Fishery Assessment Report to PIRSA Fisheries

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

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This fishery assessment report updates the 2006 report for the Central Zone abalone fishery and is part of SARDI Aquatic Sciences ongoing assessment program for the fishery. The aims of the report are to assess the current status of the resource, identify the uncertainty associated with the assessment and to identify future research needs for the fishery.

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EXECUTIVE SUMMARY

1. This report updates the 2006 report and assesses the current status of the abalone resource in the Central Zone (CZ). Data from Cowell, a separately-managed area within the CZ, are explicitly excluded.

GREENLIP ABALONE

1. The TACC for greenlip abalone has been 143.1 t (whole weight) since 1994. Most (~70%) of the catch is harvested from Fishing Area 21.

2. Catches in Fishing Areas 22 and 24 have increased substantially since 2005 following implementation of a 90 t "catch cap" on Tiparra Reef (within Fishing Area 21).

3. Mean daily catch (MDC) has declined significantly in Fishing Area 21 since 2003 and in Fishing Area 24 between 2006 and 2007. In Fishing Area 22, MDC has decreased by >45% since 2004, to the lowest level since 1993.

4. Total effort has increased significantly since 2003, to the highest level since 1999. Mean daily effort (MDE) increased significantly in Fishing Area 21 between 2006 and 2007.

5. Mean CPUE in the CZ and Fishing Area 21 has declined significantly since 2001 and 2003, respectively. Mean CPUE declined significantly between 2006 and 2007 in Fishing Areas 21 and 24. In Fishing Area 22, it has decreased by 35% since 2004.

6. The mean length of greenlip abalone in the commercial catch has decreased, and the proportion of the sample <145 mm SL has increased in Fishing Areas 21 and 24 over the last five years. For the CZ, the mean length was smallest and the proportion of the sample <145 mm SL greatest in 2007.

7. The abundances of legal-sized greenlip abalone observed on fishery-independent surveys at Tiparra Reef (Fishing Area 21) and Hardwicke Bay (Fishing Area 24) have decreased by >35% over recent years.

8. Nine of the eleven (82%) performance indicators (PI) that triggered, did so in a negative direction.

9. There is evidence that the legal-sized, greenlip abalone biomass is declining on the principal fishing grounds for this species, and that the resource on which the CZ greenlip abalone fishery is based has weakened over recent years.

10. There is no evidence to suggest that the 'catch cap' on Tiparra Reef could be increased.

11. The 'catch cap' on Tiparra Reef has increased fishing pressure elsewhere. Recent declines in fishery-dependent performance measures in these fishing areas suggest that increased spatial management, with spatially relevant catch and size limits, may be required.

BLACKLIP ABALONE

1. The TACC for blacklip abalone in 2007 was 24.3 t (whole weight), 42% below that from 1994 to 2004 (42.3 t).

2. Most (>80%) of the catch is harvested from three fishing areas (26, 27 and 29) off Kangaroo Island. In 2007, Fishing Area 26 contributed >50% of the catch. The evidence suggests this level of catch may not be sustainable.

3. In Fishing Areas 26, 27 and 29, MDC has declined substantially since 2000, 2004 and 2003, respectively. Despite increases in MDC in Fishing Areas 26 and 29 within recent years, MDC remained >20% below contemporary maxima. MDC declined further between 2006 and 2007 in Fishing Area 27.

4. CPUE in Fishing Area 26 decreased rapidly between 2000 and 2005. Although it increased between 2005 and 2007, it remains >20% below that in 2000. In Fishing Area 27, the CPUE in 2006 and 2007 was substantially lower than that in 2005. Ongoing, significant (~45%) declines in CPUE since 2003 are evident in Fishing Area 29.

5. The mean length of blacklip abalone in the commercial catch has increased, and the proportion of the sample <145 mm SL has decreased in Fishing Areas 26, 27 and 29 since 2005. These patterns suggest the progression of a cohort through the fishery, without additional recruitment in recent years.

6. Four of the eight PI (50%) that triggered, did so in a positive direction.

7. Consistent with previous assessment reports, there is continued substantial evidence that the resource on which the CZ blacklip abalone fishery is based remains in a weak position. Importantly, recent years provide indications of some of the weakest years on record.

8. There is evidence that the resource may have continued to weaken in Fishing Areas 27 and 29, where recent declines in some fishery-dependent performance measures remain consistent with declining stock abundance.

9. Increases in catch, MDC and CPUE in Fishing Area 26 since 2006, provide some evidence that reductions in legal-sized blacklip abalone biomass may have arrested in this fishing area. However, these increases follow several consecutive years of reduction, and current values remain low in a recent historical context.

10. The fishery is heavily reliant on the abalone stocks remaining in three small fishing areas (26, 27 and 29), all located off Kangaroo Island. The importance of these to the fishery suggests urgent action is required to protect the remnant stocks.

11. Consideration of alternative management arrangements for the fishery, including increased spatial management with spatially relevant catch and size limits, may be warranted.

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1. GENERAL INTRODUCTION

1.1 Overview

This fishery assessment report for the Central Zone (CZ) of the South Australian abalone fishery updates previous fishery assessment (Mayfield *et al*. 2006) and stock status reports (Mayfield & Carlson 2007), and is part of SARDI Aquatic Sciences ongoing assessment program for the fishery.

The aims of the report are (1) to assess the current status of the resource; (2) to identify the uncertainty associated with the assessment and; (3) to identify future research needs.

The report covers the period 1 January 1968 to 31 December 2007. In contrast with previous reports, data from Cowell, a separately managed area within the CZ (see Mayfield *et al*. 2007b), are explicitly excluded. The report is divided into five sections.

The first section is the general introduction that (1) outlines the aims and structure of the report, (2) describes the CZ abalone fishery including the history of the fishery, current management arrangements, and the level of recreational and illegal harvest, (3) identifies the biological performance indicators, (4) provides a synopsis of previous stock assessment reports on the fishery, and (5) summarises biological knowledge for abalone in the CZ.

Sections 2 and 3 provide an assessment of the fishery-dependent and fishery-independent data for greenlip and blacklip abalone, respectively, from 1968 to 2007. Where appropriate, this includes spatial and temporal analyses of catch, effort, catch-per-unit effort, length-frequency distribution of the catch and fishery-independent surveys. In Section 4, the performances of the greenlip and blacklip abalone fisheries are assessed against the performance indicators and reference points identified in the Management Plan (Nobes *et al*. 2004).

Section 5 is the general discussion. It synthesises the information presented in the previous sections, identifies areas of uncertainty in current knowledge and outlines future research needs for the fishery.

1.2 Description of the fishery

1.2.1 Commercial fishery

Management arrangements have evolved since the inception of the fishery in 1964. A review of the management history is provided by Shepherd & Rodda (2001). The major management milestones are listed in Table 1.1. Summaries of the fishery can be found in Prince & Shepherd (1992), Zacharin (1997), Keesing & Baker (1998) and Nobes *et al.* (2004).

The fishery expanded rapidly in the late 1960s, exceeding 100 entrants by 1970. Licences were made non-transferable in 1971 to reduce the number of operators in the fishery. By 1976 the number of operators had declined to 30 and an additional five licences were issued. There are currently 35 licence holders in the fishery.

In 1971 the South Australian abalone fishery was divided into three Zones (Western, Central and Southern; Figure 1.1). The CZ of the South Australian abalone fishery includes all coastal waters of South Australia between Meridians 136°30'E and 139°E (Figure 1.2). The fishing season extends from 1 January to 31 December each year.

Greenlip abalone comprises 85.5% of the total allowable commercial catch (TACC) in the CZ (2007 TACC: 143.1 t whole weight). The remainder, 14.5%, comprises blacklip abalone (2007 TACC: 24.3 t whole weight; Table 1.2). The greenlip abalone TACC has remained at 143.1 t since 1994. In contrast, the TACC for blacklip abalone has been reduced by >42% since 2004. This decrease occurred in two stages: from 42.3 t (1994 – 2004) to 29.7 t (2005), and then from 29.7 t to 24.3 t (2006 and 2007).

From 1997, the fishery operated under the control of a formal Management Plan (Zacharin 1997; Nobes *et al*. 2004). This Plan ensures that the fishery is managed through a regime of input (*e.g*. limited entry) and output (*e.g*. minimum legal length, quotas) controls. The current management arrangements for the CZ are provided in Table 1.3.

Minimum legal lengths (MLL) of 130 mm shell length (SL) were imposed on both species in 1971. Quotas were imposed on the CZ from 1990.

To monitor catches and facilitate compliance with quota limits, fishers must complete a Catch and Disposal Record (CDR) form immediately upon landing. In addition, a research logbook must also be completed for each fishing day and submitted to SARDI Aquatic Sciences at the end of each month. Commercial catch and effort data for this fishery have been collected since 1968. The logbook provides information on the date of fishing, the fishing area, the amount of time spent fishing, whether or not an underwater vehicle was used, the diving depth and the total catch landed.

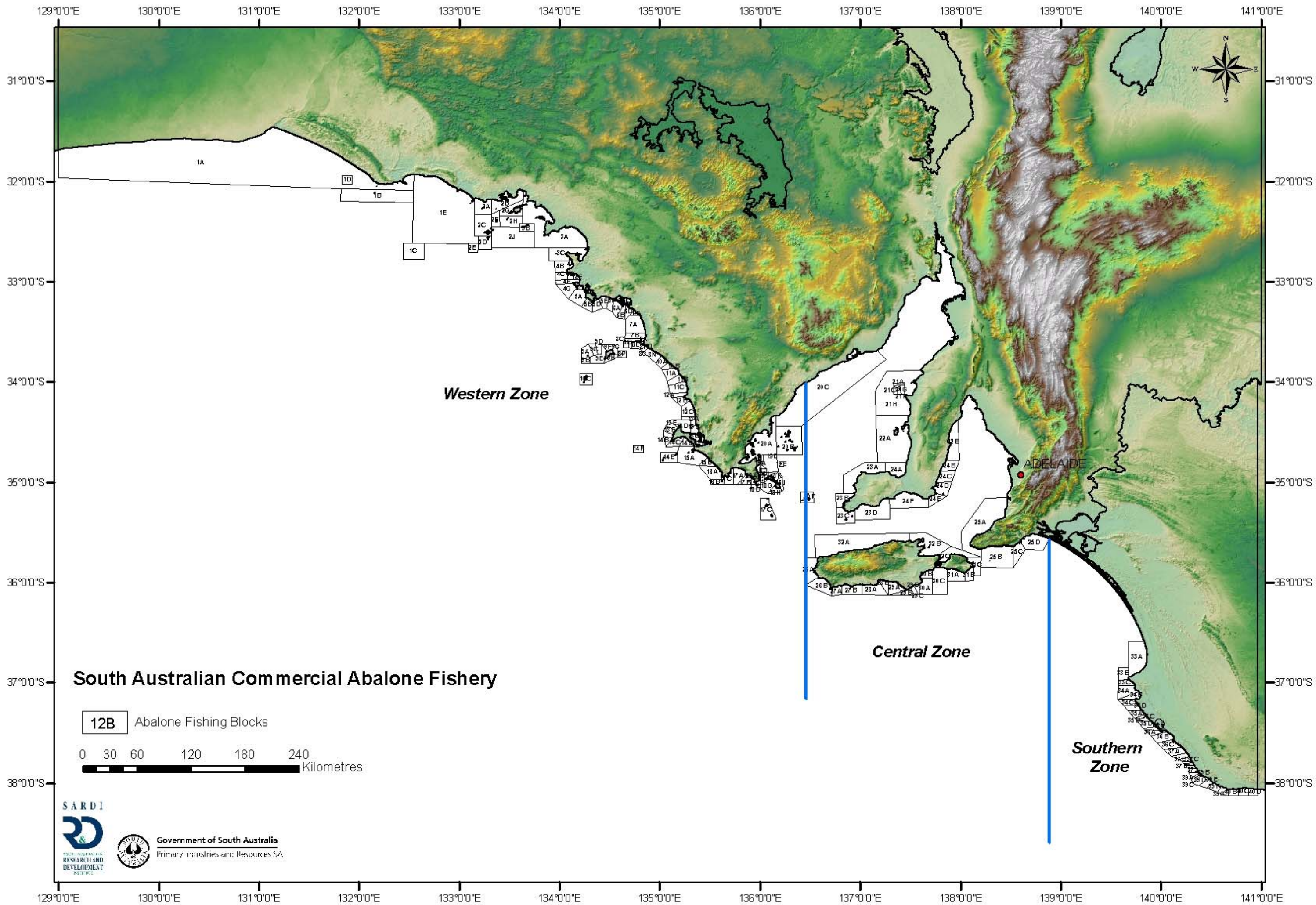

Figure 1.1: Fishing Zones and fishing areas of the South Australian abalone fishery

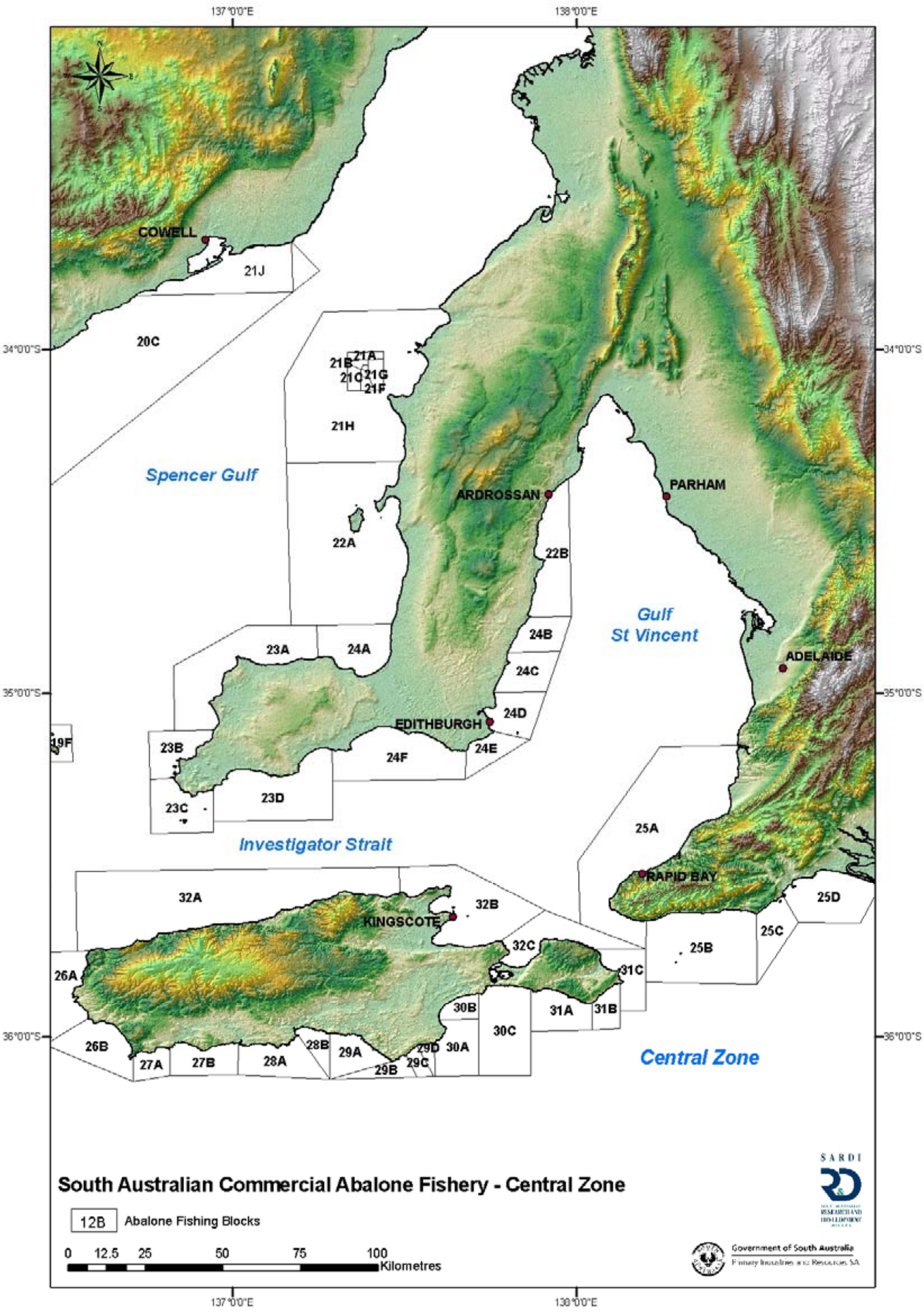

Figure 1.2: Fishing areas of the CZ of the South Australian abalone fishery.

Table 1.1: Management milestones in the CZ of the South Australian abalone fishery.

Date	Milestone
1964	Fishery started
1971	Licences made non-transferable
	Fishery divided into three Zones
	Minimum legal length set at 130 mm for both species
1976	30 Licences remained; 5 additional licences issued
1978	Sub Zones and fishing blocks replaced by map numbers and codes
1980	Licences became transferable
1989	Quota introduced
1993	Abolition of owner-operator regulation
1997	Management Plan implemented
2004	Management Plan reviewed
	Fishery assessed against the Principles of Ecologically Sustainable Development
2005	Blacklip abalone TACC reduced from 42.3 to 29.7 t (shell weight)
	Greenlip abalone catch capped at 90 t (shell weight) in Fishing Area 21
2006	Blacklip abalone TACC reduced from 29.7 to 24.3 t (shell weight)

Table 1.2: Total Allowable Commercial Catches (tonnes, whole weight) for the CZ of the South Australian abalone fishery from 1990 to 2008.

Fishing season	Greenlip abalone SL > 130 mm	Blacklip abalone SL > 130 mm
1990	142.2	41.1
1991	142.2	41.1
1992	142.2	41.1
1993	142.2	41.1
1994	143.1	42.3
1995	143.1	42.3
1996	143.1	42.3
1997	143.1	42.3
1998	143.1	42.3
1999	143.1	42.3
2000	143.1	42.3
2001	143.1	42.3
2002	143.1	42.3
2003	143.1	42.3
2004	143.1	42.3
2005	143.1	29.7
2006	143.1	24.3
2007	143.1	24.3
2008	143.1	24.3

Table 1.3: Summary of the current management arrangements for the CZ commercial abalone fishery.

Management strategy	CZ
Licence holders	6
Targeted species	Greenlip abalone Blacklip abalone
Minimum legal length	Blacklip 130 mm SL Greenlip 130 mm SL
Quota year	1/1 to 31/12
Quota transferability	Yes
Method of capture	By hand
Bycatch	Nil

Only two changes have been made to the data collection system over the last 30 years. In 1978, sub zones and fishing blocks were replaced by spatially smaller map numbers (= fishing areas) and map codes (see Figure 1.1). In 2002, the logbook datasheet was revised and additional data fields (*e.g.* GPS position, number of abalone harvested) were inserted. The logbook data supplied by divers and licence holders are used annually by SARDI Aquatic Sciences for analysis of catch, effort and catch-per-unit-effort in a Fishery Assessment Report for each Zone (see Chick *et al*. 2007, 2008; Mayfield *et al*. 2006, 2007a).

Each year, Abalone Management South Australia Inc. (AMSA; formerly the Abalone Fishery Management Committee) recommends a separate TACC for greenlip and blacklip abalone in the CZ to the Minister for Agriculture, Food and Fisheries. This advice is structured by the objectives and strategies of the Abalone Management Plan (see Section 1.3 below) and based on the annual Fishery Assessment Reports submitted to PIRSA by SARDI Aquatic Sciences and additional information provided to PIRSA and AMSA. Each licence holder is allocated an annual Individual Transferable Quota (ITQ) that is an equal share of the TACC.

1.2.2 Recreational fishery

The total recreational abalone harvest in South Australia was estimated at 17 780 abalone for the period May 2000 to April 2001 (Henry & Lyle 2003). As few of these were harvested from the CZ (Jones & Doonan 2005), the recreational catch from this Zone appears small (*c.a.* 1000 abalone; ~ 0.5 t). This represents about 0.3% of the TACC. Future estimation of the total catch of abalone by recreational fishers would be enhanced by regular creel surveys.

1.2.3 Illegal fishery

It is difficult to accurately estimate the level of the illegal catch, as many information reports are unsubstantiated and/or do not contain information concerning quantities of abalone alleged to have been taken. During 2007, PIRSA identified through information and other reports, by attributing an average quantity of abalone per report, that 26,840 individual abalone may have been taken illegally (Rob Parkes, PIRSA, personal communication). It is expected that PIRSA would not have been notified of all reports alleging that abalone theft activity had occurred within the CZ during the reporting year, so the actual extent of illegal take of abalone may have been higher. By attributing the legal minimum weight of 113 g to the meat weight of an illegally harvested whole abalone, the estimated total illegal catch of abalone in the CZ equates to ~3.03 t (meat weight), or 4.9% of TACC (Rob Parkes, PIRSA, personal communication). However, most quantities of unlawfully taken abalone are under the legal minimum weight.

1.3 Key objectives and strategies of the Management Plan

The Management Plan for the South Australian abalone fishery (Nobes *et al*. 2004) identifies biological, economic, environmental and social management objectives and strategies. The biological objectives are (1) to control, measure and regulate all catches/extractions from the resource; (2) to maintain sufficient egg and sperm production to provide for adequate levels of recruitment; and (3) to monitor and control disease.

Associated with these biological objectives are five strategies. Strategies one through five are:

1. To collect and collate fishery-dependent information;
2. To set the TACC using the best available information;
3. To harvest at an appropriate minimum legal length;
4. To maintain abalone population densities; and
5. To identify disease-infected areas.

Performance indicators are linked with the five strategies, each of which has specific trigger points. The biological performance indicators and trigger points for each of the strategies for the blacklip and greenlip abalone fisheries in the CZ are provided in Tables 1.4 and 1.5. The performance indicators to be addressed in this report are shown in bold. Annual reports on the harvest discard and illegal catch, recreational harvest and the diver's assessment of the status of the stock are provided by PIRSA Fishwatch, PIRSA Fisheries and the Abalone Industry Association of South Australia, respectively.

Table 1.4: Biological strategies and associated performance indicators, spatial scale of application and trigger points prescribed for performance assessment of the greenlip abalone fishery in the CZ of the South Australian abalone fishery. The performance indicators to be addressed in this report are shown in bold.

Strategy	Performance Indicator	Scale of Application	Trigger Point
1	**Commercial logbooks**	-	<100% received
	Catch and effort database	-	<100% of logbooks received entered into the database
	Stock assessment report	Fishing Zone	Annual report not produced
	Illegal catch	Fishing Zone	Annual report not produced
	Recreational catch	Fishing Zone	Annual report not produced
2	Illegal catch	Fishing Zone	Statistically significant 5-year trend (no. of prosecutions)
	Recreational catch	Fishing Zone	25% increase in catch
	Diver assessment of stock status	Fishing areas contributing >10% of the TACC	Change in stock status
	Commercial catch	Fishing Zone	<90% of TACC harvested
	Commercial effort	Fishing Zone	Statistically significant 5-year trend
	Spatial distribution of catch	Four most important fishing areas (by catch)	Change in order or composition
	Mean daily catch	Fishing areas contributing >10% of the TACC	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
	Mean daily effort	Fishing areas contributing >10% of the TACC	
	CPUE	Fishing areas contributing >10% of the TACC	
	Mean length	Fishing areas contributing >10% of the TACC	
	Abundance of legal-sized abalone	Tiparra Reef	
	Abundance of sub-legal-sized abalone		
3	**% Egg production relative to pristine egg production**	Tiparra Reef	<50% of the pristine level
4	**Abundance of abalone >L_{50}**	Tiparra Reef	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
5	Harvest discard	Fishing Zone	-

Table 1.5: Biological strategies and associated performance indicators, spatial scale of application and trigger points prescribed for performance assessment of the blacklip abalone fishery in the CZ of the South Australian abalone fishery. The performance indicators to be addressed in this report are shown in bold.

Strategy	Performance Indicator	Scale of Application	Trigger Point
1	**Commercial logbooks**	-	<100% received
	Catch and effort database	-	<100% of logbooks received entered into the database
	Stock assessment report	Fishing Zone	Annual report not produced
	Illegal catch	Fishing Zone	Annual report not produced
	Recreational catch	Fishing Zone	Annual report not produced
2	Illegal catch	Fishing Zone	Statistically significant 5-year trend (no. of prosecutions)
	Recreational catch	Fishing Zone	25% increase in catch
	Diver assessment of stock status	Fishing areas contributing >10% of the TACC	Change in stock status
	Commercial catch	Fishing Zone	<90% of TACC harvested
	Commercial effort	Fishing Zone	Statistically significant 5-year trend
	Spatial distribution of catch	Four most important fishing areas (by catch)	Change in order or composition
	Mean daily catch	Fishing areas contributing >10% of the TACC	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
	Mean daily effort	Fishing areas contributing >10% of the TACC	
	CPUE	Fishing areas contributing >10% of the TACC	
	Mean length	Fishing areas contributing >10% of the TACC	
	Abundance of legal-sized abalone	Cape du Couedic, Cape Bouger, Cape Gantheaume	
	Abundance of sub-legal-sized abalone		
3	**% Egg production relative to pristine egg production**	Three most important fishing areas (by catch)	<50% of the pristine level
4	**Abundance of abalone $>L_{50}$**	Cape du Couedic, Cape Bouger, Cape Gantheaume	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
5	Harvest discard	Fishing Zone	-

1.4 Previous stock assessments

The first assessment of the South Australian abalone resource was published by the South Australian Department of Fisheries in 1984 (Lewis *et al.* 1984). That report documented catch, effort and CPUE data from the start of the fishery to 1983 and concluded that fishing effort required capping at the 1971 level.

In 1996, the abalone research arrangements were reviewed (Andrew 1996). This review highlighted the need for (1) expansion of the fishery-independent surveys to include blacklip abalone in all three Zones of the fishery, (2) evaluation of the impacts of the 'fish-down' areas on blacklip abalone populations in the Southern Zone, (3) comprehensive re-assessment of the distribution of commercial catch and effort, and (4) estimation of both the recreational and illegal catch.

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

The 2001 stock assessment report provided fishery statistics for all three Zones of the fishery (Mayfield *et al.* 2001) and provided the basis for more detailed stock assessments for each Zone during 2002 (Mayfield *et al.* 2002a,b, Mayfield and Ward 2002). The first dedicated CZ report (Mayfield and Ward 2002) synthesised all fisheries data for the CZ from 1968 to 2001. That report was updated in 2003 (Mayfield and Ward 2003), 2004 (Mayfield *et al.* 2004), 2005 (Mayfield *et al.* 2005a) and 2006 (Mayfield *et al.* 2006).

The last four reports (Mayfield and Ward 2003; Mayfield *et al.* 2004, 2005a, 2006) each identified that the information available for blacklip abalone indicated that those stocks were declining. These reports were supplemented by two blacklip abalone stock status reports (Mayfield *et al.* 2005b; Mayfield & Carlson 2007) that reached similar conclusions. The two most recent reports (Mayfield *et al.* 2005a, 2006) also highlighted that declines in the abundance of sub-legal-sized abalone, low estimates of retained egg production and high levels of catch from Tiparra Reef were likely to impact the sustainability of future catches at this level from this area.

1.5 Fisheries biology of abalone

Abalone (Family: Haliotidae; Genus: Haliotis) are marine gastropods inhabiting nearshore reefs (Day & Shepherd 1995) from the shallow subtidal zone to depths around 400 m (Geiger 1999). They have a world-wide distribution in tropical and temperate waters with the richest abalone faunas found in Australia, Japan and South Africa (Geiger 1999). Over 50 species of abalone are currently recognised (Geiger 1999).

Large genetic differences exist between the northern and southern temperate species and within the southern temperate species assemblages (Brown 1991). Even on more localised scales, genetic variation can occur (Brown & Murray 1992, Elliott *et al*. 2000, Hancock 2000), suggesting limited dispersal between 'metapopulations' (Fleming 1997).

Abalone have separate sexes. Spawning is generally seasonal and synchronised. Fertilisation success is strongly influenced by adult density. Larval duration ranges between 5 and 10 days and is predominantly influenced by water temperature. As the larvae are free swimming, dispersal distances are influenced by local hydrodynamics (Prince *et al*. 1987). Recruitment may vary widely from year to year and the relationship between stock size and subsequent recruitment is uncertain (McShane *et al*. 1988; Prince *et al*. 1988; Shepherd 1990; McShane 1991; McShane & Smith 1991; Shepherd *et al*. 1992).

Growth rates are initially high and length-dependent for the first 5 years (Shepherd 1988). Thereafter, they decline and follow a von Bertalanffy model (Shepherd & Hearn 1983) with year classes becoming indistinguishable by length. Water temperature, water movement and the quantity and species of macroalgae available for consumption are the primary determinants of abalone growth rates (Day & Fleming 1992, Zacharin 1997). Recently settled abalone prefer encrusting coralline algae (Shepherd & Turner 1985, Shepherd & Daume 1996) that provide an important source of food, and protection from predation (Shepherd & Cannon 1988).

As juvenile abalone grow, their diet shifts from crustose coralline algae (individuals 5-10 mm SL) to drift red algae (Shepherd & Cannon 1988). Other abundant algae may be largely avoided, ostensibly due to non-palatability. Small abalone are preyed upon by a range of predators, including fish, crabs, starfish and octopus. Shells are frequently bored by whelks that then feed on the foot muscle. Boring polycheates also erode the shells and spire (Shepherd 1973).

1.4.1 Biology of greenlip abalone in the Central Zone

Greenlip abalone (*Haliotis laevigata)* are contiguous throughout southern Australia, with their distributions ranging from Corner Inlet (Victoria) to Cape Naturaliste (Western Australia). They commonly inhabit reefs at depths between 1 and 30 m. They occur in clusters of local populations, separated from other similar clusters over a range of spatial scales. This pattern of disaggregated spatial distribution is reflected in the population genetics with clusters representing putative 'metapopulations' (Shepherd & Brown 1993; Dr Nick Elliott, CSIRO Hobart, pers. comm.).

The length at sexual maturity of greenlip abalone can vary significantly among areas. Fifty percent of individuals were sexually mature (L_{50}) between 75 and 87 mm SL (Tiparra Reef; Table 1.6). Greenlip abalone spawned synchronously between October and March at both West Island and Tiparra Reef (Shepherd & Laws 1974, SARDI unpublished). These data match the pattern of larval settlement onto artificial collectors (Keesing *et al*. 1995, Rodda *et al*. 1997). Sex ratios seldom differ from 1 male: 1 female (SARDI, unpublished data). Relationships between biological components including length, whole weight, meat weight, bled meat weight and fecundity for greenlip abalone from Tiparra Reef and West Island are well established (Tables 1.7 & 1.8). Fresh meat weight and bled meat weight represent about 41.5 and 33.5% of whole weight, respectively (SARDI, unpublished data).

Rates of growth vary throughout the life history stages of abalone with smaller individuals generally growing faster than larger ones. The rate of growth is, however, dependent on environmental conditions that often vary through time and space. For example, juvenile *H. laevigata* grew rapidly and attained a length of 40 mm within one year at West Island (~0.12 $mm.day^{-1}$). However, their growth rates vary temporally; at West Island the mean juvenile growth rate was 0.06 $mm.day^{-1}$ five years later (Shepherd 1988). Sub-adult growth rates in the CZ ranged between 20.3 and 20.9 $mm.yr^{-1}$ (Table 1.9). Adult greenlip abalone growth is non linear and can be represented by the parameters K and L_{∞} from the von Bertalanffy growth equation. K (rate of growth) ranged from 0.41 (Tiparra Reef) to $0.48.yr^{-1}$ (West Island) and L_{∞} (average maximum attainable length) between 130.8 mm (Tiparra Reef) and 137.9 mm (West Island; Table 1.10).

Rates of natural mortality vary spatially and temporally. Natural mortality rates (M) of greenlip abalone at West Island were 0.26 $year^{-1}$. This was greater than that observed at Tiparra Reef (M = 0.22 $year^{-1}$; Table 1.11). For juvenile *H. laevigata* at West Island, M was 0.24 $month^{-1}$ (0-8 months); individuals between 1 and 4 years of age had natural mortality rates of 0.23 – 0.4 $year^{-1}$ (Shepherd & Baker 1998).

Table 1.6: Length at 50% maturity (mm, shell length) for greenlip (*H. laevigata*) abalone in the CZ of the South Australian abalone fishery.

Year	Site	Length at 50% maturity (mm)	CI (95%)	Reference
1964	West Island	87	-	Shepherd & Laws (1974)
1969	Tiparra Reef	75	-	Shepherd & Laws (1974)
2003	Tiparra Reef - West bottom	78.9	78.2 – 79.6	SARDI unpublished data
2004	Tiparra Reef - Coal ground	88.4	88.0 – 88.7	SARDI unpublished data
2004	Tiparra Reef - West bottom	83.3	81.7 – 84.9	SARDI unpublished data
2007	Tiparra Reef - Coal ground	79.9	79.3 – 80.4	SARDI unpublished data
2007	Tiparra Reef - Midwest bottom	75.9	70.2 – 81.6	SARDI unpublished data

Table 1.7: Relationship between shell length (SL, mm) and shell weight (SW, g) for greenlip abalone in the CZ. The equation is of the form $SW = aSL^b$.

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

Table 1.8: Relationship between fecundity (F, millions of eggs) and shell weight (SW, g) and between fecundity and shell length (SL, mm) for greenlip abalone at Tiparra Reef and West Island in the CZ. The equations are of the form $F = c + dSW$ and $F = aSL^b$

Year	Site	a	b	c	d	Reference
1986	Tiparra Reef	-	-	-1.51	0.02	Shepherd & Baker (1998)
1986	West Island	-	-	-0.36	0.015	Shepherd & Baker (1998)
2004	Tippara Reef - Coal Ground	0.4271	3.09	-	-	SARDI unpublished data
2004	Tippara Reef -Mid West Bottom	0.0007	4.26	-	-	SARDI unpublished data

Table 1.9. Growth rate ($mm.yr^{-1}$) of greenlip abalone tagged and recaptured in the CZ of the South Australian abalone fishery.

Site	Length range	Growth rate ± SE	Reference
West Island	42-141	20.3±0.4	Shepherd (1988)
Tiparra Reef	51-129	20.9±0.7	Shepherd & Triantafillos (1997)

Table 1.10: Growth rate, K (yr^{-1}) and L_∞ (mm SL) for greenlip abalone tagged and recaptured in the CZ of the South Australian abalone fishery. Length ranges are shell length (mm).

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

Table 1.11: Natural mortality rates (M yr^{-1}) for adult (emergent) greenlip abalone at two sites in the CZ.

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

1.4.2 Biology of blacklip abalone in the Central Zone

Blacklip abalone (*Haliotis rubra)* are contiguous throughout southern Australia between Coffs Harbour (New South Wales) and Rottnest Island (Western Australia). They commonly occur in shallow water (0 – 30 m) along rocky coastlines.

Blacklip abalone have a broad-scale population structure (Brown 1991); however, significant genetic differentiation can occur between sites less than 15 km apart (Shepherd & Brown 1993).

The length at which 50% of the blacklip abalone population are sexually mature (L_{50}) can vary significantly among areas. L_{50} was reached at 76 and 109.2 mm SL at West Island and Vennachar Point, respectively (Table 1.12). Blacklip abalone spawn during summer and autumn, although spawning is poorly synchronised (Shepherd & Laws 1974). The annual spawning cycle may be driven by seasonal fluctuations in water temperature (Shepherd & Laws 1974).

Rates of growth vary throughout the life history stages of abalone with smaller animals growing faster than larger ones. The rate of growth is, however, dependent on environmental conditions that often vary through time and space. Emergent blacklip abalone growth is non linear and best represented by the von Bertalanffy growth model. Model parameter K ranged from 0.32 (Tiparra Reef) to 0.34 $.yr^{-1}$ (West Island) while L_∞ varied between 138.8 (West Island) and 142.6 mm SL (Tiparra Reef; Table 1.13).

As for growth, rates of natural mortality vary spatially and temporally. Natural mortality rates of blacklip abalone were estimated at 0.36 $year^{-1}$ at West Island and 0.21 $year^{-1}$ at Tiparra Reef (Table 1.14).

Table 1.12: Length at 50% maturity (mm, shell length) for blacklip (*H. rubra*) abalone in the CZ of the South Australian abalone fishery. The equation is of the form $f(x) = (1+\exp(-(L_{50}-x)/\delta))^{-1}$.

Year	Site	Length at 50% maturity (mm)	CI (95%)	Reference
1964	West Island	76	-	Shepherd & Laws (1974)
1969	Tiparra Reef	93	-	Shepherd & Laws (1974)
2004	Cape Bedout	92.2	89.8 – 94.7	SARDI unpublished data
2004	Cape du Couedic	97.9	96.1 – 99.7	SARDI unpublished data
2004	Weirs Cove	99.6	98.3 – 100.9	SARDI unpublished data
2005	Cape Bedout	97.2	95.7 – 98.7	SARDI unpublished data
2007	Vennachar Point	109.2	107.4 - 111	SARDI unpublished data

Table 1.13: K (yr^{-1}) and L_∞ (mm SL) for blacklip abalone tagged and recaptured in the CZ of the South Australian abalone fishery. Errors provided are standard errors. Length ranges are shell length (mm).

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

Table 1.14: Natural mortality rates (yr^{-1}) for adult (emergent) blacklip abalone at two sites in the CZ of the South Australian abalone fishery.

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

2. GREENLIP ABALONE

Commercial catch and effort data for this fishery have been collected since 1968. Fishers complete a research logbook for each fishing day and submit those data to SARDI Aquatic Sciences at the end of each month. The logbook data supplied have been used to provide the spatial and temporal analyses of catch, effort and catch-per-unit-effort (CPUE), from 1 January 1968 to 31 December 2007, presented in this section of the report. To avoid bias in determining mean CPUE as the mean of daily CPUE, estimates of CPUE were computed using the mean ratio estimator (after Rice 1995). Data on the length-frequency distribution of the commercial catch from 2002 to June 2005 were obtained by measuring samples provided to SARDI by commercial fishers; data from July 2005 were primarily provided by the Abalone Industry Association of SA (AIASA) and includes measurements obtained 'at sea' using electronic shell measuring machines. These data were supplemented by samples provided by commercial fishers to SARDI. Estimates of greenlip abalone abundance were obtained from fishery-independent diver surveys. Estimates of egg production, relative to those in an unfished (virgin) population were determined using models developed by SARDI.

Fishery statistics in this section are provided at three spatial scales. These are (1) the whole greenlip abalone fishery (*i.e.* all areas of the CZ combined); (2) individual fishing areas; and (3) Tiparra Reef (mapcodes 21A-21G; Figure 1.2). Estimates of the mean daily catch (MDC; $kg.day^{-1}$), total effort (hr), mean daily effort (MDE; $hr.day^{-1}$) and CPUE ($kg.hr^{-1}$) over the last 15 years (1993 – 2007) were determined for Tiparra Reef (mapcodes 21A – 21G) and for Fishing Areas 21 (that includes data from Tiparra Reef), 22 and 24 because, cumulatively, >85% of the TACC was harvested from these three fishing areas in 2007. The CPUE on greenlip abalone, from 1978 to 2007, was also estimated for all fishing areas of the CZ combined. Insufficient data (*i.e.* $n < 3$) prevented calculation of MDC, MDE and CPUE in some years at some spatial scales. This was the case for Fishing Area 22 during 1996, 1998 and from 2000 to 2003, and for Fishing Area 24 in 2000 and 2001.

MDC, MDE, CPUE and total effort for greenlip abalone in each area were calculated from daily records where blacklip abalone catch was zero. Justification for this includes: (1) >70% of the fishing records between 1978 and 2007 report a blacklip abalone catch of zero; (2) >80% of the greenlip abalone catch is obtained on days when no blacklip abalone are harvested; (3) greenlip and blacklip abalone are typically harvested from different fishing areas; and (4) effort is not proportioned among species on each fishing day. Data are typically presented as mean ± 1 standard error (SE). Fishery data since exploratory fishing began at Cowell are excluded.

2.1 Catch

Total catch of greenlip abalone increased significantly from <100 $t.yr^{-1}$ in 1968 and 1969 to a maximum of 252.5 t in 1989 (Linear Regression (LR): r^2 = 0.62, df = 20, $p < 0.001$; Figure 2.1). The catch in 1973 and 1974 was <50 t, but since 1978 has been >100 $t.yr^{-1}$. Quotas have limited annual catch since 1990. The annual TACC was not attained in 1992 or 1993, and has remained unchanged at 143.1 t since 1994 (Table 1.2; Figure 2.1).

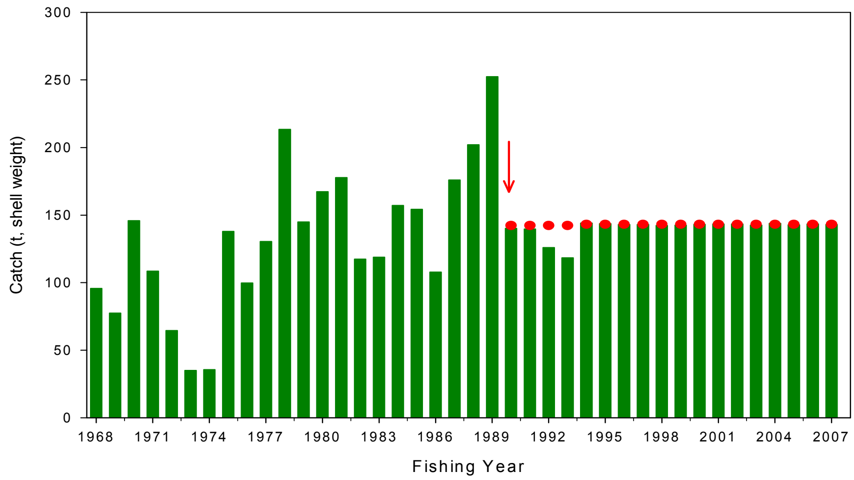

Figure 2.1: Catch (t, shell weight) of greenlip abalone in the CZ from 1968 to 2007. Red dots indicate the greenlip abalone TACC.

Since 2003, ~85% of the greenlip abalone TACC has been harvested from Fishing Areas 21, 22 and 24 (Figure 2.2). Proportions of the TACC harvested from the remaining fishing areas (20, 23 and 25 – 32) are negligible and typically <3%.

The proportion of the catch harvested from Fishing Area 21 increased substantially from <50% to >90% between 1986 and 2001, whereafter it has declined (Figure 2.2). This reduction reflects the agreement among licence holders in the CZ to limit the catch from the principal fishing ground in Fishing Area 21, Tiparra Reef (mapcodes 21A to 21H), to 90 $t.yr^{-1}$ from 2005. In response to this catch limit, the proportions of the catch harvested from Fishing Areas 22 and 24 have increased rapidly since 2003 (Figure 2.2).

These patterns are reflected in the catch history for each fishing area (Figure 2.3). For example, the catch increased in Fishing Area 21 from <30 t in 1978 to almost 190 t in 1989, whereafter it declined sharply to 50.1 t in 1990. Catches from this fishing area again increased between 1991 (57.8 t) and 2001 (137.5 t), but have declined to ~90 $t.yr^{-1}$ since 2005.

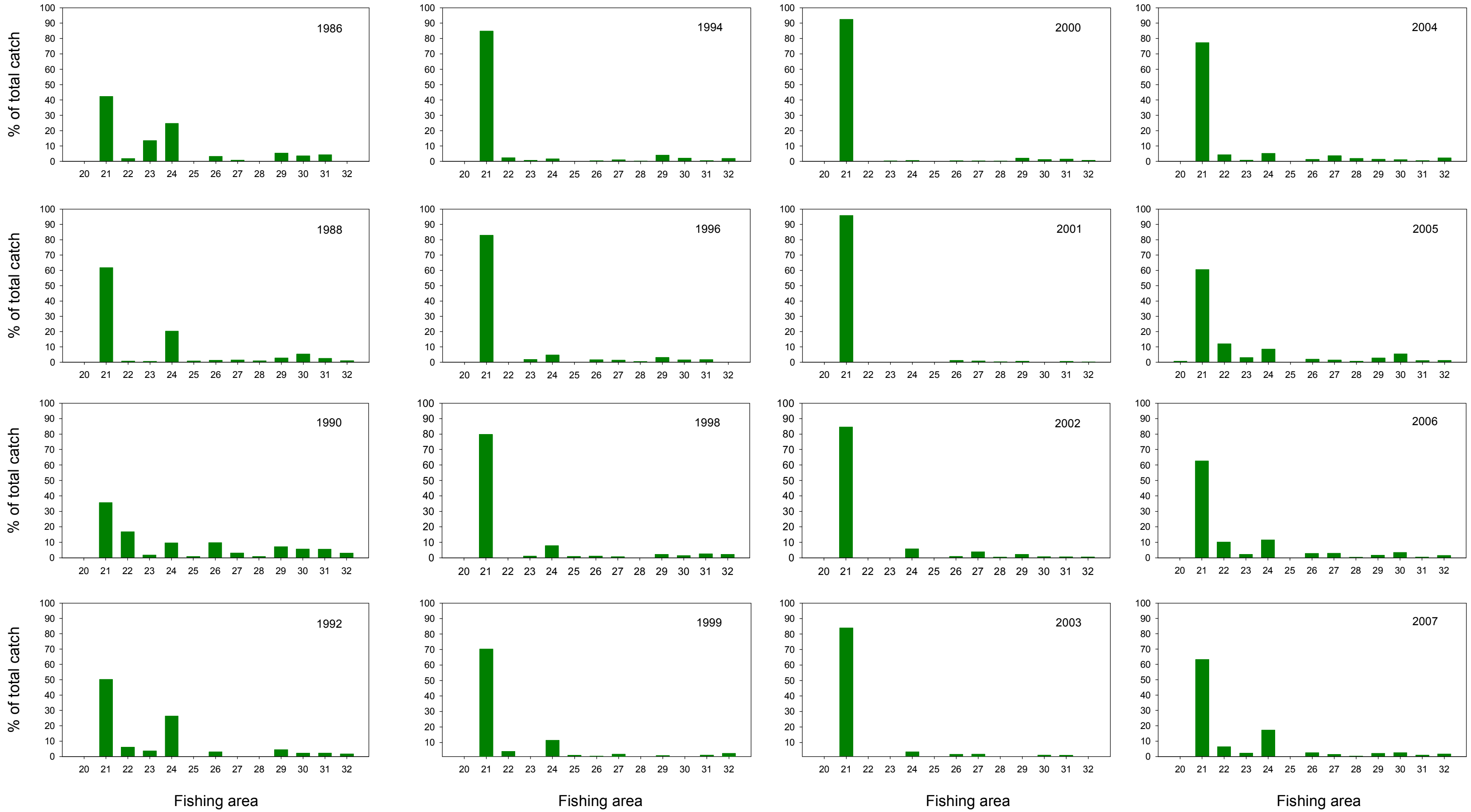

Figure 2.2: Spatial distribution of the greenlip abalone catch (% of total catch) among each of the fishing areas in the CZ in 1986, 1988, 1990, 1992, 1994, 1996 and from 1998 to 2007.

Figure 2.3: Catch of greenlip abalone (t, shell weight) in each of the fishing areas comprising the CZ from 1978 to 2007.

Catches of greenlip abalone have increased rapidly over the last five years in other fishing areas. The catch from Fishing Area 24 has increased from 5.5 t in 2003 to 24.7 t in 2007; the catch in 2007 was similar to the mean catch from this area between 1978 and 2002 (24.5 t). Annual catches from Fishing Areas 22 and 30 increased rapidly between 2002 and 2005 (from 0.0 to 17.2 t and from 1.1 to 7.9 t, respectively), but have declined substantially over the last two years to 9.0 and 3.5 t in 2007, respectively. These represent reductions in catch exceeding 50% over this two-year period.

2.2 Mean daily catch (MDC)

Temporal patterns in MDC were similar for both Tiparra Reef and Fishing Area 21 (Figure 2.4). MDC in these areas was largely stable between 1993 and 1999 (range: 342.3 – 444.7 $kg.day^{-1}$), but increased substantially between 1999 (Tiparra Reef: 412.7 $kg.day^{-1}$; Fishing Area 21: 417.1 $kg.day^{-1}$) and 2000 (Tiparra Reef: 633.2 $kg.day^{-1}$; Fishing Area 21: 634.3 $kg.day^{-1}$). Since 2000, MDC has declined significantly at both Tiparra Reef (LR: r^2 = 0.57, df = 7, $p < 0.05$) and in Fishing Area 21 (LR: r^2 = 0.61, df = 7, $p < 0.05$).

MDC increased from 368.0 to 597.9 $kg.day^{-1}$ in Fishing Area 22 between 1993 and 1999, whereafter it has declined rapidly, reaching 281 $kg.day^{-1}$ in 2007 (Figure 2.4). This represents a decrease of >45% over four years to the lowest value since 1993.

In Fishing Area 24, MDC increased from 346.0 to 664.3 $kg.day^{-1}$ between 1993 and 1997, whereafter it decreased rapidly, to 314.6 $kg.day^{-1}$ in 2002 (Figure 2.4). Although it increased by ~25% between 2002 and 2005, MDC remained well below that observed in 1997. MDC decreased by 18% between 2005 and 2007 (333.4 $kg.day^{-1}$) to the lowest value since 2002.

2.3 Effort

Temporal patterns in total effort were similar for both Tiparra Reef and Fishing Area 21 (Figure 2.5). Total effort has declined significantly in these areas since 1994 (Tiparra Reef LR: r^2 = 0.80, df = 13, $p < 0.01$; Fishing Area 21 LR: r^2 = 0.93, df = 13, $p < 0.01$). Nevertheless, it has increased slightly (<10%) in Fishing Area 21 and at Tiparra Reef since 2006 and 2005, respectively.

Total effort decreased rapidly in Fishing Area 22 between 1993 and 1996, with sporadic and low levels of effort through to 2003 (Figure 2.5). It increased rapidly between 2003 and 2006, but decreased >40% between 2006 and 2007. In Fishing Area 24, total effort decreased substantially between 1995 and 2001, whereafter it has increased rapidly (Figure 2.5). In 2007 it was at the highest since 1995, and >70% greater than that in 2006.

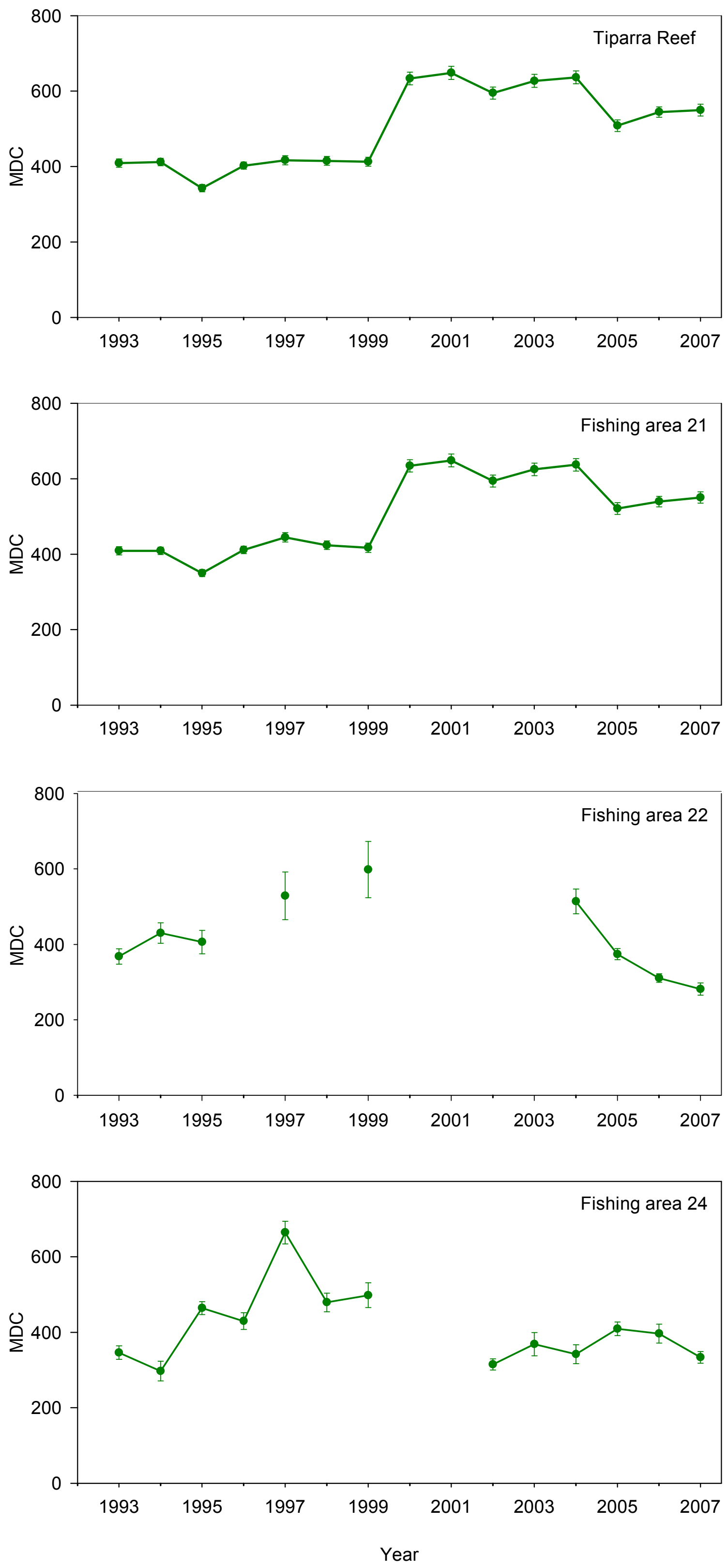

Figure 2.4: MDC (kg.day^{-1}) of greenlip abalone at Tiparra Reef and in Fishing Areas 21, 22 and 24 from 1993 to 2007.

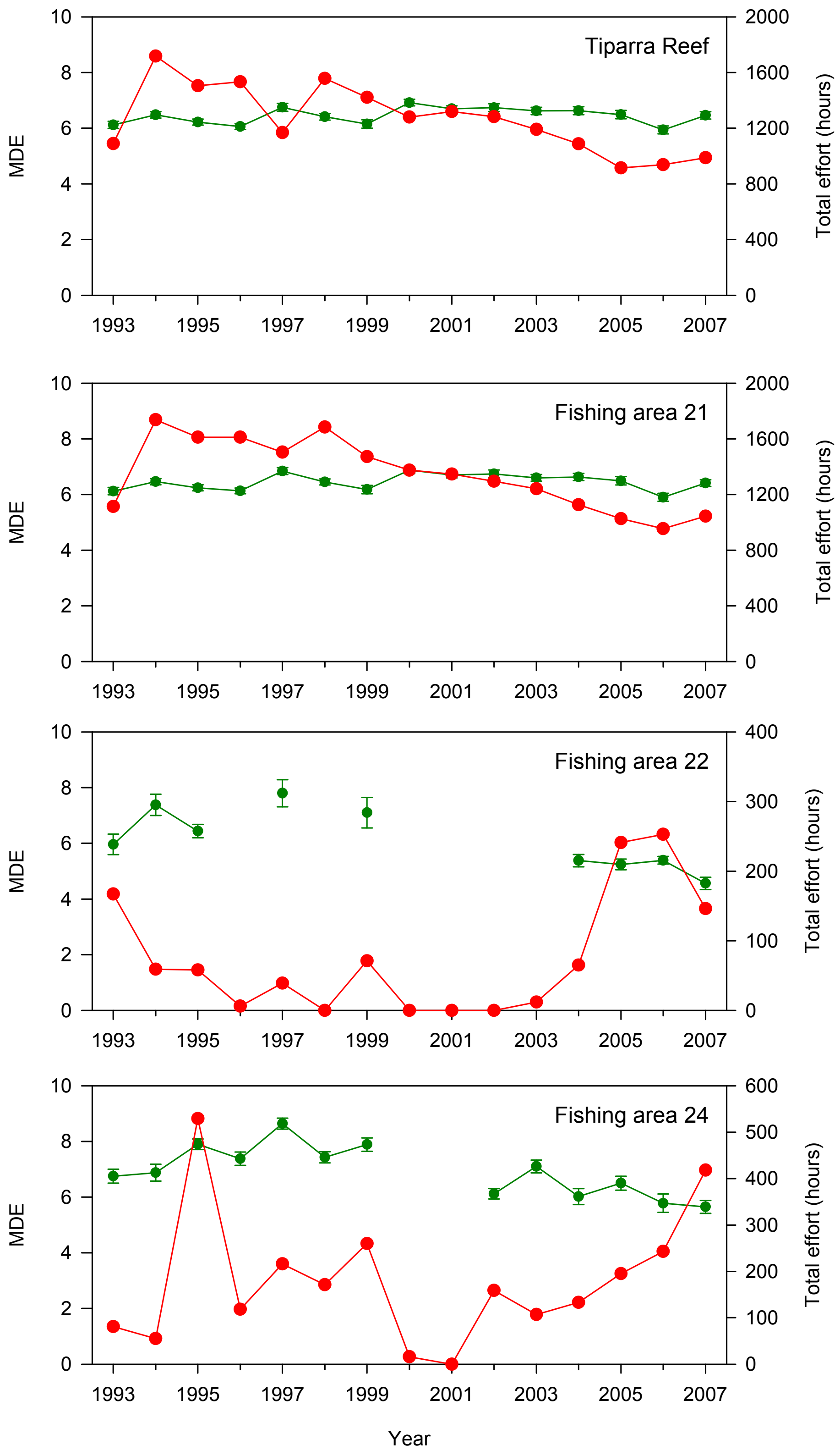

Figure 2.5: Total (red lines) and MDE (hr.day^{-1}) on greenlip abalone at Tiparra Reef and in Fishing Areas 21, 22 and 24 from 1993 to 2007.

2.4 Mean daily effort (MDE)

Temporal patterns in MDE were similar for Tiparra Reef and Fishing Area 21 (Figure 2.5). In both areas, MDE has shown no long-term trend since 1993, ranging between 5.9 and 6.9 hr.day^{-1}.

MDE in Fishing Area 22 has declined significantly since 1997 (LR: r^2 = 0.97, df = 5, p < 0.01; Figure 2.5). This represents a decrease of >40% over 10 years to the lowest value since 1993. In Fishing Area 24, MDE increased steadily between 1993 and 1997, whereafter it has decreased significantly (LR: r^2 = 0.81, df = 8, p < 0.01; Figure 2.5). Since 1998, it has decreased >30%.

2.5 Catch-per-unit effort (CPUE)

The CPUE on greenlip abalone, in all fishing areas of the CZ combined, fluctuated between 50.6 and 75.9 kg.hr^{-1} from 1978 to 1999 (Figure 2.6). It increased significantly between 1999 and 2000 (t-test: t = 10.9, df = 367.9, p < 0.01), and again between 2000 and 2001, to the highest level observed since 1978. However, since 2001, CPUE has declined significantly (LR: r^2 = 0.80, df = 6, p < 0.05). It has decreased by 21% over six years, to a level equivalent to the lowest value since 1999.

Temporal patterns in CPUE were similar for both Tiparra Reef and Fishing Area 21 (Figure 2.6): it was largely stable between 1993 and 1999, but increased substantially between 1999 and 2000 and again between 2000 and 2001. While the CPUE in both areas has fluctuated among years since 2001, it has generally declined. Levels of CPUE in 2007 were >10% lower than those in 2001. CPUE increased in Fishing Area 22 between 1993 and 2004, whereafter it has declined substantially (Figure 2.6). Levels of CPUE in 2005 and 2006 were ~40% lower than that in 2004. In Fishing Area 24, CPUE increased between 1993 and 1997, whereafter it decreased rapidly, to 314.6 kg.day^{-1} in 2002 (Figure 2.4). Although it increased steadily between 2003 and 2006, CPUE remained below that observed in 1997. CPUE decreased significantly between 2006 and 2007 (t-test: t = 2.4, df = 64.7, p < 0.05). This represented a 14% decrease in CPUE between years.

2.6 Length-frequency distribution of the catch

Sample sizes of shells measured from the commercial catch ranged between 2,979 (2002) and 8,572 (2004) from 2002 to 2005 (Figure 2.7). Those samples represented <2% of the total catch. During 2006, <2 500 shells were measured. However, in 2007, the sample size was the highest on record, exceeding 12,000 shell measurements. Notably, >97% of these were obtained from the electronic shell measuring machines.

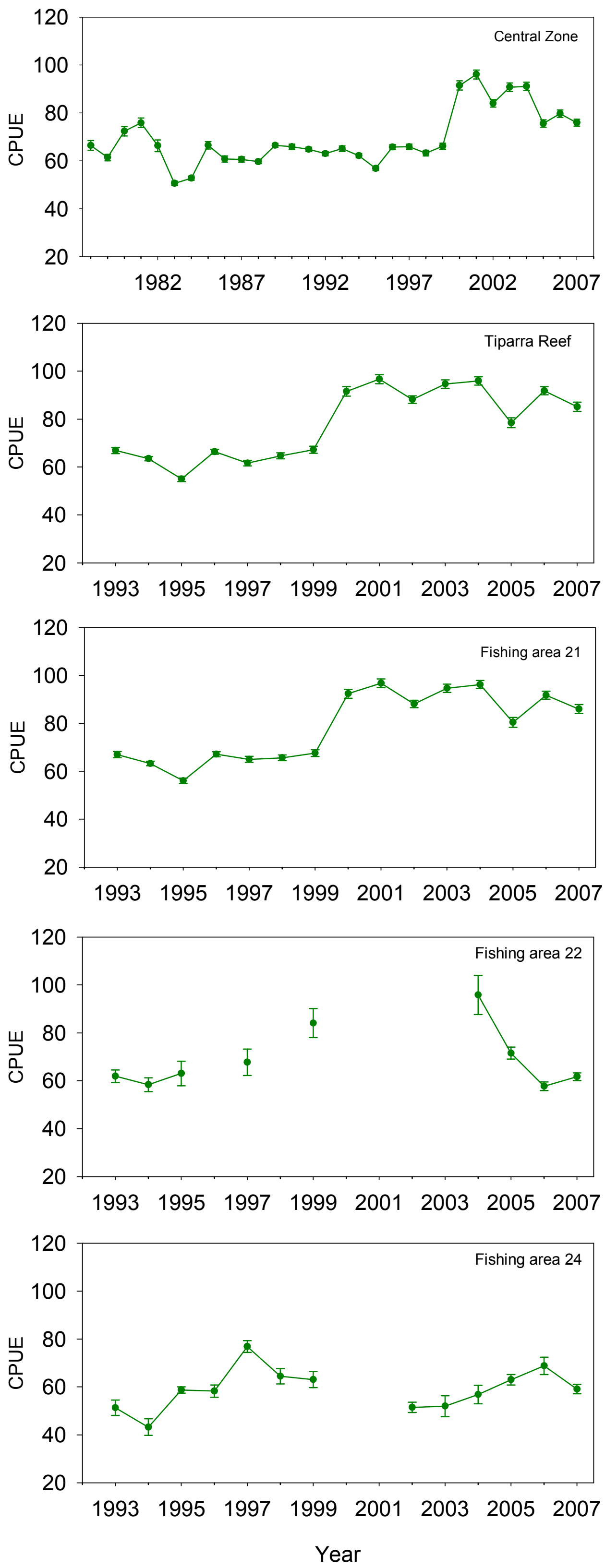

Figure 2.6: CPUE (kg.hr^{-1}) on greenlip abalone for all fishing areas of the CZ combined from 1978 to 2007, and at Tiparra Reef and in Fishing Areas 21, 22 and 24 from 1993 to 2007.

Examination of the data from the shell measuring machines identified numerous inconsistencies. These included (1) provision of length measurements for greenlip abalone in one fishing area (as determined from the GPS position linked to each shell length measurement) when the catch on that day was reported to a different fishing area, (2) provision of length measurements for blacklip abalone in fishing areas within which the total catch of blacklip in 2007 was reported as zero, and (3) several (<1%) shell length measurements exceeding the largest greenlip abalone previously measured (*i.e* >199 mm SL).

The inconsistencies identified suggest that while probably useful, data from the electronic shell measuring machines should be cautiously interpreted. This is because the reliability of those data is poorly understood. The data presented in this report, reflect (1) the metadata recorded (*i.e*. GPS position, species) simultaneously with each length measurement, with (2) the data truncated to exclude greenlip abalone shell length measurements >200 mm SL.

The number of licences contributing commercial shell samples (maximum possible is six) declined from five in 2003 to only two in 2006 (Figure 2.7). In 2007, three licences contributed length measurements.

The spatial distribution of the commercial length-frequency data has changed since 2005 (Figure 2.7). Notably, while data were obtained from catches harvested across a similar number of fishing areas each year (range: 4 – 8), the number of mapcodes (*e.g.* 21A, 30B) sampled in more recent years (~10) is substantially lower than the number sampled in 2004.

There were strong relationships between levels of catch among fishing areas and commercial shell samples from 2003 to 2007 (Figure 2.8). In each year, the greatest number of commercial shell samples were obtained from Fishing Area 21, which produced the highest levels of catch. Few samples were obtained from those fishing areas that contributed only small catches.

There were few substantial changes in the length-frequency distributions of greenlip abalone in the commercial catch, for all fishing areas of the CZ combined, between 2002 and 2007 (Figure 2.9). During this six-year period, the mean length ranged between 147.6 and 153.3 mm SL and the modal length class varied by <10 mm SL. However, the proportion of the sample <145 mm SL has generally increased, from ~18% in 2001 to >40% in 2007. The mean length was smallest and the proportion of the sample <145 mm SL greatest in 2007.

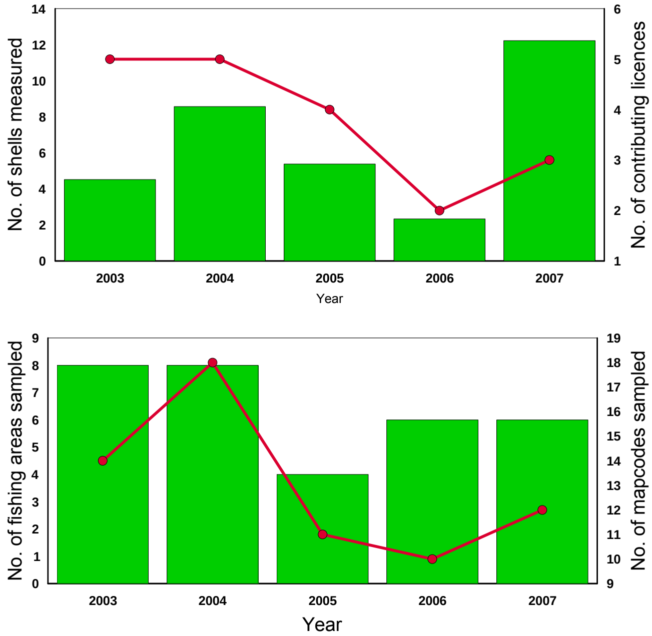

Figure 2.7: Numbers of shells measured (thousands; green bars) and contributing licences (red line; top) and numbers of fishing areas (green bars) and mapcodes (red line; bottom) from which commercial catches were sampled from 2003 to 2007.

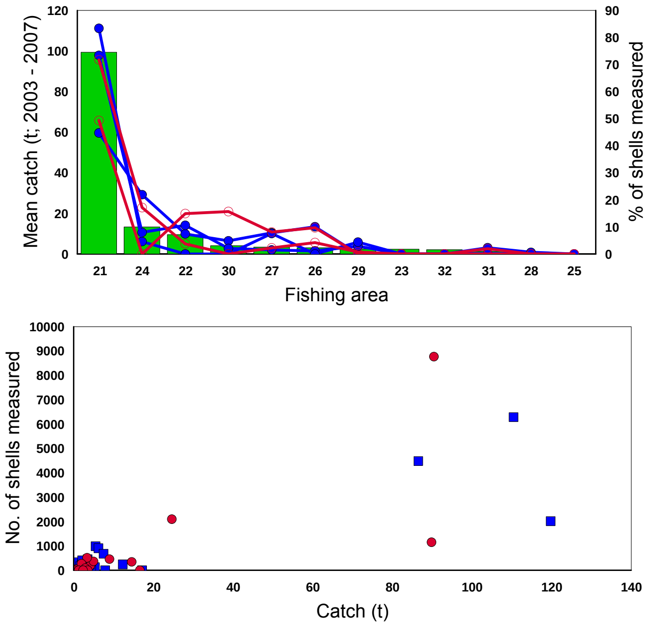

Figure 2.8: Relationships between (top) mean catch (green bars) and the percentage of commercial shell measurements (blue lines: 2003, 2004 and 2005; red lines: 2006 and 2007) and (bottom) total catch in each fishing area and total number of commercial shell measurements (blue dots: 2003, 2004 and 2005; red dots: 2006 and 2007).

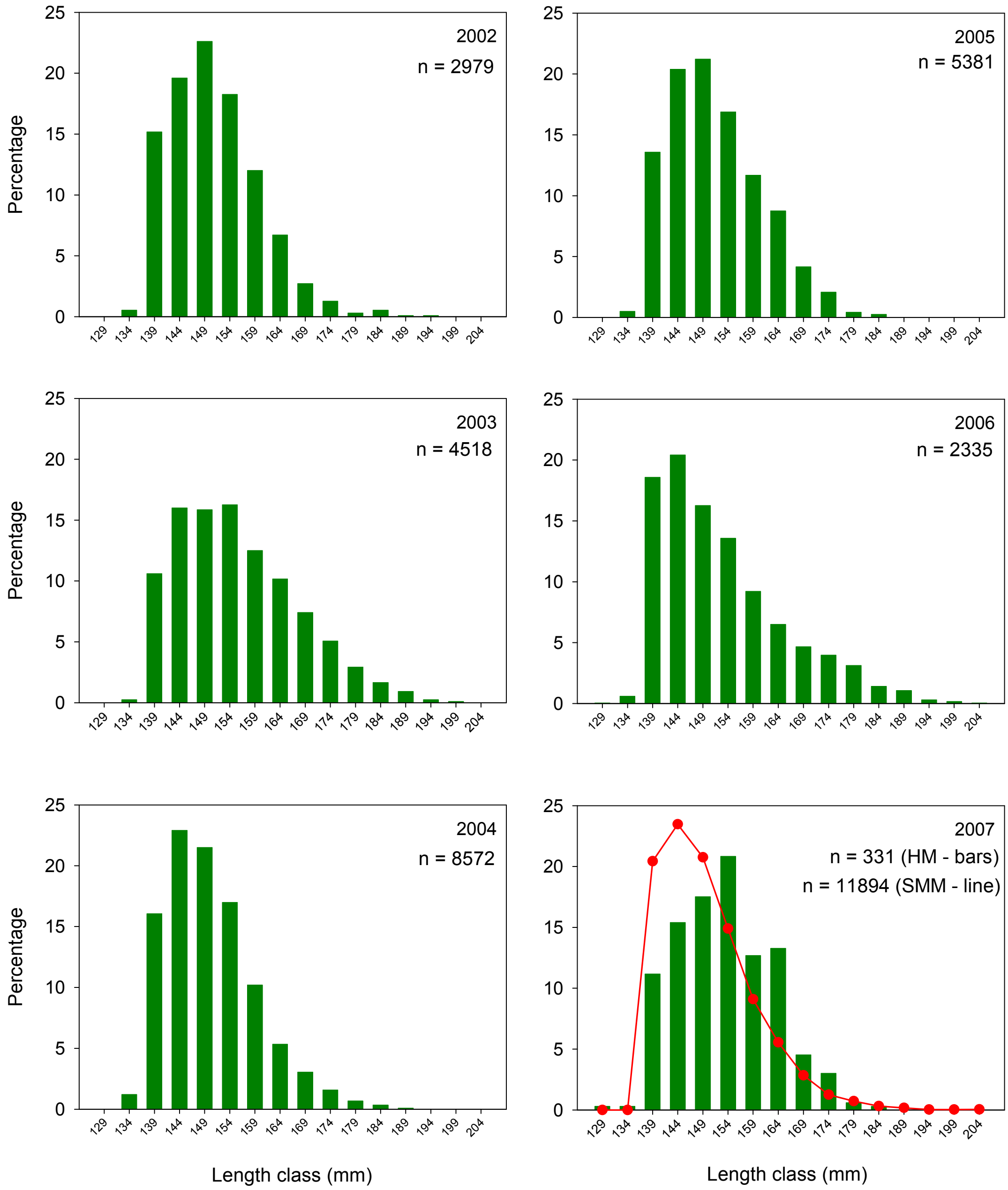

Figure 2.9: Length-frequency distributions obtained from measuring greenlip abalone shells (hand measured (HM): bars; and electronic shell machine measured (SMM): red line) from the commercial fishery in the CZ from 2002 to 2007. Length classes are mm SL.

The most important fishing areas for greenlip abalone in the CZ are 21, 22, 24, 27 and 29 (see Section 2.1). There are no commercial length-frequency data for Fishing Area 22 in 2005, for Fishing Area 24 in 2002 and 2006, for Fishing Area 27 in 2002 and for Fishing Area 29 in 2003 and 2006 (Figure 2.10). The irregular sampling of commercial catches from these key fishing areas substantially impedes the ability to detect and quantify temporal changes in the length structure of commercially fished greenlip abalone.

In contrast to the more limited changes in the length-frequency distributions of the commercial catch observed for the whole CZ, temporal changes in three key fishing grounds (Fishing Areas 21, 22 and 24) are more substantial (Figure 2.10). In Fishing Area 21, the mean length has decreased by 0.9 mm SL and the proportion of the sample <145 mm SL increased (from ~45 to ~50%) between 2003 and 2007. The decline in the mean length since 2003 was significant (ANOVA of regression: $F_{1,22694} = 52.0$, $p < 0.01$). In Fishing Area 22, the mean length decreased by 4.2 mm SL, the modal length class decreased by 10 mm SL and the proportion of the sample <145 mm SL increased (from 15.8 to 40.5%) between 2002 and 2006. These trends were reversed between 2006 and 2007. In Fishing Area 24, the modal length class has decreased by 5 mm SL, the mean length has decreased by 8 mm SL and the proportion of the sample <145 mm SL has increased from 8.3 to >30% since 2003. Temporal patterns in Fishing Area 27 were more variable. Nevertheless, the modal length class decreased by 10 mm SL and the mean length decreased by 7.5 mm SL between 2006 and 2007. Similar patterns, between 2005 and 2007, were evident for Fishing Area 29.

2.7 Estimates of egg production

A simple egg-production model was used to estimate the proportion of pristine egg production conserved for greenlip abalone at Tiparra Reef in Fishing Area 21. Details of the biological data and the model assumptions are provided in Appendix 1. The estimate of retained egg production in 2007 was 40.6%, slightly lower than that for 2006 (41.3%).

2.8 Fishery-independent abalone surveys

Fishery-independent abalone surveys (FIAS) undertaken by SARDI Aquatic Sciences are used to monitor changes in greenlip abalone abundance and population structure at three sites in the CZ. Two survey methods are currently used. Surveys initiated Tiparra Reef in 1968 use the timed-swim method (Shepherd 1984). This long-term data set provides information on temporal changes in the relative abundance and length structure of greenlip abalone for this key fishing ground.

The second approach, termed the ‘leaded-line’ method (McGarvey 2006; McGarvey *et al*. in press), has the primary objective of measuring absolute abalone density, from which the total biomass can be quantified, within pre-defined and bounded survey regions. The method requires divers to count and measure all abalone within 1 m on either side of a 100-m, boat-deployed, leaded-rope line transect. Transect locations are determined prior to each survey and are systematically distributed within the survey region (Byth & Ripley 1980). This ensures the measures of density and length-frequency are spatially representative.

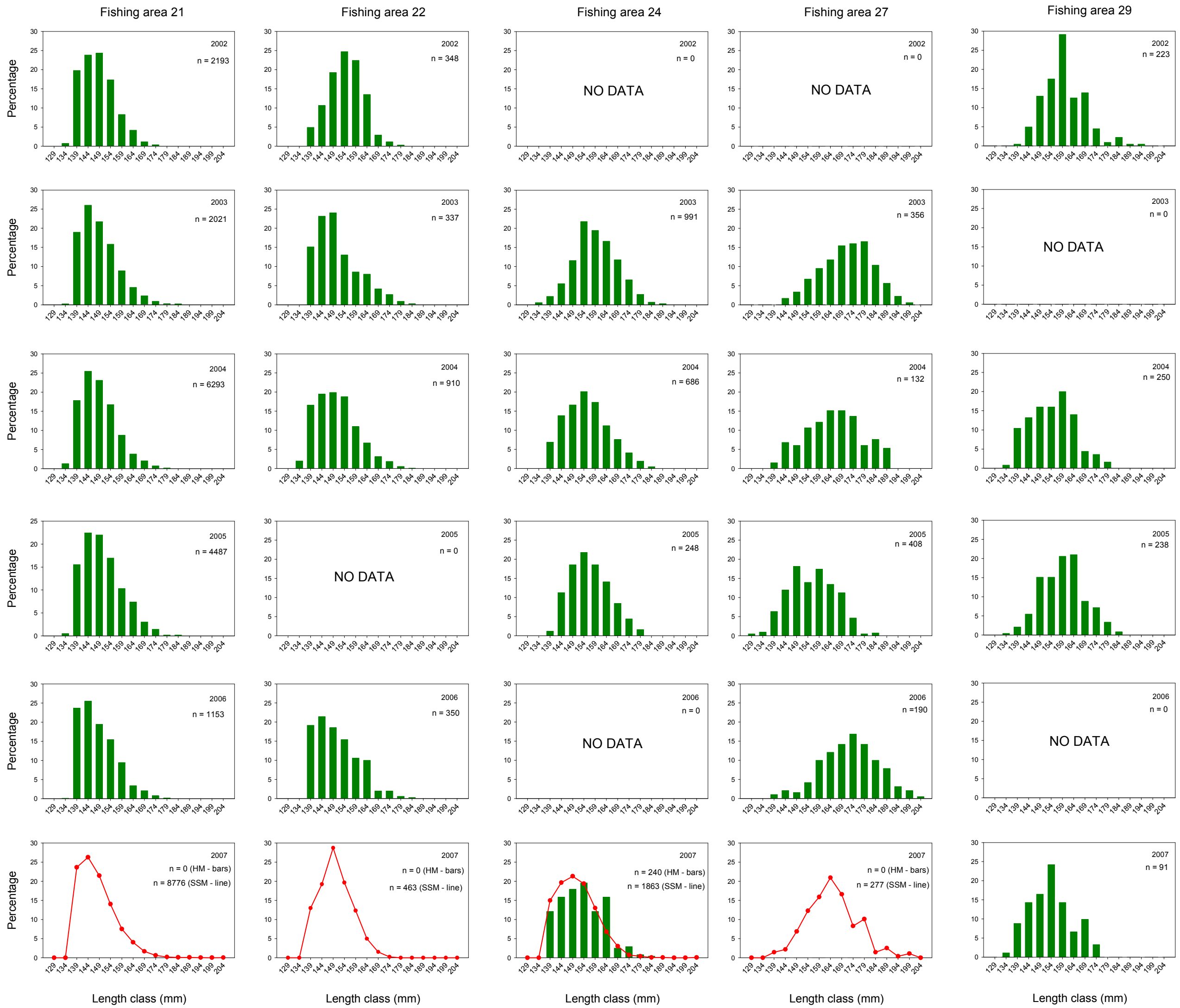

Figure 2.10: Length-frequency distributions obtained from measuring greenlip abalone shells (hand measured (HM): bars; and electronic shell machine measured (SMM): red lines) from the commercial fishery in Fishing Areas 21, 22, 24, 27 and 29 of the CZ from 2002 to 2007. Length classes are mm SL.

These survey results of abalone density, combined with representative data describing shell length, total-weight and meat-weight relationships are used to calculate the average density and biomass, with confidence intervals.

In response to recent increases in greenlip abalone catch from Fishing Areas 22 and 24 (see Section 2.1), additional fishery-independent surveys, using the leaded line method, were established in Hardwicke Bay and off Port Victoria in 2006 and 2007, respectively. These survey regions, associated strata and leaded-line locations are being refined as additional fishery-dependent data become available, and may change considerably in future years.

2.8.1 Tiparra Reef (Mapcodes 21A – 21G)

Up to 22 replicate, timed-swim surveys have been completed each year. In general, each replicate consisted of two divers each doing two 10-minute surveys. During each 10 minute survey, all emergent (visible) greenlip abalone observed were measured (Shepherd 1984).

To calculate the relative abalone abundance, two assumptions were made: (1) it took four seconds to measure each abalone, and (2) 20 metres were covered in 1 minute (Shepherd 1984). The total time taken to measure all the abalone observed in each 10-minute count was subtracted from 10 minutes and the remaining time used to calculate the distance swum using assumption 2. This distance was then used in the density estimation. Resulting estimates of abalone density were used to assess changes in relative abalone abundance and the length-frequency data were used to assess changes in population structure.

2.8.1.1 Changes in the abundance of greenlip abalone

Between 1968 and 1986 greenlip abalone abundance declined significantly (LR: $r^2 = 0.81$, df = 10, $p < 0.01$; Figure 2.11). It increased over the next four years, reaching the second-highest value in 1990. Between 1990 and 1994, the abundance declined by almost 65%. Since 1998, estimates of abundance have been substantially greater than that observed in 1994, but lower than that observed in 1990, the first year in which there was a TACC in the CZ. The estimate of abundance in 2007 was greater than that observed in 2006, but substantially lower than that observed in 2005.

The mean abundance of legal-sized greenlip abalone (>130 mm SL) declined substantially between 1990 and 1994. Since 1998 (*i.e.* eight surveys), their mean abundance has exceeded that observed in 1990, with that observed in 2005 the highest value on record. However, the mean abundance of legal-sized abalone has declined substantially since 2005, decreasing by 35% over two years. Importantly, there was a significant correlation, over the last 12 years, between the mean abundance of legal-sized greenlip abalone and commercial CPUE at Tiparra Reef in the following year (LR: r^2 = 0.69, df = 11, $p < 0.01$; see insert on Figure 2.11). This relationship supports the inference that estimates of legal-sized, greenlip abalone obtained from these fishery-independent surveys are a valuable index of stock status.

The mean abundance of sub-legal-sized greenlip abalone (<130 mm SL) declined sharply between 1990 and 1994 (Figure 2.9). The estimate of mean abundance was substantially greater in 1998, but again low in 2001. Since 2001, estimates of mean abundance have fluctuated among years, provided no evidence of any long-term trend (LR: r^2 = 0.25, df = 6, $p > 0.01$), and remained below the mean abundance observed in 1990. The estimate in 2007 was 48% greater than that observed in 2006, but below that in 2005.

2.8.1.2 Changes in greenlip abalone population length structure

The length-frequency distributions of greenlip abalone at Tiparra Reef show two distinct trends (Figure 2.12). Firstly, the proportion of large greenlip abalone has increased over the last decade. This is supported by three lines of evidence: (1) the proportion of legal-sized greenlip abalone has increased from ~15% to ~40%; (2) the modal length class has increased from <125 mm SL to >125 mm SL; and (3) the mean length has increased from <115 to >119 mm SL. Secondly, the shape of the distribution has changed from bell shaped, to increasingly left-skewed through the period from 2001 to 2007, although this is less pronounced in 2006 and 2007. These patterns are the result of a reduction in the proportion of greenlip abalone in the length range 65 – 110 mm SL being observed on the fishery-independent surveys at Tiparra Reef, perhaps indicating a long-term, low level of recruitment.

2.8.2 Port Victoria (Mapcode 22A)

A total of 151 greenlip abalone were observed on the 21, 100-m, leaded-line transects at Port Victoria in 2007. Their mean density was 0.036 abalone.m^{-2} and >70% exceeded the MLL. In 2007, the mean density of legal-sized greenlip abalone was 0.026 abalone.m^{-2}.

2.8.3 Hardwicke Bay (Mapcode 24A)

A total of 89 and 62 greenlip abalone were observed on the 18, 100-m, leaded-line transects in Hardwicke Bay during 2006 and 2007, respectively. The mean density in 2007 (0.017 greenlip abalone.m^{-2}) was 30% lower than that in 2006 (0.026 greenlip.m^{-2}). In both years >80% exceeded the MLL. Mean densities of legal-sized greenlip abalone were 0.024 and 0.014 abalone.m^{-2} in 2006 and 2007, respectively. This represented a reduction of >40% between years.

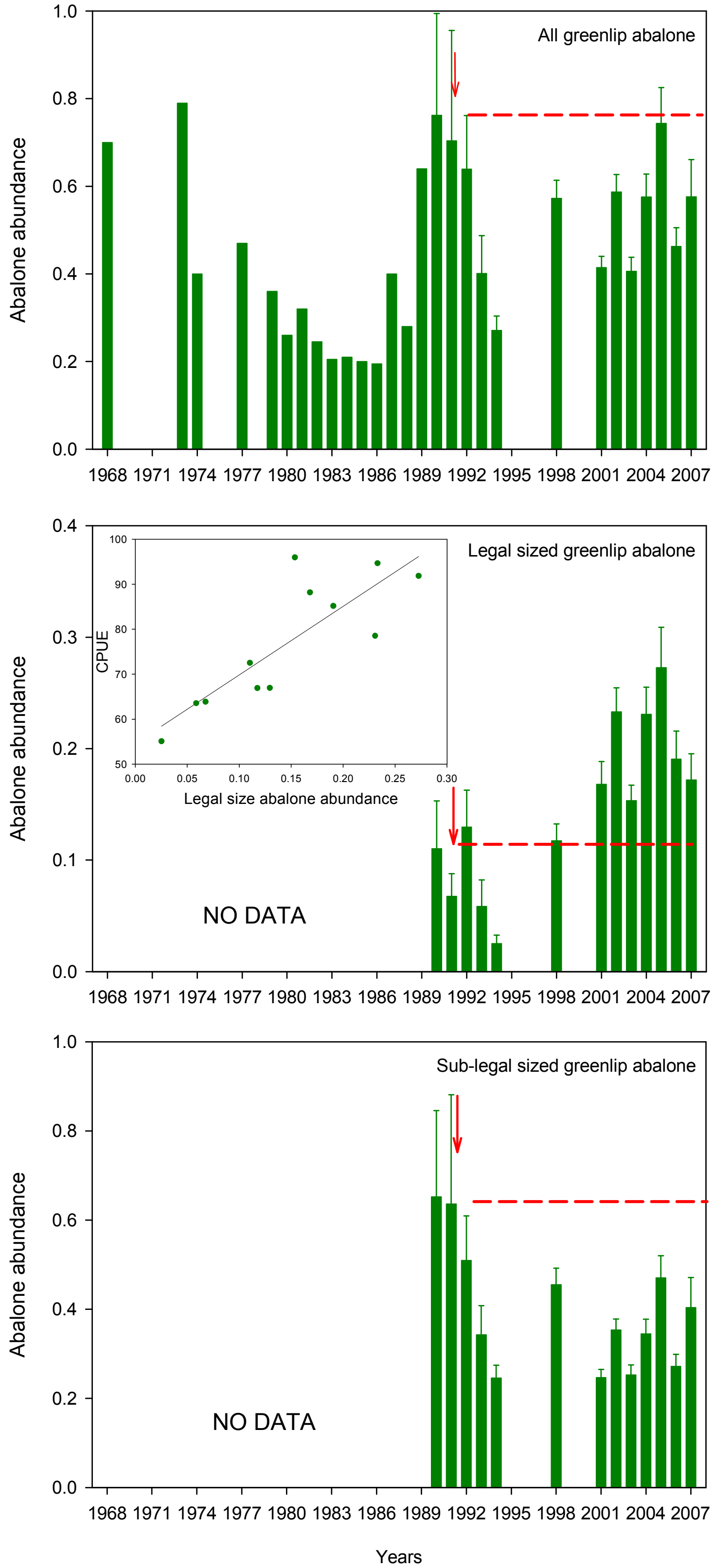

Figure 2.11: Estimated abundance (abalone.m^{-2}) of all (top), legal-sized (middle) and sub-legal-sized (bottom) greenlip abalone at Tiparra Reef from 1968 to 2007. The red horizontal line in each plot indicates the estimated abundance in 1990, the first year in which a TACC was implemented (indicated by the red arrow).

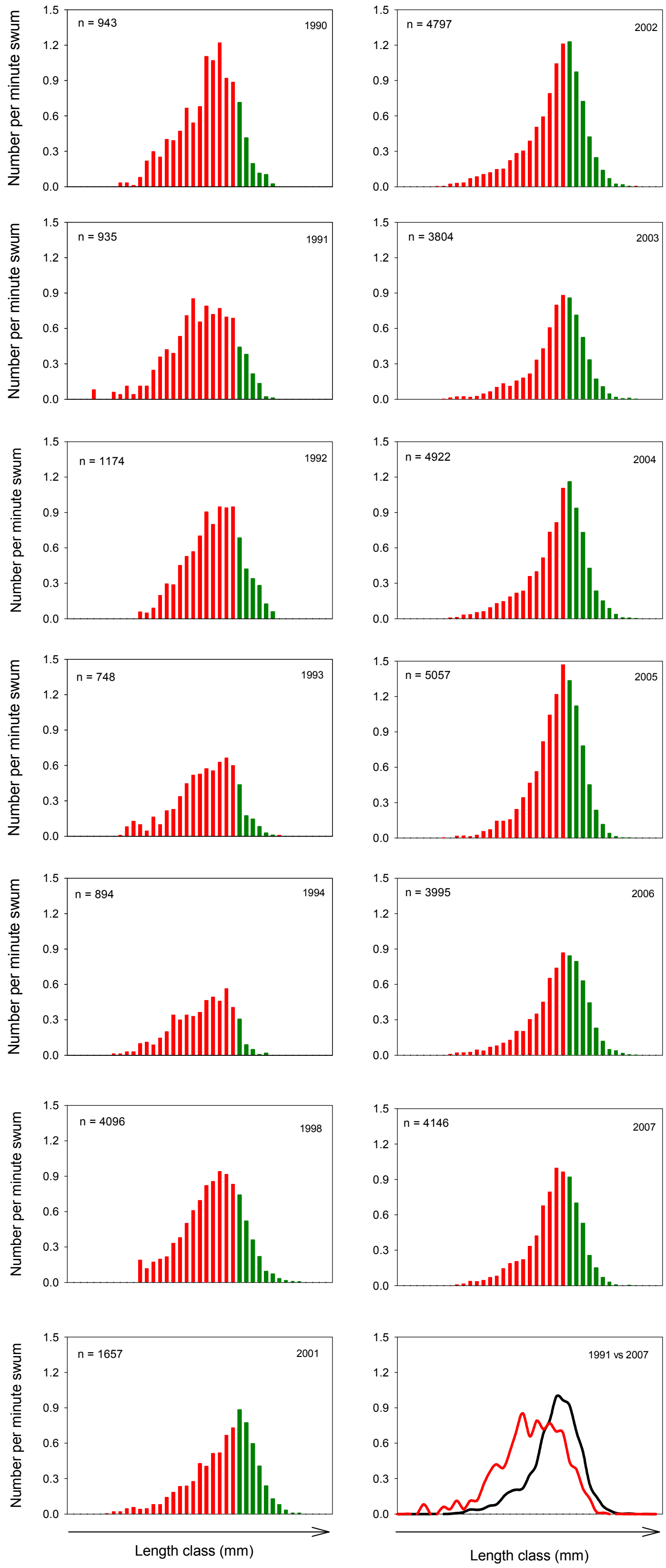

Figure 2.12: Length-frequency distribution of legal-sized (green bars) and sub-legal-sized (red bars) greenlip abalone at Tiparra Reef observed on fishery-independent surveys from 1990 to 1994, in 1998 and from 2001 to 2007. The bin size is 5 mm SL. The y-axis shows the number of abalone observed per minute swum.

3. BLACKLIP ABALONE

Commercial catch and effort data for this fishery have been collected since 1968. Fishers complete a research logbook for each fishing day and submit those data to SARDI Aquatic Sciences at the end of each month. The logbook data supplied have been used to provide the spatial and temporal analyses of catch, effort and catch-per-unit-effort (CPUE), from 1 January 1968 to 31 December 2007, presented in this section of the report. CPUE was computed using the mean ratio estimator (after Rice 1995). Data on the length-frequency distribution of the commercial catch from 2002 to June 2005 were obtained by measuring samples provided to SARDI by commercial fishers; data from July 2005 were primarily provided by AIASA and includes measurements obtained 'at sea' using electronic shell measuring machines. These data were supplemented by samples provided by commercial fishers to SARDI. Estimates of egg production, relative to those in an unfished (virgin) population were determined using models developed by SARDI.

Fishery statistics in this section are provided at three spatial scales. These are (1) the whole blacklip abalone fishery (*i.e.* all areas of the CZ combined), (2) individual fishing areas, and (3) Fishing Areas 26 – 30 combined. Estimates of mean daily catch (MDC; $kg.day^{-1}$) and CPUE ($kg.hr^{-1}$) over the last 15 years (1993 – 2007) were determined for (1) Fishing Areas 26, 27 and 29 as, cumulatively, ~85% of the TACC was harvested from these three fishing areas in 2007, and (2) for Fishing Areas 26 – 30 combined, because collectively these five areas comprise the principal regions of blacklip abalone harvest in the CZ, with an average of >90% of the catch being harvested from them since 2002. The MDC and CPUE on blacklip abalone, from 1979 to 2007, were also estimated for all fishing areas of the CZ combined.

MDC and CPUE for each area were calculated from only those daily records where the blacklip abalone catch was greater than or equal to 50% of the total catch. This was justified for five reasons: (1) few fishing records between 1978 and 2007 report a blacklip abalone catch of zero; (2) only between 10 and 33% of the blacklip abalone catch in this Zone is obtained on fishing days when no greenlip abalone are harvested; (3) using daily records where the blacklip abalone catch is less than 50% of the total catch is inappropriate as blacklip abalone were probably not being targeted on those days; (4) effort is not differentiated or proportioned among species on each fishing day; and (5) evaluation of alternative 'decision rules' for analysing trends in MDC and CPUE on blacklip abalone undertaken in 2007 showed consistent temporal patterns (Mayfield & Carlson 2007). Data are typically presented as mean ± 1 standard error (SE).

3.1 Catch

Over the first decade of the fishery (1968 – 1977), the catch of blacklip abalone in the CZ fluctuated between 7 and 123 $t.yr^{-1}$ (Figure 3.1). Annual catch increased significantly from ~22 t in 1979 to >55 t in 1989 (LR: $r^2 = 0.53$, df = 9, $p < 0.05$). Quotas have limited annual catch since 1990; these were generally stable between 1990 and 2004, but were reduced successively in the 2005 and 2006 quota years (Table 1.2; Figure 3.1). The TACC was not attained in 1992 or 1993 and from 2002 to 2004. Reported catches between 2002 and 2004 ranged between 84 and 89% of the TACC.

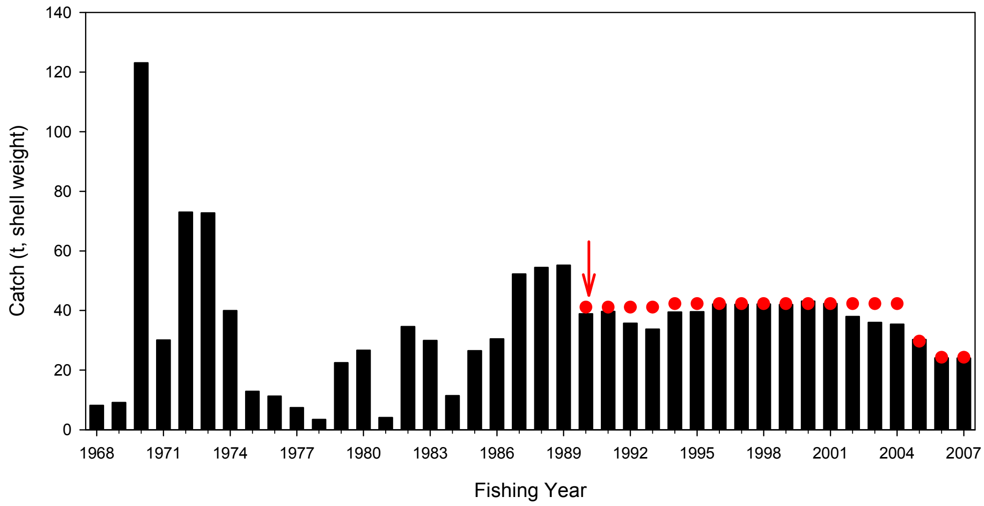

Figure 3.1: Catch (t, shell weight) of blacklip abalone in the CZ from 1968 to 2007.

Since 2003, ~75% of the blacklip abalone TACC has been harvested from Fishing Areas 26, 27 and 29 (Figure 3.2). The proportion of the catch harvested from Fishing Area 26 decreased from >50% to <20% between 2001 and 2005, whereafter it has increased rapidly. The proportion of the catch harvested from Fishing Area 27 has almost halved since 2002. There were also substantial reductions in the proportion of the catch harvested from Fishing Areas 28 and 29 between 2006 and 2007. These reductions were from 13.3 to 0.1% and from 22.8 to 8.2%, respectively. Proportions of the TACC harvested from the remaining fishing areas are small, and variable.

These patterns are reflected in the catch history for each fishing area (Figure 3.3). For example, the catch from Fishing Area 29 in 2007 was the lowest since 1979, and represents a 10-t reduction from contemporary high catch levels (~12 t in each of 1995 and 1996). This pattern is reflected in the ongoing decline in MDC (see section 3.2) and CPUE (see Section 3.3) on blacklip abalone in this fishing area since 2003.

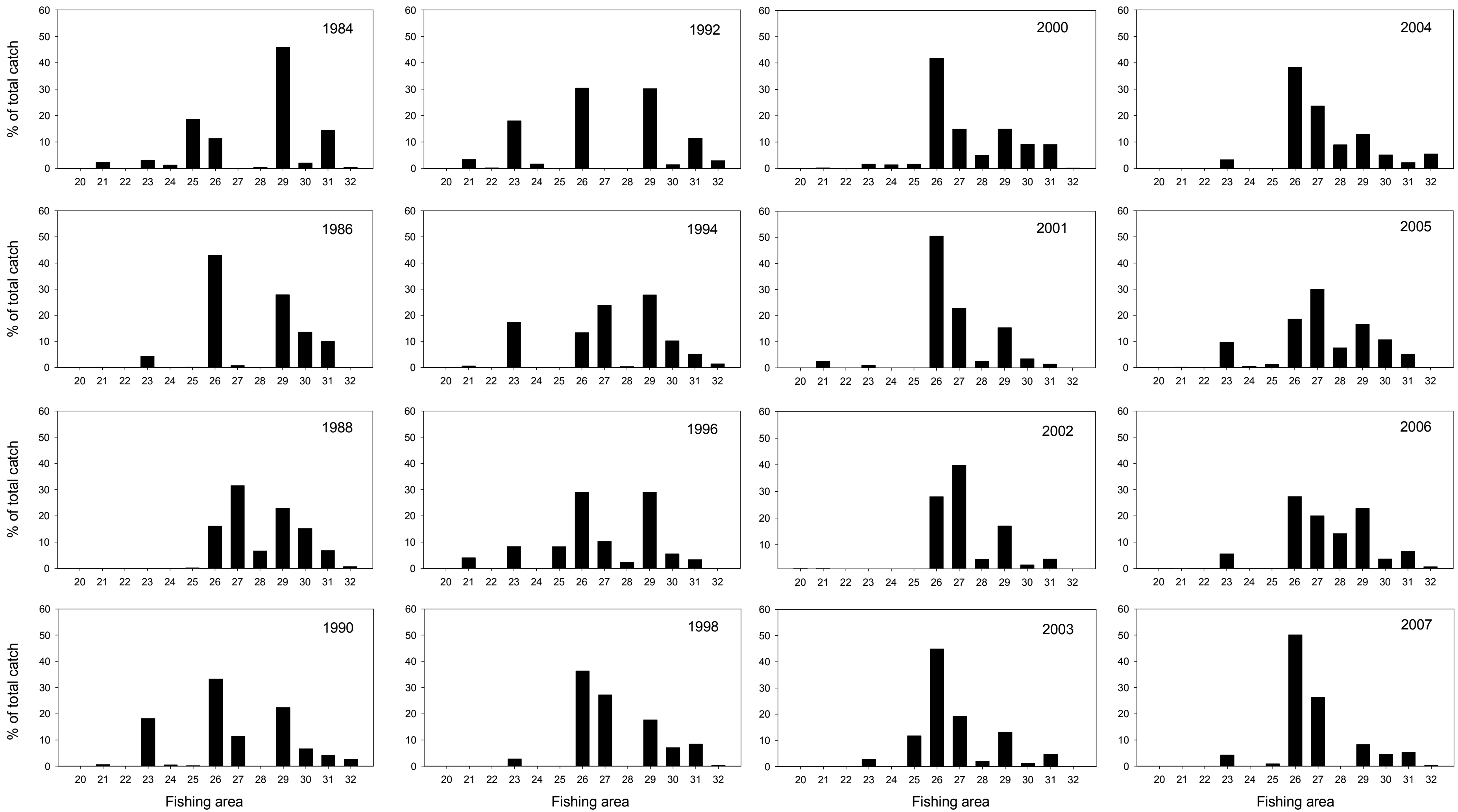

Figure 3.2: Spatial distribution of the blacklip abalone catch (% of total catch) among each of the fishing areas in the CZ in 1984, 1986, 1988, 1990, 1992, 1994, 1996, 1998 and from 2000 to 2007.

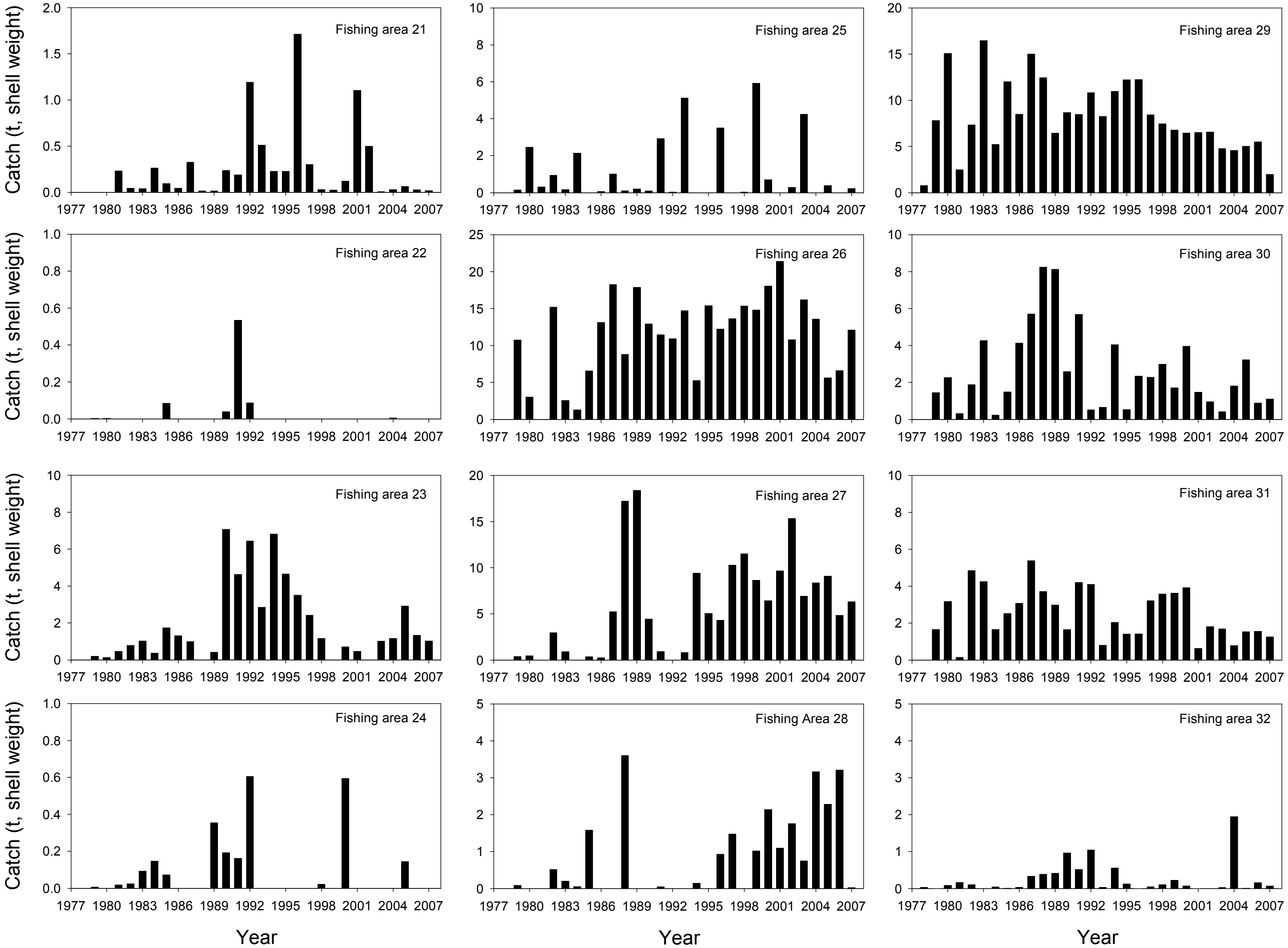

Figure 3.3: Catch of blacklip abalone (tonnes) in each of the fishing areas comprising the CZ from 1978 to 2007.

The temporal patterns in Fishing Areas 26, 27 and 28 were more complex (Figure 3.3). In Fishing Area 26, catch increased substantially between 1985 and 2001 (to >20 $t.yr^{-1}$). Although it declined sharply to <6 t in 2005, catch increased markedly between 2005 and 2007. Catches from Fishing Area 27 increased steadily between 1991 and 2002, whereafter they have generally declined. The catch from Fishing Area 27 in 2007 was the second-lowest since 1996. As with Fishing Area 29, this probably reflects the ongoing decline in MDC (see section 3.2) and CPUE (see Section 3.3) on blacklip abalone in this fishing area observed in recent years. Catch from Fishing Area 28 trebled between 1996 and 2006. However, only 200 kg (0.02 t) were harvested from this fishing area in 2007. This represents a 99% reduction in catch between 2006 and 2007, to the lowest level since 1996.

Blacklip abalone catch from remaining fishing areas have been low and sporadic, particularly for Fishing Areas 21, 22, 23, 24, 25, 30, 31 and 32. Catches from several of these have declined substantially since the TACC was imposed in 1990 (Figure 3.3).

3.2 Mean Daily Catch (MDC)

MDC, in all fishing areas of the CZ combined, generally increased between 1979 (353.5 $kg.day^{-1}$), and the maximum observed value in 2000 (458.7 $kg.day^{-1}$; Figure 3.4). Although average MDC has declined significantly since 2000 (LR: $r^2 = 0.61$, df = 7, $p < 0.05$), in 2007 it was 12% greater than in 2006. Nevertheless, it remained 20% below that observed in 2000. Similar temporal patterns were evident for Fishing Areas 26 – 30 (Figure 3.4): MDC generally increased from 1993, to the maximum observed value in 2000 and then declined significantly between 2000 and 2007 (LR: $r^2 = 0.68$, df = 7, $p < 0.05$). Although MDC over these five areas increased by 11% between 2006 and 2007, it remained 27% below that observed in 2000.

There were strong temporal trends in MDC in Fishing Areas 26, 27 and 29 (Figure 3.4), within which it has declined substantially since 2000, 2004 and 2003, respectively. The reduction was greatest in Fishing Area 29 (43.6%), but was substantial in Fishing Areas 26 (20%) and 27 (37.5%). However, MDC increased slightly between 2005 and 2006 in Fishing Area 26 (4%), and between 2006 and 2007 in Fishing Areas 26 (14%) and 29 (14.6%). These small increases occurred after several consecutive years of reductions, and provide tentative evidence that the rate of reduction in legal-sized biomass, clearly apparent during recent years, may have lessened in these two fishing areas. Notably, this pattern was not observed in Fishing Area 27, where the MDC continued to decline between 2006 and 2007, to the lowest level since 1993 (14 years). Thus, it is likely that reductions in the biomass of legal-sized blacklip abalone, clearly apparent during recent years, are probably continuing in this area.

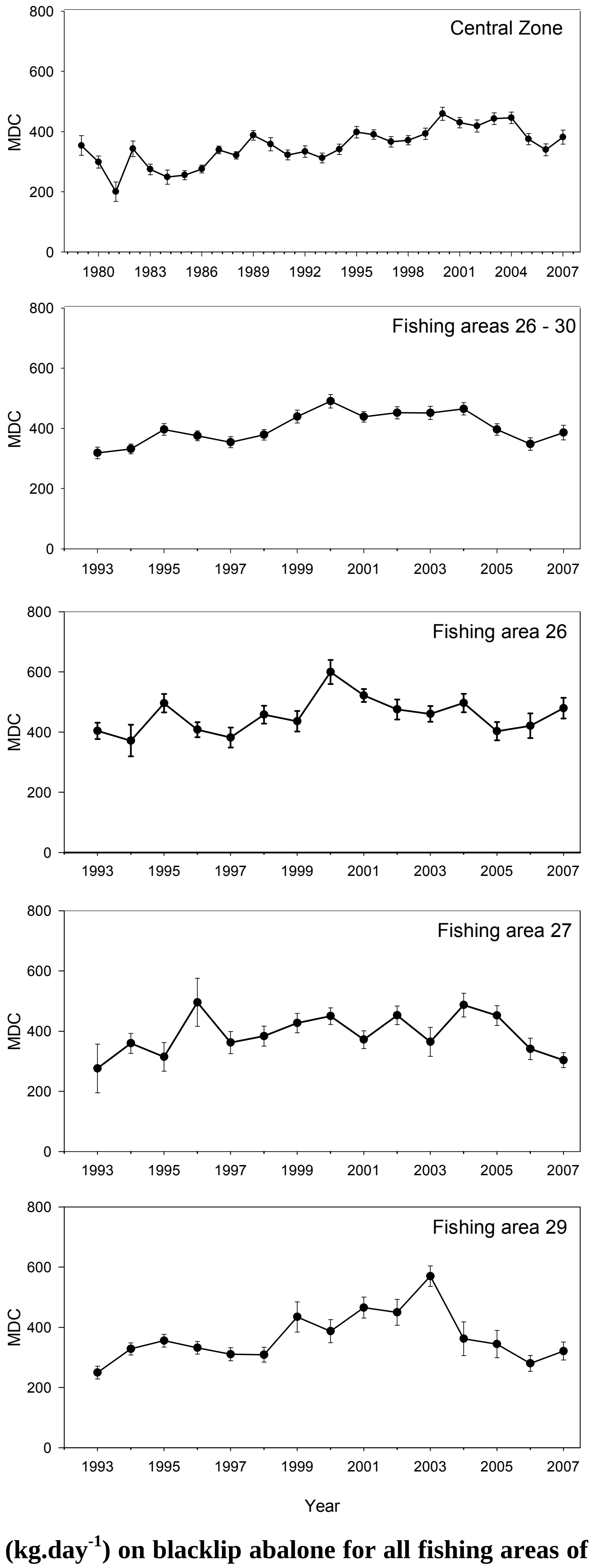

Figure 3.4: MDC (kg.day^{-1}) on blacklip abalone for all fishing areas of the CZ combined from 1979 to 2006, and for Fishing Areas 26 – 30 (combined), 26, 27 and 29 from 1993 to 2007.

3.3 Catch-per-unit effort (CPUE)

The CPUE, in all fishing areas of the CZ combined, generally increased between 1979 and 1989 (Figure 3.5). Although it declined by 23% between 1989 and 1990 it generally increased again to a contemporary maximum in 2003, that was 10% below that in 1989. CPUE decreased by >15% between 2003 and 2006, during which it was at the lowest level since 1999 (seven years). CPUE increased by 12% between 2006 and 2007, exceeding 70 $kg.hr^{-1}$ for the first time since 2004. Nevertheless, it remained 5% below that observed in 2003, and 17% below that in 1989.

Similar temporal patterns were evident for Fishing Areas 26 – 30 combined (Figure 3.5): CPUE generally increased from 1993 to the maximum observed value in 2000; declined substantially (15%) between 2000 and 2006, to the lowest level since 1998 (eight years); and increased marginally (10%) between 2006 and 2007. CPUE in 2007 remained 7% below that observed in 2000.

These patterns were also evident in Fishing Area 26 (Figure 3.5), where CPUE declined significantly between 2000 and 2006, a reduction of 19% over six years to the lowest level since 1998 (LR: $r^2 = 0.67$, df = 6, $p < 0.05$). Despite increasing by 11% between 2006 and 2007, and exceeding 80 $kg.hr^{-1}$ for the first time since 2001, it remained 10% below that observed in 2000.

The small increases in CPUE between 2006 and 2007, observed for all fishing areas of the CZ combined, Fishing Areas 26 – 30 combined and in Fishing Area 26, occurred after several consecutive years of reductions in CPUE. Nevertheless, they provide tentative evidence that the rate of reduction in legal-sized blacklip abalone biomass, clearly apparent during recent years, may have lessened in some fishing areas.

These patterns were only weakly evident in Fishing Area 27 and were not apparent in Fishing Area 29 (Figure 3.5). The CPUE in Fishing Area 27 decreased by 24% between 2005 and 2006 – from a recent maximum to the lowest value since 1997. It increased by just 3% between 2006 and 2007, thereby remaining well below that on 2005.

Ongoing declines in CPUE, despite decreasing levels of catch, are evident in Fishing Area 29. The CPUE has declined significantly between 2003 and 2007 (LR: $r^2 = 0.74$, df = 4, $p < 0.05$). This represents a reduction of ~45% over five years to the lowest level since 1997 (10 years). Consequently, it is likely that reductions in the biomass of legal-sized blacklip abalone biomass are probably continuing in Fishing Areas 27 and 29.

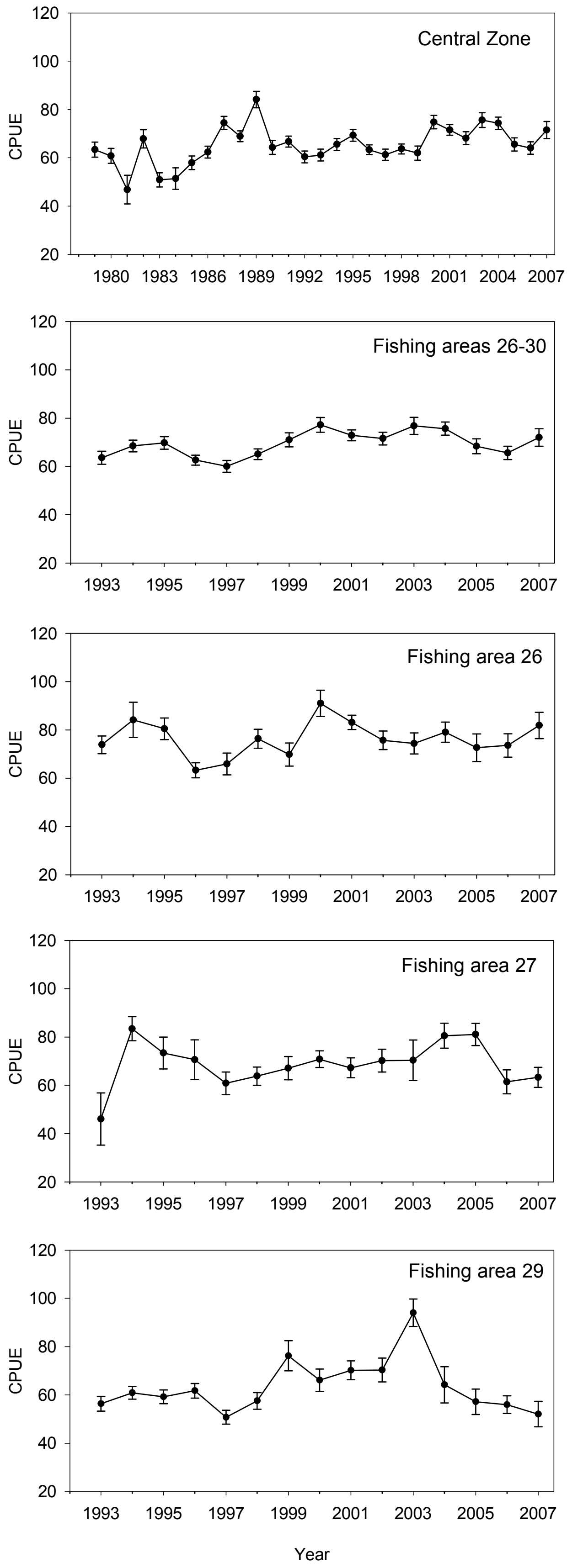

Figure 3.5: Catch-per-unit effort (CPUE, kg.hr^{-1}) on blacklip abalone for all fishing areas of the CZ combined from 1979 to 2006, and for Fishing Areas 26 – 30 (combined), 26, 27 and 29 from 1993 to 2007.

3.4 Length-frequency distribution of the catch

Sample sizes of shells measured from the commercial catch ranged between 1 185 (2002) and 3 980 (2004) from 2002 to 2005 (Figure 3.6). Those samples represented ~3% of the total catch. During 2006, <2 000 shells were measured. However, in 2007, the sample size was the highest on record, exceeding 9 500 shell measurements. Notably, >60% of these were obtained from the electronic shell measuring machines.

Examination of the data from the electronic shell measuring machines identified numerous inconsistencies that included provision of length measurements for blacklip abalone in fishing areas within which the total catch of blacklip in 2007 was reported as zero. The latter was particularly evident for Fishing Area 24, within which 1,252 shell measurements were provided, but no catch reported in 2007. This suggests that while useful, data from the electronic shell measuring machines should be cautiously interpreted, because their reliability is poorly understood. The data presented in this report, reflect (1) the metadata recorded (*i.e*. GPS position, species) simultaneously with each length measurement, with (2) the data truncated to exclude blacklip abalone shell length measurements >200 mm SL.

The number of licences contributing commercial shell samples (maximum possible is six) declined substantially between 2003 (n = 5) and 2006 (n = 2; Figure 3.6). In 2007, this increased to four. Aside from 2006, annual data were obtained from catches harvested across a similar number of fishing areas (range: 4 – 6) and mapcodes (range: 6 – 9) (Figure 3.6). In 2006, samples were only obtained from catches in three fishing areas and five mapcodes.

There were also strong relationships between levels of catch and commercial shell samples from 2003 to 2007 (Figure 3.7). In most years, the greatest numbers of commercial shell samples were obtained from Fishing Area 26, the fishing area from which the highest levels of catch were obtained. The exception was 2005, when >1 000 shell samples were obtained from Fishing Area 29. Aside from Fishing Area 24 in 2007, few samples were obtained from those fishing areas that contributed only small levels of catch during this period.

There were few substantial changes in the length-frequency distribution of blacklip abalone in the commercial catch, for all fishing areas of the CZ combined, between 2002 and 2007 (Figure 3.8). During this six-year period, the mean length ranged between 143.5 and 147.8 mm SL and the modal length class did not vary. However, during this period the proportion of the sample <145 mm SL has varied substantially. In 2007, it was at the lowest level since 2003.

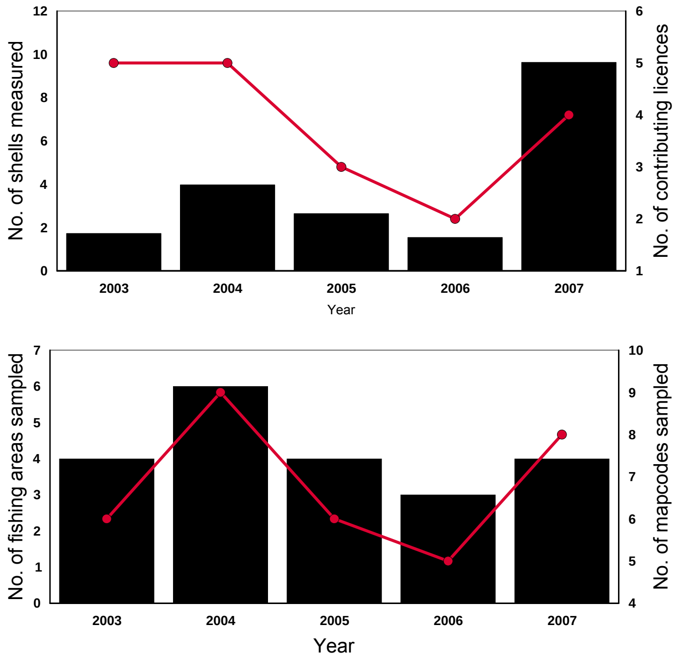

Figure 3.6: Numbers of shells measured (thousands; black bars) and contributing licences (red line; top) and numbers of fishing areas (black bars) and mapcodes (red line; bottom) from which commercial catches were sampled from 2003 to 2007.

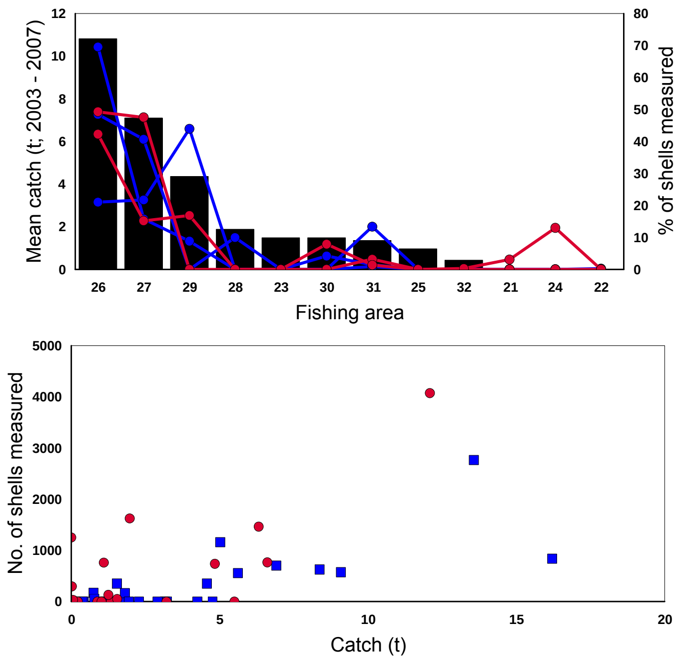

Figure 3.7: Relationships between (top) mean catch (black bars) and the percentage of commercial shell measurements (blue lines: 2003, 2004 and 2005; red lines: 2006 and 2007) and (bottom) total catch in each fishing area and total number of commercial shell measurements (blue dots: 2003, 2004 and 2005; red dots: 2006 and 2007).

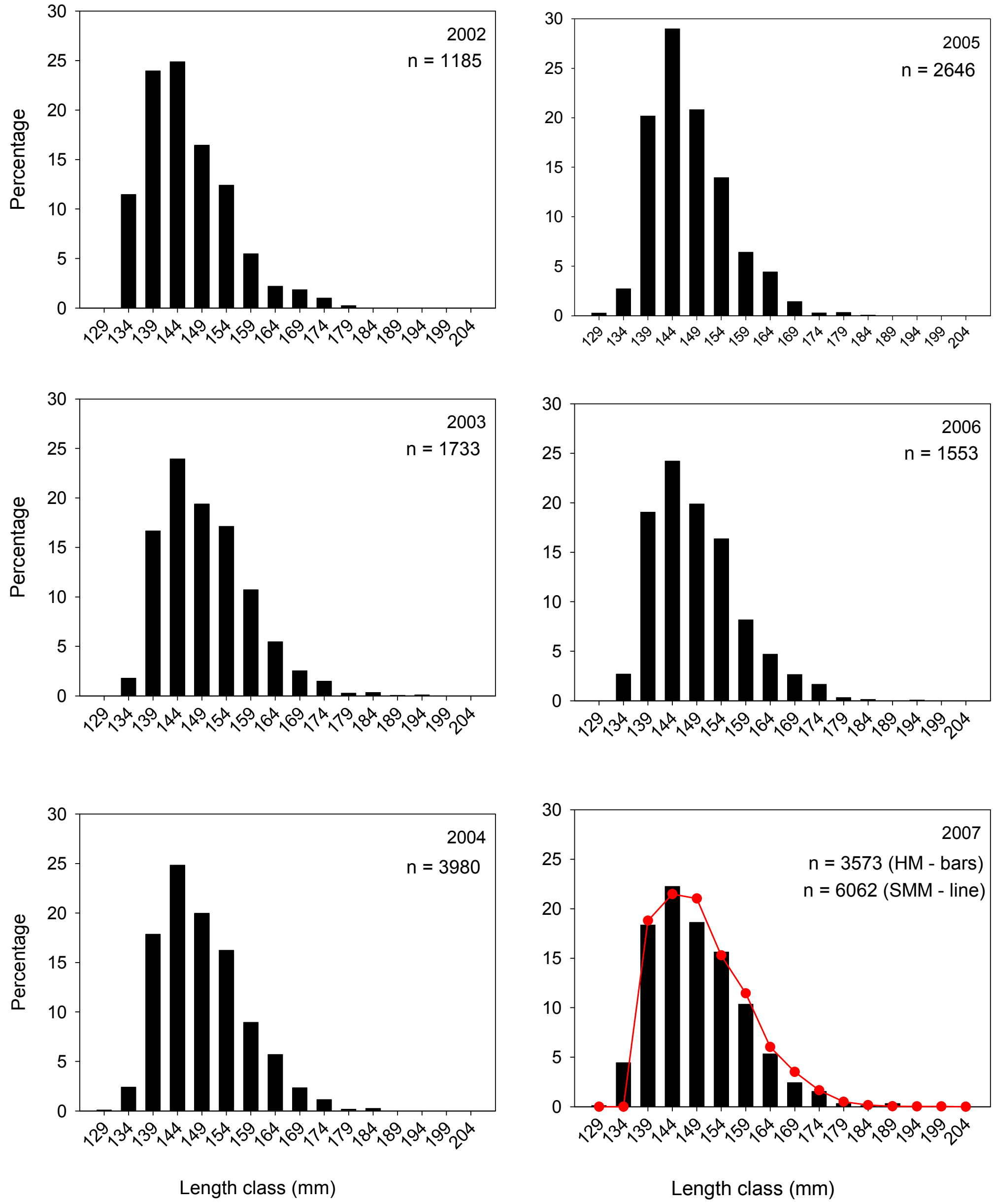

Figure 3.8: Length-frequency distributions obtained from measuring blacklip abalone shells (hand measured (HM): bars; and electronic shell machine measured (SMM): red line) from the commercial fishery in the CZ from 2002 to 2007. Length classes are mm SL.

The principal fishing areas for blacklip abalone are 26, 27, 29, 30 and 31 (see Section 3.1). There are no commercial length-frequency data for Fishing Area 29 in 2003 or 2006, for Fishing Area 30 in 2003, 2005 or 2006, and for Fishing Area 31 in 2002 (Figure 3.9). While the relatively consistent sampling of commercial catches from Fishing Areas 26 and 27 aides assessment, the irregular commercial catch sampling from several key fishing areas impedes the ability to detect and quantify temporal changes in the length structure of commercially fished abalone.

Several patterns are evident for the key fishing areas (Figure 3.9). In Fishing Area 26, from 2002 to 2006, the mean length declined by >4 mm SL, the modal length class decreased by 5 mm SL and the proportion of the sample <145 mm SL increased substantially from <25% to >40%. The mean length and model length class both increased between 2006 and 2007, and the proportion of the sample <145 mm SL decreased by 8%. Patterns from Fishing Area 27 are less clear. However, since 2005 the mean length has been increasing (by ~4 mm SL) and the proportion of the sample <145 mm SL decreasing (from >60 to <45%). In Fishing Area 29, the mean length and modal length class increased by 6 and 5 mm SL, respectively, and the proportion of the sample <145 mm SL decreased from >80 to ~50% between 2002 and 2007.

Decreases in the proportion of the samples <145 mm SL and increases in the proportion of the samples >155 mm SL in Fishing Areas 26 (19 to 28%) and 27 (6 to 20%) since 2005, and in Fishing Area 29 (9 to 15%) since 2004 were unexpected. These patterns are inconsistent with comments from commercial divers in the fishery that substantial numbers of sub-legal-sized blacklip abalone were being observed. Recruitment of these individuals to the fishery should have been reflected in an increase in the proportion of the samples <145 mm SL, rather than the decrease that was observed. Thus, current data suggest recruitment to the fishery remains low, and that the fishery is currently harvesting an ageing population.

3.5 Estimates of egg production

A simple egg-production model was used to estimate the proportion of pristine egg production conserved under the current management arrangements for blacklip abalone in Fishing Areas 26, 27 and 29. Full details of the biological data used in the model, and the model assumptions are provided in Appendix 2.

The estimates of the percentage of unfished egg production conserved in Fishing Areas 26, 27 and 29 during 2007 were 64.4, 48.4 and 37.5%, respectively. This is the first year for which estimates have been >50% in Fishing Area 26 since they were first determined in 2002. The estimates in Fishing Areas 27 and 29 were at their highest levels since 2003.

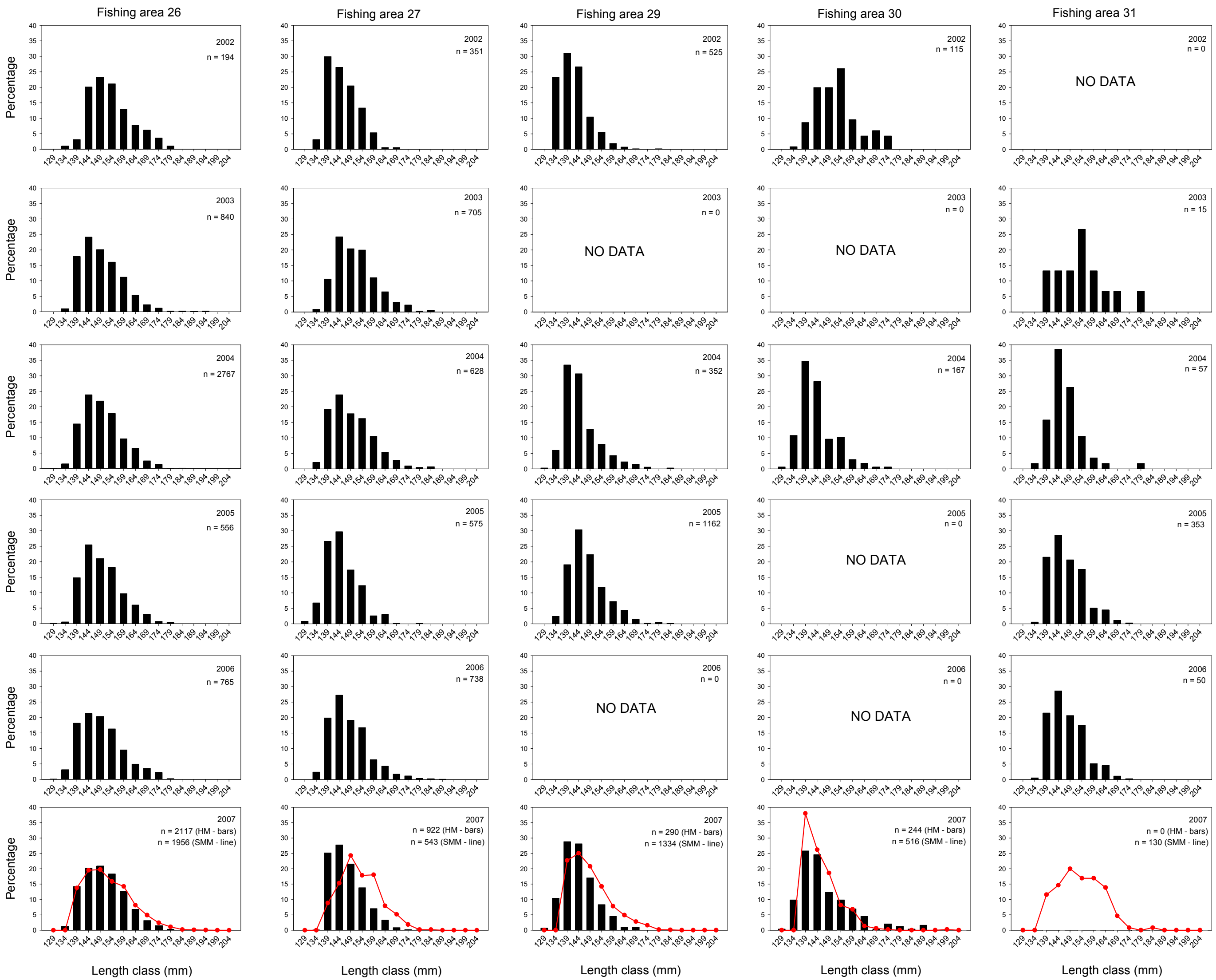

Figure 3.9: Length-frequency distributions obtained from measuring blacklip abalone shells (hand measured (HM): bars; and electronic shell machine measured (SMM): red lines) from the commercial fishery in Fishing Areas 26, 27, 29, 30 and 31 of the CZ from 2002 to 2007. Length classes are mm SL.

4. PERFORMANCE INDICATORS

This section provides a report on the performance of the fishery against the reference points for the CZ as defined in the Management Plan (Nobes *et al.* 2004) and documented in Tables 1.4 and 1.5 (Section 1.3).

Commercial logbooks from all licence holders for the period ending 31 December 2007 were received and the data entered into the database.

4.1 Greenlip abalone

There are 31 biological PI specified for greenlip abalone in the CZ in 2007, of which 26 are addressed in this report. The remaining five (diver assessment of stock status (in Fishing Areas 21 and 24); harvest discard; illegal catch; and recreational catch) are addressed in other reports submitted to PIRSA Fisheries.

Data are available to assess the performance of the greenlip abalone fishery against 24 of the 26 (92%) PI to be addressed in this report. Eleven of these 24 PI (46%) have triggered (Table 4.1; Appendix 3). Of these, nine (82%) may be considered negative for the fishery.

Fishing effort on greenlip abalone has increased significantly from 1,387 hr (2003) to 1,691 hr (2007) over the last five years.

Mean daily effort decreased significantly in Fishing Areas 21 and 24 from 2003 and 2007, but increased in Fishing Area 21 between 2006 and 2007.

Mean daily catch decreased significantly in Fishing Area 24 between 2006 and 2007, and in Fishing Area 21 from 2003 to 2007.

Similarly, CPUE decreased significantly in Fishing Areas 21 and 24 between 2006 and 2007, and in Fishing Area 21 from 2003 to 2007.

The mean length of greenlip abalone in the commercial catch decreased significantly between 2003 and 2007 in Fishing Area 21.

The estimate of retained egg production at Tiparra Reef in 2007 was 40.6%.

Table 4.1: Assessment of the performance of the greenlip abalone fishery in the CZ and in Fishing Areas 21 and 24 against the Performance Indicators prescribed in the Management Plan.

Performance indicator	Temporal scale	CZ	Area 21	Area 24
Commercial catch	Annual			
Commercial effort	5-year trend			
Spatial distribution of catch	Inter-annual			
Mean daily catch	Inter-annual			
	5-year trend			
Mean daily effort	Inter-annual			
	5-year trend			
CPUE	Inter-annual			
	5-year trend			
Mean length	Inter-annual			
	5-year trend			

Performance indicator	Temporal scale	Tiparra Reef
Abundance of legal-sized abalone	Inter-annual	
	5-year trend	
Abundance of sub-legal-sized abalone	Inter-annual	
	5-year trend	
Abundance of abalone larger than L_{50}	Inter-annual	
	5-year trend	
Egg production/pristine	Annual	

- Trigger Point exceeded
- Significant increase
- No data
- Trigger Point not exceeded
- Significant decrease
- PI not applicable

4.2 Blacklip abalone

There are 41 biological PI specified for blacklip abalone in the CZ in 2007, of which 36 are addressed in this report. The remaining five (diver assessment of stock status (in Fishing Areas 26 and 27); harvest discard; illegal catch; and recreational catch) are addressed in other reports submitted to PIRSA Fisheries.

Data are available to assess the performance of the blacklip abalone fishery against 18 of the 36 (50%) PI to be addressed in this report. Eight of these 36 PI (22%) have triggered (Table 4.2; Appendix 4). Four (50%) of these would be considered positive for the fishery.

Fishing effort on blacklip abalone has decreased significantly from 439 hr (2003) to 272 hr (2007) over the last five years.

The proportion of the TACC harvested from Fishing Areas 28 and 29 declined between 2006 and 2007 (from 13.3% to 0.1% and from 22.8% to 8.2%, respectively). In contrast, the proportion of the TACC harvested from Fishing Areas 26 and 27 increased over the same period (from 27.4% to 50.2% and from 20.1% to 26.2%, respectively). These resulted in a change to the composition and sequence of the four most important Fishing Areas, by catch, between 2006 and 2007.

Mean daily catch decreased significantly in Fishing Area 27 between 2003 and 2007.

The mean length of blacklip abalone in the commercial catch increased significantly in Fishing Area 26 from 2003 to 2007 and increased significantly between 2006 and 2007 in Fishing Areas 26 and 27.

Estimates of egg production in Fishing Areas 27 and 29 were 48.4% and 37.5% of 'unfished' levels, respectively.

Table 4.2: Assessment of the performance of the blacklip abalone fishery in the CZ and Fishing Areas 26, 27 and 29 against the Performance Indicators prescribed in the Management Plan.

Performance Indicator	Temporal scale	CZ	Area 26	Area 27	Area 29
Commercial catch	Annual				
Commercial effort	5-year trend				
Spatial distribution of catch	Inter-annual				
Mean daily catch	Inter-annual				
	5-year trend				
Mean daily effort	Inter-annual				
	5-year trend				
CPUE	Inter-annual				
	5-year trend				
Mean length	Inter-annual				
	5-year trend				
Egg production/pristine	Annual				

Performance indicator	Temporal scale	Cape du Couedic	Cape Bouger	Cape Gantheaume
Legal-sized abalone abundance	Inter-annual			
	5-year trend			
Sub-legal-sized abalone abundance	Inter-annual			
	5-year trend			
Abundance of abalone larger than L_{50}	Inter-annual			
	5-year trend			

Trigger Point exceeded
Significant increase
No data
Trigger Point not exceeded
Significant decrease
PI not applicable

5. GENERAL DISCUSSION

5.1 Information available for fishery assessment

Substantial information and data are available to aid the assessment of abalone stocks in the CZ. These include: (1) a well documented history and management of the commercial fishery; (2) fine-scale, catch and effort data from 1968 to 2007; (3) commercial-catch, length-frequency data; (4) long-term, fishery-independent surveys at Tiparra Reef; (5) a broad suite of fishery performance indicators; and (6) biological data. There are few data on the magnitude of the illegal and recreational catches. This prevents reliable estimation of the total catch and, hence, impedes assessment of the fishery. Similarly, the lack of fishery-independent survey data for blacklip abalone necessitates that assessment of the blacklip abalone stocks is heavily weighted by the interpretation of commercial catch, effort and length-frequency data. Data from planned fishery-independent surveys on blacklip abalone off Kangaroo Island will substantially improve future assessments for this species.

Interpretation of catch, effort and CPUE data are complicated by the necessity to apply different decision rules when calculating the level of 'directed effort', catch-per-unit effort (CPUE), mean daily catch (MDC) and mean daily effort (MDE) for each species. This problem arises because, in the CZ, greenlip and blacklip abalone can be harvested on the same fishing day, despite fishing effort not being differentiated or proportioned among species. Since 2003, different approaches have been used for each species. For greenlip abalone, these indices are calculated from only those daily records where the blacklip abalone catch was zero (see Section 2.1). For blacklip abalone, these measures are determined using only those daily records where the blacklip abalone catch was greater than or equal to 50% of the total catch (see Section 3.1). This approach is consistent with that used elsewhere in the South Australian abalone fishery, notably Regions A and B of the Western Zone (Chick *et al*. 2007, 2008). The validity of this method for the CZ was examined by Mayfield & Carlson (2007). Importantly, they demonstrated that temporal trends in MDC and CPUE were consistent among the four alternative 'data decision rules' tested. As the '50%' rule provides the largest dataset of the approaches tested, this method of determining the blacklip abalone indices was used for this report.

CPUE has been used in this report to assess stock status. Its use is based on the assumption that changes in CPUE, particularly declines in this measure, reflect a change in the size of the fishable stock (Tarbath *et al*. 2005). This measure can be strongly influenced by numerous factors, and is often viewed as a biased index of change in abalone abundance (Harrison 1983; Breen 1992; Prince & Shepherd 1992; Gorfine *et al*. 2002). For example, catch rates may remain high as a result of re-aggregation of abalone (hyperstability), masking fluctuations in population size arising from local depletion (Officer *et al*. 2001a,b).

The reliability of this assessment is also influenced by the quality and the degree to which the commercial catch length-frequency data are representative of the fishery. These data are required to detect and quantify temporal changes in the mean, mode and shape of the length structure of commercially fished abalone. This is because changes to the length structure of the commercial catch are indicative of changes to the fished populations and the pressures exerted on them. Nevertheless, these datasets are often difficult to interpret because differentiating between the effects of fishing, demography and population dynamics (*e.g.* recruitment variability), in the absence of reliable age data, is challenging.

Sample sizes of shells measured from the commercial catch in 2007 were at their highest level for both species, with most of these data obtained from electronic shell measuring machines (Scielex, Hobart). Examination of these data identified numerous inconsistencies, including (1) shell length measurements that greatly exceeded the largest abalone previously measured in the CZ (*i.e* >199 mm SL); (2) provision of length measurements for greenlip abalone in one fishing area, while the catch on that day was reported to a different fishing area; and (3) provision of length measurements for blacklip abalone in fishing areas within which the total catch of blacklip in 2007 was reported as zero. The inconsistencies identified in these data suggest that while useful, data from the electronic shell measuring machines should be cautiously interpreted, because their reliability is poorly understood. Nevertheless, these data, provided by AIASA, were used in this report to assess changes in the length structure of the commercial catch and to estimate levels of retained egg production. In each case, the data were truncated to exclude abalone with shell length measurements >200 mm SL, with their use determined by the metadata recorded simultaneously with each length measurement (*i.e*. using the GPS position to allocate each record into a fishing area or mapcode; using the species code to allocate each record against greenlip or blacklip abalone).

5.2 Status of the Central Zone abalone fishery

5.2.1 Greenlip abalone

There is evidence that the legal-sized, greenlip abalone biomass is declining on the principal fishing grounds for this species, and that the resource on which the CZ greenlip abalone fishery is based has weakened over recent years. The downward trends are strongest for Fishing Area 22, but are also evident for the entire CZ, Fishing Area 21 and Fishing Area 24. While there is no evidence to suggest that the ‘catch cap’ on Tiparra Reef could be increased, there is evidence that its implementation has increased fishing pressure elsewhere in the fishery. Consequently, consideration of alternative management arrangements for the fishery, including increased spatial management with spatially relevant catch and size limits, may be warranted.

Prior to TACC implementation in 1990, catches were relatively evenly distributed throughout the CZ; by 2004, >85% of the TACC was harvested from Fishing Area 21. The catch from Tiparra Reef was limited to 90 t (shell weight; hereafter referred to as a 'catch cap') from 2005, representing a 20% reduction in catch from this area between 2004 and 2005. Despite the reduction in catch, current estimates of MDC and CPUE are depressed relative to contemporary maxima (*i.e.* 2000 – 2002), but remain high in a historical context (*i.e.* 1978 – 1999). Both measures have declined significantly since 2000. Notably, total effort and MDE increased between 2006 and 2007, causing a significant decline in CPUE over the same time period. Changes in the length structure of the commercial catch to 2007, in combination with changes in the length-frequency distribution of greenlip abalone observed on fishery-independent surveys, suggest increasing levels of fishing pressure and an elevated reliance on new recruits to the fishery. Finally, the abundance of legal-sized greenlip abalone observed on fishery-independent surveys decreased sharply between 2005 and 2007 (37%), to the lowest level since 2003. In combination with recent reductions in catch, the downward trends in these fishery-dependent and fishery-independent measures provide credible evidence that legal-sized, greenlip abalone biomass has recently declined in Fishing Area 21, from the peak in 2000 and 2001.

Implementation of the 'catch cap', in combination with a static TACC, resulted in changes in the spatial distribution of the catch and, consequently, an increase in fishing pressure on greenlip abalone stocks elsewhere in the CZ. The greatest changes were observed in Fishing Areas 22 and 24. Compared with Fishing Area 21, information on the abalone stocks in these areas is limited. Nevertheless, the data that are available again indicate that legal-sized, greenlip abalone biomass has decreased in both these fishing areas over recent years. The recent patterns in the fishery-dependent data for Fishing Areas 22 and 24 also suggest that stocks of greenlip abalone, outside of Fishing Area 21, that can sustain relatively large catches (~10 $t.yr^{-1}$) are rare.

Catches harvested from Fishing Area 22 increased markedly between 2003 and 2005, to the largest catch from this area since 1991. Catches of this magnitude may not be sustainable because patterns in the data suggest increasing and unsustainable exploitation rates. Notably (1) the catch halved between 2005 and 2007; (2) CPUE and MDC declined substantially between 2004 and 2006; (3) MDC decreased between 2006 and 2007, to the lowest level since 1993; and (4) changes in the length structure of the commercial catch suggest an increase in fishing pressure and greater reliance on new recruits to the fishery.

While catch from Fishing Area 24 has trebled since 2002, the data available suggest that catches of this magnitude may also not be sustainable. For example, MDC decreased significantly between 2006 and 2007, to the lowest level since 2002. In addition, total effort increased substantially between 2006 and 2007 – to the highest level since 1995 – while total catch increased by a lesser amount over the same time period. The disproportionate increase in effort compared with catch caused the significant decline in CPUE between 2006 and 2007. Changes in the length structure of the commercial catch suggest an increase in fishing pressure and enhanced reliance on new recruits to the fishery. Finally, the density of legal-sized greenlip abalone observed on fishery-independent surveys in Hardwicke Bay (mapcode 24A) declined by >40% between 2006 and 2007. These reductions are consistent with, but substantially greater than those observed in MDC and CPUE over the same time period. In combination, these patterns suggest reductions in legal-sized, greenlip abalone biomass in this area during recent years.

In summary, there is evidence that legal-sized, greenlip abalone biomass is declining on the principal fishing grounds for this species, and that the resource on which the CZ greenlip abalone fishery is based has weakened over recent years. This evidence includes (1) an increase in total fishing effort to the highest level since 1999; (2) recent reductions in MDC and CPUE in the principal fishing grounds; (3) decreases in the mean length and modal length class of the commercial catch and increases in the proportion of the sample <145 mm SL in Fishing Areas 21 and 24; (4) reductions in the abundance of legal-sized, greenlip abalone observed on fishery-independent surveys at Tiparra Reef and Hardwicke Bay in recent years; and (5) the triggering of nine of 11 performance indicators (82 %) in a direction that would be considered negative for the status of the fishery.

While these data provide convincing evidence that the resource has weakened over recent years, the extent of decline in the fishable biomass is less well understood. Nevertheless, the contagious distribution of abalone, coupled with the diver's ability to target aggregations and the associated hyperstability in CPUE and MDC, suggest that the declines in abundance exceed those indicated by the fishery-dependent data. The downward trends provide no evidence to suggest that the 'catch cap' on Tiparra Reef could be increased. They also suggest that consideration of alternative management arrangements for the fishery, including increased spatial management, may be warranted.

5.2.2 Blacklip abalone

The last four fishery assessment reports (Mayfield & Ward 2003; Mayfield *et al*. 2004, 2005a, 2006), and two stock status reports (Mayfield *et al*. 2005b; Mayfield & Carlson 2007), provided evidence that the resource on which the CZ blacklip abalone fishery is based was declining, and that the resource had weakened despite the voluntary reductions in catch between 2002 and 2004, and reductions in the TACC since 2005 (Mayfield *et al*. 2006; Mayfield & Carlson 2007). Data presented in this report are largely consistent with recent assessments of the fishery, and confirm that it remains in a weak position.

Most (>80%) of the catch is harvested from Fishing Areas 26, 27 and 29, indicating the fisheries reliance on the blacklip abalone stocks remaining in these three small fishing areas, all located off Kangaroo Island. In conjunction with the spatial and temporal patterns in catch from most other areas, these data suggest that blacklip abalone have a limited distribution in the CZ, and that few commercially-fishable populations occur away from the south-western corner of Kangaroo Island.

For each of the three key fishing areas, data available in recent years suggest some of the weakest years on record for these populations. For Fishing Areas 27 and 29, there is evidence that the resource may have continued to weaken, because ongoing declines in some fishery-dependent performance measures remain consistent with declining stock abundance. In Fishing Area 29, one of the historically most productive fishing areas, catches have more than halved over the last decade. In the remaining area, Fishing Area 26, catches fell sharply between 2003 and 2004, but have increased rapidly since then. Over >50% of the catch in 2007 was harvested from this area. While recent increases in catch, MDC and CPUE in this fishing area provide some evidence that the reduction in legal-sized blacklip abalone biomass may have halted, the current level of catch may not be sustainable. This is because the small increases in these key fishery-dependent measures: (1) follow several successive years of reduction and remain below contemporary maximum levels (*i.e.* current values are low in a recent historical context) and (2) are likely to exceed any increase in biomass indicated by the data as the contagious distribution of blacklip abalone, coupled with the divers ability to target aggregations, often leads to hyperstability in these measures (Tarbath 2005).

MDC has declined substantially since 2000, 2004 and 2003 in Fishing Areas 26, 27 and 29, respectively. However, it has increased slightly since 2005 in Fishing Area 26, and between 2006 and 2007 in Fishing Area 29. In both areas MDC remained below contemporary maxima. This pattern was not observed in Fishing Area 27, within which the MDC continued to decline between 2006 and 2007, to lowest level in 14 years. Temporal patterns in CPUE mimicked that of MDC in Fishing Area 26. However, in Fishing Area 27, CPUE increased marginally between 2006 and 2007, while MDC decreased. The opposite pattern was apparent in Fishing Area 29, in which the CPUE has declined significantly since 2003, to the lowest level in a decade.

Estimates of MDC and CPUE for the CZ and in the principal blacklip abalone fishing areas (Fishing Areas 26 – 30 combined) declined substantially between 2000 and 2006. Although both measures increased across both spatial scales between 2006 and 2007, each remained below contemporary maxima. Importantly, the estimates of MDC and CPUE in the CZ and in the principal blacklip abalone fishing areas (Fishing Areas 26 – 30 combined) in 2007 are heavily influenced by data from Fishing Area 26 because >50% of the catch was obtained from this area. Thus, increases in MDC and CPUE between 2006 and 2007 at these broader spatial scales are primarily driven by the patterns in Fishing Area 26, and provide a positively-biased index of current stock status across the CZ and principal fishing grounds.

Decreases in the proportion of small abalone and increases in the proportion of large abalone over recent years in the commercial catch were unexpected because they are inconsistent with comments from commercial divers in the fishery that substantial numbers of sub-legal-sized blacklip abalone were being observed. Recruitment of these reported, sub-legal individuals to the fishery should have been reflected in an increase in the proportion of the samples <145 mm SL, rather than the observed decrease. The current data suggest recruitment to the fishery remains low and, consequently, it is likely that the fishery is harvesting an ageing population with few recruits available to support continued levels of current harvest.

Consistent with previous assessment reports, there is substantial evidence that the resource on which the CZ blacklip abalone fishery is based remains in a weak position and that the responses of the blacklip abalone populations to the recent TACC reductions are not yet clearly evident. The fishery is heavily reliant on the stocks remaining in Fishing Areas 26, 27 and 29. For each of these, the recent years include some of the weakest years on record. In Fishing Areas 27 and 29, ongoing declines in some fishery performance measures suggest that the resource may have continued to weaken. Recent increases in catch, MDC and CPUE in Fishing Area 26 provide some evidence that the reduction in legal-sized blacklip abalone biomass may have halted. However, this area contributed >50% of the catch in 2007 and this level of catch may not be sustainable. The importance of Fishing Areas 26, 27 and 29 to the fishery suggest urgent action is required to protect the remnant abalone stocks. This could include consideration of alternative management arrangements for the fishery, such as increased spatial management with spatially relevant catch and size limits.

5.3 Future research needs

For both species, there is a need to reconsider the spatial management arrangements in the fishery, to more closely align scales of assessment and management with those of the component stocks (Mayfield & Saunders 2008). This is particularly the case for blacklip abalone off Kangaroo Island and greenlip abalone outside of Tiparra Reef, for which spatial management, including variable size limits, may be most urgent. This review should include consideration of alternative size limits at appropriate spatial scales throughout the fishery.

There is a clear need to undertake the planned fishery-dependent survey of blacklip abalone off Kangaroo Island. These data are vital to understanding the current status of this stock, especially potential levels of recruitment to the fishery. Similarly, the development and implementation of fishery-independent surveys for blacklip abalone – particularly in Fishing Areas 26 (West Bay and Cape du Couedic), 27 (Cape Bouger) and 29 (Cape Gantheaume) – is urgently required. These data are essential for (1) validating current assessments of stock status, and (2) determining changes in the abundance and population structure of blacklip abalone. It is also important to continue to obtain fishery-independent measures of greenlip abalone stock status in 'lightly-fished' areas, including Hardwicke Bay and Port Victoria, and to expand usage of the leaded-line method (Mc Garvey *et al*. in press) to estimating the level of harvestable biomass at Tiparra Reef. For this to be effective and efficient, GPS and depth-logger data will be required from all fishing vessels over multiple years – as these data are essential for determining and stratifying survey areas (see Mayfield *et al*. 2007b).

The commercial catch sampling program should be reviewed to ensure it provides adequate levels of high-quality data to inform future assessment of this fishery. As the length-frequency distribution of the commercial catch varies among areas, divers and days, sampling at spatial and temporal scales representative of the fishery is required to reliably detect and quantify changes. Determining the appropriate sampling level requires a robust cost-benefit analysis. Andrew and Chen (1997) described the use of Monte Carlo simulations to (1) investigate the influence of numerous sources of variation on the estimates of mean length and length structure in the commercial blacklip abalone catch in NSW and (2) suggest a representative commercial catch-sampling approach. The likely improvements in efficiency and accuracy of a more robust commercial-catch sampling program should be evaluated.

It would also be useful to (1) improve estimates of the recreational and illegal catch; (2) evaluate the influence of fleet dynamics on the performance measures; and (3) assess the direct and indirect effects on the ecosystem arising from the harvest of abalone in this Zone.

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Appendix 1: Greenlip abalone egg-production model

1.1 Assumptions and model structure

1. The stock structure is in a steady state and recruitment is constant. Therefore, the total yield (or egg production) in any one year from all age classes is the same as that from a single cohort over its whole lifespan.

2. The model follows a single cohort through its life. Initial recruitment was arbitrarily selected at 100 individuals. The model was run on a monthly basis up to 240 months.

3. Length-at-age was predicted using the von Bertalanffy equation based on parameters estimated for each area. The model is sensitive to changes in either K or L_∞.

4. The proportion of mature individuals ($f(x) = a/(1+\exp(-((x-L_{50})/b)))$) and number of eggs in each size class (fecundity = a SL^b) were determined from parameters estimated at each site.

5. Egg quality, size and fertilisation rate were considered constant across all sizes of abalone.

6. Selectivity increased linearly from zero at the MLL (130 mm SL) to 1 for abalone larger than the lower limit of the modal size class from the commercial catch (L_{msc}). Thus, all abalone larger than L_{msc} observed by a diver have an equal probability (P) of capture.

7. The estimate of F_{2005} in all areas was determined from commercial shell samples obtained during 2005 after King (1995). There is considerable uncertainty in estimating F. Estimates of retained egg production are highly sensitive to F.

8. Growth data are representative of fished areas.

1.2 Biological data

Model inputs	Parameter	Size / age	Fishing Area 21
Growth rate[1]	L_∞	-	179
	K	-	0.215
Size at maturity[2]	a	-	1.0029
	b	-	5.2136
	L_{50}	-	80.3
Fecundity[3]	a	-	0.0023
	b	-	4.143
Natural Mortality[4]	M	0 – 6 months	4
		7 – 36 months	0.64
		37 – 48 months	0.5
		49 – 60 months	0.3
		>60 months	0.15
Length fully selected	L_{msc}	-	144
Fishing mortality	F_{2007}	-	0.418

1. Mean value obtained from individuals tagged and recaptured at Tiparra Reef (Dixon & Day 2004).
2. Parameter estimates for the logistic function describing the relationship between shell length and proportion mature for greenlip abalone at Tiparra Reef in 2003 and 2004.
3. Data from Tiparra Reef (SARDI unpublished data).
4. Data from Shepherd and Breen (1992) and Shepherd and Baker (1998).

Appendix 2: Blacklip abalone egg-production model

2.1 Assumptions and model structure

1. The stock structure is in a steady state and recruitment is constant. Therefore, the total yield (or egg production) in any one year from all age classes is the same as that from a single cohort over its whole lifespan.

2. The model follows a single cohort through its life. Initial recruitment was arbitrarily selected at 100 individuals. The model was run on a monthly basis up to 240 months.

3. Length-at-age was predicted using the von Bertalanffy equation based on parameters estimated for each area. The model is sensitive to changes in either K or L_∞.

4. The proportion of mature individuals ($f(x) = a/(1+\exp(-((x-L_{50})/b)))$) and number of eggs in each size class (fecundity = a SL^b) were determined from parameters estimated at each site.

5. Egg quality, size and fertilisation rate were considered constant across all sizes of abalone.

6. Selectivity increased linearly from zero at the MLL (130 mm SL) to 1 for abalone larger than the lower limit of the modal size class from the commercial catch (L_{msc}). Thus, all abalone larger than L_{msc} observed by a diver have an equal probability (P) of capture.

7. The estimate of F_{2005} in all areas was determined from commercial shell samples obtained during 2005 after King (1995). There is considerable uncertainty in estimating F. Estimates of retained egg production are highly sensitive to F.

8. Growth data are representative of fished areas.

2.2 Biological data

			Fishing Area		
Model inputs	Parameter	Size / age	26	27	29
Growth rate[1]	L_∞	-	170	170	170
	K	-	0.34	0.34	0.34
Size at maturity[2]	a	-	1.0017	0.9894	1.0005
	b	-	6.9110	5.4712	6.5574
	L_{50}	-	95.1783	96.2188	96.0040
Fecundity[3]	a	-	1×10^{-6}	1×10^{-6}	1×10^{-6}
	b	-	5.7143	5.7143	5.7143
Natural Mortality[4]	M	0 – 12 months	3	3	3
		13 – 24 months	0.9	0.9	0.9
		25 – 36 months	0.45	0.45	0.45
		>36 months	0.2	0.2	0.2
Length fully selected	L_{msc}	-	146	140	136
Fishing mortality	F_{2007}	-	0.123	0.216	0.345

1. Data from Shepherd & Hearn 1983 (K) and estimated from commercial catch samples (L_∞).
2. Parameter estimates for the logistic function describing the relationship between shell length and proportion mature for blacklip abalone off SW Kangaroo Island in 2004 (SARDI unpublished data).
3. Data from Cape Bedout & Cape du Couedic (SARDI unpublished data).
4. Data from Shepherd and Breen (1992) and Shepherd and Baker (1998).

Appendix 3: Assessment of the greenlip abalone fishery in the CZ of the South Australian abalone fishery against the biological performance indicators prescribed in the Management Plan. Values are mean ± SE. Red indicates statistical significance.

Performance Indicator	Units	Spatial Scale	2003	2004	2005	2006	2007	Inter-annual change	5-year trend
Commercial effort	hr	Zone[1,2]	1387	1376	1561	1588	1691	-	$r^2 = 0.91$, df = 3 $p < 0.05$
Mean daily catch	$kg.day^{-1}$	Area 21[1,2]	624.8±16.5	636.9±16.7	521.0±15.5	539.8±13.9	550.1±14.8	$t = 0.51$, df = 323 $p > 0.05$	$F_{1,839} = 25.4$ $p < 0.05$
		Area 24[2]	368.6±30.7	341.8±25.0	409.0±18.2	396.5±25.0	333.4±15.5	$t = 2.26$, df = 114 $p < 0.05$	$F_{1,181} = 1.40$ $p > 0.05$
Mean daily effort	$hr.day^{-1}$	Area 21[1,2]	6.6±0.1	6.6±0.1	6.5±0.1	5.9±0.1	6.4±0.1	$t = 2.70$, df = 323 $p < 0.05$	$F_{1,839} = 7.08$ $p < 0.05$
		Area 24[2]	7.1±0.2	6.0±0.3	6.5±0.3	5.8±0.3	5.7±0.2	$t = 0.34$, df = 114 $p > 0.05$	$F_{1,181} = 8.33$ $p < 0.05$
CPUE	$kg.hr^{-1}$	Area 21[1,2]	94.6±1.7	96.2±1.7	80.4±2.0	91.7±1.7	86.0±1.9	$t^3 = 2.29$, df = 319.7 $p < 0.05$	$F^4_{1,839} = 8.31$ $p < 0.05$
		Area 24[2]	52.0±4.4	56.8±3.8	63.0±2.2	68.8±3.6	59.1±1.9	$t^3 = 2.85$, df = 13.1 $p < 0.05$	$F_{1,181} = 0.84$ $p > 0.05$
Mean size	mm, SL	Area 21[1]	146.8±0.2	147.1±0.1	147.9±0.1	145.7±0.2	145.9±0.1[5]	$t = 0.81$, df = 9893 $p > 0.01$	$F_{1,22694} = 52.0$ $p < 0.01$
		Area 24	157.0±0.3	153.1±0.4	154.5±0.6	NO DATA	148.9±0.2[5]	-	-
Legal-sized abalone abundance	$no.m^{-2}$	Tiparra Reef	0.16±0.01	0.24±0.02	0.28±0.04	0.20±0.03	0.18±0.02	$t = 0.51$, df = 158 $p > 0.05$	$F_{1,406} = 0.003$ $p > 0.05$
Sub-legal-sized abalone abundance	$no.m^{-2}$	Tiparra Reef	0.25±0.02	0.34±0.03	0.46±0.05	0.27±0.03	0.40±0.07	$t = 1.83$, df = 158 $p > 0.05$	$F_{1,406} = 2.71$ $p > 0.05$
Abundance of abalone $>L_{50}$	$no.m^{-2}$	Tiparra Reef	0.39±0.03	0.55±0.05	0.72±0.08	0.44±0.04	0.55±0.08	$t = 1.19$, df = 158 $p > 0.05$	$F_{1,406} = 1.31$ $p > 0.05$
Egg production retained	%	Tiparra Reef	37.9	36.9	40.3	41.3	40.6[5]	N/A	N/A

1. Excludes data from Cowell from 2004 to 2007.
2. Daily records where catch of blacklip abalone exceeds 0 kg are excluded.
3. Based on the ratio estimator (after Rice 1995).
4. Based on daily CPUE.
5. Includes data from the electronic shell measuring machines, truncated to exclude records >200 mm SL.

Appendix 4: Assessment of the blacklip abalone fishery in the CZ of the South Australian abalone fishery against the biological performance indicators prescribed in the Management Plan. Values are mean ± SE. Red indicates statistical significance.

Performance Indicator	Units	Spatial Scale	2003	2004	2005	2006	2007	Inter-annual change	5-year trend
Commercial effort[1]	hr	Zone	439	426	389	322	272	-	r^2 = 095, df = 3 $p < 0.05$
Mean daily catch[1]	$kg.day^{-1}$	Area 26	459.8±26.1	496.6±30.5	402.8±30.4	420.8±41.1	479.2±34.2	$t = 0.81$, df = 36 $p > 0.05$	$F_{1,108} = 0.06$ $p > 0.05$
		Area 27	364.4±48.4	486.6±39.2	451.8±32.7	340.8±35.4	303.6±24.5	$t = 0.87$, df = 28 $p > 0.05$	$F_{1,77} = 5.05$ $p < 0.05$
Mean daily effort[1]	$hr.day^{-1}$	Area 26	6.2±0.2	6.3±0.1	5.6±0.3	5.7±0.3	5.9±0.3	$t = 0.06$, df = 36 $p > 0.05$	$F_{1,108} = 2.98$ $p > 0.05$
		Area 27	5.2±0.3	6.0±0.4	5.6±0.3	5.6±0.4	4.8±0.3	$t = 1.34$, df = 28 $p > 0.05$	$F_{1,77} = 1.86$ $p > 0.05$
CPUE[1]	$kg.hr^{-1}$	Area 26	74.4±4.4	79.1±4.2	72.6±5.7	73.6±4.8	81.9±5.4	$t^2 = 1.14$, df = 34.3 $p > 0.05$	$F^3_{1,108} = 0.64$ $p > 0.05$
		Area 27	70.4±8.4	80.5±5.2	81.0±4.6	61.4±5.0	63.3±4.1	$t^2 = 0.29$, df = 20.9 $p > 0.05$	$F^3_{1,77} = 2.43$ $p > 0.05$
Mean size	mm, SL	Area 26	147.5±0.3	147.6±0.2	147.2±0.3	147.2±0.4	149.3±0.1[4]	$t = 5.70$, df = 4836 $p < 0.01$	$F_{1,8999} = 65.1$ $p < 0.01$
		Area 27	148.9±0.3	147.0±0.4	142.8±0.3	146.0±0.3	147.2±0.2[4]	$t = 3.21$, df =2199 $p < 0.01$	$F_{1,4107} = 7.2$ $p > 0.01$
Egg production retained	%	Area 26	45.4	46.5	42.4	47.9	64.4[4]	N/A	N/A
		Area 27	39.9	43.0	24.2	32.6	48.4[4]	N/A	N/A
		Area 29	21.8	24.4	28.0	No Data	37.5[4]	N/A	N/A

1. Daily records where catch of greenlip abalone exceeds 50% of the total catch are excluded.
2. Based on the ratio estimator (after Rice 1995).
3. Based on daily CPUE.
4. Includes data from the electronic shell measuring machines, truncated to exclude records >200 mm SL.