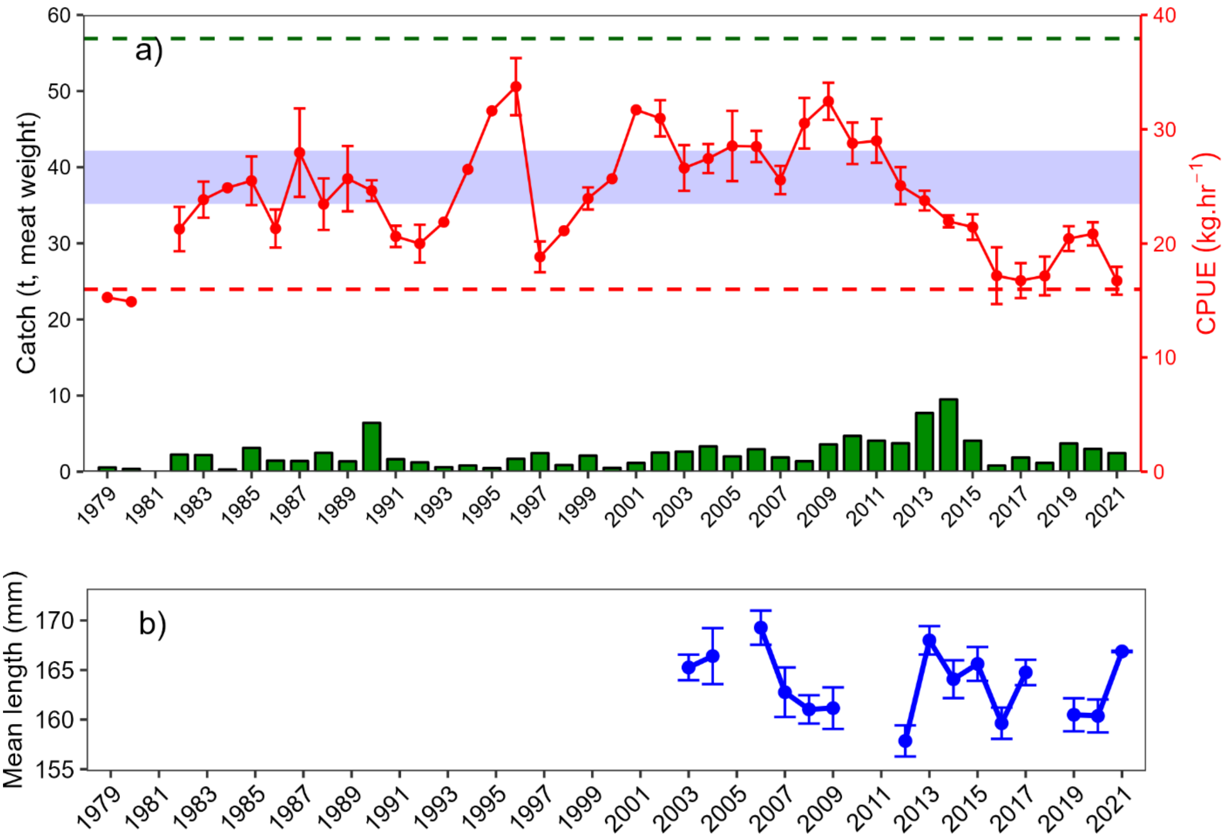

Figure 3-11 West Kangaroo Island SAU data available from 1979 to 2021. a) Catch (green bars, tonnes), CPUE (red line), CPUE Target Range (score of 5, blue shading), CPUE upper limit (score of 10, green dashed line), and CPUE lower limit (score of 0, red dashed line). b) mean length (blue line). Gaps in all time series indicate no data.

South Kangaroo Island

Prior to 1992 catches from this SAU were relatively high (~5 $t.yr^{-1}$; Figures 3-12a). Following this, a period of lower catches was observed for over a decade, until they increased again, reaching 6.3 t in 2010. After 2012, catches decreased, and have remained between 1.5 and 3.1 $t.y^{-1}$ since 2014. Catch-per-unit-effort was high in most years from 1999 to 2012, peaking at a maximum of 32.1 $kg.hr^{-1}$ in 2008. Subsequently, CPUE declined to 16.9 $kg.hr^{-1}$ in 2014, where after CPUE has fluctuated between 19 and 25 $kg.hr^{-1}$. The 2021 estimate of 19.5 $kg.hr^{-1}$ was below the target range, equating to a score of 3.8 out of 10 (Table 3-1). Historically, there has been a high level of inter-annual variation in the mean length of greenlip in the commercial catch for South KI. The 2021 estimate of 162 mm was among the upper range of estimates observed since 2001 (Fig. 3-12b).

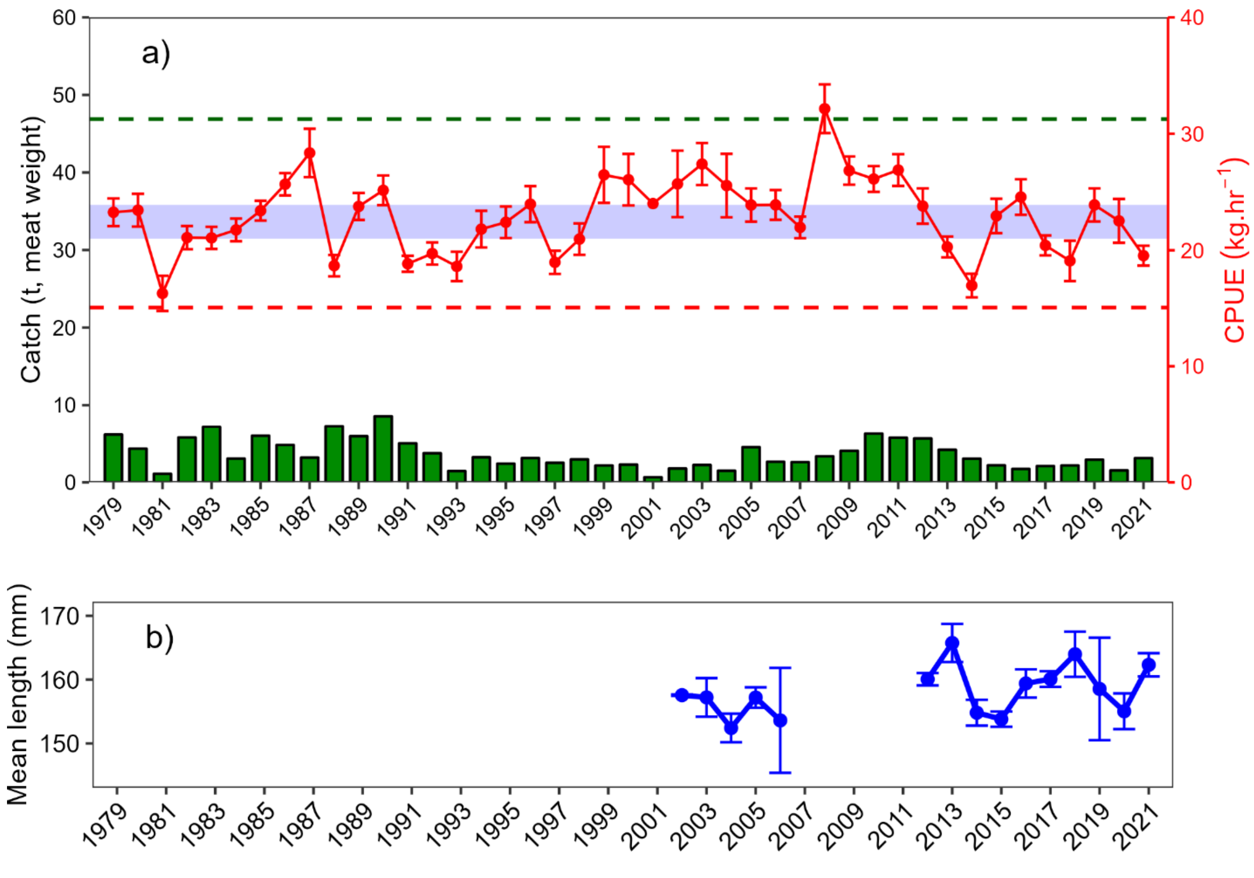

Figure 3-12 South Kangaroo Island SAU data available from 1979 to 2021. a) Catch (green bars, tonnes), CPUE (red line), CPUE Target Range (score of 5, blue shading), CPUE upper limit (score of 10, green dashed line), and CPUE lower limit (score of 0, red dashed line). b) mean length (blue line). Gaps in all time series indicate no data.

3.1.2.4 Temporal patterns in data limited SAUs

Catches and catch rates from the data limited SAUs were variable among years (Figure 3-13a,b). In 2021, the total catch from the combined data limited SAUs was 1.0 t (Figure 3-13a). The 2021 CPUE estimate was 12.7 kg.hr^{-1}, equating to a score of **0 out of 10** (Table 3-1). Traditionally, Cape Elizabeth supported the highest catch among the data limited SAUs, however, catches have not exceeded 2 t.y^{-1} since 2013. Catches from the other data limited SAUs have generally been low.

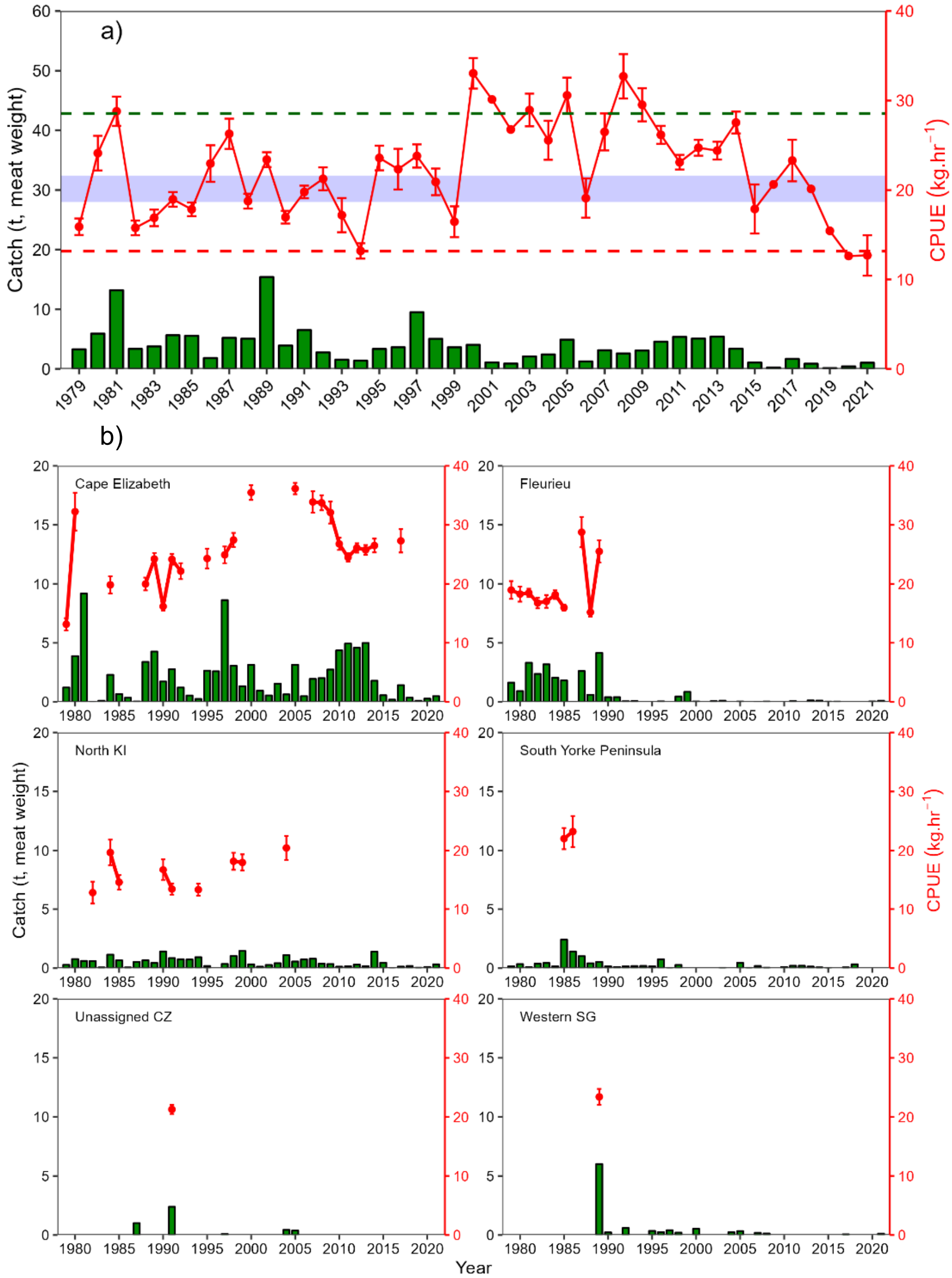

Figure 3-13 Data limited SAUs data available from 1979 to 2021. a) Combined data limited SAUs from 1979 to 2021. CPUE Target Range (score of 5, blue shading), CPUE upper limit (score of 10, green dashed line), CPUE lower limit (score of 0, red dashed line). b) Data limited SAUs from 1979 to 2021. Catch (green bars, tonnes) and CPUE (red line). Gaps in the time series no data.

3.1.3 Harvest strategy – zone score and stock status

The catch-weighted, zone score (i.e., biomass proxy) for greenlip in 2021 was **4.4 out of 10** (Table 3.1, Figure 3.14). In combination with the zone trend score (i.e., fishing mortality proxy) in 2021 of **4.9 out of 10** (reflecting a decreasing trend), these define the zonal stock status for greenlip in the CZ in 2021 as 'depleting' (Figure 3.15). The zone score of 4.4 in 2021 translates to a recommended zonal catch of 40.1 t for 2023.

Table 3-1 Outcome of application of the harvest strategy described in the Management Plan for greenlip in 2021.

SAU	Year	CPUE (kg.hr^{-1})	CPUE score	Legal density (abs.m^{-2})	Legal density score	Combined score	Catch (t)	Catch (proportion)	Weighted SAU score
Tiparra Reef	2021	21.1	5.0	0.08	5.0	5.0	7.7	0.36	1.80
West Yorke Peninsula	2021	19.0	4.6	0.03	4.6	4.6	9.1	0.34	1.56
West KI	2021	16.7	0.5		NA	0.5	2.4	0.09	0.04
East Yorke Peninsula	2021	23.7	9.0		NA	9.0	1.4	0.08	0.72
South KI	2021	19.5	3.8		NA	3.8	3.1	0.08	0.30
Data limited SAUs	2021	12.7	0.0		NA	0.0	1.0	0.05	0.00
								Zone Score	4.42

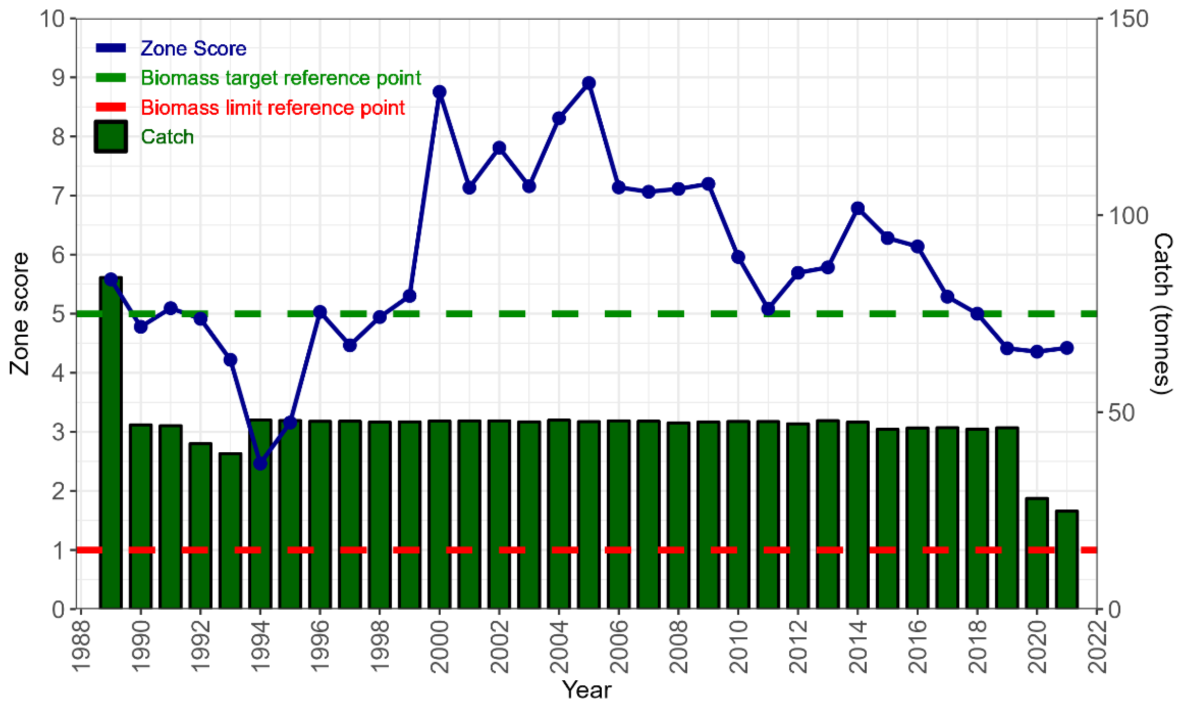

Figure 3-14 Zone score plot for CZ greenlip between 1989 and 2021. Zone score (blue symbols and line), biomass target reference point (green line), biomass limit reference point (red line) and catch (green bars, tonnes).

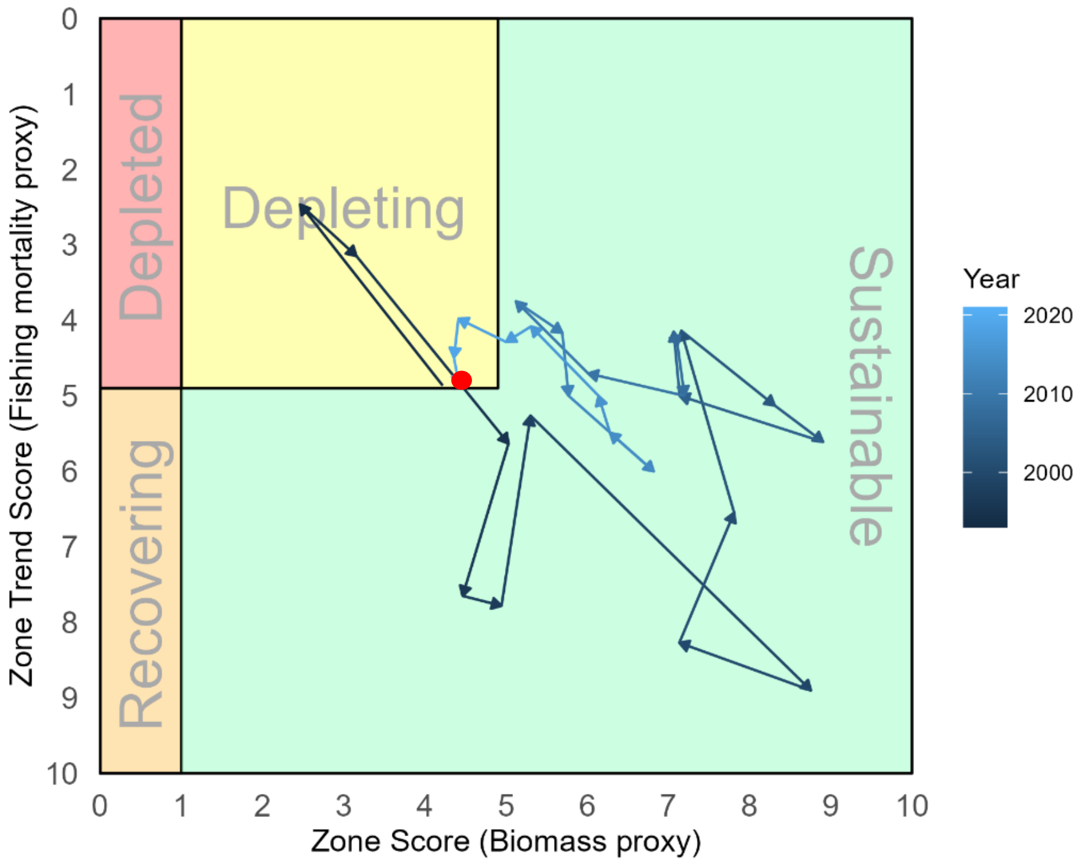

Figure 3-15 Phaseplot indicating changes in Central Zone greenlip stock status between 1993 and 2021. Red symbol indicates 2021 stock status (i.e., depleting).

3.2 Blacklip

3.2.1 Central Zone

3.2.1.1 Catch and CPUE

There have been limited data available for blacklip since 2018, when the fishery was closed and the TACC was zero (Figure 3-16a). The current, small catches of blacklip contrast with much larger historical catches. After TACC implementation in 1990, blacklip catch was relatively stable averaging 13.2 $t.yr^{-1}$ during the 1990s. From the early to mid-2000s both catch and TACC declined. A further TACC reduction from 8.1 to 6.4 t occurred in 2015, reflecting the implementation of the marine park sanctuary zones. Following the fishery closure in 2018 and subsequent reopening in 2019, approximately 1 t of blacklip has been harvested annually.

Catch-per-unit-effort was relatively stable between 1990 and 2009 (range: 22.4-28.9 $kg.hr^{-1}$; average: 25.9 $kg.hr^{-1}$). After 2009, CPUE has generally declined, but increased slightly between 2012 and 2015. Prior to the fishery closure, the 2017 estimate of 18.3 $kg.hr^{-1}$ was the lowest value on record. From the comparable paucity of data in 2020, the CPUE was 18.9 $kg.hr^{-1}$ (with elevated uncertainty compared to previous estimates); there were insufficient data to estimate zonal CPUE in 2019 or 2021 (i.e., <10 blacklip fishing days, Figure 3.16b).

There was no CPUE value in 2021 to extend the trend in relative catch and CPUE. The value for 2020 was the second lowest value on record, reflecting the low catch and catch rate in 2020 (Figure 3.16c).

3.2.2 Spatial assessment units

3.2.2.1 Distribution of catch among SAUs

The West KI SAU has contributed an average of 56% of the blacklip catch since 1979, increasing to 75% over the last decade (Figure 3-16d). The South KI SAU has contributed an average of 35% of the blacklip catch since 1979, decreasing to 20% over the last decade (Figure 3-16d). The current distribution of blacklip catches in 2021 reflects ongoing low levels of harvest from both West and South KI (Figure 3-16d). Prior to the fishery closure in 2018, catches harvested from West KI remained relatively high, whereas those from South KI have gradually decreased since the late 1980s. Blacklip catches from the data limited SAUs have typically been low.

3.2.2.2 Temporal patterns in unsurveyed SAUs

West Kangaroo Island

Catches have varied among years with peaks in 1989 (12.1 t) and 2001 (10.7 t; Figure 3-17a). Catch increased between 1990 and 1997, and then remained relatively stable at an average of 8.8 $t.yr^{-1}$ between 1997 and 2004. Lower caches were harvested from 2005 and 2017 (range: 4.4–6.9 t; average 5.5 $t.yr^{-1}$), prior to the fishery closure in 2018. Catches ranging from 0.6 and 1 t were harvested from this SAU between 2019 and 2021.

Catch-per-unit-effort was relatively stable from 1990 to 2009 (average: 27.4 $kg.hr^{-1}$), albeit with some inter-annual variability (range: 24.3-31.7 $kg.hr^{-1}$; Figure 3-17a). After a contemporary peak in 2009 at 31.3 $kg.hr^{-1}$, CPUE declined, before stabilising at approximately 25 $kg.hr^{-1}$ from 2012 to 2015. By 2017, CPUE had dropped sharply to 18.9 $kg.hr^{-1}$, which was lowest value on record. Following the reopening of the fishery, and from the comparable paucity of data, low values of 19.7 $kg.hr^{-1}$ and 22.3 $kg.hr^{-1}$ were estimated for CPUE in 2020 and 2021. The estimate in 2021 was based off the three-year running mean CPUE.

South Kangaroo Island

Annual catch from the South KI has decreased steadily since the late 1980s (Figure 3-18a). Prior to 2000, annual harvests from this SAU averaged 5 $t.yr^{-1}$, including historical highs of >8 $t.yr^{-1}$ in 1983, 1987 and 1988. During the 2000s, moderate catches were observed, averaging approximately 2.8 $t.yr^{-1}$. While a relatively large catch was obtained from this SAU in 2012 (3.3 t), subsequent catches have seldom exceeded 1 $t.yr^{-1}$, with 0.3 t harvested in 2021.

Catch-per-unit-effort was relatively stable from 1979 to 1998 (average: 25.1 $kg.hr^{-1}$), before a period of large fluctuation from 1999 to 2003. After 2003, CPUE generally declined, dropping to record lows of ~19 $kg.hr^{-1}$ from 2011 to 2014. Higher estimates of CPUE, ranging from 21 to 24 $kg.hr^{-1}$, were recorded between 2015 and 2017. There were insufficient data after 2017 to estimate CPUE.

3.2.2.3 Temporal patterns in data limited SAUs

Combined catches from the data limited SAUs peaked at ~3 $t.y^{-1}$ during the 1990s, but have generally remained low since 2000 (Figure 3-19a). Except for West Yorke Peninsula, blacklip catches from the data limited SAUs have been small and intermittent (Figure 3-19b). Catches from the West Yorke Peninsula have seldom exceeded 2 $t.yr^{-1}$ and, following the larger catches in the early 1990s, have not exceeded 1 $t.yr^{-1}$. While CPUE estimates are possible in most years due to the implementation of the running mean in the HS, there were insufficient data after 2017 to estimate CPUE.

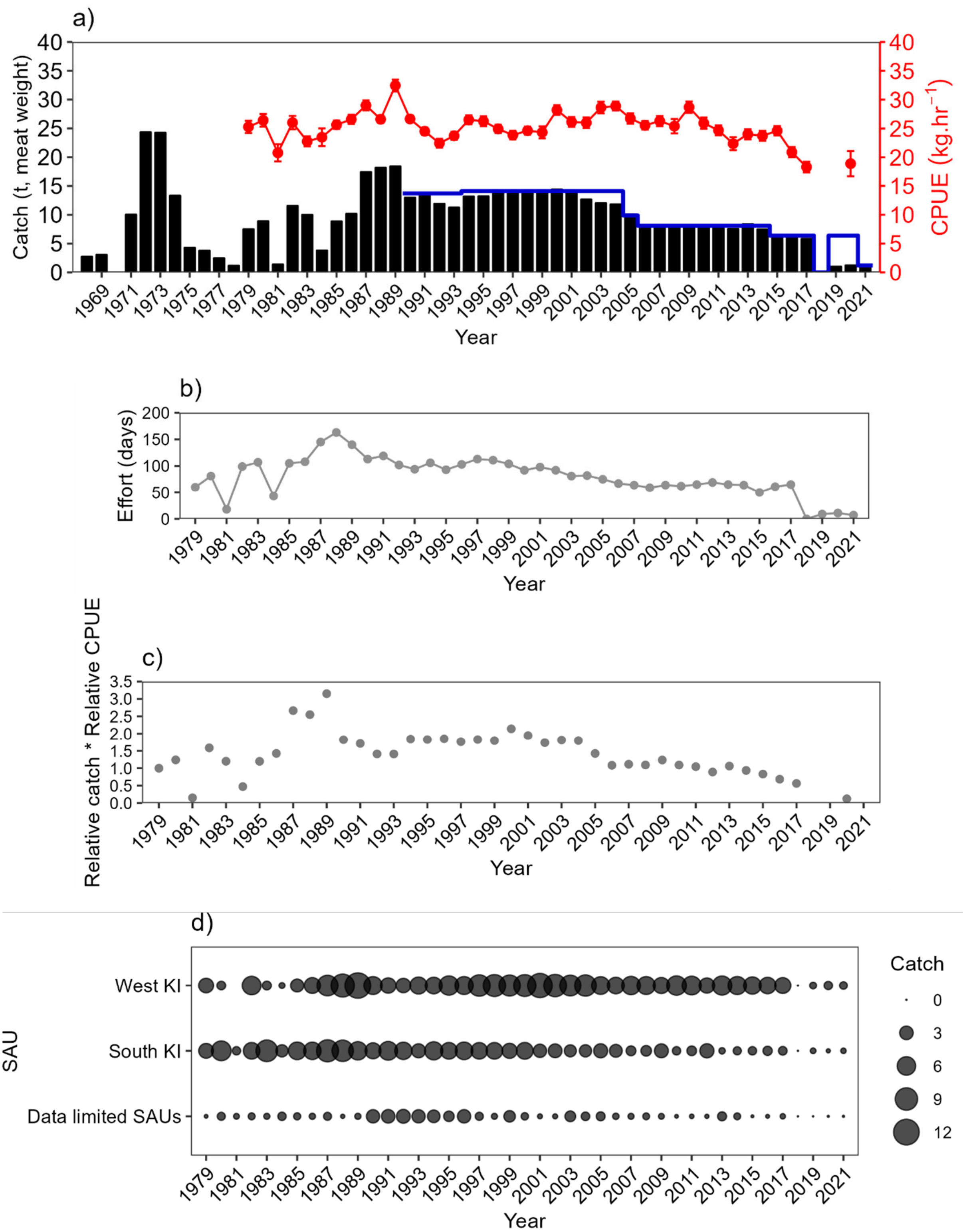

Figure 3-16 Zonal catch, CPUE, Effort, Catch * CPUE and the distribution of catch among SAUs available from 1968 to 2021 a) Total catch (black bars, tonnes), CPUE (red line) and TACC (blue line) of blacklip in the CZ 1968-2021. B) Effort (days) where blacklip are ≥30% of the daily catch in the CZ from 1968-2021 (grey line). C) Combined trend of relative catch and relative CPUE from from 1979 to 2021. D) Bubble plot showing the spatial distribution of the blacklip catch (black symbols) among each of the SAUs in the CZ from 1979 to 2021 (data limited SAUs from the HS are combined).

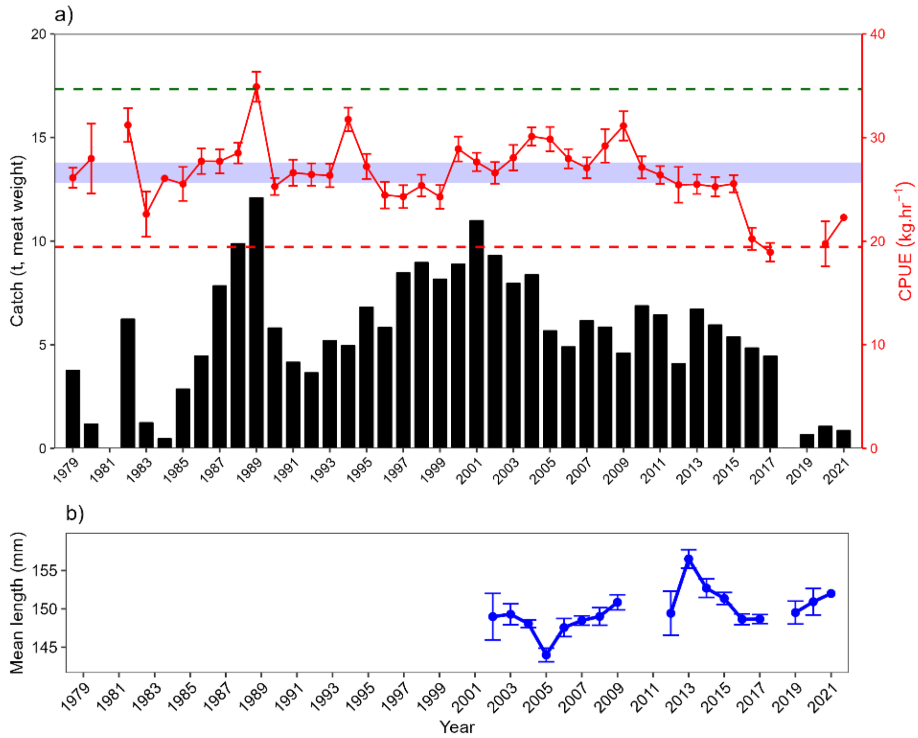

Figure 3-17 West Kangaroo Island SAU data available from 1979 to 2021. A) Catch (black bars, tonnes), CPUE (red line), CPUE Target Range (score of 5, blue shading), CPUE upper limit (score of 10, green dashed line), and CPUE lower limit (score of 0, red dashed line). B) mean length (blue line). Gaps in all time series indicate no data.

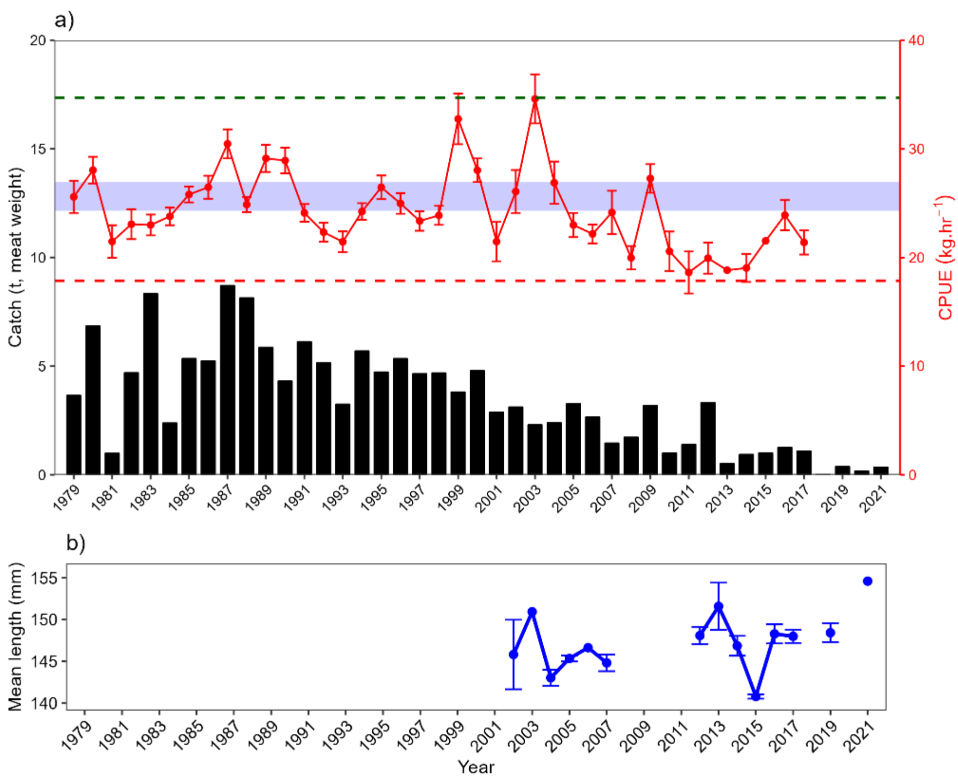

Figure 3-18 South Kangaroo Island SAU data available from 1979 to 2021. A) Catch (black bars, tonnes), CPUE (red line), CPUE Target Range (score of 5, blue shading), CPUE upper limit (score of 10, green dashed line), and CPUE lower limit (score of 0, red dashed line). B) mean length (blue line). Gaps in all time series indicate no data.

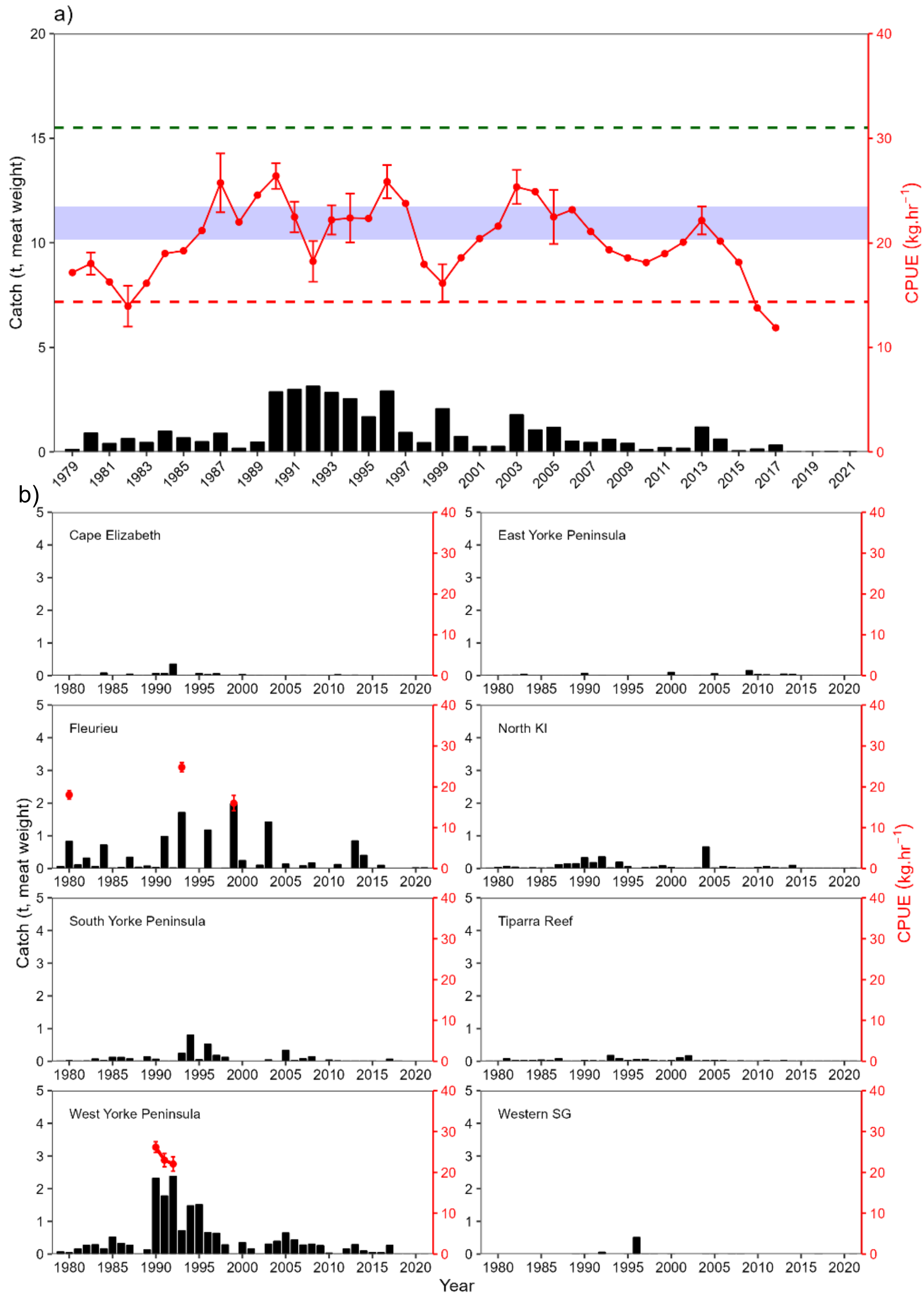

Figure 3-19 Data limited SAUs data available from 1979 to 2021. A) Combined data limited SAUs from 1979 to 2021. CPUE Target Range (score of 5, blue shading), CPUE upper limit (score of 10, green dashed line), CPUE lower limit (score of 0, red dashed line). B) Data limited SAUs from 1979 to 2021. Catch (black bars, tonnes) and CPUE (red line). Gaps in all the time series indicate no data.

3.3 GPS and depth logger data

Potential depth and spatial Pis are presented at the SAU scale from 2013 to 2021 (Figures 3-20 to 3-26). The data coverage of the logger program has declined substantially since 2020, associated with equipment breakdowns and non-replacement. In 2021, only 39 fishing days were recorded on the gps and depth loggers, compared with 224 from the logbook (Figure 3-20). The fishing effort for each SAU reflects this reduction in data collection.

For greenlip, the magnitude of the potential Pis varied among SAUs (Figures 3-21 to 3-26). In the SAUs around the Gulfs (i.e., Tiparra, West Yorke and East Yorke Peninsula), fishing effort generally occurred in waters <10 m depth, whilst off KI fishing at depths >10 m were most common. The highest catch density was at Tiparra Reef (~11 to 22 $kg.ha^{-1}$, Figure 3-21c), with lower levels in West and East Yorke Peninsula (~5-15 $kg.ha^{-1}$, Figures 3-22c and 3-23c), and the lowest was off KI (<10 $kg.ha^{-1}$, Figures 3-24c and 3-25c). Swim speed was greatest off KI (generally >400 $lm.hr^{-1}$, Figures 3-24b & 3-25b), and lower in the SAUs around the Gulfs (generally <400 $lm.hr^{-1}$, Figures 3-21b, 3-22b & 3-23b). In most SAUs the dive distance followed a similar temporal trend to swim speed. The median number of dives per day in most SAUs and years was between 1 and 3.

There were also different temporal trends evident in the potential PIs for each SAUs. Those for catch density are discussed briefly. For Tiparra Reef, catch density peaked in 2014, and has declined thereafter (Figure 3-21c). In West Yorke Peninsula, catch density has been variable among years, but has remained low since 2019 (Figure 3-22c). At East Yorke Peninsula, catch density increased between 2013 and 2020 (Figure 3-23c). Catch density in the West and South KI SAUs has varied among years, with very low levels of effort recorded since 2018 (Figures 3-24c & 3-25c).

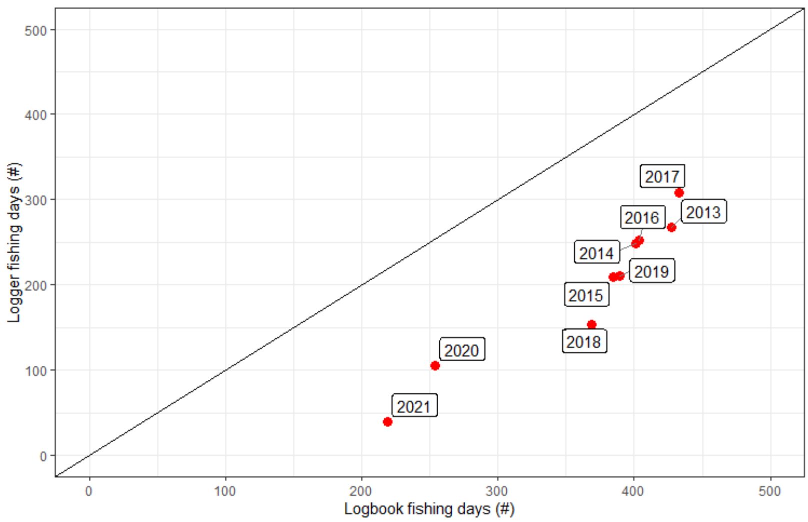

Figure 3-20 Fishing days recorded in the logbook versus the logger data from 2013 to 2021.

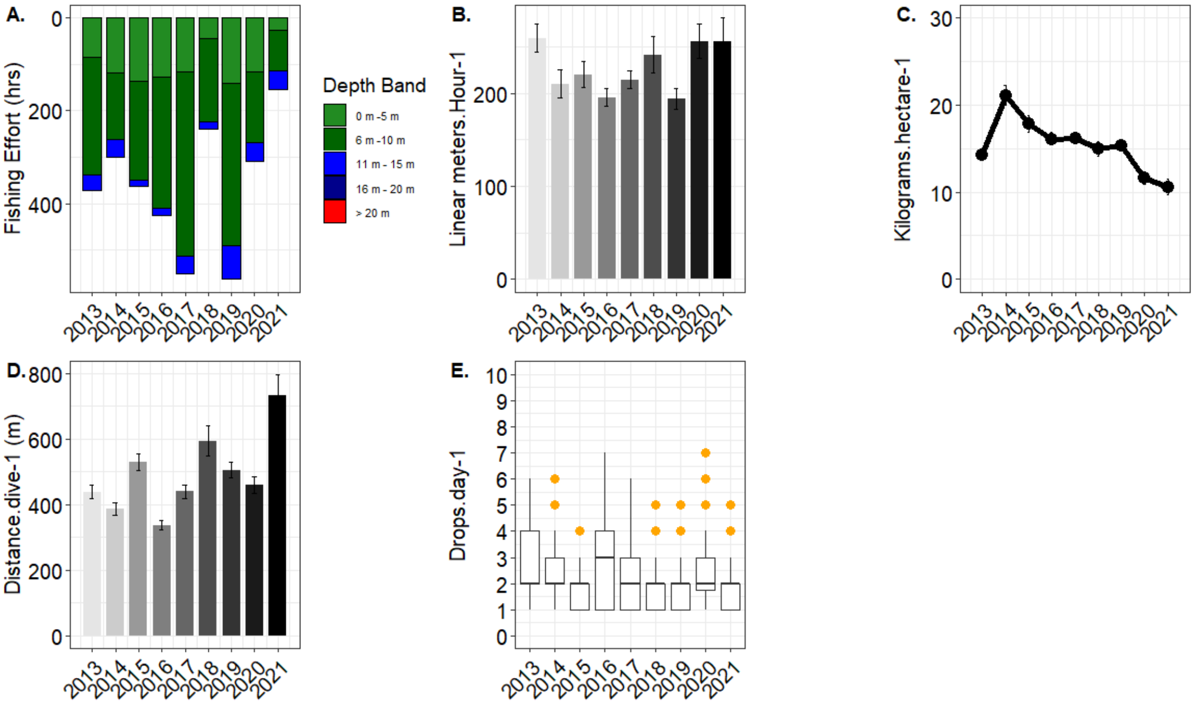

Figure 3-21 Potential logger based performance indicators for greenlip in the Tiparra Reef SAU from 2013 to 2021. a) effort (hours) from each 5m depth, b) linear meters.hour^{-1} (mean ±SE, greyscale bars), and c) kilograms.hectare^{-1} (mean ±SE, black line), d) maximum distance.dive^{-1} (mean ±SE, greyscale bars) and e) drops.day^{-1} (box plots).

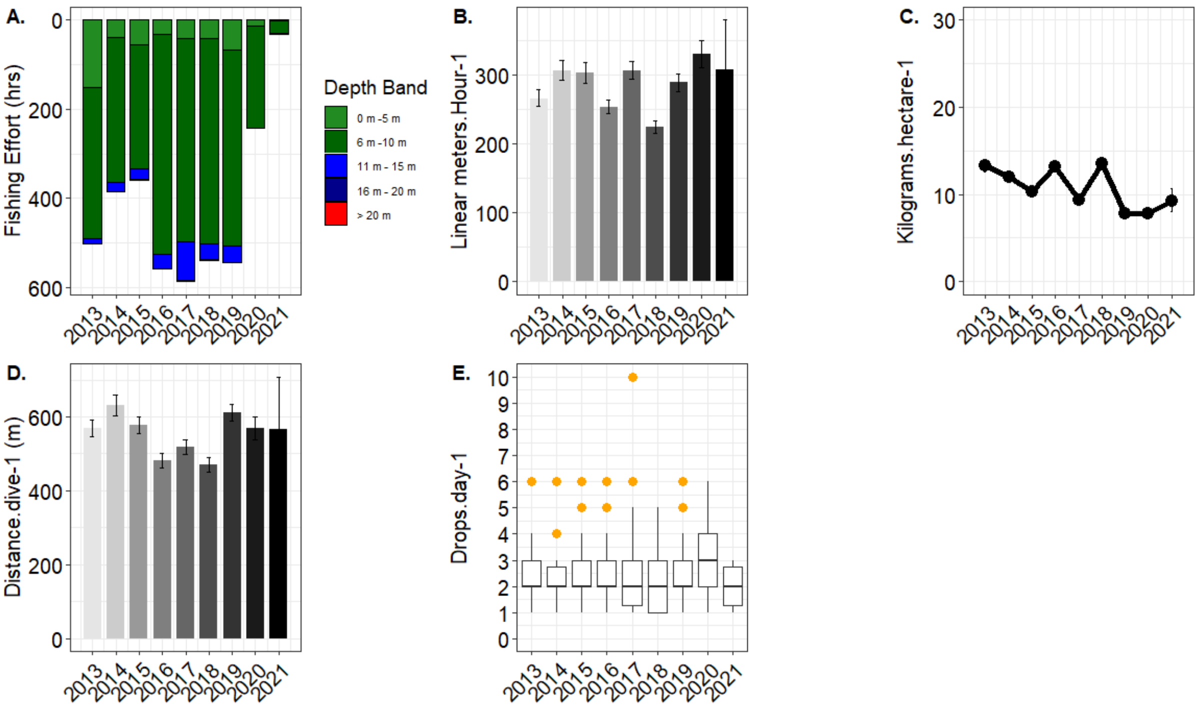

Figure 3-22 Potential logger based performance indicators for greenlip in the West Yorke Peninsula SAU from 2013 to 2021. a) effort (hours) from each 5m depth, b) linear meters.hour^{-1} (mean ±SE, greyscale bars), and c) kilograms.hectare^{-1} (mean ±SE, black line), d) maximum distance.dive^{-1} (mean ±SE, greyscale bars) and e) drops.day^{-1} (box plots).

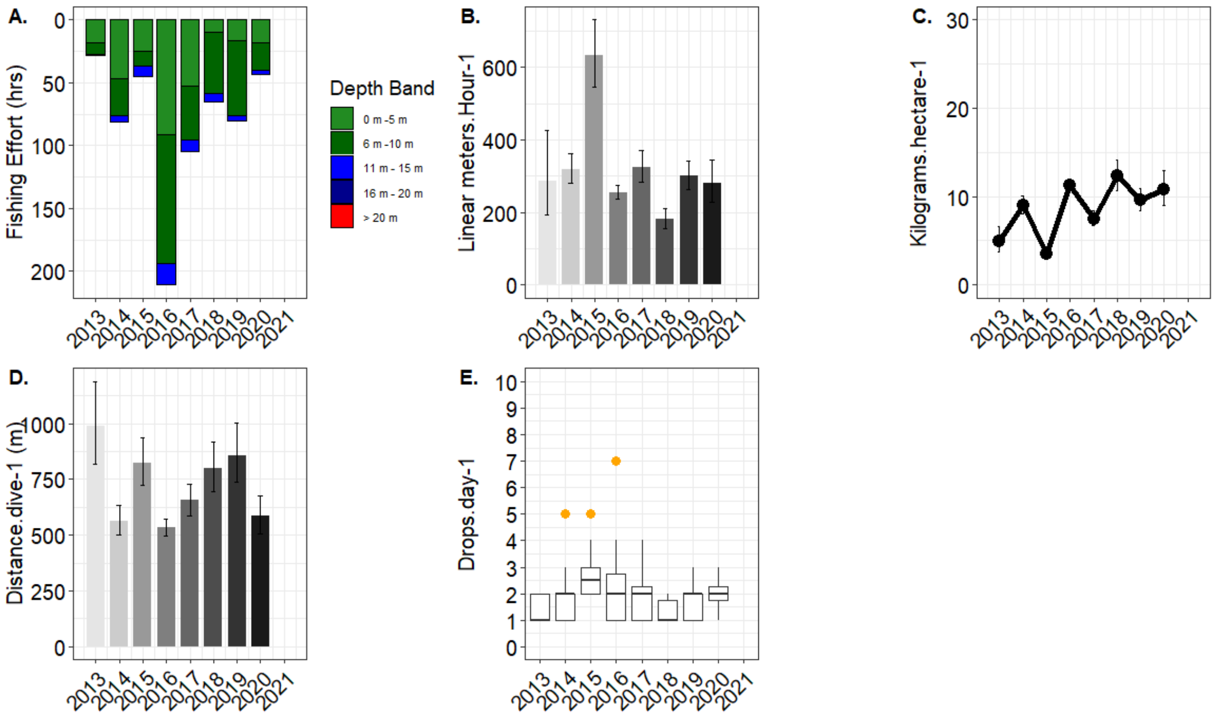

Figure 3-23 Potential logger based performance indicators for greenlip in the East Yorke Peninsula SAU from 2013 to 2021. a) effort (hours) from each 5m depth, b) linear meters.hour^{-1} (mean ±SE, greyscale bars), and c) kilograms.hectare^{-1} (mean ±SE, black line), d) maximum distance.dive^{-1} (mean ±SE, greyscale bars) and e) drops.day^{-1} (box plots).

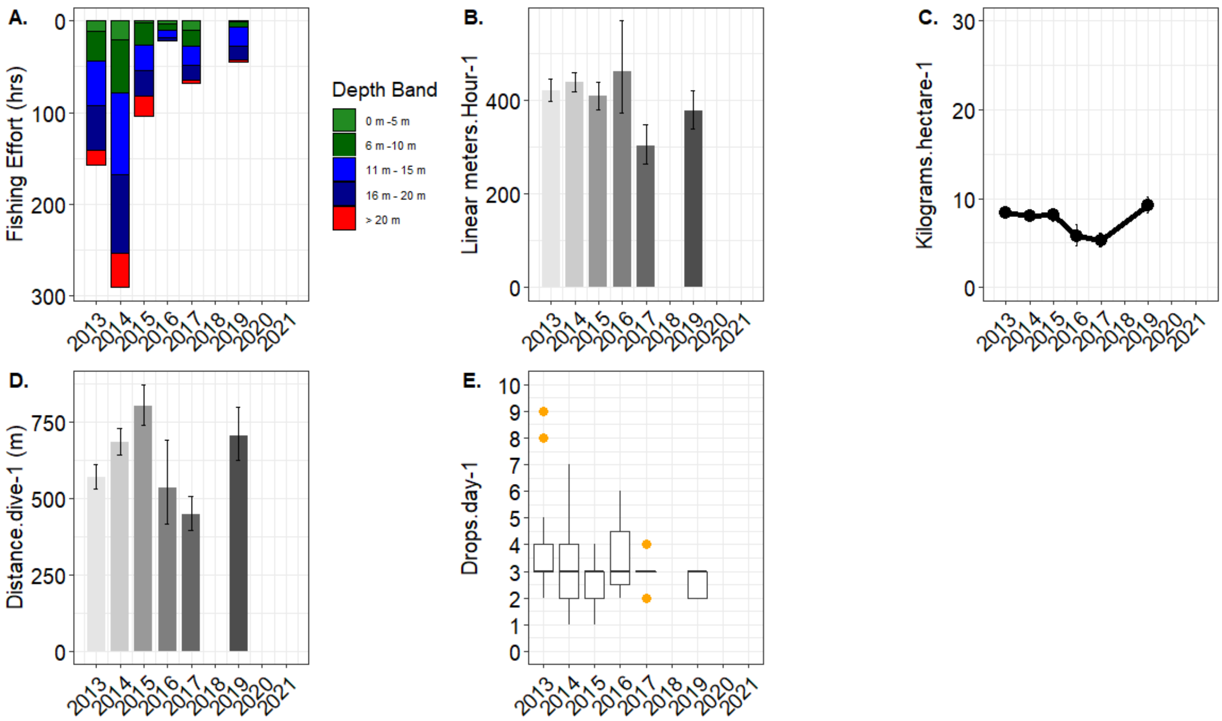

Figure 3-24 Potential logger based performance indicators for greenlip in the West Kangaroo Island SAU from 2013 to 2021. a) effort (hours) from each 5m depth, b) linear meters.hour^{-1} (mean ±SE, greyscale bars), and c) kilograms.hectare^{-1} (mean ±SE, black line), d) maximum distance.dive^{-1} (mean ±SE, greyscale bars) and e) drops.day^{-1} (box plots).

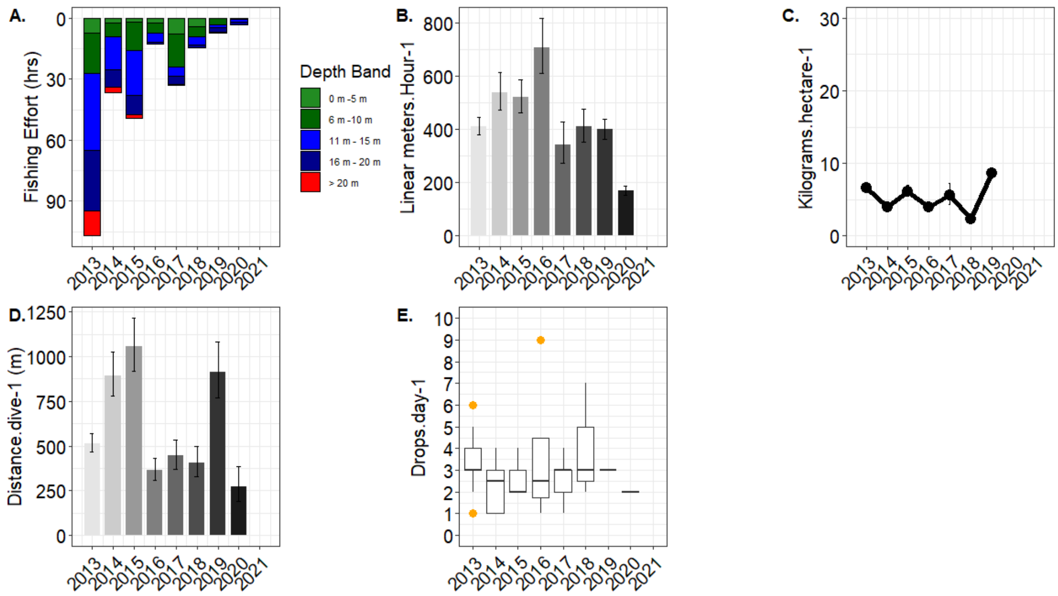

Figure 3-25 Potential logger based performance indicators for greenlip in the South Kangaroo Island SAU from 2013 to 2021. a) effort (hours) from each 5m depth, b) linear meters.hour^{-1} (mean ±SE, greyscale bars), and c) kilograms.hectare^{-1} (mean ±SE, black line), d) maximum distance.dive^{-1} (mean ±SE, greyscale bars) and e) drops.day^{-1} (box plots).

For blacklip, the effort recorded on the loggers in has been negligible since 2018 (Figure 3-26a). The catch density was highest in 2014, subsequently declining until 2019. Swim speed declined between 2013 and 2016, but increased thereafter.

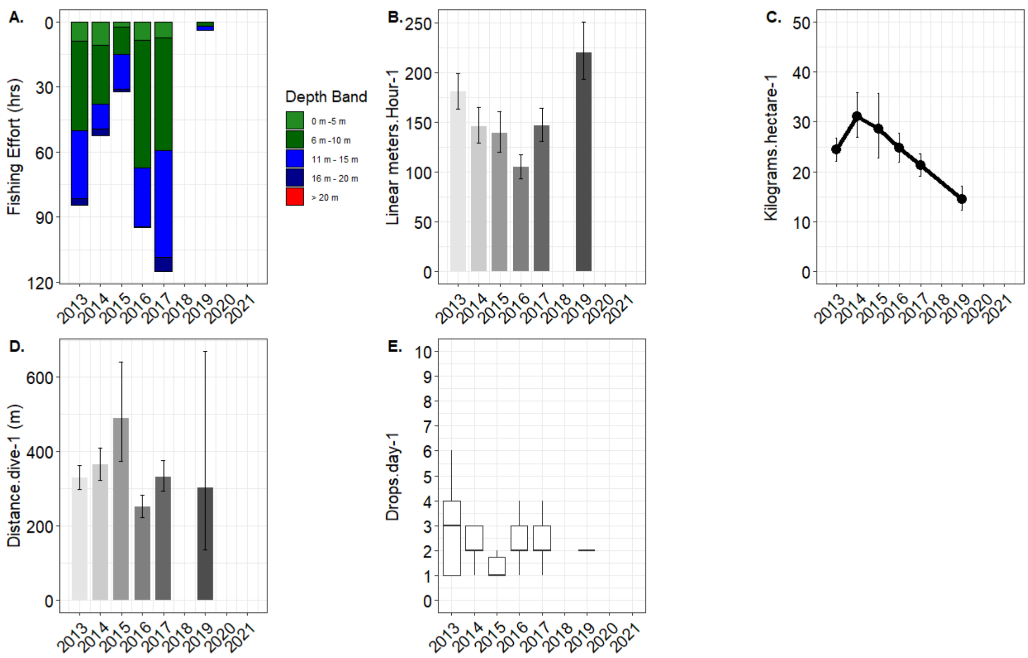

Figure 3-26 Potential logger based performance indicators for blacklip from 2013 to 2021. a) effort (hours) from each 5m depth, b) linear meters.hour^{-1} (mean ±SE, greyscale bars), and c) kilograms.hectare^{-1} (mean ±SE, black line), d) maximum distance.dive^{-1} (mean ±SE, greyscale bars) and e) drops.day^{-1} (box plots).

4 DISCUSSION

4.1 Current status of greenlip and blacklip

The stock status for greenlip was determined using the Harvest Strategy from the Abalone Management Plan (PIRSA 2021), which is aligned with outcomes consistent with the national fishery status reporting framework (NFSRF; Piddock *et al.* 2021). The HS applies two key indicators, CPUE and abalone legal density from the FIS, to generate proxies for biomass and fishing mortality.

There were a number of limitations associated with this assessment. First, CPUE is used as a key index of relative abundance. Yet, CPUE can be influenced by numerous factors unrelated to abalone abundance (Stobart *et al.* 2017), and this measure is often viewed as a biased index of relative abundance (Harrison 1983, Breen 1992, Prince and Shepherd 1992, Gorfine *et al.* 2002, Stobart *et al.* 2017). Second, there was a need to scale estimates of biomass from the surveyed area to the Tiparra Reef and West Yorke Peninsula SAUs. This approach relies on assumptions regarding abalone density outside of the surveyed area and the total area of fishable reef, which introduces uncertainty into the scaled estimates. Third, since the 2018 closure there are limited commercial logbook data for blacklip, and there are no FIS data for this species. This means that assessment of blacklip stocks in the CZ after 2018 is not possible.

4.1.1 Greenlip

Prior to 2020, catches of greenlip in the CZ fishery were consistent with the TACC and around 46 t per year. In 2020, greenlip catch declined to 28 t and remained low at 25 t in 2021. These declines in greenlip catch do not reflect TACC reductions, but rather voluntary under-catch from industry relating to concerns for greenlip stocks. This decline in catch is analogous with many other abalone fisheries across southern Australia, which are currently characterised by ongoing low levels of catch and productivity (Burnell *et al.* 2022; Stobart and Mayfield 2021; Mundy and McAllister 2022; Piddocke *et al.* 2021).

Following record high CPUEs in the early 2000s, over the last 20 years catch-rate has declined from 31 kg.hr^{-1} in 2001 to 19.2 kg.hr^{-1} in 2021, and is now among the lowest levels observed since the TACC was introduced in 1990. Among the six SAUs identified in the HS, two had CPUE values above or within the target range (i.e., Tiparra Reef & East Yorke Peninsula), whereas the remaining four SAUs had values below the target range (i.e., West Yorke Peninsula, South Kangaroo Island West Kangaroo Island and the combined data-limited SAUs).

The legal density of greenlip from the FIS were within, or slightly below, the target range of the HS. At Tiparra Reef (HS score of 5.0 out of 10) the legal density of greenlip declined by 20% between 2019 and 2021 and was among levels observed during the 1990s and 2010s. At West Yorke Peninsula (HS score of 4.6 out of 10), the legal density of greenlip increased by 17% between 2019 and 2021 but remained 29% below the peak level recorded in 2017.

Since 2019, substantial reductions in catch have been observed in the two key SAUs, Tiparra Reef and West Yorke Peninsula, which combined, have supported >70% of historical greenlip catches in the CZ. Similarly, CPUE has declined substantially from recent peaks, and is now among the lowest level at Tiparra Reef since the late 1990s and among the lowest level at West Yorke Peninsula in the last decade. The estimated harvestable biomass has also declined by 27% at Tiparra Reef and 40% at West Yorke Peninsula from peak levels recorded in 2017. Thus, despite combined scores of 5.0 (Tiparra Reef) and 4.6 (West Yorke Peninsula) from the HS, there is evidence the harvestable biomass of these key greenlip stocks in the CZ is low, and that recruitment may also be impaired. Importantly, the decline in catch (39% and 46% below 2020 and 2021 TACCs, respectively), has exceeded that of harvestable biomass, resulting in reduced fishing mortality reflected in the estimated HFs for Tiparra Reef (0.09 - 0.17) and West Yorke Peninsula (0.07), falling to the lowest level since the biomass surveys commenced.

Reductions in harvest fraction and fishing mortality improve the likelihood of successful recruitment and future stock recovery. The industry-led initiative to reduce catch is timely, particularly given the current low levels of sub-legal greenlip recorded in the FIS across key grounds of the CZ (i.e., Tiparra Reef, Corny Point and Port Victoria), when compared with the historical estimates. At Tiparra Reef, the density of sub-legal greenlip remained substantially below peak levels observed during the 1990s and 2000s, despite an almost 40% increase in 2021. At West Yorke Peninsula, the density of sub-legal sized greenlip has been relatively stable since the expanded survey commenced, although this is largely attributable to stable numbers in the Hardwicke Bay mapcode. In 2021, the FIS at both Port Victoria and Corny Point yielded the lowest estimates of sub-legal greenlip density since the survey design was expanded in 2015, with densities approximately 50% below 2015 levels.

There is additional evidence of low and/or declining greenlip stock status from the GPS loggers in the two key SAUs, since the collection of these data commenced in 2013. Logger estimates of catch density ($kg.ha^{-1}$) for Tiparra Reef and West Yorke Peninsula were at or among the lowest values recorded in recent years, having declined since the early-to-mid 2010s. This decline in catch density indicates divers are covering a greater area to harvest the same amount of greenlip. A notable exception to this pattern was the East Yorke Peninsula SAU, where catch density has increased since 2013. It is important to note the data coverage from the GPS loggers has reduced in recent years (see section 4.2 Future research needs).

The SAUs from the CZ fishery without FIS (i.e., unsurveyed SAUs) have supported <30% of historical greenlip catches. The assessment of stocks in these SAUs is limited to analysis of catch and effort information available from the commercial logbook. Collectively, both catch and CPUE from these SAUs are among historically low levels, having declined considerably over the last decade. One exception to this in 2021 was a sharp increase in CPUE in the East Yorke Peninsula SAU. However, catch in this SAU remains low. For the two SAUs from Kangaroo Island (i.e., West and South KI) moderate greenlip catches were harvested in 2021, that were similar to average historical levels. However, CPUE estimates remained below target levels, scoring 0.5 and 3.8 in the HS, respectively. Following lower catches from the Kangaroo Island SAUs since the mid-2010s, there has not been a sustained increase in CPUE to levels at, or above, the target range, indicating the harvestable biomass of greenlip in these SAUs remains low. Catch and CPUE from the combined data limited SAUs were both among record low levels.

Application of the HS in 2021 resulted in a **zone score of 4.4 out of 10** that, in combination with the **zone trend score of 4.9 out of 10** (reflecting a decreasing trend), define the stock status for greenlip in the CZ in 2021 as **'depleting'**, which is consistent with recent classifications in 2019 and 2020. This means that biomass is declining and fishing mortality is too high (i.e., overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired (see Table 1-1). The zone score of 4.4 in 2021 translates to a recommended zonal catch of 40.1 t for 2023.

The Zone Score of 4.4 and 'depleting' status from the HS in 2021 reflects declining greenlip biomass. However, this likely underestimates the recent decline of the CZ greenlip stocks, relative to historic catches or available biomass. The current low catch and CPUE are indicative of low abalone density, and there is evidence that some stocks are already recruitment impaired. For example, the current catch for the CZ and Tiparra Reef – the lowest since 1974 – were harvested at CPUEs among the lowest on record, demonstrating recent levels of recruitment to the fishable biomass are substantially lower than those which supported previous, long-term, higher catches and catch rates. It is likely that these declines reflect a combination of overfishing and environmentally-driven changes in productivity, potentially via reductions in recruitment, as evident for other fisheries across southern Australia (e.g., Rock Lobster; Linnane *et al.* 2010, 2019). This information, in conjunction with the current mismatch between the recommended catch from the HS and reported catches, suggests lower catches may be required to support rebuilding of the CZ greenlip stock.

4.1.2 Blacklip

Since the 2018 fishery closure, there have been limited data available for the assessment of blacklip stocks, or to measure the impact of that closure and subsequent low levels of fishing on stock recovery. This is because the low catches of blacklip in 2019, 2020 and 2021 were harvested from relatively few fishing events due to the lower TACC, with daily catches reported in the logbook often dominated by greenlip, resulting in the measures of catch rate differing from those obtained previously when mixed species fishing occurred at a higher blacklip TACC. Thus, the blacklip CPUE estimates from 2019 differ substantially from, and cannot be directly compared with, CPUE estimates prior to 2018. Using a 'weight-of-evidence' approach, the fishery was classified as depleted in 2017 under the NFSRF (Burnell et al. 2018). As there are no recent data suitable for assessing changes in blacklip harvestable biomass, informing any potential change in stock status, or for application of the HS, blacklip in 2021 remains classified as '**depleted**'. Stock status classifications for blacklip in 2019 and 2020 (reported in Burnell et al. 2020, 2021) have been updated following the approach taken in this report to assign stock status for 2021. A depleted stock status means that biomass is depleted (from catch and/or non-fishing effects) and that recruitment is impaired. Adequate management measures, including a closure in 2018, low catches from 2019 to 2021, and a second closure from 2022, have been put in place but have not yet resulted in measurable improvements. It is likely a dedicated research program will be required before information that can be used to identify changes in the blacklip stocks become available.

4.2 Future research needs

The highest priority research need is to ensure that GPS and depth logger data collected in the CZ fishery are available to SARDI for assessment. These data are no longer collected using SciElex loggers and are not currently available for analysis by SARDI. As was highlighted in Burnell *et al.* (2020) a longer time-series of data across different levels of stock abundance is important for formalised testing and validation of logger PIs. Given the current low biomass across the CZ fishery, collecting these data now is critical to inform their assessment as a potential PI, and evaluating their potential for use in the harvest strategy. There is potential for logger derived PIs to provide, 1) a more direct measure of stock abundance than CPUE that is less hyperstable, and 2) a less costly and more spatially representative method of data collection than FIS. There is also ongoing research regarding the potential of using logger data as a variable that could be used to spatially standardise CPUE, as part of FRDC Project 2017-026 - *Can spatial fishery-dependent data be used to determine abalone stock status in a spatially structured fishery?* (Principal Investigator Dr Craig Mundy).

Consistent with the previous assessments (see Burnell *et al.* 2018, 2020, 2021), the next priority for the CZ abalone fishery is to determine the level of blacklip harvestable biomass. Currently, there are no recent data suitable for assessing changes in blacklip harvestable biomass, informing any potential change in stock status, or for application of the HS.

The third research priority is to continue exploring best practice stock enhancement methods that could help accelerate rebuilding of greenlip and blacklip stocks. Following FRDC project 2020-116 (*Accelerating Greenlip Abalone stock recovery in South Australia using release of hatchery-reared juveniles. Phase 1 - genetic risk assessment and preliminary cost-benefit analysis*), there is an upcoming planned release of juvenile greenlip at the Glenelg Shellfish Restoration Reef. This release will be an opportunity for the CZ Industry to develop the necessary skills required for abalone reseeding, including the planning and monitoring required for successful stock enhancement.

The fourth research priority is the completion of FRDC Project 2019-118 - *Drawing strength from each other: simulation testing of Australia's abalone harvest strategies* (Principal Investigator Dr Cathy Dichmont). This project is comparing the strengths and weaknesses of abalone harvest strategies from across Australia, with a focus on the CZ greenlip fishery as one of its key research subjects. As such, the adoption of learnings and outcomes from this project has the potential to significantly improve future harvest strategies applied in SA.

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1. **Appendix 1.** Abalone Biology

Table A1-1 Shell length (mm) at 50% maturity for greenlip in the CZ.

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

Table A1-2 Relationship between shell length (mm) and bled meat weight (BMW, g) for greenlip in the CZ. The equation is of the form BMW = aSLb.

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

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

Table A1-3 Relationship between fecundity (F, millions of eggs) and shell weight (SW, g) and between fecundity and shell length (mm) for greenlip at Tiparra Reef and West Island in the CZ. The equations are of the form F = aSLb and F = c + dSW.

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

Table A1-4 Mean growth rate ($mm.yr^{-1}$) of greenlip tagged and recaptured in the CZ.

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

Table A1-5 Growth rate parameters k (yr^{-1}) and L_∞ (mm SL) for greenlip tagged and recaptured in the CZ of the South Australian Abalone Fishery. Length ranges are shell length (mm).

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

Table A1-6 Natural mortality rates ($M.yr^{-1}$) for adult (emergent) greenlip at two sites in the CZ.

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

Table A1-7 Shell length at 50% maturity (mm) for blacklip in the CZ.

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

Table A1-8 Relationship between fecundity (F, millions of eggs) and shell length (mm) for blacklip in the CZ. The equation is of the form $F = aSL^b$.

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

Table A1-9 Growth rate parameters k (yr^{-1}) and L_∞ (mm SL) for blacklip tagged and recaptured in the CZ. Errors provided are standard errors. Length ranges are shell length (mm).

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

Table A1-10 Natural mortality rates ($M.yr^{-1}$) for adult (emergent) blacklip at two sites in the CZ.

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

2. **Appendix 2.** Performance indicators and other calculations

Table A2-1 Summary of the Performance Indicators and other metrics and the formulae and data constraints underpinning their computation.

Metric use	Description	Formulae	Data constraints
Performance indicator			
CPUE	Commercial catch-per-unit effort (kg.hr^{-1})	$CPUE_{wp} = \frac{\Sigma_{i=1}^{n} wi(\frac{Csi}{Ei * wi})}{\Sigma_{i=1}^{n} wi}$	All records where: CPUE (total catch/total effort) was >66.66 kg.hr^{-1}; fishing effort was >8 hr; fishing effort was <3 hr.; the reported catch of the species for which CPUE was being estimated was <30% of the total catch were excluded. Minimum sample size: 10 records
Density$_{legal}$	Density of legal-sized abalone on surveys	$\text{Density}_{\text{Legal}} = \frac{\sum \text{Legal counted}}{\text{Total area surveyed}}$	>90% of survey completed Greenlip ≥135 mm SL defined as legal-sized
General assessment			
Mean Length	Mean length of abalone from shell sampling program of commercial catch	$L_{\text{mean}} = \frac{\sum \text{Shell length}}{\text{n shells}}.$	Abalone ≥135 mm SL
Density$_{sublegal}$	Density of sublegal (i.e., those under the MLL) abalone on surveys	$\text{Density}_{\text{Pre-recruit}} = \frac{\sum \text{Sublegal counted}}{\text{Total area surveyed}}$	>90% of survey completed Greenlip <135 mm SL defined as legal-sized

3. **Appendix 3.** Harvestable Biomass calculations

Tiparra Reef

The GPS logger data were used to stratify Tiparra Reef into areas of high (stratum 1), medium (stratum 2) and low (stratum 3) fishing intensity based on the KUD (Table A3-1). The locations of the leaded-lines sampled are based on GPS logger data collected in two periods (2006 to 2009 and January to June 2013). Data where vessels were moving at ≥5 $km.hr^{-1}$ were excluded from all analyses. The total area in which surveys were conducted was 3.2 km^2. The leaded-line method was used to estimate the bled-meat weight (BMW) harvestable biomass of greenlip (i.e., ≥ 135 mm SL) within this survey area following the approaches described in Carlson *et al.* (2006), McGarvey *et al.* (2008), Mayfield *et al.* (2008a,b, 2011) and Burnell *et al.* (2016, 2018). Greenlip were collected from Tiparra Reef in spring 2013 and used to establish the SL to BMW relationship required to estimate harvestable biomass ($BMW = 5.65x10^{-4} * SL^{2.507}$).

As only a subset of the fishing grounds on Tiparra Reef are surveyed, the harvestable biomass estimates were 'scaled' to the Tiparra Reef SAU using five methods (equations shown in Table A3-2). Three of these methods have been applied biennially since 2013. Two methods introduced in 2017 reflect comments received during an external review of the fishery assessment program for the CZ, which suggested estimates of total reef area at Tiparra Reef were underestimated by the first three methods (Prof. Keith Sainsbury, personal communication). The repeated methods were (1) assuming the area surveyed represents the area from which 77% of the catch was harvested (based on the 2006-2013 GPS data; Table A3-2 eq. 1); (2) assuming the area surveyed represents the area from which 75% of the catch was harvested (mean estimate from commercial divers following their assessment of the survey design; Table A3-2 eq. 2); and (3) determining the area that contained a further 13% of GPS points (i.e., stratum 4 - total area encompassing 90% GPS points) and adding the estimated harvestable biomass of greenlip in this unsurveyed area to the harvestable biomass estimate for strata 1-3. The harvestable biomass of greenlip in this area (2.8 km^2) was estimated using a predicted survey density for stratum 4 (Table A3-2 eq. 3 & 4). The two newer methods yield a revised estimate for the area of stratum 4 and were combined with the same predicted survey density applied in Method 3. These were (4) a revised estimate of 3.3 km^2 for stratum 4, calculated by subtracting the survey area (3.2 km^2) from the total fished reef area estimate derived from the combined daily KUD_{90} between 2013 and 2017 (6.5 km^2); and (5) a revised estimate of 10.3 km^2 for stratum 4, calculated by subtracting the survey area (3.2 km^2) from the total fished reef area estimate derived from the intersection of the combined daily KUD_{90} with the one-hectare hexagonal grid overlay between 2013 and 2017 (13.5 km^2).

For method 5, the level of intersection of the combined daily KUD_{90} with the one-hectare hexagonal grid (e.g., fractional, partial, complete) was ignored.

The reported catch from Tiparra Reef at the mid-point of the survey was then added to scale each estimate of harvestable biomass to pre-season levels (Table A3-2). Total annual catch was then used to estimate the potential range of exploitation rates for this SAU. This approach required two key assumptions: the net effect of natural mortality and recruitment were zero until the survey midpoint and the SL-meat weight relationship is time invariant. While it is reasonable to assume that recruitment would be offset by natural mortality, seasonal variation in greenlip meat weights (Stobart *et al.* 2013) suggests that the survey estimates of harvestable biomass would be under, rather than overestimated.

West Yorke Peninsula

Based on the GPS data three strata were surveyed in each location, which encompassed areas of high (stratum 1), medium (stratum 2) and low (stratum 3) fishing intensity based on the KUD (Table A3-1). The locations of the sixty leaded-lines sampled are based on GPS logger data collected in two periods (2006 to 2009 & 2013 to March 2015). GPS data where vessels were moving at ≥10 $km.hr^{-1}$ were excluded from all analyses. Hardwicke Bay encompassed the largest total area (21.7 km^2), followed by Corny Point (7.6 km^2) and Port Victoria (4.0 km^2). The percentage of GPS points and number of leaded-lines surveyed in each stratum are listed in Table A3-1. Four lead-lines at Corny Point were removed from the survey design in 2021, due to very low greenlip densities from 2015 to 2019. For the purpose of the biomass estimates the size and number of greenlip at these discontinued sites was assumed to be identical to 2019 levels. Greenlip were collected from Hardwicke Bay and Corny Point in spring 2015, and used to establish a shell length to bled meat weight relationship that was required to estimate harvestable biomass ($BMW_{Hardwicke\ Bay} = 9.33x10^{-7}*SL^{3.750}$ and $BMW_{Corny\ Point} = 3.20x10^{-6}*SL^{3.515}$). For Port Victoria, no samples were collected. Therefore, all available data from the West Yorke Peninsula and Tiparra Reef SAU were combined to establish the SL to BMW relationship for this fishing ground ($BMW_{Port\ Victoria} = 5.63x10^{-5}*SL^{2.952}$).

As only a subset of the fishing grounds within the West Yorke Peninsula SAU were included in the harvestable biomass estimate, these estimates were 'scaled' to the SAU level using two methods (1) assuming the area surveyed represents the area from which 85% of the catch was harvested (based on the GPS data, Table A3-2 eq. 5); and (2) determining the area outside the surveyed locations where GPS data densities were equivalent to those in each of the three fishing intensity strata and adding the estimated harvestable biomass of greenlip in these areas to the harvestable biomass estimate obtained from the surveyed strata (Table A3-2 eq. 6,7 & 8). The harvestable biomass of greenlip in this unsurveyed area (2.3 km^2) was estimated using a predicted survey density for each of these strata derived from the combined mean densities obtained from all leaded-lines surveyed in these strata at the Hardwicke Bay, Port Victoria and Corny Point survey locations. This area contained a further 3.5% of GPS points, totalling to 89% GPS points encapsulated after scaling. This approach was different to Method 3 for Tiparra Reef because, from the GPS data, the fishing grounds in the West Yorke Peninsula SAU appear much more spatially discrete compared to the more continuous fishing grounds at Tiparra Reef.

The reported catch from the West Yorke Peninsula SAU at the mid-point of the survey was then added to scale each estimate of harvestable biomass to pre-season levels (Table A3-2). Total annual catch was then used to estimate the potential range of exploitation rates for this SAU and mapcodes within.

Table A3-1 The area (km^2), GPS points (%) and survey sites (number) within the surveyed and unsurveyed strata from the Tiparra Reef and West Yorke Peninsula SAUs used for the estimates of harvestable biomass. Note: Three separate areas are surveyed in the West Yorke Peninsula SAU (Hardwicke Bay, Port Victoria and Corny Point).

Tiparra Reef SAU	Area (km2)	GPS points 2006-2013 (%)	survey sites (#)
Tiparra Reef			
strata 1	0.4	21.0	15
strata 2	0.9	30.2	16
strata 3	1.9	25.9	20
Total - surveyed area	3.2	77.1	51
Tiparra Reef - Other			
strata 4 (method 1)	NA	NA	NA
strata 4 (method 2)	NA	NA	NA
strata 4 (method 3)	2.8	13.0	0
strata 4 (method 4)	3.3	NA	0
strata 4 (method 5)	10.3	NA	0
Sub-total - unsurveyed area	2.8-10.3	NA	0
Total - SAU	6.0-13.5	NA	51

West Yorke Peninsula SAU	Area (km2)	GPS points 2006-2015 (%)	survey sites (#)
Hardwicke Bay			
strata 1	1.6	13.4	5
strata 2	7.6	25.9	11
strata 3	12.5	13.3	10
Sub-total - surveyed area	21.7	52.6	26
Port Victoria			
strata 1	0.4	3.5	4
strata 2	1.1	3.8	6
strata 3	2.5	2.5	7
Sub-total - surveyed area	4.0	9.8	17
Corny Point			
strata 1	1.0	8.7	7
strata 2	3.1	11.4	6
strata 3	3.5	3.0	4
Sub-total - surveyed area	7.6	23.1	17
Total - surveyed area	33.3	85.5	60.0
West Yorke Peninsula - Other			
strata 1	0.0	0.0	0
strata 2	0.2	1.1	0
strata 3	2.1	2.3	0
Sub-total - unsurveyed area	2.3	3.4	0
Total - SAU	35.6	88.9	60

Table A3-2 Equations used to scale estimates of harvestable biomass of greenlip in the Tiparra Reef and West Yorke Peninsula SAUs. B = harvestable biomass, ST = stratum, A = area, BMW = bled meat weight, YTD Catch = year-to-date catch, (*) denotes unsurveyed areas.

Tiparra Reef	Eq. No.	Equations
B_{TOTAL} (method 1)	1	$B = ((B_{ST1} + B_{ST2} + B_{ST3}) \times (1/0.77)) + YTD\ Catch$
B_{TOTAL} (method 2)	2	$B = ((B_{ST1} + B_{ST2} + B_{ST3}) \times (1/0.75)) + YTD\ Catch$
B_{TOTAL} (method 3, 4 & 5)	3	$B = B_{ST1} + B_{ST2} + B_{ST3} + B_{ST4(*)} + YTD\ Catch$
$B_{ST4(*)}$	4	$B_{ST4(*)} = A_{ST4(*)} \times (BMW.m^{-2}{}_{ST3} \times (\frac{\left(\frac{BMW.m^{-2}{}_{ST2}}{BMW.m^{-2}{}_{ST1}}\right) + \left(\frac{BMW.m^{-2}{}_{ST3}}{BMW.m^{-2}{}_{ST2}}\right)}{2}))$
West Yorke Peninsula		
B_{TOTAL} (method 1)	5	$B = ((B_{ST1} + B_{ST2} + B_{ST3}) \times (1/0.85)) + YTD\ Catch$
B_{TOTAL} (method 2)	6	$B = B_{ST1} + B_{ST2} + B_{ST3} + B_{ST2(*)} + B_{ST3(*)} + YTD\ Catch$
$B_{ST2(*)}$	7	$B_{ST2(*)} = Area_{ST2(*)} \times BMW.m^{-2}{}_{ST2}$
$B_{ST3(*)}$	8	$B_{ST3(*)} = Area_{ST3(*)} \times BMW.m^{-2}{}_{ST3}$

Table A3-3 Estimates of harvestable biomass (tonnes) and harvest fractions for the Tiparra Reef and West Yorke Peninsula SAUs from 2013 to 2021. Harvestable biomass estimates are for the surveyed areas (± confidence estimates), unsurveyed areas and total harvestable biomass at the beginning of the fishing season (i.e., January). Harvest fractions for Tiparra Reef are presented at the SAU scale and for West Yorke Peninsula at the SAU and mapcode scale.

Tiparra Reef		Season				
		2013	2015	2017	2019	2021
Biomass (t) - surveyed area		23.2	27.3	37.5	35.5	30.6
90% probabililty (≥)	survey strata 1-3	19.2	25.7	35.6	31.9	27.2
10% probabililty (≥)		27.6	29.1	39.5	39.6	34.4
Biomass (t) - unsurveyed area	method 1	6.9	8.1	11.1	10.5	4.2
	method 2	7.7	9.1	12.5	11.8	5.3
	method 3	10.4	10.4	15.6	14.8	7.2
	method 4	12.5	12.6	18.7	17.9	14.6
	method 5	38.7	38.8	58.0	55.3	45.2
Biomass (t) - surveyed + unsurveyed	method 1	30.1	35.4	48.6	46.0	39.7
	method 2	30.9	36.4	50.0	47.3	40.8
	method 3	33.7	37.7	53.1	50.3	42.7
	method 4	35.7	39.9	56.2	53.4	45.2
	method 5	61.9	66.1	95.4	90.8	75.7
Year-to-Date Catch (t) - survey midpoint		6.7	14.2	15.9	15.8	7.2
Total Biomass (t) - January	method 1	36.8	49.6	64.5	61.8	46.9
	method 2	37.6	50.6	65.9	63.1	48.0
	method 3	40.4	51.9	69.0	66.1	49.9
	method 4	42.4	54.0	72.1	69.2	52.4
	method 5	68.6	80.3	111.4	106.6	82.9
Total Catch (t) - season		9.0	16.9	17.7	19.3	7.7
Harvest Fraction (SAU)	method 1	0.24	0.34	0.27	0.31	0.17
	method 2	0.24	0.33	0.27	0.31	0.16
	method 3	0.22	0.33	0.26	0.29	0.16
	method 4	0.21	0.31	0.25	0.28	0.15
	method 5	0.13	0.21	0.16	0.18	0.09

West Yorke Peninsula		Season				
		2013	2015	2017	2019	2021
Corny Point						
Biomass (t)	survey strata 1-3	NA	18.6	21.0	26.5	24.3
90% probabililty (≥)		NA	15.1	16.4	19.1	16.7
10% probabililty (≥)		NA	22.6	26.6	36.0	34.6
Hardwicke Bay						
Biomass (t)	survey strata 1-3	NA	114.9	151.6	59.1	72.8
90% probabililty (≥)		NA	103.2	138.8	45.5	56.6
10% probabililty (≥)		NA	127.4	165.2	75.3	90.9
Port Victoria						
Biomass (t)	survey strata 1-3	NA	18.3	14.5	10.0	15.1
90% probabililty (≥)		NA	15.8	12.3	7.1	11.3
10% probabililty (≥)		NA	21.0	16.9	13.5	19.6
Biomass (t) - surveyed area			151.7	187.1	95.6	112.2
Biomass (t) - unsurveyed area	method 1	NA	25.8	31.8	16.3	14.2
	method 2	NA	8.9	9.6	5.8	6.1
Biomass (t)- survey + unsurveyed	method 1	NA	177.5	219.0	111.9	126.4
	method 2	NA	160.6	196.7	101.4	118.3
Year-to-Date Catch (t) - survey midpoint			10.9	15.6	14.3	6.6
Total Biomass (t) - January	method 1	NA	188.4	234.5	126.1	132.9
	method 2	NA	171.5	212.3	115.6	124.8
Total Catch (t) - season			16.3	20.4	18.3	8.8
Harvest Fraction (Site)						
Corny Point	method 1	NA	0.33	0.17	0.16	0.08
Hardwicke Bay	method 1	NA	0.02	0.06	0.15	0.06
Port Victoria	method 1	NA	0.19	0.18	0.10	0.06
Harvest Fraction (SAU)	method 1	NA	0.09	0.09	0.15	0.07
	method 2	NA	0.10	0.10	0.16	0.07

4. **Appendix 4.** Fishery-independent survey outputs at Tiparra Reef

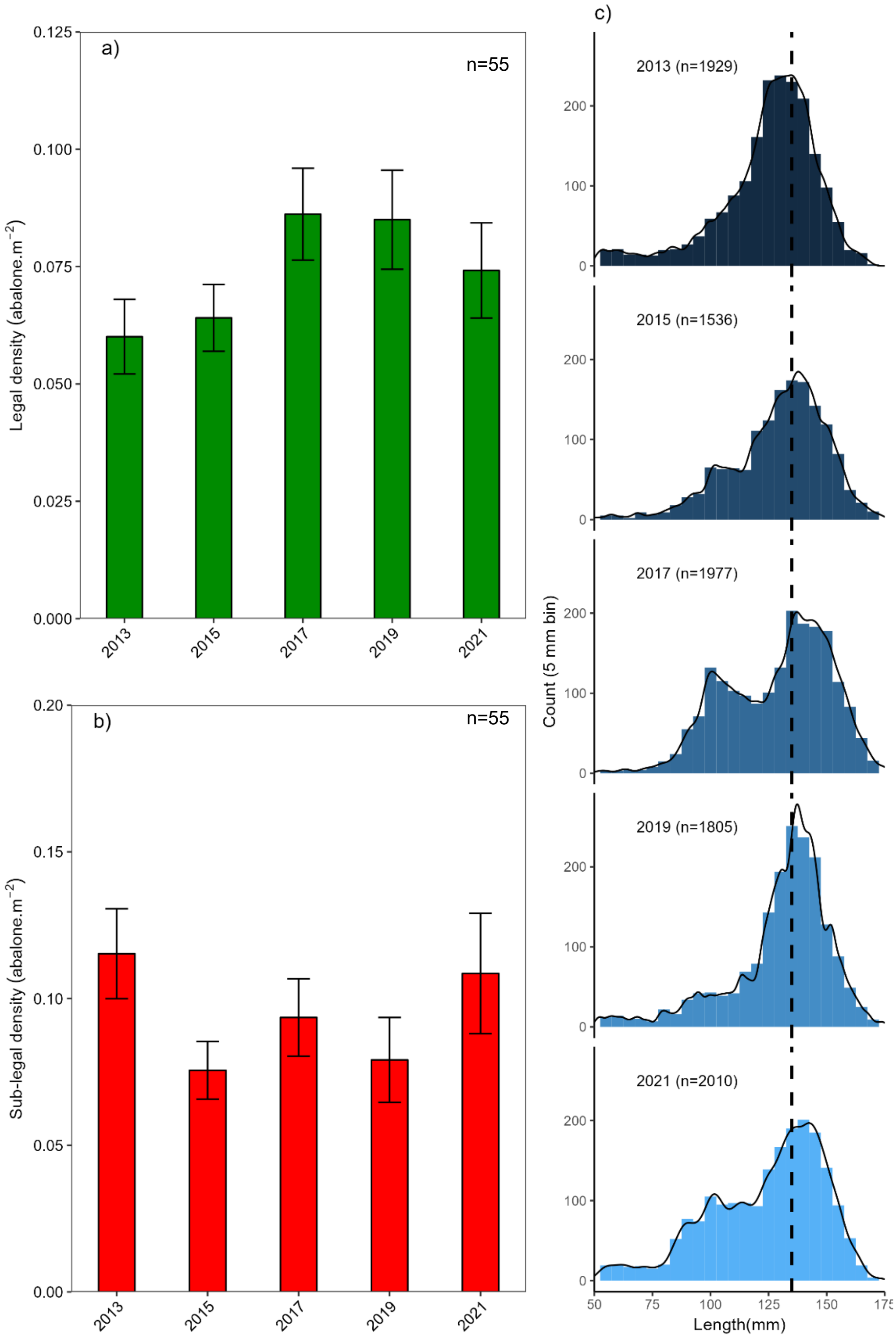

Figure A4-1 Current fishery independent survey outputs from the expanded survey design at Tiparra Reef from 2013 to 2021. a) legal density (abalone ≥135 mm SL, green bars), b) sub-legal density (abalone <135 mm SL, red bars) and c) Length counts. Gaps in the time series indicate no data.

5. **Appendix 5.** Quality Assurance

5.1 Research planning

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

5.2 Data collection

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

5.3 Data entry, validation, storage and security

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

5.4 Data and statistical analyses

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

5.5 Data interpretation and report writing

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

6. Appendix 6. Summary tables

Table A6-1 Greenlip and blacklip catch (t meat weight) from CZ SAUs. Abbreviations for Yorke Peninsula (YP) and Kangaroo Island (KI).

Greenlip

Year	Cape Elizabeth	East YP	Fleurieu	North KI	South KI	South YP	Tiparra Reef	Unassigned CZ	West KI	West YP	Western SG
1979	1.22	18.19	1.63	0.28	6.16	0.15	16.75	0.00	0.56	3.38	0.00
1980	3.89	19.89	0.92	0.77	4.34	0.35	21.92	0.00	0.39	3.33	0.00
1981	9.18	14.01	3.32	0.61	1.09	0.09	29.13	0.00	0.00	1.84	0.00
1982	0.00	5.37	2.37	0.60	5.78	0.38	21.03	0.00	2.25	1.37	0.00
1983	0.10	9.67	3.18	0.06	7.18	0.44	14.20	0.00	2.19	2.61	0.00
1984	2.30	10.31	2.05	1.15	3.05	0.15	16.94	0.00	0.29	16.17	0.00
1985	0.66	0.08	1.82	0.66	6.00	2.42	28.98	0.00	3.13	7.71	0.00
1986	0.35	0.03	0.00	0.06	4.81	1.41	14.84	0.00	1.45	12.98	0.00
1987	0.04	0.14	2.62	0.54	3.19	1.02	21.42	1.01	1.41	27.29	0.00
1988	3.39	0.08	0.60	0.67	7.27	0.41	38.29	0.00	2.48	14.13	0.00
1989	4.27	0.16	4.15	0.44	5.94	0.53	52.20	0.00	1.36	9.11	6.01
1990	1.73	0.10	0.40	1.42	8.57	0.16	14.75	0.00	6.41	13.00	0.23
1991	2.76	0.00	0.40	0.86	5.02	0.10	16.50	2.40	1.65	16.89	0.00
1992	1.22	0.19	0.06	0.75	3.75	0.15	19.29	0.00	1.23	14.77	0.60
1993	0.54	0.00	0.07	0.74	1.46	0.18	30.23	0.00	0.60	5.65	0.00
1994	0.26	0.00	0.00	0.93	3.22	0.19	40.56	0.00	0.83	2.05	0.00
1995	2.65	0.01	0.00	0.18	2.40	0.16	29.57	0.00	0.47	12.09	0.35
1996	2.60	0.00	0.05	0.00	3.13	0.75	36.71	0.00	1.69	2.50	0.24
1997	8.62	0.00	0.00	0.36	2.52	0.02	26.45	0.09	2.45	6.78	0.41
1998	3.07	0.00	0.46	1.03	2.96	0.27	34.61	0.00	0.88	3.98	0.21
1999	1.32	0.00	0.85	1.46	2.17	0.00	34.12	0.00	2.12	5.49	0.00
2000	3.13	0.00	0.04	0.32	2.28	0.00	40.52	0.00	0.50	0.41	0.54
2001	0.95	0.00	0.00	0.12	0.65	0.00	44.89	0.00	1.15	0.03	0.00
2002	0.55	0.00	0.07	0.27	1.77	0.00	39.89	0.00	2.51	2.73	0.00
2003	1.55	0.17	0.11	0.42	2.23	0.03	38.38	0.00	2.63	2.03	0.00
2004	0.64	0.00	0.00	1.11	1.49	0.00	35.75	0.44	3.33	4.95	0.25
2005	3.14	0.02	0.03	0.56	4.53	0.45	25.29	0.38	2.02	10.85	0.34
2006	0.49	0.46	0.00	0.74	2.65	0.03	29.47	0.00	2.96	11.01	0.00
2007	1.95	0.55	0.00	0.80	2.60	0.19	28.02	0.00	1.88	11.51	0.19
2008	2.01	9.63	0.03	0.37	3.35	0.04	27.82	0.00	1.38	2.48	0.13
2009	2.74	5.34	0.00	0.35	4.05	0.00	29.43	0.00	3.59	2.00	0.00
2010	4.36	4.73	0.00	0.13	6.27	0.09	26.86	0.00	4.70	0.50	0.00
2011	4.94	6.35	0.07	0.17	5.74	0.20	20.21	0.00	4.08	5.87	0.00
2012	4.59	3.58	0.00	0.30	5.66	0.20	13.77	0.00	3.74	15.20	0.00
2013	4.99	3.55	0.13	0.17	4.20	0.13	8.98	0.00	7.71	17.99	0.00
2014	1.80	3.00	0.11	1.41	3.04	0.06	13.23	0.00	9.50	15.30	0.00
2015	0.57	5.11	0.02	0.46	2.19	0.02	16.90	0.00	4.07	16.33	0.00
2016	0.19	6.93	0.02	0.00	1.73	0.00	16.09	0.00	0.82	20.21	0.00
2017	1.42	2.36	0.00	0.13	2.09	0.06	17.69	0.00	1.86	20.38	0.06
2018	0.36	1.77	0.00	0.18	2.18	0.33	17.82	0.00	1.16	21.90	0.00
2019	0.10	1.70	0.00	0.04	2.92	0.00	19.26	0.00	3.72	18.30	0.00
2020	0.27	1.74	0.04	0.10	1.53	0.00	10.06	0.00	3.00	11.34	0.00
2021	0.49	1.44	0.10	0.32	3.12	0.00	7.75	0.00	2.45	9.09	0.12

Blacklip

Year	Cape Elizabeth	East YP	Fleurieu	North KI	South KI	South YP	Tiparra Reef	Unassigned CZ	West KI	West YP	Western SG
1979	0.00	0.00	0.05	0.00	3.64	0.00	0.00	0.00	3.74	0.06	0.00
1980	0.00	0.00	0.82	0.03	6.84	0.01	0.00	0.00	1.16	0.04	0.00
1981	0.01	0.01	0.10	0.06	0.98	0.00	0.07	0.00	0.00	0.15	0.00
1982	0.00	0.01	0.31	0.03	4.69	0.00	0.02	0.00	6.23	0.26	0.00
1983	0.00	0.03	0.05	0.00	8.33	0.06	0.01	0.00	1.22	0.28	0.00
1984	0.07	0.00	0.71	0.02	2.37	0.01	0.02	0.00	0.45	0.16	0.00
1985	0.00	0.00	0.00	0.00	5.34	0.12	0.03	0.00	2.85	0.51	0.00
1986	0.00	0.00	0.02	0.01	5.23	0.11	0.02	0.00	4.45	0.32	0.00
1987	0.04	0.00	0.34	0.11	8.70	0.07	0.07	0.00	7.83	0.26	0.00
1988	0.01	0.00	0.03	0.13	8.13	0.00	0.00	0.00	9.87	0.00	0.00
1989	0.01	0.00	0.07	0.14	5.85	0.13	0.00	0.00	12.09	0.13	0.00
1990	0.06	0.06	0.03	0.32	4.31	0.06	0.02	0.00	5.80	2.31	0.00
1991	0.06	0.00	0.97	0.17	6.11	0.00	0.01	0.00	4.15	1.78	0.00
1992	0.34	0.00	0.01	0.35	5.15	0.00	0.00	0.00	3.63	2.38	0.05
1993	0.00	0.00	1.71	0.01	3.24	0.24	0.17	0.00	5.18	0.71	0.00
1994	0.00	0.00	0.00	0.19	5.69	0.80	0.08	0.00	4.94	1.47	0.00
1995	0.06	0.00	0.00	0.04	4.72	0.04	0.02	0.00	6.81	1.51	0.00
1996	0.02	0.00	1.17	0.00	5.34	0.52	0.05	0.00	5.82	0.65	0.51
1997	0.05	0.00	0.00	0.02	4.64	0.18	0.05	0.00	8.46	0.63	0.00
1998	0.00	0.00	0.00	0.03	4.68	0.12	0.01	0.00	8.95	0.28	0.00
1999	0.01	0.00	1.98	0.08	3.79	0.00	0.00	0.00	8.15	0.00	0.00
2000	0.02	0.09	0.23	0.02	4.78	0.00	0.02	0.00	8.87	0.35	0.00
2001	0.00	0.00	0.00	0.00	2.87	0.00	0.10	0.00	10.98	0.15	0.00
2002	0.00	0.00	0.09	0.00	3.11	0.00	0.16	0.00	9.30	0.00	0.00
2003	0.00	0.00	1.42	0.01	2.29	0.04	0.00	0.00	7.95	0.30	0.00
2004	0.00	0.00	0.00	0.65	2.39	0.00	0.01	0.00	8.37	0.39	0.00
2005	0.00	0.05	0.13	0.00	3.26	0.33	0.02	0.00	5.66	0.64	0.00
2006	0.00	0.00	0.00	0.05	2.64	0.01	0.01	0.00	4.89	0.43	0.00
2007	0.01	0.00	0.07	0.02	1.44	0.07	0.00	0.00	6.14	0.27	0.00
2008	0.00	0.00	0.16	0.00	1.72	0.14	0.00	0.00	5.84	0.30	0.00
2009	0.00	0.15	0.00	0.00	3.17	0.00	0.00	0.00	4.59	0.26	0.00
2010	0.00	0.03	0.00	0.03	0.99	0.03	0.00	0.00	6.87	0.03	0.00
2011	0.02	0.01	0.12	0.05	1.39	0.00	0.01	0.00	6.43	0.00	0.00
2012	0.00	0.00	0.00	0.01	3.31	0.00	0.00	0.00	4.08	0.15	0.00
2013	0.01	0.04	0.84	0.00	0.50	0.00	0.01	0.00	6.70	0.29	0.00
2014	0.00	0.03	0.40	0.09	0.92	0.00	0.00	0.00	5.94	0.09	0.00
2015	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.00	5.37	0.05	0.00
2016	0.00	0.00	0.09	0.00	1.25	0.00	0.00	0.00	4.83	0.04	0.00
2017	0.00	0.00	0.00	0.00	1.08	0.06	0.00	0.00	4.44	0.26	0.00
2018	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.64	0.00	0.00
2020	0.00	0.00	0.01	0.00	0.16	0.00	0.00	0.00	1.04	0.00	0.00
2021	0.00	0.00	0.01	0.00	0.34	0.00	0.00	0.00	0.85	0.00	0.00

Table A6-2 Greenlip and blacklip CPUE (kg.hr^{-1}) from CZ SAUs. Abbreviations for Yorke Peninsula (YP) and Kangaroo Island (KI). Note empty cells denote no CPUE estimate due to fewer than 10 fishing days in a given year.

Greenlip

Year	Cape Elizabeth	East YP	Fleurieu	North KI	South KI	South YP	Tiparra Reef	Unassigned CZ	West KI	West YP	Western SG
1979	13.15	19.44	18.96		23.25		20.49			21.29	
1980	32.24	19.04	18.27		23.43		27.18			29.10	
1981	42.52	23.73	18.47		16.28		22.62			24.07	
1982		17.78	16.76	12.79	21.07		22.93		21.25	18.66	
1983		15.31	17.02		21.05		18.55		23.83	16.77	
1984	19.83	23.18	18.17	19.66	21.73		18.73			14.56	
1985			15.97	14.55	23.38	22.02	23.17		25.48	19.36	
1986					25.65	23.22	22.35		21.30	18.52	
1987			28.75		28.35		21.28		27.95	18.91	
1988	19.98		15.19		18.66		21.18		23.44	18.03	
1989	24.22		25.50		23.75		21.27		25.67	22.40	23.39
1990	16.17			16.72	25.13		21.61		24.62	23.26	
1991	24.15			13.39	18.82		23.97	21.27	20.61	19.91	
1992	22.16				19.70		21.44		19.98	19.65	
1993					18.59		21.87			19.39	
1994				13.28	21.80		20.44			16.41	
1995	24.29				22.39		18.06			19.22	
1996					23.95		21.61		33.73	18.88	
1997	24.91				18.95		20.08		18.82	21.82	
1998	27.44			18.18	20.94		21.02			21.40	
1999				17.97	26.46		23.86		23.93	18.94	
2000	35.47				26.05		30.09				
2001							31.48				
2002					25.69		29.13		30.96	17.19	
2003					27.39		31.86		26.60	18.06	
2004				20.44	25.54		32.25		27.43	23.89	
2005	36.14				23.87		27.64		28.53	23.11	
2006					23.88		31.30		28.49	20.55	
2007	33.87				21.95		29.06		25.55	20.19	
2008	33.74	19.22			32.14		30.07		30.52	16.85	
2009	32.09	20.49			26.83		28.42		32.44	19.66	
2010	26.77	24.07			26.11		24.66		28.76		
2011	24.49	20.17			26.88		23.56		28.98	19.82	
2012	26.09	20.08			23.78		23.35		25.05	26.74	
2013	25.75	17.21			20.27		24.02		23.75	25.75	
2014	26.49	18.73			16.95		30.44		21.93	25.27	
2015		17.08			22.93		27.93		21.43	23.71	
2016		18.39			24.56		27.33		17.17	23.88	
2017	27.29	15.16			20.40		26.23		16.74	22.54	
2018		16.98			19.07		24.61		17.15	22.31	
2019		16.87			23.88		24.02		20.42	18.43	
2020		18.21			22.51		19.96		20.83	19.91	
2021		23.69			19.52		21.09		16.73	19.03	

Blacklip

Year	Cape Elizabeth	East YP	Fleurieu	North KI	South KI	South YP	Tiparra Reef	Unassigned CZ	West KI	West YP	Western SG
1979					25.58				26.11		
1980			18.02		28.04				27.96		
1981					21.47						
1982					23.07				31.20		
1983					22.99				22.60		
1984					23.78						
1985					25.80				25.52		
1986					26.47				27.71		
1987					30.46				27.70		
1988					24.88				28.50		
1989					29.12				34.89		
1990					28.92				25.27	26.19	
1991					24.10				26.60	23.00	
1992					22.32				26.43	22.07	
1993			24.77		21.44				26.34		
1994					24.24				31.74		
1995					26.46				27.21		
1996					24.98				24.43		
1997					23.36				24.29		
1998					23.88				25.36		
1999			15.97		32.75				24.27		
2000					28.03				28.89		
2001					21.46				27.64		
2002					26.07				26.58		
2003					34.60				28.04		
2004					26.88				30.10		
2005					22.99				29.84		
2006					22.17				27.95		
2007					24.15				27.07		
2008					19.97				29.19		
2009					27.27				31.12		
2010					20.57				27.11		
2011					18.62				26.38		
2012					19.94				25.43		
2013									25.48		
2014					19.03				25.25		
2015									25.54		
2016					23.90				20.22		
2017					21.38				18.92		
2018											
2019											
2020					19.73						
2021											