Western Zone Abalone

(*Haliotis laevigata & H. rubra*) Fishery 1.

Region A

Fishery Assessment Report to PIRSA

October 2006

Chick, R.C., Mayfield, S., Turich, N. & B. Foureur

This Fishery Assessment Report updates the 2005 report for Region A of the Western Zone Abalone Fishery and is part of SARDI Aquatic Sciences ongoing assessment program for this 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.

Fishery Assessment Report to PIRSA

Western Zone Abalone

(*Haliotis laevigata & H. rubra*) Fishery 1.

Region A

Chick, R.C., Mayfield, S., Turich, N. & B. Foureur

October 2006

SARDI Aquatic Sciences

SARDI Aquatic Sciences Publication No. RD05/0017-3

SARDI Research Report Series No. 167

This Fishery Assessment Report updates the 2005 report for Region A of the Western Zone Abalone Fishery and is part of SARDI Aquatic Sciences ongoing assessment program for this 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.

This report may be cited as:

Chick, R.C., Mayfield, S., Turich, N. and B. Foureur. (2006) Western Zone Abalone (*Haliotis laevigata* & *H. rubra*) Fishery 1. Region A. Fisheries assessment report to PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 124pp. SARDI Publication Number RD05/0017-3.

South Australian Research and Development Institute

SARDI Aquatic Sciences

2 Hamra Avenue

West Beach SA 5024

Telephone: (08) 8200 2400

Facsimile: (08) 8200 2406

http://www.sardi.sa.gov.au

DISCLAIMER

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

Printed in Adelaide October 2006

Reviewers:	Dr Adrian Linnane and Greg Ferguson (SARDI Aquatic Sciences) Martin Smallridge (PIRSA)
Approved by:	Dr Tim Ward, Principal Scientist: Wild Fisheries
Signed:	
Date:	30 October 2006
Distribution:	PIRSA, Abalone Fishery Management Committee, SARDI Aquatic Sciences Library, Western Zone Abalone Fishery licence holders
Circulation:	Public Domain

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

1. This fishery assessment report updates the 2005 report and assesses the current status of the abalone stocks in Region A of the Western Zone abalone fishery.
2. Total effort has declined from 7 222 hr in 1989 to 5 327 hr in 2005 – the lowest level since 1979. The rate of decline was greatest between 1999 and 2005.
3. The total allowable commercial catch (TACC) was 500 t (shell weight) from 1989 – 1995 and from 1997 – 2005. It was 465 t (shell weight) in 1996.

Greenlip abalone

4. Data and information to assess the status of greenlip abalone (hereafter referred to as greenlip) are balanced among those provided by commercial fishers, that collected by SARDI Aquatic Sciences and outputs from two models.
5. Greenlip comprise 41.4% (207 t) of the TACC in Region A.
6. Since 2001, >70% of the TACC has been harvested from four of the 18 fishing areas.
7. Catches have declined in 12 fishing areas since 1985. Current catches from eight of these are the lowest on record. Declines in catches from six areas exceed 50%.
8. Catch from fishing area 9 has doubled since 1985 and current catches are among the highest since 1979. The sustainability of this level of catch is poorly understood.
9. In 2005, 56% of the TACC was harvested in January, when recovery rates are lowest. This considerably reduces the potential productivity of the fishery.
10. 'Directed effort' on greenlip abalone has declined by 23% since 1989 - 1993 and declined 18% between 2001 and 2005. The TACC was unchanged over this time period.
11. The raw CPUE in Region A has increased significantly since 1996. In 2005 it was at the highest level since 1979. Similar patterns were observed in each of the main fishing areas. Temporal patterns in standardised CPUE mimic those in raw CPUE. Together, these data suggest that stock abundance has probably increased in recent years.
12. In 2005, the mean length of the commercial catch exceeded the MLL (145 mm SL) by >10 mm SL in all fishing areas. Modal length classes in Region A and the main fishing areas were also high, relative to the MLL, and were >25 mm above the MLL in 3 areas.
13. The abundance of total and legal-sized greenlip have increased at Hotspot, Pearson Island and 'The Gap' since 1994. The abundance of sub-legal and legal-sized greenlip has also increased at Hotspot and Ward Island, respectively, since 2000.
14. The abundance of sub-legal-sized greenlip has decreased at Point Avoid since 1989 and estimates during more recent surveys at Ward Island, Pearson Island and 'The Gap' were low, relative to historical levels.
15. The abundance of greenlip in all three size categories declined between 2004 and 2005 at Flinders Island, Hotspot, Pearson Island and 'The Gap'.
16. 18 of the 36 performance indicators (PI) that triggered, did so in a positive direction.

Blacklip abalone

17. Assessment of blacklip abalone (hereafter referred to as blacklip) is heavily weighted by the interpretation of commercial catch and effort data. Data from fishery-independent surveys, ongoing collection of biological data and outputs from a range of developing models will improve future assessments.
18. Blacklip comprise 58.6% (293 t) of the TACC in Region A. This TACC is 27% greater than the mean catch from 1968 to 1984.
19. Since 2001, cumulatively ~30% of the TACC has been harvested from fishing areas 9 and 11. However, >5% of the TACC was harvested from each of nine fishing areas.
20. Catch from fishing area 9 has more than doubled since 1985. The catch in 2005 was the second highest since 1979. The sustainability of this level of catch is poorly understood. In contrast, declines in catches from fishing areas 10 and 15 since 2000 have been substantial (>50%).
21. 'Directed effort' on blacklip has declined from 3 760 $hr.yr^{-1}$ to 3 189 $hr.yr^{-1}$ over the last 17 years. The TACC remained virtually unchanged over this time period.
22. The raw CPUE on blacklip in Region A has increased significantly since 1979 and was at the highest observed level in 2005. Similar patterns were observed in each of the main fishing areas.
23. Temporal patterns in standardised CPUE in Region A and fishing area 9 mimic those in the raw CPUE. In contrast, standardised CPUE declined between 1993 and 2000 and from 2001 to 2005 in fishing area 11.
24. In 2005, the mean length and modal length class of the commercial catch were substantially greater than the MLL (130 mm SL) in most fishing areas. The exception was fishing area 12 where the length-frequency distribution was left-skewed and the mean length and modal length class were smaller than for any other fishing area.
25. 12 of the 21 PI that triggered, did so in a positive direction.

Conclusions

26. Much of the data support the conclusion that greenlip stocks in Region A are being fished within sustainable limits. This evidence includes substantial declines in 'directed effort', increases in raw and standardised CPUE in most major fishing areas, large mean length and modal length class of the commercial catch and general increases in the abundance of legal-sized greenlip at several fishery-independent survey sites.
27. However, the current high catches and continued low estimates of retained egg production in fishing area 9, reductions in the mean length of commercial shells in three of the major fishing areas, significant declines in the abundance of sub-legal-sized greenlip at "The Gap' since 2001, significant declines in the abundance of legal-sized greenlip at Pearson Island and 'The Gap' between 2004 and 2005 do not support this conclusion. Rather, they suggest that the status of the resource may have weakened between 2004 and 2005 and that these stocks warrant careful monitoring over future years.
28. Despite the limited series of data to assess the status of blacklip stocks in Region A much of the data support the conclusion that stocks are being fished within sustainable limits. Nevertheless, other data, of equal weight, support the alternative conclusion that the stocks, particularly in fishing area 11 and possibly fishing area 12, have declined. This problem reflects the lack of data and information for the fishery.

ACKNOWLEDGEMENTS

Funds for this research were provided by PIRSA, obtained through licence fees. SARDI Aquatic Sciences provided substantial in-kind support. We are grateful to, Mr Ian Carlson, Mr Andrew Hogg, Mr Shane Penny and Mr Thor Saunders for assistance with diving and the collection and management of data. Dr Rick McGarvey provided substantial statistical support including development of a mean ratio estimator for CPUE performance indicators. Dr Yongshun Xiao provided assistance in the standardisation of CPUE data. Ms Annette Doonan created the maps. Mr Thor Saunders provided valuable assistance with the application of 'Estimatrix'. Dr Duncan Worthington provided valuable assistance with the application of 'AbModeller', a review of previous model description, and general comments that improved section 3.7 in this report. PIRSA Fisheries provided valuable information on estimates of illegal catch during 2005 and interpretation of these data. This report was formally reviewed by Dr Adrian Linnane and Greg Ferguson (SARDI Aquatic Sciences) and Martin Smallridge (PIRSA). It was approved for release by Dr Tim Ward, Wild Fisheries Principal Scientist, SARDI Aquatic Sciences.

1. GENERAL INTRODUCTION

1.1 Overview

This fishery assessment report for Region A of the Western Zone of the South Australian abalone fishery (hereafter referred to as Region A) updates the previous fishery assessment report for this Region (Mayfield *et al.* 2005b) and is part of SARDI Aquatic Sciences ongoing assessment program for this fishery. The aims of the report are (1) to assess the current status of the resource; (2) identify the uncertainty associated with the assessment; and (3) to identify future research needs for the fishery.

This report covers the period 1 January 1968 to 31 December 2005 and 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 western zone abalone fishery including the fisheries history, current management arrangements, and the level of recreational and illegal catch, (3) identifies the biological performance indicators, (4) summarises biological knowledge of South Australian abalone, and (5) provides a synopsis of previous stock assessment reports on the fishery.

Sections two and three provide an assessment of the fishery-dependent and fishery-independent data for greenlip abalone (hereafter referred to as greenlip) and blacklip abalone (hereafter referred to as blacklip), respectively, in Region A from 1968 to 2005. Where appropriate, this includes spatial and temporal analyses of catch, effort, raw and standardised catch-per-unit effort (CPUE), size-frequency distribution of the catch and fishery-independent surveys.

In section four, the performance of the greenlip and blacklip fisheries in Region A is assessed against the performance indicators identified in the management plan.

Section five is the general discussion. It synthesises the information presented in the previous sections, identifies areas of uncertainty in current knowledge, comments on the status of the resource 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) and major management milestones are listed in Table 1.1. Summaries of the fishery can be found in Prince & Shepherd (1992), Zacharin (1997), Keesing & Baker (1998) 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 5 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) to facilitate more effective management (Figure 1.1). The Western Zone of the South Australian abalone fishery includes all coastal waters of South Australia between the Western Australia/South Australia border and Meridian 136°30'E. This Zone was further subdivided into Region A (Meridian 133°50.8'E to Meridian 136°30'E) and Region B in 1985 (Figure 1.2). The fishing season extends from 1 January to 31 December each year.

In region A, 58.6% of the Total Allowable Commercial Catch (TACC) comprises blacklip (2005 TACC: 293.25 t shell weight). The remaining 41.4% comprises greenlip (2005 TACC: 207 t shell weight). The TACCs did not change in Region A from 1997 to 2005 (Table 1.2). In 2006, the TACC on greenlip was increased to 227.7 t. The data presented in this report does not include any information after the revision of this TACC.

Since 1997, the fishery has 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 size, quotas) controls. The current management arrangements in the Western Zone are summarised in Table 1.3.

Minimum legal lengths (MLL) of 130 mm shell length (SL) were imposed on both species in 1971. The minimum legal size for blacklip has remained unchanged. The minimum legal length for greenlip was increased to 145 mm SL in 1984.

Quotas were imposed on Region A from 1985. Each year, the Abalone Fishery Management Committee (AFMC) recommends a separate TACC for greenlip and blacklip in Region A to the Minister for Agriculture, Food and Fisheries. This advice is structured by the objectives and strategies of the Abalone Fishery Management Plan (see Section 1.3 below) and based on a number of submissions to the AFMC including the annual fishery assessment reports submitted to PIRSA by SARDI Aquatic Sciences. Each licence holder is allocated an annual individual transferable quota (ITQ) that is an equal share of the TACC.

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 on 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.

Table 1.1 Management milestones in 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
1984	Blacklip minimum legal length amended to 120 mm in the Southern Zone
	Greenlip minimum legal length amended to 145 mm in the Western Zone
1985	Western Zone divided into Regions A and B
	Quota introduced to Region A in the Western Zone
1989	Quota introduced to the Central Zone
1991	Quota introduced to Region B in the Western Zone
1993	Abolition of owner-operator regulation
1994	Four 'fish-down' areas declared in the Southern Zone
1997	Management Plan implemented
2004	Management Plan reviewed
	Fishery assessed against the Principles of Ecologically Sustainable Development
2006	TACC in Western Zone Region A greenlip fishery increased to 227.7 t

Table 1.2 Total allowable commercial catches (tonnes, shell weight) for Region A from 1989 to 2006.

Fishing season	Greenlip abalone	Blacklip abalone
1989	207	293.25
1990	207	293.25
1991	207	293.25
1992	207	293.25
1993	207	293.25
1994	207	293.25
1995	207	293.25
1996	207	258.00
1997	207	293.25
1998	207	293.25
1999	207	293.25
2000	207	293.25
2001	207	293.25
2002	207	293.25
2003	207	293.25
2004	207	293.25
2005	207	293.25
2006	227.7	293.25

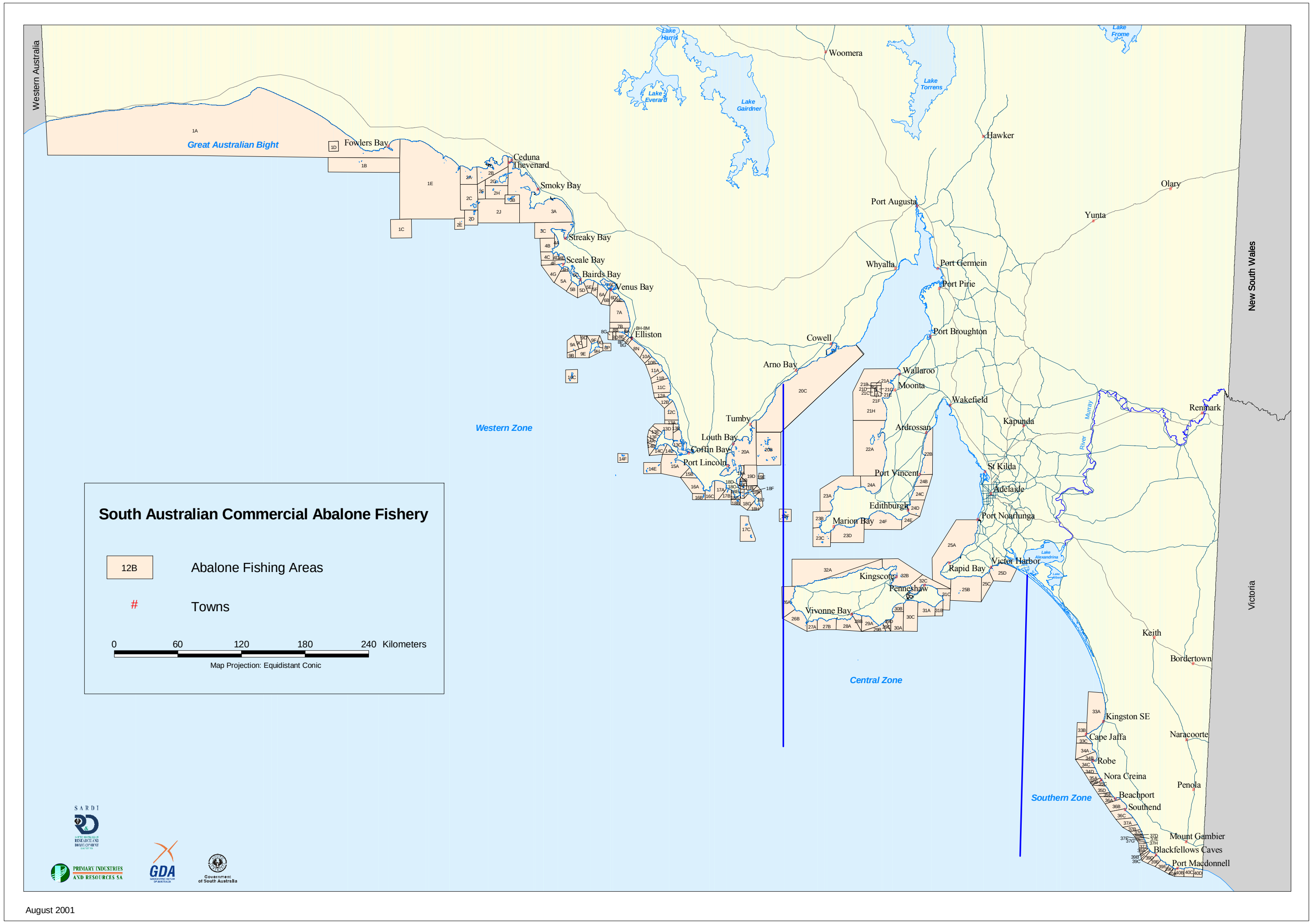

Figure 1.1 Fishing Zones and Fishing Areas of the South Australian abalone fishery

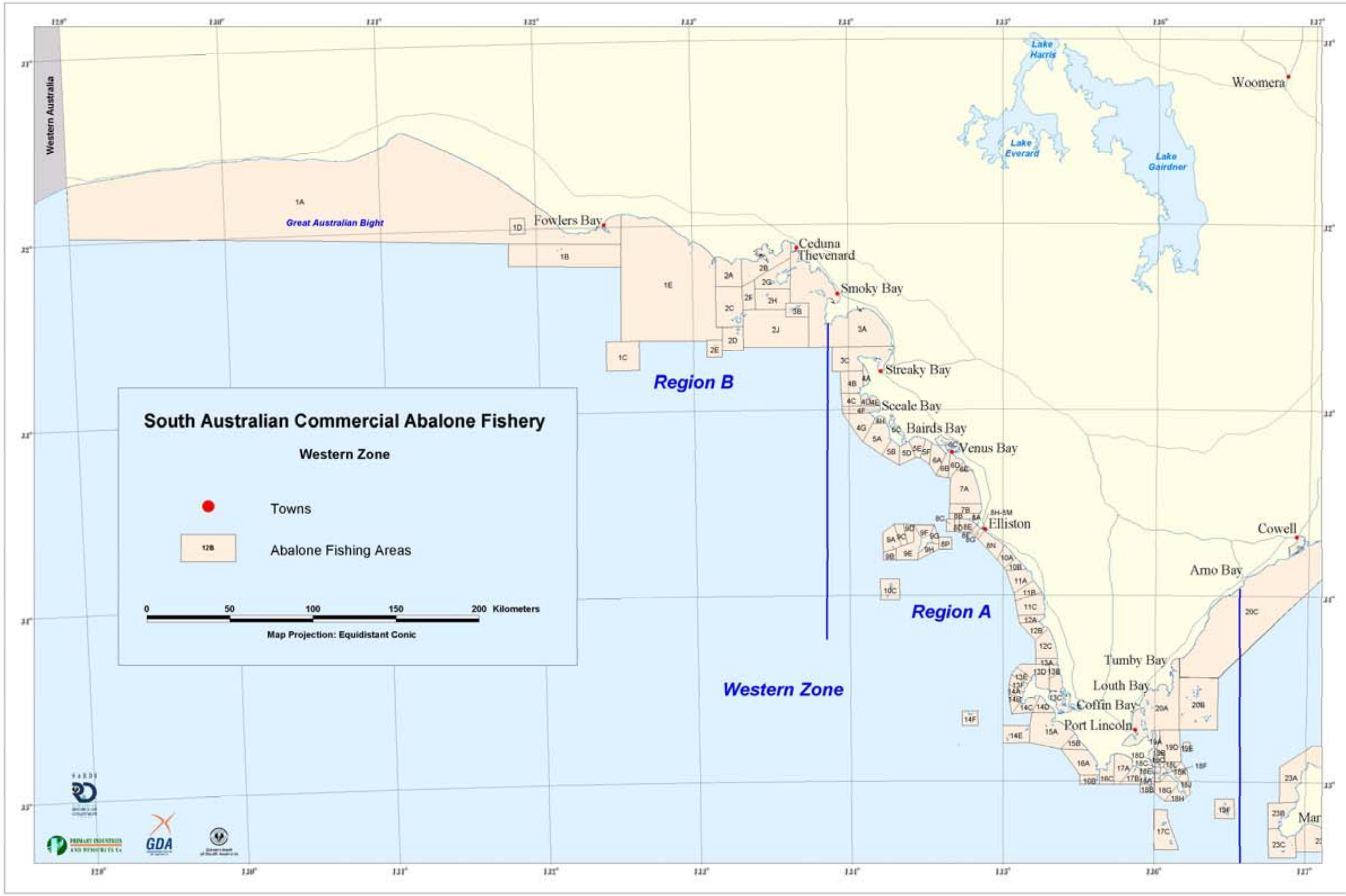

Figure 1.2 Fishing areas of the Western Zone of the South Australian abalone fishery.

Table 1.3 Summary of the current management arrangements for the Western Zone commercial abalone fishery.

Management strategy	Western Zone
Licence holders	23
Targeted species	Greenlip Blacklip
Minimum legal length	Blacklip 130 mm Greenlip 145 mm
Quota year	1 Jan. to 31 Dec.
Quota transferability	Yes
Other species permitted	*H. roei, H. scalaris, H. cyclobates*
Method of capture	By hand
By-catch	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 1.2). 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 by SARDI Aquatic Sciences to provide analyses of catch, effort and CPUE in the annual Stock Assessment Reports for each Zone (e.g. Mayfield *et al.* 2005b, Mayfield *et al.* 2005c).

1.2.2 Recreational fishery

The total recreational abalone catch in South Australia was estimated at 17 780 abalone for the period May 2000 to April 2001 (Henry & Lyle 2003). Previous surveys within South Australia suggested that 29.3% of recreational fishing effort was expended in the Western Zone (Mayfield *et al.* 2001). Under this assumption, approximately 5 210 abalone (3 t) are recreationally harvested from the Western Zone annually. This represents about 0.6% of the TACC. No separate estimates of the proportion of the recreational catch from Regions A and B are available. 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. During 2005, PIRSA identified, through information and other reports, that 7 340 individual abalone may have been taken illegally. In addition to this, information reports also indicated that approx 2 365 kg (meat weight) of abalone may have been illegally harvested within the Western Zone. It would be expected that PIRSA would not have been notified of all reports alleging that abalone theft activity had occurred within the Western Zone during 2005, so the actual extent of illegal take of abalone is likely to have been higher. By attributing an estimate of 140 g to the meat weight of an illegal harvested whole abalone, the estimated total illegal catch of abalone in the Western Zone equates to ~3.4 tonnes meat weight (PIRSA Fisheries).

1.3 Objective 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 associated strategies. The three biological objectives are relevant to this report and 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. These are:

Strategy 1: To collect and collate fishery-dependent information;

Strategy 2: To set the TACC using the best available information;

Strategy 3: To harvest at an appropriate minimum legal length;

Strategy 4: To maintain abalone population densities; and

Strategy 5: To identify disease-infected areas

Performance indicators and specified trigger points are linked with each strategy. The biological performance indicators and trigger points for each of the strategies for the greenlip and blacklip fisheries in Region A are provided in Tables 1.4 and 1.5.

Annual reports on the harvest discard, illegal catch and recreational catch, and the diver's assessment of the status of the stock are provided by PIRSA 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 fishery in Region A of the Western Zone 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 >5% 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	Five most important fishing areas (by catch)	Change in order or composition
	Mean daily catch	Fishing areas contributing >5% of the TACC	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
	Mean daily effort	Fishing areas contributing >5% of the TACC	
	CPUE	Fishing areas contributing >5% of the TACC	
	Mean size	Fishing areas contributing >5% of the TACC	
	Abundance of legal-sized abalone	The Gap, Hotspot, Ward Island, Flinders Island, Pearson Island, Avoid Bay	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
	Abundance of sub-legal-sized abalone		
3	**% Egg production relative to pristine egg production**	Fishing areas contributing >5% of the TACC	<50% of the pristine level
4	**Abundance of abalone >L_{50}**	The Gap, Hotspot, Ward Island, Flinders Island, Pearson Island, Avoid Bay	(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 fishery in Region A of the Western Zone 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 >5% 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	Five most important fishing areas (by catch)	Change in order or composition
	Mean daily catch	Fishing areas contributing >5% of the TACC	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
	Mean daily effort	Fishing areas contributing >5% of the TACC	
	CPUE	Fishing areas contributing >5% of the TACC	
	Mean size	Fishing areas contributing >5% of the TACC	
	Abundance of legal-sized abalone	Pt Labatt, Talia, Ward Island, Sheringa, Reef Head	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
	Abundance of sub-legal-sized abalone		
3	**% Egg production relative to pristine egg production**	Fishing areas contributing >5% of the TACC	<50% of the pristine level
4	**Abundance of abalone >L_{50}**	Pt Labatt, Talia, Ward Island, Sheringa, Reef Head	(1) Statistically significant inter-annual change (2) Statistically significant 5-year trend
5	Harvest discard	Fishing Zone	-

1.4 Abalone biology

Abalone (Family: Haliotidae; Genus: *Haliotis*) are marine gastropods that inhabit near-shore reefs (Day & Shepherd 1995) from the shallow sub-tidal zone to a depth of around 400 m (Geiger 1999). They have a world-wide distribution in tropical and temperate waters (Geiger 1999) with Australia, Japan and South Africa having the greatest number of abalone species. 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, Elliot *et al.* 2000, Hancock 2000), suggesting limited dispersal between ‘metapopulations’ (Fleming 1997), although detecting significant differences within species has frequently proven difficult.

Abalone are dioecious broadcast spawners. Spawning is seasonal and fertilisation success is strongly influenced by adult density. Larval duration ranges between 5 and 12 days and is predominantly dependent on water temperature. Since the larvae are free swimming, dispersal distances are influenced by local hydrodynamics. Recruitment may vary widely from year to year and relationships between stock size and subsequent recruitment are ambivalent (McShane & Smith 1988, Prince *et al.* 1988, Shepherd 1990, McShane 1991, McShane & Smith 1991, Shepherd *et al.* 1992a).

Growth rates are high initially and size-dependent for the first 5 years (Shepherd 1988). Thereafter, they decline and conform to an asymptotic growth pattern (Shepherd & Hearn 1983) with year classes becoming indistinguishable by size. Water temperature, water movement and the quantity and species of macro-algae available for consumption are the primary determinants of growth rate (Zacharin 1997).

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 may also erode the shells (Shepherd 1973).

Recently-settled abalone prefer 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 shell length (SL)) to dead seagrass and drift red algae (Shepherd & Cannon 1988). Other dominant algae may be avoided, ostensibly due to non-palatability.

1.4.1 Biology of greenlip abalone in Region A

Greenlip (*Haliotis laevigata)* are contiguous throughout southern Australia, with their distributions ranging from Corner Inlet (Victoria) to Cape Naturaliste (Western Australia). They tend to inhabit water depths between 10 and 30 m, where they form clusters of local populations, separated from other similar clusters over a broad range of spatial scales. Table 1.6 contains a summary of fishery-independent biological data that have been collected for greenlip in Region A.

The size at sexual maturity of greenlip varies substantially among areas. The length at which 50% of individuals are sexually mature (L_{50}) varied between 76.6 mm SL at Anxious Bay (2005) and 102 mm SL in Waterloo Bay (1974; Appendix 1, Table A1.1). Greenlip spawn during summer and early autumn (Keesing *et al.* 1995, Rodda *et al.* 1997), with the annual spawning cycle probably driven by fluctuations in water temperature (Shepherd & Laws 1974).

The relationships between length-fecundity (Appendix 1, Table A1.2), whole weight-fecundity (Appendix 1, Table A1.3) and length-weight (Appendix 1, Table A1.4) for greenlip in the Western Zone are generally well established.

Growth rates vary considerably in both time and space. Newly settled *H. laevigata* grew rapidly, at around 20 – 30 µm.day^{-1} (Preece *et al.* 1997, Rodda *et al.* 1997). Sub-adult growth rates in the Western Zone ranged between 15.3 mm and 39.6 mm.yr^{-1} at Yanerbie and Taylor Island, respectively (Appendix 1, Table A1.5). For adult greenlip (> 90 mm SL), growth is non-linear and can be represented by the parameters K (yr^{-1}) and L_∞ (mm SL) from the von Bertalanffy growth curve. K ranged from 0.186 yr^{-1} at Sceale Bay to 0.595 yr^{-1} at Waterloo Bay, and L_∞ ranged between 119.5 mm SL (Anxious Bay) and 214.0 mm SL (Hotspot (2003) (Appendix 1, Table A1.7).

Adult mortality rates (M) ranged from 0.13 yr^{-1} at Ward Island to 0.40 yr^{-1} at Waterloo Bay (Appendix 1, Table A1.6).

1.4.2 Biology of blacklip abalone in Region A

Blacklip (*Haliotis rubra)* are contiguous throughout southern Australia between Coffs Harbour (New South Wales) and Rottnest Island (Western Australia). They tend to live in shallow water (0 - 30 m) along rocky coastlines. Table 1.7 contains a summary of fishery independent biological data that have been collected for blacklip in Region A.

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

Blacklip spawn during summer and autumn, though spawning may not be synchronous (Shepherd & Laws 1974, Keesing *et al.* 1995, Rodda *et al.* 1997)). The annual spawning cycle may be driven by seasonal variation in water temperature (Shepherd & Laws 1974). Their size at sexual maturity varies substantially among areas. The length at which 50% of individuals are sexually mature (L_{50}) varied between 82.3 mm SL at Hotspot (2004) and 120.1 mm SL at Waldegrave Island (Appendix 1, Table A1.8).

Growth rates of adult blacklip can be represented by the von Bertalanffy growth equation, K (yr^{-1}) and L_∞ (mm SL). K ranged from 0.05 yr^{-1} at Reef Head (2001) to 0.312 yr^{-1} at Venus Bay (2000), while L_∞ ranged between 131.2 mm SL and 219.4 mm SL at Reef Head (Appendix 1, Table A1.9).

The length-weight relationships for blacklip in Region A are generally well established (Appendix 1, Table A1.10).

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

Fishery Assessment Reports were produced annually between 1998 and 2000 (Rodda *et al.* 1998, Shepherd *et al.* 1999, Rodda *et al.* 2000). 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, 2002b, Mayfield & Ward 2002). The first dedicated Western Zone Report (Mayfield *et al.* 2002a) synthesised relevant fisheries data for the Western Zone from 1968 to 2001. That report has subsequently been updated annually. Substantial improvements over the previous reports have included standardised catch rates, estimates of egg production relative to pristine levels and a detailed description of the biological data available for greenlip and blacklip in this Zone.

Table 1.6 **Summary of the biological data (blue blocks) and ongoing research (red blocks) on greenlip (*H. laevigata)* in the Western Zone of the South Australian abalone fishery. Sites are arranged according to mapcodes. Numbers in brackets indicate the number of years for which data are available. L/Wt, Bled Wt, L_{50}, F, SS, Sex ratio, K, and L_{inf}, refer to shell length and whole weight, blood loss weight as a percentage of whole weight (period of 24 hours), length at which 50% of individuals are predicted to be sexually mature, fecundity, spawning season, sex ratio, growth rate and theoretical maximum length, respectively.**

Location		Biomass					Reproductive biology					Growth		
Mapcode	Site	L / Wt (1)	L / Wt (2)	L / Wt (3)	L / Wt (4)	Bled Wt	L_{50}(1)	L_{50}(2)	F	SS	Sex ratio	K, L_{inf} (1)	K, L_{inf} (2)	Mortality
4D	Speeds Point													
4E	Yanerbie	blue							blue			blue		
4F	Sceale Bay	blue							blue			blue		blue
4H or 5A	Searcy Bay	blue				blue					blue			
8A	Anxious Bay	blue	blue	blue			blue		blue		blue	blue	blue	
8H,J,K,L,M	Waterloo Bay	blue	blue	blue		blue	blue		blue		blue	blue		blue
9A	Ward Island	blue	blue	red			red		red		red	blue		blue
9D	Hotspot	blue	blue	blue	red	blue	red		red		blue	blue	blue	
9F	Flinders Island (Flinders Bay)	blue									blue	blue		
9G	Flinders Island (Windmill)	blue	blue			blue					blue	blue		
14D	Avoid Bay													
15A	Price Island	blue	blue			blue					blue			
18F	The Gap	blue	blue	blue	blue	blue	blue	blue			blue	blue		blue
19A	Maclaren Point	blue							blue			blue		
19A	Rowly Bay	blue									blue			
19C	Taylor Island	blue							blue			blue		

Table 1.7 **Summary of the biological data (blue blocks) and ongoing research (red blocks) on blacklip (*H. rubra)* in the Southern Zone of the South Australian abalone fishery. Sites are arranged according to mapcodes. Numbers in brackets indicate the number of years for which data are available. L/Wt, Bled Wt, L_{50}, F, SS, Sex ratio, K, and L_{inf}, refer to shell length and whole weight, blood loss weight as a percentage of whole weight (period of 24 hours), length at which 50% of individuals are predicted to be sexually mature, fecundity, spawning season, sex ratio, growth rate and theoretical maximum length, respectively.**

Location		Biomass			Reproductive biology					Growth		
Mapcode	Site	L / Wt (1)	L / Wt (2)	Bled Wt	L_{50}(1)	L_{50}(2)	F	SS	Sex ratio	K, L_{inf} (1)	K, L_{inf} (2)	Mortality
4B	Highcliff											
4C	Smoothpool											
5A	Point Labatt											
6A,B or D	Venus Bay											
8B	Waldergrave Island											
8H,J,K,L,M	Waterloo Bay											
9A	Ward Island											
9D	Hot Spot											
9F or E	Flinders Island											
10A or B	Tungketta											
11A	Sheringa											
11C	Kiana											
12B	Point Drummond											
13F	Reef Head											
14C	Point Whidbey											
14D	Avoid Bay											
15A	Price Island											
18A	West Bay											
19C	Taylor Island											

2. GREENLIP ABALONE

Commercial catch and effort data on this fishery have been collected since 1968. Fishers complete a research logbook for each fishing day and submit that 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 and catch-per-unit-effort (CPUE), from 1 January 1968 to 31 December 2005, presented in this section of the report. Due to low levels of accurate reporting and extraction of commercial fishery data from historical data sources for the year 1978 previous Fishery Assessment Reports have under reported commercial catches of greenlip in Region A for that year. CPUE was computed using the mean ratio estimator (after Rice 1995). Information on the length-frequency distribution of the commercial catch were obtained from samples provided to SARDI by commercial fishers (1 January 2004 – 30 June 2005) and data provided by the Abalone Industry Association of South Australia (AIASA; 1 July 2005 – 31 December 2005). The CPUE was standardised, and estimates of egg production, relative to those in an unfished (virgin) population, determined using models developed by SARDI Aquatic Sciences. Estimates of greenlip abalone abundance were obtained from fishery-independent diver surveys.

Fishery statistics in this section are provided at two spatial scales. These are (1) the whole greenlip abalone fishery (*i.e.* all fishing areas of Region A combined) and (2) individual fishing areas. Data are presented as mean ± 1 standard error (SE) unless otherwise stated.

The TACC for greenlip in this fishery was increased from 207 t to 227.7 t from 1 January 2006. As this report only includes data to 31 December 2005 it does not provide any information to assess the impact on the greenlip stocks of the increase in the TACC.

2.1 Catch

The catch of greenlip from Region A in 1968 was the highest in the history of the fishery (991 t; Figure 2.1). Annual catch declined significantly over the next 6 years, with 203 t harvested in 1974 (Linear Regression (LR): $r^2 = 0.76$, df = 5, $p < 0.05$). Between 1975 and 1984, catches fluctuated between 239 t (1975) and 463 t (1982). Following the implementation of TACC in 1985, catches have generally been stable, with the TACC remaining unchanged from 1989 to 2005 at 207 $t.yr^{-1}$.

The proportion of the greenlip catch that has been harvested from fishing areas 9 and 18, combined, increased significantly from 23.7% in 1979 to 60.8% in 1999 (LR: $r^2 = 0.81$, df = 19, $p < 0.01$). Over the last five years an average of 29.9% and 22.4% of the catch was obtained from fishing areas 9 and 18, respectively (Table 2.1c; Figure 2.2). This represents almost a doubling in the proportion of the catch obtained from these two areas (14.5 and 13.3%, respectively) since the five-year period from 1981 to 1985.

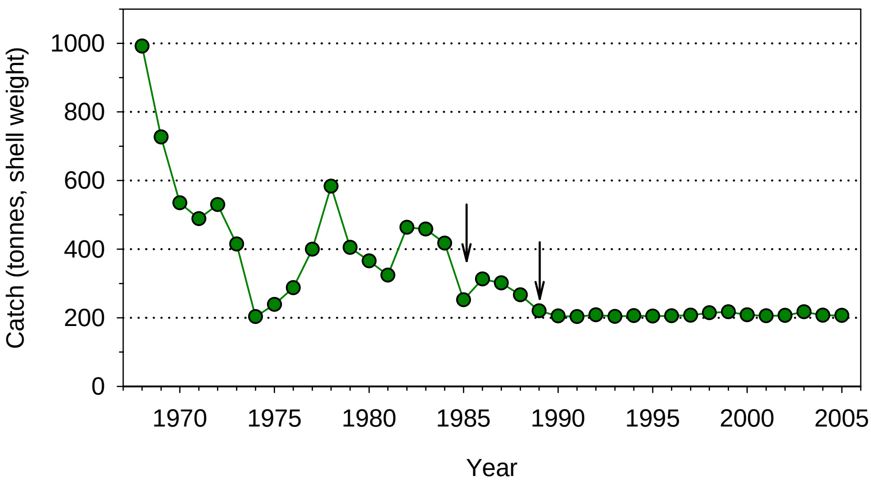

Figure 2.1 Total catch (t, shell weight) of greenlip in Region A from 1968 to 2005. ↓ indicate the implementation (1985) and amendment (1989) of TACCs. Dotted lines are for reference.

Since 1980, the number of fishing areas utilised to obtain >60% of the catch has declined from six (1981 – 1985) to four (1991 – 1995) to three (2001 – 2005; Table 2.1a-c; Figure 2.2). Since 2001, >90% TACC has been harvested from just eight of the available fishing areas (Table 2.1c).

Similar patterns were also apparent when the spatial distribution of the catch was examined at a finer temporal scale. Prior to the imposition of TACC (1985), the greenlip abalone catch was more evenly spread among the available fishing areas (Figure 2.2). Since 1985 an increasing proportion of the catch has been harvested from two fishing areas (9 and 18), with typically less than ~5% of the TACC being harvested from the majority of the remaining 16 fishing areas (Figure 2.2).

Levels of catch have fluctuated inter-annually within each fishing area (Figure 2.3a, b). Between 1979 and the mid 1980s, catches of greenlip abalone generally increased in each fishing area. The exceptions were fishing areas 8 and 20, within which catches fluctuated inter-annually during this period, and fishing area 7, within which catches declined from >15 t in 1979 to <2 t in 1984. Since the minimum legal length was increased from 130 to 145 mm SL (1984) and TACC imposed (1985), the catch of greenlip abalone has increased in fishing area 9 (from 29 to >60 $t.yr^{-1}$), with catches within the last five years in excess of 60 $t.yr^{-1}$ among the highest since 1979. Over the same time period, the catch of greenlip has declined (fishing areas 3, 4, 5, 6, 8, 11, 12, 13, 14, 15, 16 and 19), fluctuated among years with no indication of a long-term trend (fishing areas 7, 10, 17 and 18), or increased (fishing area 20).

In some areas the declines in catch since 1985 are substantial, to the extent that current catches from these areas are among the lowest on record (*e.g.* fishing areas 6, 7, 11, 12, 13, 15, 16 and 17). For example, catch of greenlip declined from ~25 to ~15 $t.yr^{-1}$ in fishing area 4, from >10 to <2 $t.yr^{-1}$ in fishing area 6, from >30 to <15 $t.yr^{-1}$ in fishing area 8, from ~5 to <1 $t.yr^{-1}$ in fishing area 11, from >15 to <5 $t.yr^{-1}$ in fishing area 13, from >10 to <5 $t.yr^{-1}$ in fishing area 16 and from >20 to ~10 $t.yr^{-1}$ in fishing area 19 (Figure 2.3a, b).

More recently, catches from fishing areas 6, 9 and 17 have declined substantially. In fishing area 6, catch has declined by ~75% from 6.7 t in 2000 to 1.6 t in 2005, while the reduction in fishing area 9 was from 70.1 t (2000) to 60.5 t (2005), a decrease of 14%. Catch in fishing area 17 has declined from >4 t prior to 2000 to an average of <1 $t.yr^{-1}$ for the last 5 years. Over the same period of time, catch from fishing area 14 has more than doubled, from 8 t in 2001 to 20.6 t in 2005.

Two hypotheses have been proposed to explain the observed changes in the spatial and temporal distribution of greenlip catch, and, in particular, the declines in the level of catch from several, previously important fishing areas. The first suggests that these areas currently support few greenlip (Shepherd & Rodda 2001). The second suggests that diver behaviour has altered in response to factors other than changes in greenlip abundance. The abundance of greenlip in these areas is unknown, and the collection of data to address the dichotomy between these hypotheses is central to addressing the status of the greenlip stocks in Region A.

2.2 Catch-per-unit-effort (CPUE)

The CPUE on greenlip was defined as greenlip abalone catch (kg) / total effort (hours) computed from only those daily records where the greenlip catch was greater than or equal to 50% of the total catch. This was justified for three reasons: (1) few fishing records between 1979 and 2005 report a blacklip abalone catch of zero; (2) only between 12 and 26% of the greenlip catch in Region A is obtained on fishing days when no blacklip are harvested and; (3) using daily records where the greenlip catch is less than 50% of the total catch is inappropriate as greenlip abalone were probably not being targeted on those days.

The mean CPUE on greenlip, in all fishing areas of Region A combined, declined significantly from 58.1 ± 0.8 $kg.hr^{-1}$ in 1979 to 48.5± 0.8 $kg.hr^{-1}$ in 1988 (LR: $r^2 = 0.59$, df = 8, $p < 0.01$; Figure 2.4). Between 1988 and 1989, CPUE increased by ~15% to 56.4 ± 1.2 $kg.hr^{-1}$. From 1989 to 1996 the CPUE varied minimally among years, ranging between 54.7± 0.9 (1996) and 57.8 ± 1.0 $kg.hr^{-1}$ (1994). Since 1996 the CPUE has increased significantly (LR: $r^2 = 0.95$, df = 8, $p < 0.01$). The CPUE in 2005, 79.0 ± 1.3 $kg.hr^{-1}$, was the highest since 1979.

Similar temporal patterns were observed in fishing areas 5, 9, 18 and 19 and, generally, in fishing areas 4, 8 and 14, all of which combined account for ~90% of the TACC over the last five years (2001 – 2005). The CPUE in all these areas has generally been increasing since 1996; the CPUE in fishing areas 5 (70.1 ± 3.7 $kg.hr^{-1}$), 9 (81.9 ± 2.5 $kg.hr^{-1}$), 18 (80.1 ± 1.9 $kg.hr^{-1}$) and 19 (84.5 ± 4.5 $kg.hr^{-1}$) during 2005 was at the highest recorded level for these fishing areas since 1980. Notably, the CPUE declined in fishing area 4 between 2003 and 2005, and in fishing areas 8 and 14 between 2004 and 2005. Nevertheless, it remained amongst the highest levels recorded since 1979 (Figure 2.4).

Table 2.1a Average catch (t, shell weight) of greenlip, percent of annual catch and cumulative percent of average annual catch for the top 15 fishing areas (by catch) for the period 1981-1985.

Fishing Area	Average catch (t)	% of annual catch	Cumulative %
9	62.6	14.5	14.5
18	50.3	13.3	27.8
15	49.1	9.9	37.7
8	40.8	8.7	46.4
14	39.6	8.6	54.9
13	32.3	7.7	62.6
4	23.7	6.9	69.5
12	22.5	5.5	75.0
5	22.3	8.5	83.4
19	16.6	4.5	88.0
16	15.7	4.3	92.3
6	8.5	2.5	94.8
11	7.7	1.8	96.7
17	4.7	1.2	97.9
7	4.6	0.7	98.6

Table 2.1b Average catch (t, shell weight) of greenlip, percent of annual catch and cumulative percent of average annual catch for the top 15 fishing areas (by catch) for the period 1991-1995.

Fishing Area	Average catch (t)	% of annual catch	Cumulative %
18	48.6	23.7	23.7
9	45.1	22.0	45.7
8	18.2	8.9	54.6
19	15.9	7.8	62.3
14	13.3	6.5	68.8
5	12.5	6.1	74.9
4	11.8	5.8	80.7
6	7.3	3.5	84.2
15	6.3	3.1	87.2
16	5.7	2.8	90.0
13	5.6	2.7	92.7
17	4.8	2.3	95.1
3	3.9	1.9	97.0
12	2.4	1.2	98.1
11	2.0	1.0	99.1

Table 2.1c Average catch (t, shell weight) of greenlip, percent of annual catch and cumulative percent of average annual catch for the top 15 fishing areas (by catch) for the period 2001-2005.

Fishing Area	Average catch (t)	% of annual catch	Cumulative %
9	62.4	29.9	29.9
18	46.7	22.4	52.3
8	24.4	11.7	64.0
5	13.0	6.3	70.3
14	12.8	6.1	76.4
19	12.7	6.1	82.5
4	12.1	5.8	88.3
15	5.6	2.7	91.0
13	3.8	1.8	92.8
16	3.1	1.5	94.3
6	3.1	1.5	95.8
12	3.0	1.4	97.2
7	2.2	1.1	98.3
3	1.3	0.6	98.9
11	1.0	0.5	99.4

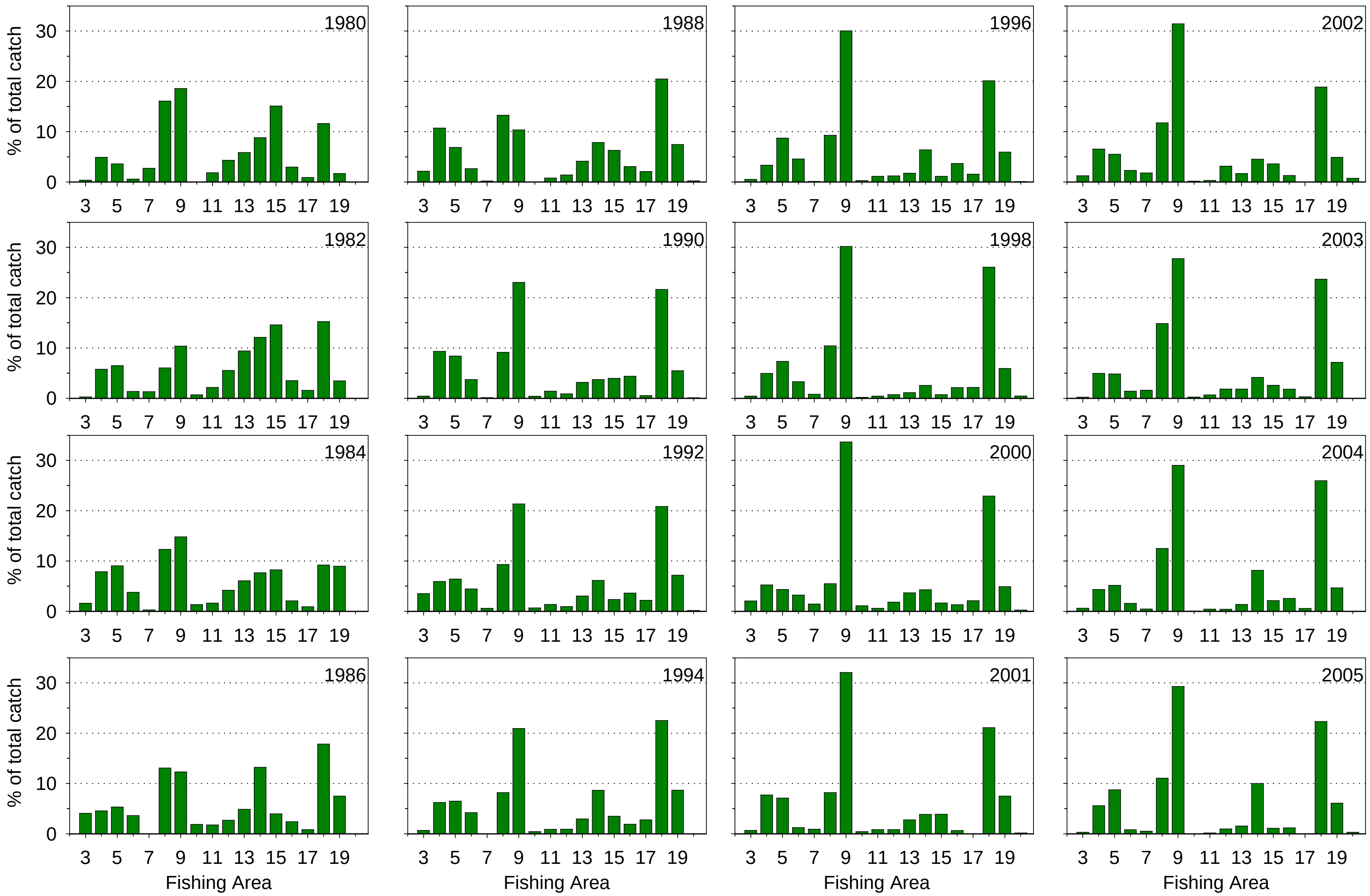

Figure 2.2 Spatial distribution of the greenlip catch (% of total catch) among each of the fishing areas in Region A of the Western Zone in alternate years from 1980 until 2000 and annually to 2005.

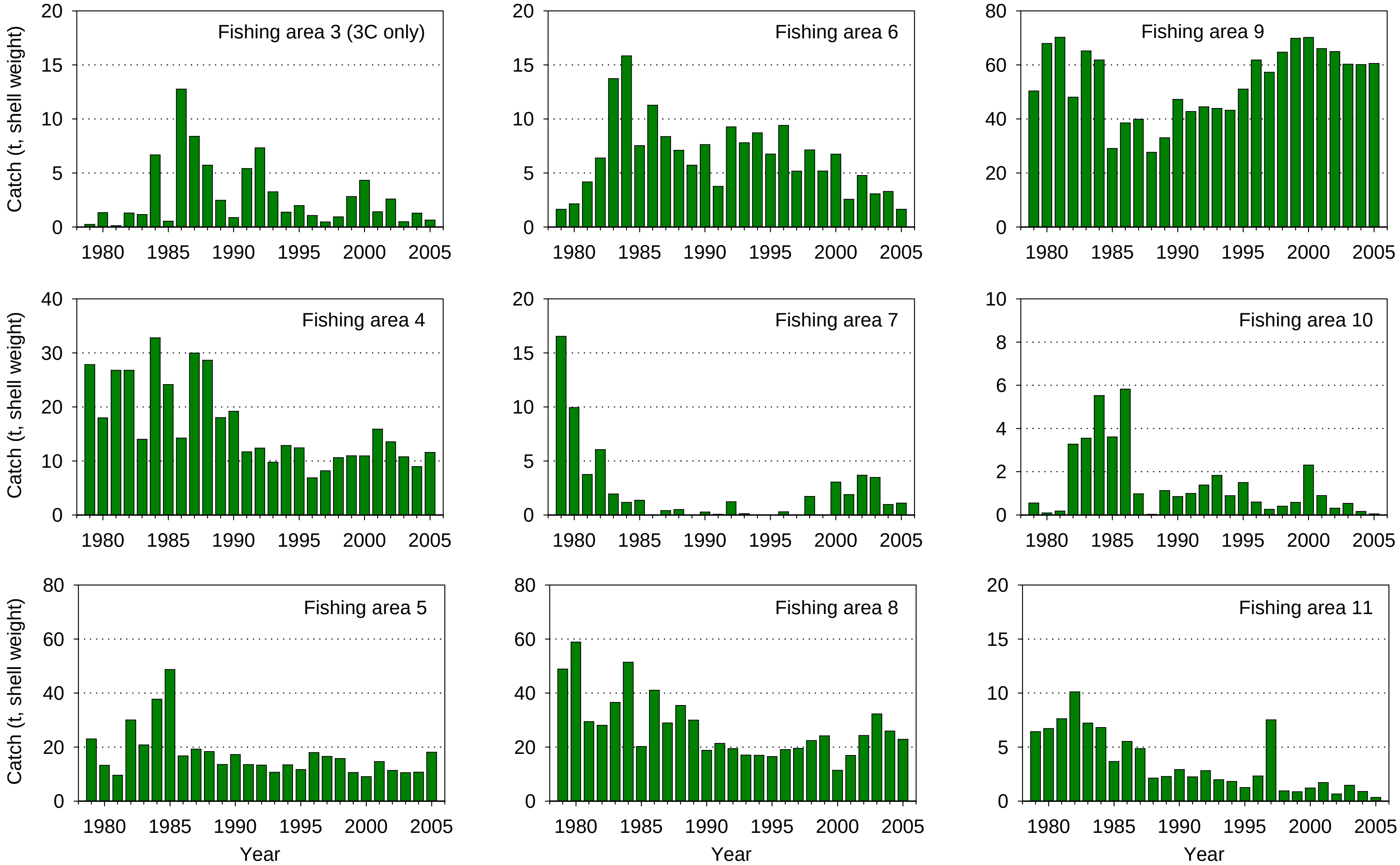

Figure 2.3a Catch of greenlip (t, shell weight) in each of the fishing areas comprising Region A of the Western Zone from 1979 to 2005.

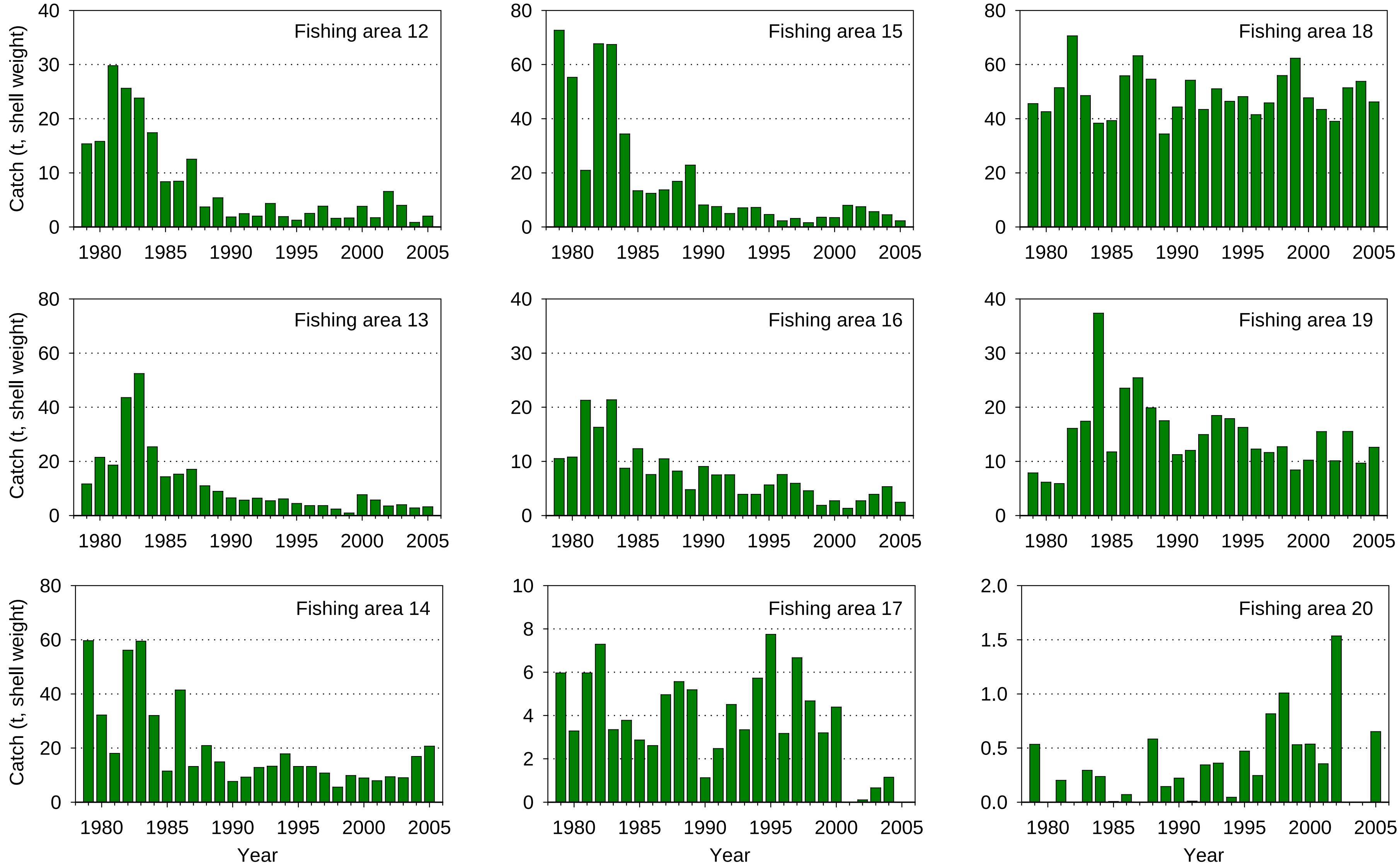

Figure 2.3b Catch of greenlip (t, shell weight) in each of the fishing areas comprising Region A of the Western Zone from 1979 to 2005.

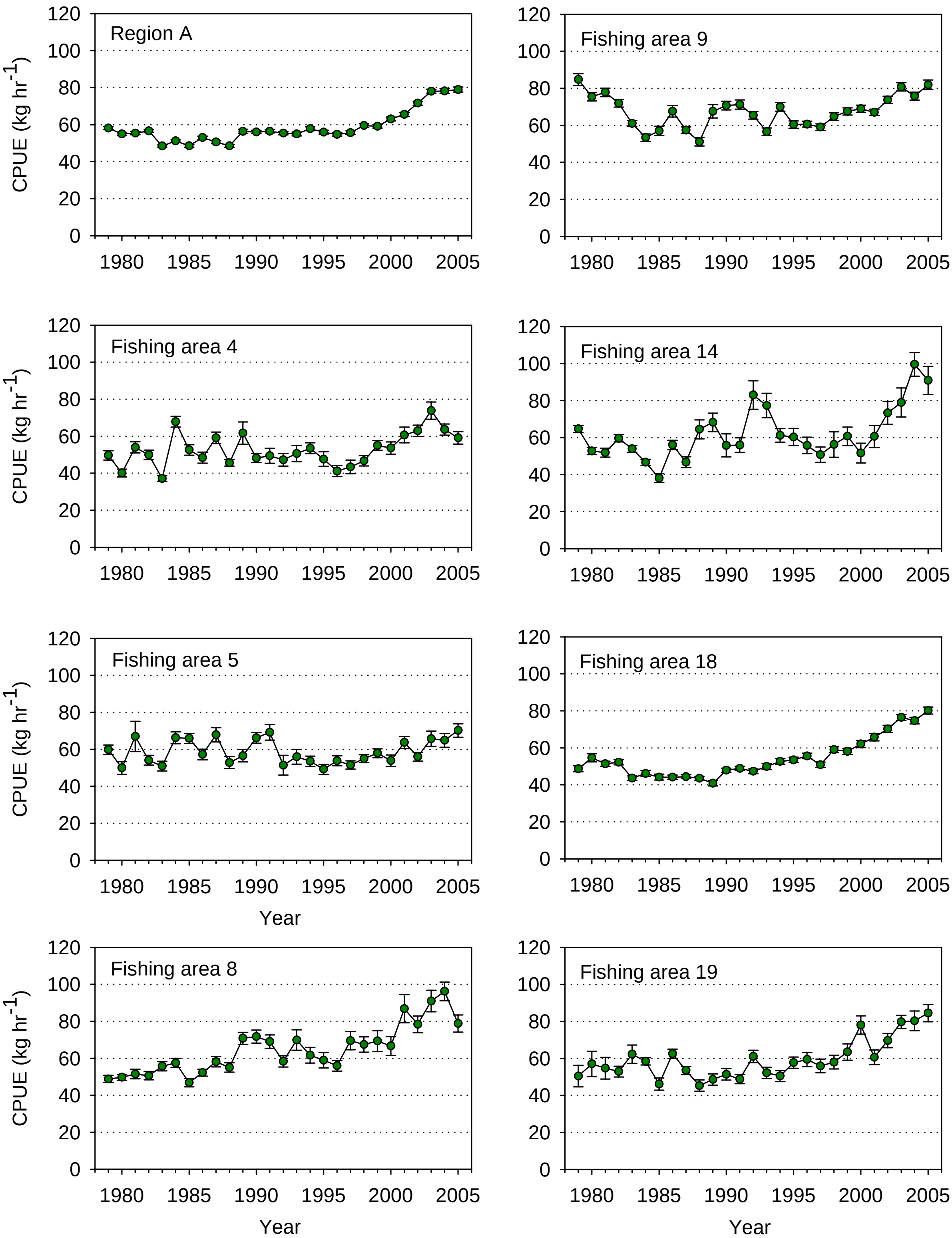

Figure 2.4 Mean catch-per-unit-effort (CPUE (kg.hr^{-1}) (± SE) on greenlip for all fishing areas of Region A combined, and for fishing areas 4, 5, 8, 9, 14, 18 and 19 from 1979 to 2005.

2.3 Standardised CPUE

To account for changes in effective fishing effort (*i.e.* technological advancement, diver behaviour and diver efficiency), historical catch and effort data were standardised (Mayfield *et al.* 2003, Mayfield *et al.* 2004) by year (from 1978 to 2005), using information from licence holders on their fishing practices using a generalised linear model (GLM) of the form

$$\text{Ln}(\text{catch}_g) = \mu + \beta_0(\text{season}) + \beta_1(\text{map}) + \beta_2(\text{month}) + \beta_3(\text{licence,c-diver}) + \beta_4\ln(\text{effort}) + \beta_5\ln(\text{catch}_b) + \beta_6(\text{licence,UWV}) + \beta_7(\text{licence,GPS}) + \beta_8(\text{licence,ECHO}) + \beta_9(\text{licence,HWS}) + \varepsilon$$

where

β_0(season) captures the relative abundance of greenlip abalone in the different fishing seasons;

β_1(map) captures the relative differences in abundance of greenlip abalone in the different fishing areas comprising Region A;

β_2(month) is the relative monthly change in fishing efficiency arising from changes in seasonally varying factors, such as swell and underwater visibility;

β_3(licence,c-diver) captures the differing fishing efficiency of individual divers employed by each licence;

$\beta_4\ln$(effort) captures the effect of fishing effort in that a 1% change in fishing effort gives approximately a β_4% change in the greenlip abalone catch;

$\beta_5\ln(\text{catch}_b)$ captures the effect of targeting greenlip abalone in that a 1% change in blacklip abalone catch gives approximately β_5% change in the greenlip abalone catch;

β_6(licence,UWV) captures the effect from the use of an under-water vehicle (cage) for each licence in the fishery;

β_7(licence,GPS) captures the effect of use of a GPS for each licence in the fishery;

β_8(licence,ECHO) captures the effect of use of an echo sounder for each licence in the fishery;

β_9(licence,HWS) captures the effect of use of a hot-water suit for each licence in the fishery; and ε is the error term (assumed to be normally distributed with a mean of zero and a constant variance).

For all fishing areas of Region A combined, the temporal patterns of both standardised and raw (observed) CPUE were similar (Figure 2.5). Both measures (1) declined between 1979 and 1988; (2) increased substantially between 1988 and 1990; (3) decreased slightly from 1990 to 1996; (4) increased significantly between 1996 and 2005 (LR: $r^2 = 0.95$, df = 8, $p < 0.01$ and LR: $r^2 = 0.87$, df = 8, $p < 0.01$, respectively).

The temporal patterns in raw and standardised CPUE were also similar in fishing areas 9 and 18 (Figure 2.5). In both areas, the CPUE generally declined between 1979 and the late 1980s, before increasing substantially thereafter. The standardised CPUE increased significantly in both areas between 1996 and 2005 (LR: $r^2 = 0.87$, df = 8, $p < 0.01$ and LR: $r^2 = 0.90$, df = 8, $p < 0.01$, respectively).

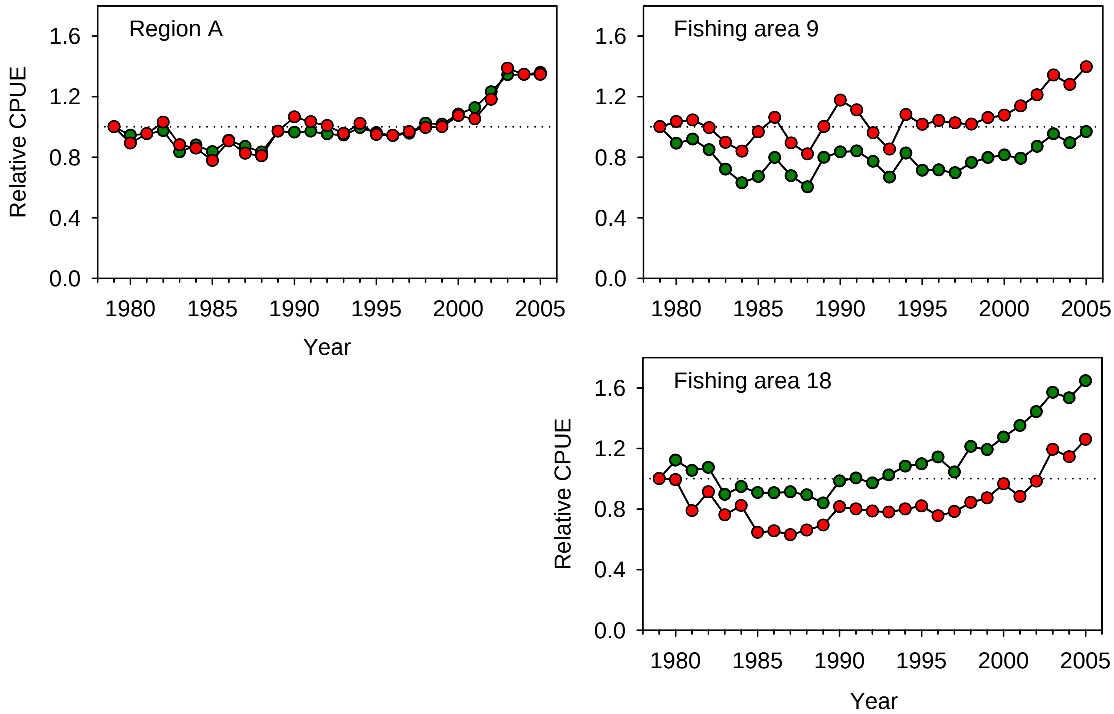

Figure 2.5 Relative (to that in 1979) raw (green) and standardised (red) CPUE on greenlip in all the fishing areas of Region A combined, and in fishing areas 9 and 18 separately.

2.4 Length-frequency distribution of the catch

Estimates of individual lengths of abalone in the commercial greenlip catch have been obtained from shell samples since 1979. During that year, 10 753 shells (≥ 120 mm) were sampled. More recent sample sizes, especially those obtained since 1982 have been considerably smaller, ranging between 512 (1999) and 6 261 (2004) shells.

In all years for which data are available, both the modal length class and the mean length of the commercial catch in Region A were substantially greater than the MLL (130 mm SL prior to 1984, 145 mm SL from 1984 to 2005; Figure 2.6). In each year, the frequency distribution was generally normal, although slightly left skewed as large (>180 mm SL) greenlip comprised a substantial proportion of the samples (range: 3 - 31%).

Approximately 20% of the greenlip measured from Region A during 2000 were smaller than 155 mm SL. The modal length class was 160 – 164 mm SL, and the mean length 163.8 ± 0.3 mm SL (Figure 2.6). In the following years, to 2004, the proportion of shells <155 mm SL has been less than in 2000 and the modal length class at or above 160 - 164 mm SL for each year (Figure 2.6). In 2005, 17% of the greenlip measured from

Region A were smaller than 155 mm SL, an increase of 5% from 2004. The modal length class was 160 - 164 mm SL, and the mean length 166.3 ± 0.2 mm SL.

During 2005, the mean length of the commercial catch exceeded 170 mm SL in fishing area 6 only (178.1 ± 2.6 mm SL), and the low sample size (n = 31) does not provide a high level of confidence in the representivity of this sample. The mean length was greater than the 2005 Regional average (166.3± 0.2 mm SL) in 4 (fishing areas 6, 9, 18 and 19) of the 12 fishing areas where more than 30 individuals were sampled (Figure 2.7). In these 4 areas mean length ranged ~22 mm SL between 156.2 ± 0.8 mm SL (fishing area 12) and 178.1 ± 2.6 mm SL (fishing area 6). In each of the fishing areas (5, 6, 8, 9, 11, 12, 13, 15, 18 and 19) the mean length exceeded the MLL (145 mm SL) by >10 mm SL. The modal length class in each area was >5 mm greater than the MLL and ranged from 150 - 154 mm SL (fishing areas 8 and 12) to 170 – 174 mm SL (fishing areas 6, 18 and 19).

Cumulatively ~52% of the greenlip TACC was harvested from fishing areas 9 and 18 during 2005 (see section 2.1). In fishing area 9, the modal length classes has remained unchanged since 2002 (160 – 164 mm SL; Figure 2.8). However, the mean length has increased from 165.2 ± 0.7 mm SL (2000) to 169.1 ± 0.3 mm SL (2005). Both the modal length class and mean length have increased in fishing area 18 since 2000: from 155 – 159 mm SL (2000) to 170 - 174 mm SL (2005) and 160.8 ± 0.6 mm SL (2000) to 167.2 ± 0.3 mm SL (2005).

There was no evidence of 'knife-edge' fishing (individuals having a high probability of capture as they attain the MLL) on greenlip in Region A during 2005.

2.5 Estimates of egg production

A simple egg-production model, based on the (Beverton & Holt 1957) yield-per-recruit model (after King 1995) that considers the dependence of egg production on growth, age at first capture and fishing mortality (F), was used to estimate the proportion of pristine egg production conserved under the current management arrangements for greenlip in fishing areas 9 and 18. 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 pristine egg production conserved in fishing areas 9 and 18 in 2005 were 27.8% and 46.5%, respectively. These figures represent a reduction of pristine egg production from that estimated in 2004 (Mayfield *et al.* 2005b) of 14% and 24%, respectively.

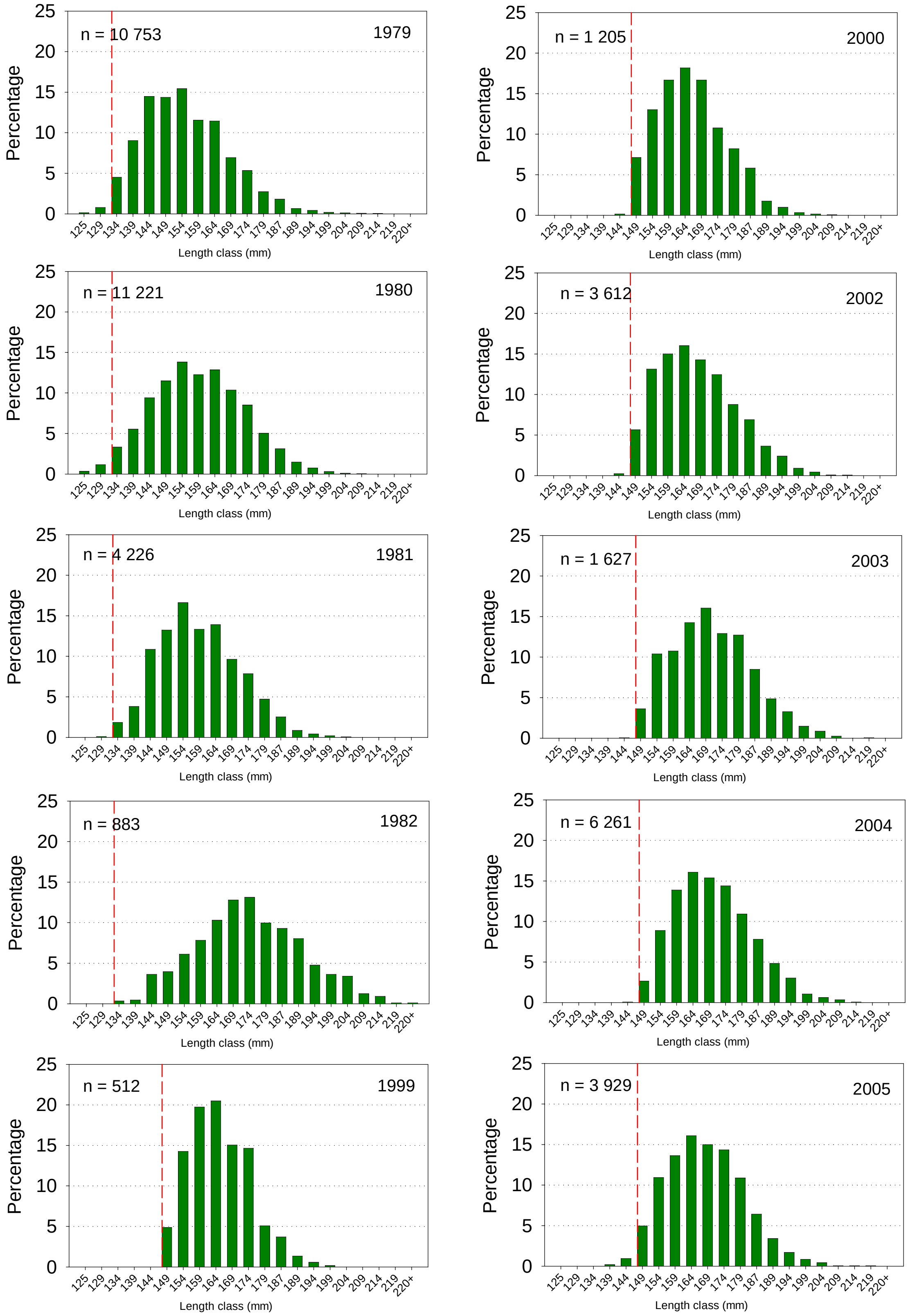

Figure 2.6 Length-frequency distribution obtained from measuring greenlip shells from the commercial fishery from Region A during the years 1979-1982, 1999, 2000 and 2002-2005. Vertical red line indicates MLL (130 mm SL (<1984) and 145 mm SL (≥1984)).

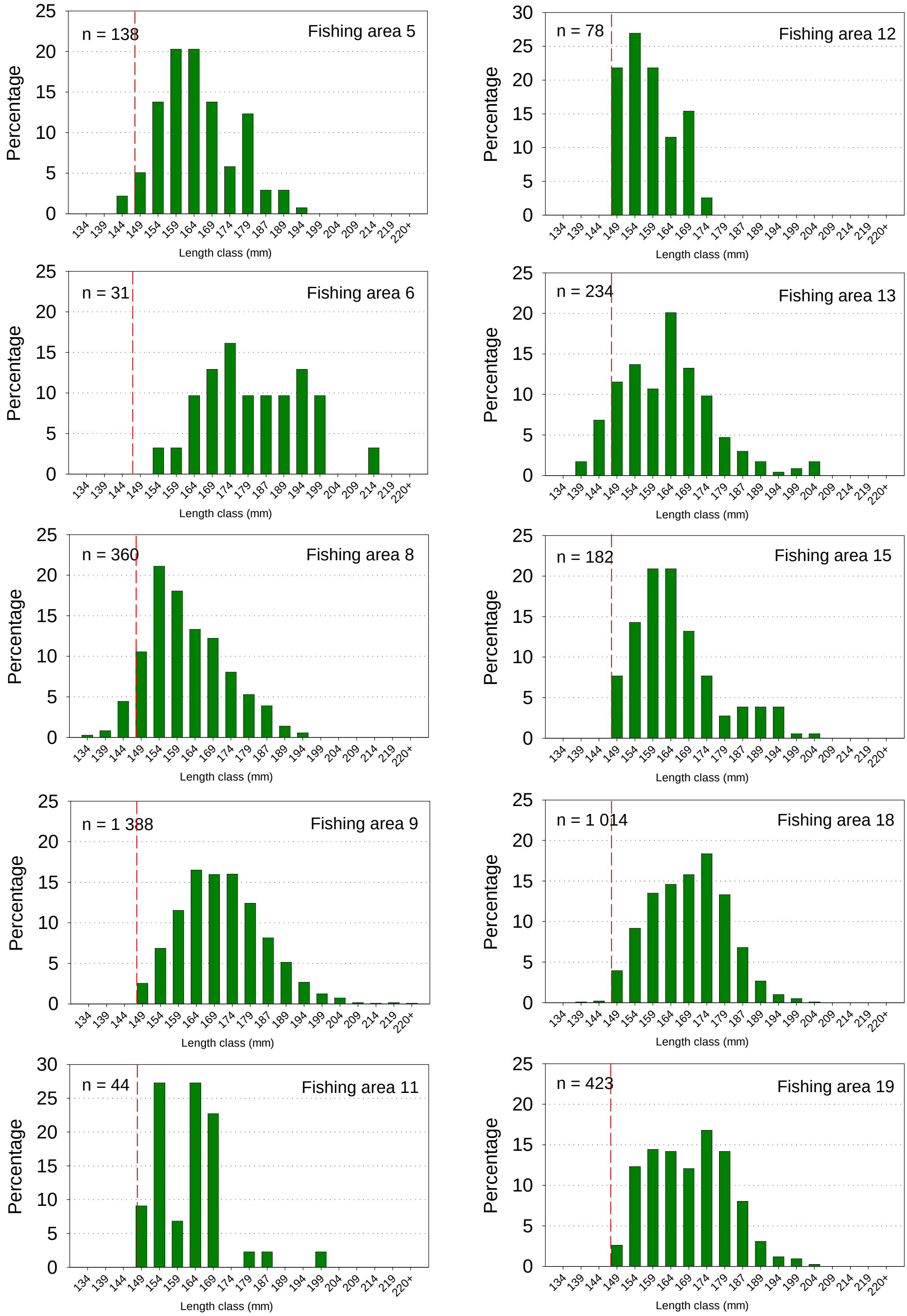

Figure 2.7 Length-frequency distribution obtained from measuring greenlip shells from the commercial fishery in fishing areas 5, 6, 8, 9, 11, 12, 13, 15, 18 and 19 during 2005. Vertical red line indicates MLL (145 mm SL).

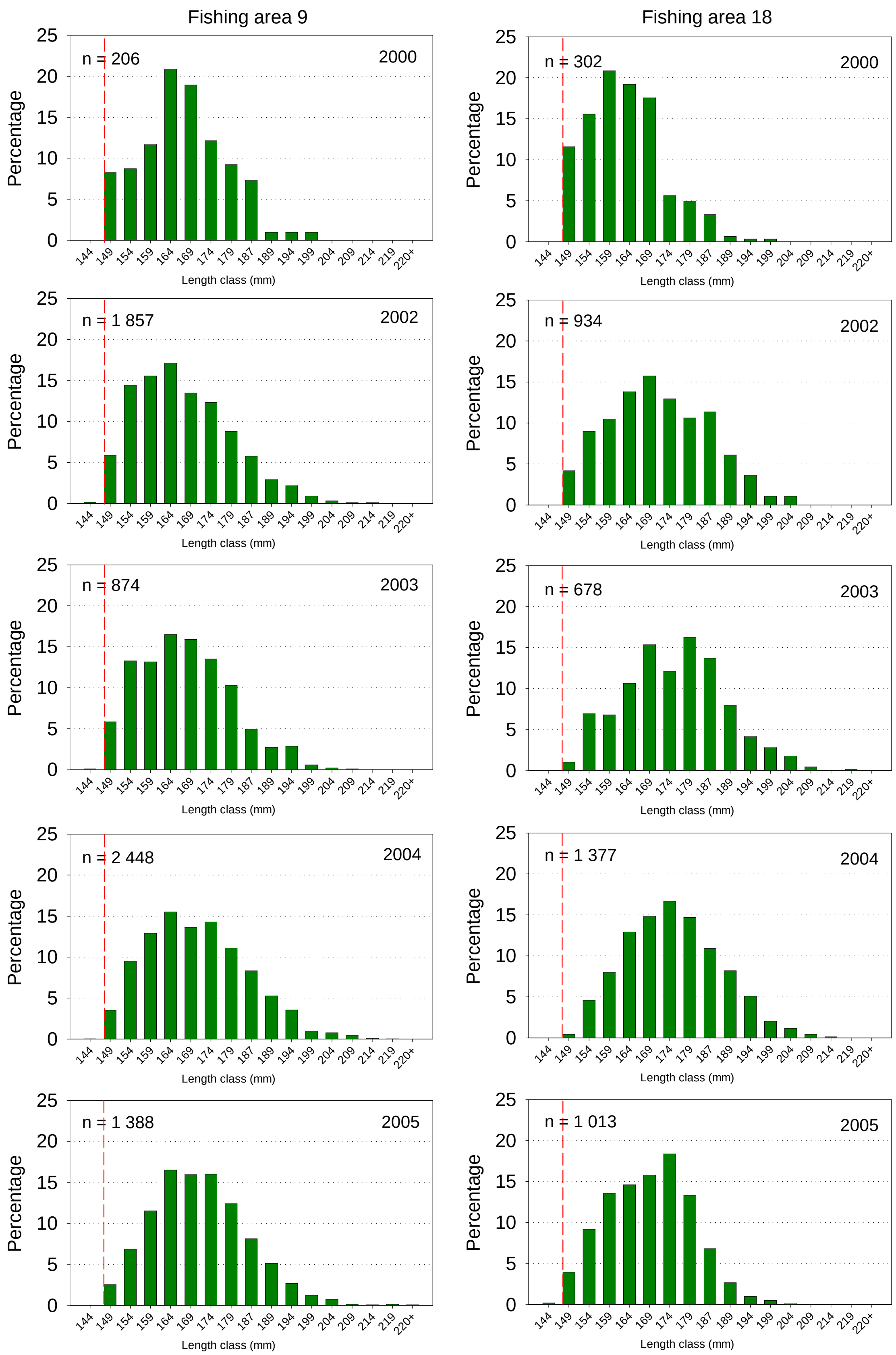

Figure 2.8 Length-frequency distribution obtained from measuring greenlip shells from the commercial fishery in fishing areas 9 and 18 during 2000 and 2002 to 2005. Vertical red line indicates MLL (145 mm SL).

2.6 Fishery-independent abalone surveys

Fishery-independent abalone surveys (FIAS) in South Australia undertaken by SARDI Aquatic Sciences (and the former Department of Fisheries) have monitored changes in greenlip abundance and population structure at six sites in Region A.

Surveys commenced at the six sites in 1980 (Ward Island), 1981 (Hotspot), 1987 (Avoid Bay), 1989 (The Gap), 1990 (Pearson Island) and 1996 (Flinders Island). These long-term data sets provide information on changes in the relative abundance and size structure of greenlip populations through time and are particularly valuable given that methodological changes have been minimal.

At each site, up to 16 replicate surveys are carried out. In general, each replicate consists of two divers each doing two 10-minute surveys. During each 10-minute survey, all emergent greenlip observed are measured. This provided an estimate of abalone density and population length structure. To calculate the relative abalone density (abundance) two assumptions are made: (1) it takes 4 seconds to measure each abalone, and (2) 20 metres is covered in 1 minute. The total time taken to measure all the abalone observed in each 10-minute count is subtracted from 10 minutes and the distance swum calculated using assumption 2. This distance is then used in the density estimation. These estimates of density are used to assess relative changes in abalone abundance and length-frequency data are used to assess changes in population structure.

Alternative methods for estimating abalone abundance have been tested periodically. For example, during April and October 1998, fixed site two-by-10-minute surveys were replaced by random site, one-by-10-minute surveys. These were not substantially dissimilar from the long-term surveys so the data obtained have not been excluded from the analyses presented.

SARDI Aquatic Sciences has recently completed a FRDC-funded research project to develop and field-test survey methods for greenlip in South Australia (FRDC 2001/076; McGarvey in press). This study concluded that leaded-line transects deployed at evenly-distributed (systematic) locations, within a bounded study region provided the most tractable method to estimate the absolute abundance of greenlip. This survey design proved robust in that the difference in the number of abalone between surveys closely matched the number of abalone removed by commercial fishers undertaking directed 'fish-down' harvesting within pre-defined study regions. Surveys using this approach were implemented in Anxious Bay in 2004 and at Flinders Bay in 2005. Results from these alternative fishery-independent survey methods will be presented in subsequent years.

2.6.1 Changes in abundance of greenlip abalone

In 2005 greenlip abundance ranged from 0.37 ± 0.03 abalone.m^{-2} at Hotspot to 0.13 ± 0.01 abalone.m^{-2} at Pearson Island. At the remaining sites abundance ranged between 0.22 ± 0.03 ('The Gap') and 0.26 ± 0.03 abalone.m^{-2} (Ward Island). Between 2004 and 2005 greenlip abundance increased at Ward Island and declined at Flinders Island, Hotspot, Pearson Island and 'The Gap'. Sites at Point Avoid were not sampled in 2005.

Ward Island (Fishing area 9)

From 1980 to 1984 mean abundance of greenlip at Ward Island fluctuated among years (Figure 2.9). Since 1985, abundance has declined significantly (LR: $r^2 = 0.37$, df = 17, $p < 0.01$) and, in 2005, was 50% of that observed in 1985. The decline in overall abundance from 1989 to 2005 is a result of a significant decrease in the mean abundance of sub-legal-sized greenlip (LR: $r^2 = 0.36$, df = 13, $p < 0.05$). Mean abundance of legal-sized greenlip has fluctuated among years with no apparent long-term trend. In 2005 abundance of legal-size greenlip was 0.17 ± 0.02 abalone.m^{-2}, the highest since surveys began in 1989.

Flinders Island (Fishing area 9)

Data on the abundance of greenlip at Flinders Island are only available from 1996 (Figure 2.9). The mean abundance of all, legal-sized and sub-legal-sized greenlip has fluctuated among years with no indication of any long-term trends. For all size classes considered, the estimated abundance during 2005 was greater than that in 1996, but the lowest since 2002.

Hotspot (Fishing area 9)

Mean abundance of greenlip declined at Hotspot between 1981 and 1988, but has increased significantly since 1988 (LR: $r^2 = 0.58$, df = 13, $p < 0.01$; Figure 2.9). Abundance during the last five survey periods was between 16 and 65% greater than that observed in 1985.

The increase in abundance of all greenlip at Hotspot is the consequence of a significant increase in the abundance of legal-sized abalone at this site since surveys began (1990; LR: $r^2 = 0.72$, df = 11, $p < 0.01$). Since 1990 the abundance of sub-legal-sized greenlip at Hotspot has ranged between 0.10 ± 0.01 (1997) and 0.29 ± 0.03 abalone.m^{-2} (1998), but there was no significant evidence of any long-term trend. However, the abundance of all sizes classes has declined for the last two consecutive years.

Pearson Island (Fishing area 10)

Data on the abundance of greenlip at Pearson Island are only available from 1990 (Figure 2.10). The mean abundance of all and legal-sized greenlip has fluctuated among years with no indication of any long-term trends. Mean abundance of sub-legal-sized greenlip has declined significantly since 1990 (LR: $r^2 = 0.32$, df = 11, $p < 0.05$). Abundance of all size classes declined by >40% between 2004 and 2005 (All: 0.22 ± 0.03 to 0.13 ± 0.01; legal: 0.20 ± 0.03 to 0.12 ± 0.01; and sub-legal: 0.02 ± 0.004 to 0.01 ± 0.003).

Point Avoid (Fishing area 15)

The mean abundance of greenlip at Point Avoid has declined significantly since surveys began in 1987 (LR: $r^2 = 0.46$, df = 10, $p < 0.05$; Figure 2.10). However, abundance increased by ~50% between 2003 (0.13 ± 0.04 abalone.m^{-2}) and 2004 (0.19 ± 0.05 abalone.m^{-2}) – the highest value since 1994. Abundance of legal-sized greenlip has fluctuated among years with no significant long-term trend despite attaining the highest recorded abundance in 2004 (0.08 ± 0.02 abalone.m^{-2}). In contrast, abundance of sub-legal-sized greenlip has declined significantly (LR: $r^2 = 0.47$, df = 7, $p < 0.05$), with the abundance in 2004 (0.11 ± 0.03 abalone.m^{-2}) being ~30% of that in 1989 (0.31 ± 0.05 abalone.m^{-2}).

'The Gap' (Fishing area 18)

Mean total and sub-legal-sized abundance showed no evidence of a long-term trend from 1993 to 2005. All greenlip have declined from 2003 to 2005, driven by the substantial decline in sub-legal-sized greenlip over the same period. However, legal-sized abundance has increased significantly since 1993 (LR: $r^2 = 0.78$, df = 8, $p < 0.01$), and has exceeded that observed in 1989 during all of the last eight surveys.

2.6.2 Changes in greenlip abalone population length structure

The proportion of legal-sized greenlip observed during 2005 ranged from 48% (Flinders Island) to 92% (Pearson Island; Figure 2.11). Sub-legal-sized greenlip were less frequently encountered at Pearson Island (0.20 abalone.minute swum^{-1}) when compared to any of the other sites (range: 1.60 abalone.minute swum^{-1} (Ward Island) to 3.30 abalone.minute swum^{-1} (Hotspot)). The number of both legal and sub-legal sized abalone.minute swum^{-1} were similar at both Flinders Island and Hotspot between 2004 and 2005. At Pearson Island and 'The Gap', the number of both length classes had declined between 2004 and 2005. The only site at which the number of abalone.minute swum^{-1} increased between 2004 and 2005 was Ward Island, where the number of legal-size increased from 2.1 to 3.4 abalone.minute swum^{-1}.

Few consistent temporal patterns were evident within the sites surveyed (Figures 2.12-2.17). Most noticeable is that the proportion of sub-legal-sized greenlip has been <40% and <50% at Ward Island and 'The Gap' from 2002 and 2004, respectively, representing the lowest proportions of sub-legal sized greenlip at these sites since surveys began.

Prior to 1997, the lengths of greenlip measured were pooled into 5 mm length classes to a maximum length of 190 mm, with greenlip in excess of 190 mm pooled into the 190+ mm length class. From 1997 to 2001 this maximum length class was extended to 200+ mm, with original records unavailable for reclassification. This restriction of the maximum size class reflects some of the abrupt upper ends of the distributions at some sites (*e.g.* Pearson Island). Since 2001, all records of individual lengths are available and the maximum length class presented provides a range to fully describe the distribution of greenlip measured at all sites.

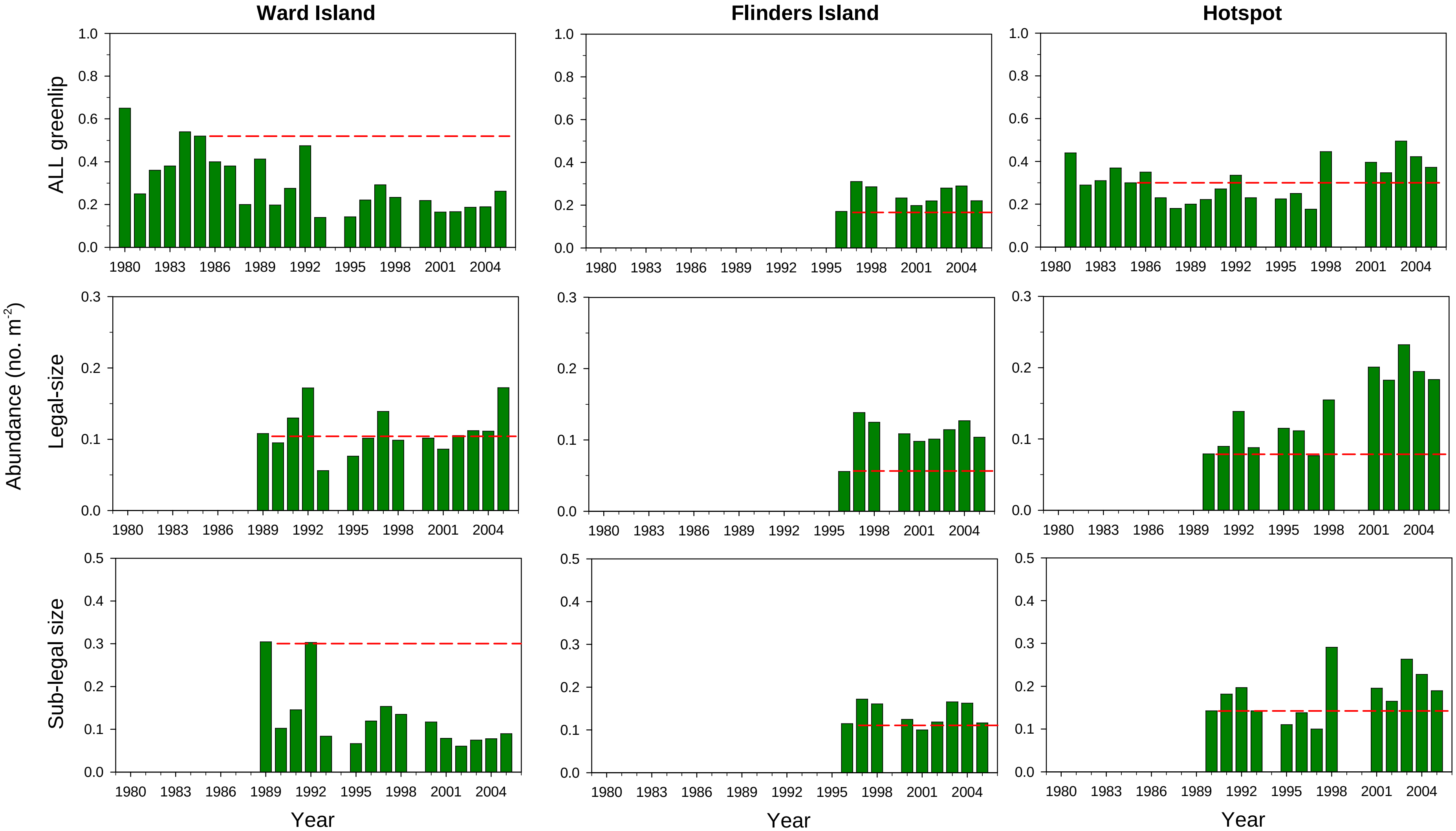

Figure 2.9 **Estimated abundance (no.m^{-2}) of all (top), legal-sized (middle) and sub-legal sized (bottom) greenlip at Ward Island, Flinders Island and Hotspot, since surveys commenced. The dashed red line indicates estimated density in 1985 (the first year of a TACC) or the first year for which there are data. Gaps in the annual estimates indicate there are no comparable data available.**

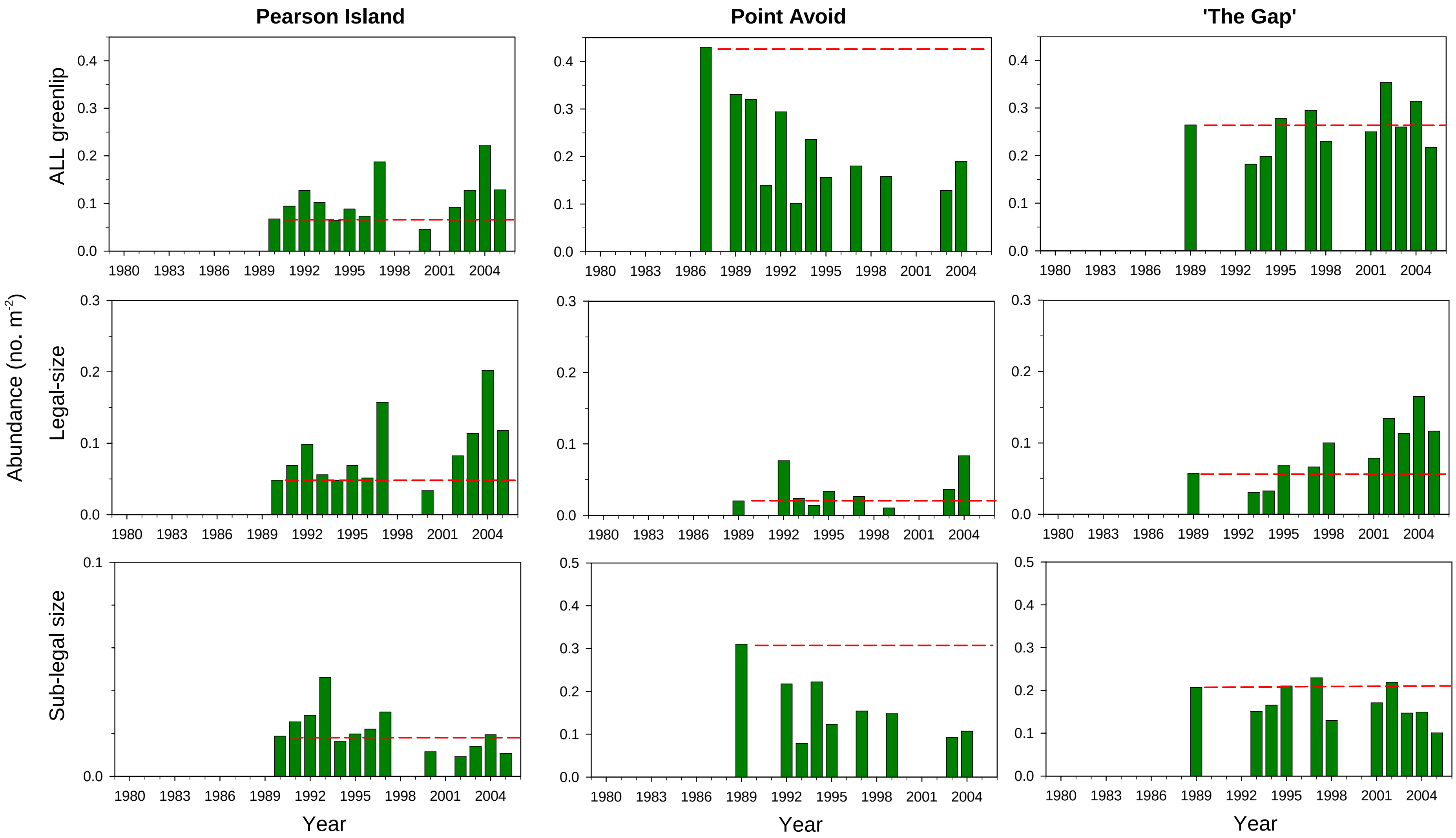

Figure 2.10 Estimated abundance (no.m^{-2}) of all (top), legal-sized (middle) and sub-legal sized (bottom) greenlip at Pearson Island, Point Avoid and 'The Gap', since surveys commenced. The dashed red line indicates estimated density in 1985 (the first year of a TACC) or the first year for which there are data. Gaps in the annual estimates indicate there are no comparable data available.

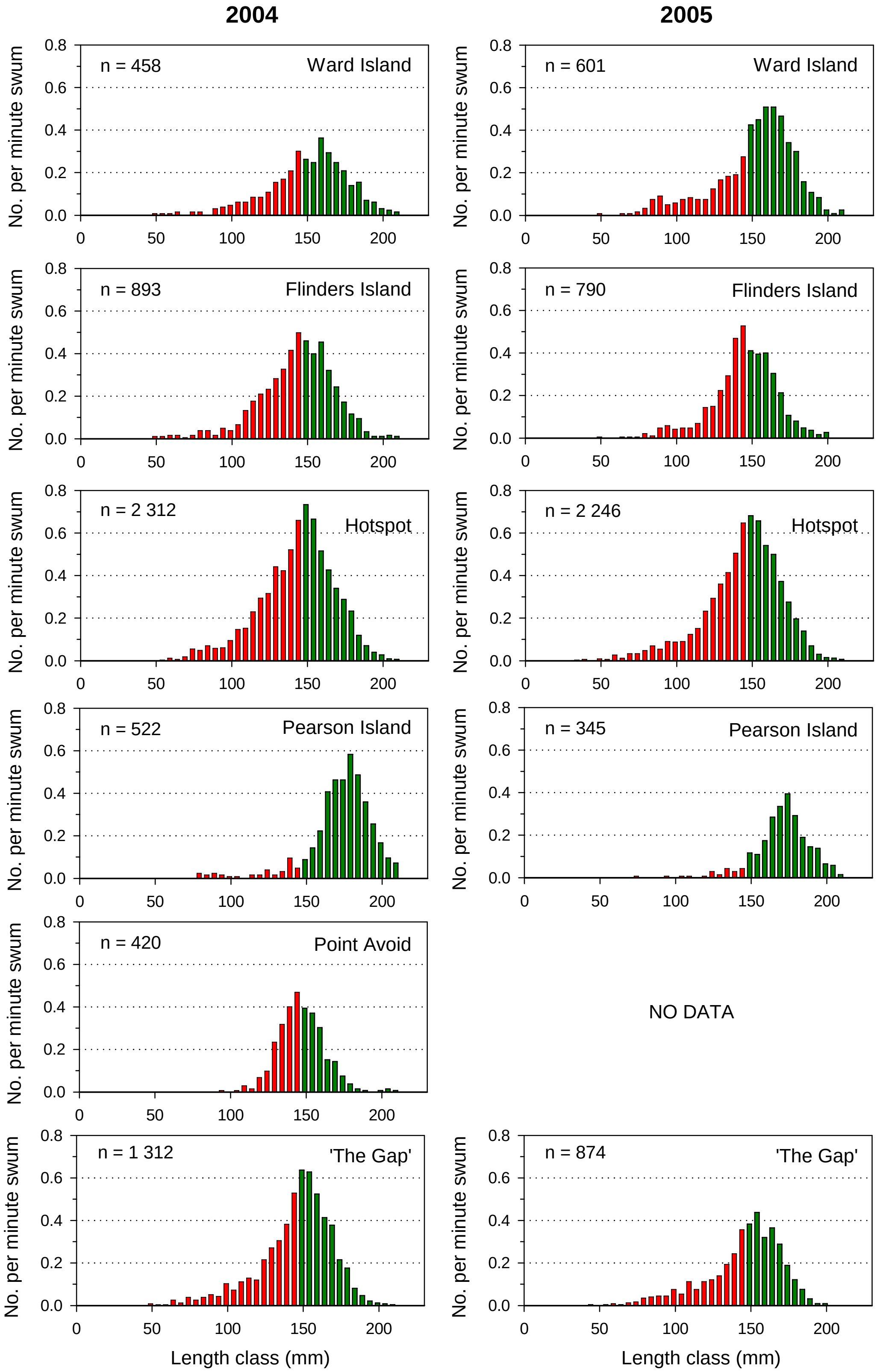

Figure 2.11 Length-frequency distribution of legal-sized (≥145 mm SL, green bars) and sub-legal-sized (<145 mm SL, red bars) greenlip surveyed per-minute-swum at Ward Island, Flinders Island, Hotspot, Pearson Island, Point Avoid and 'The Gap' during fishery-independent surveys in 2004 and 2005. Length classes are 5 mm SL.

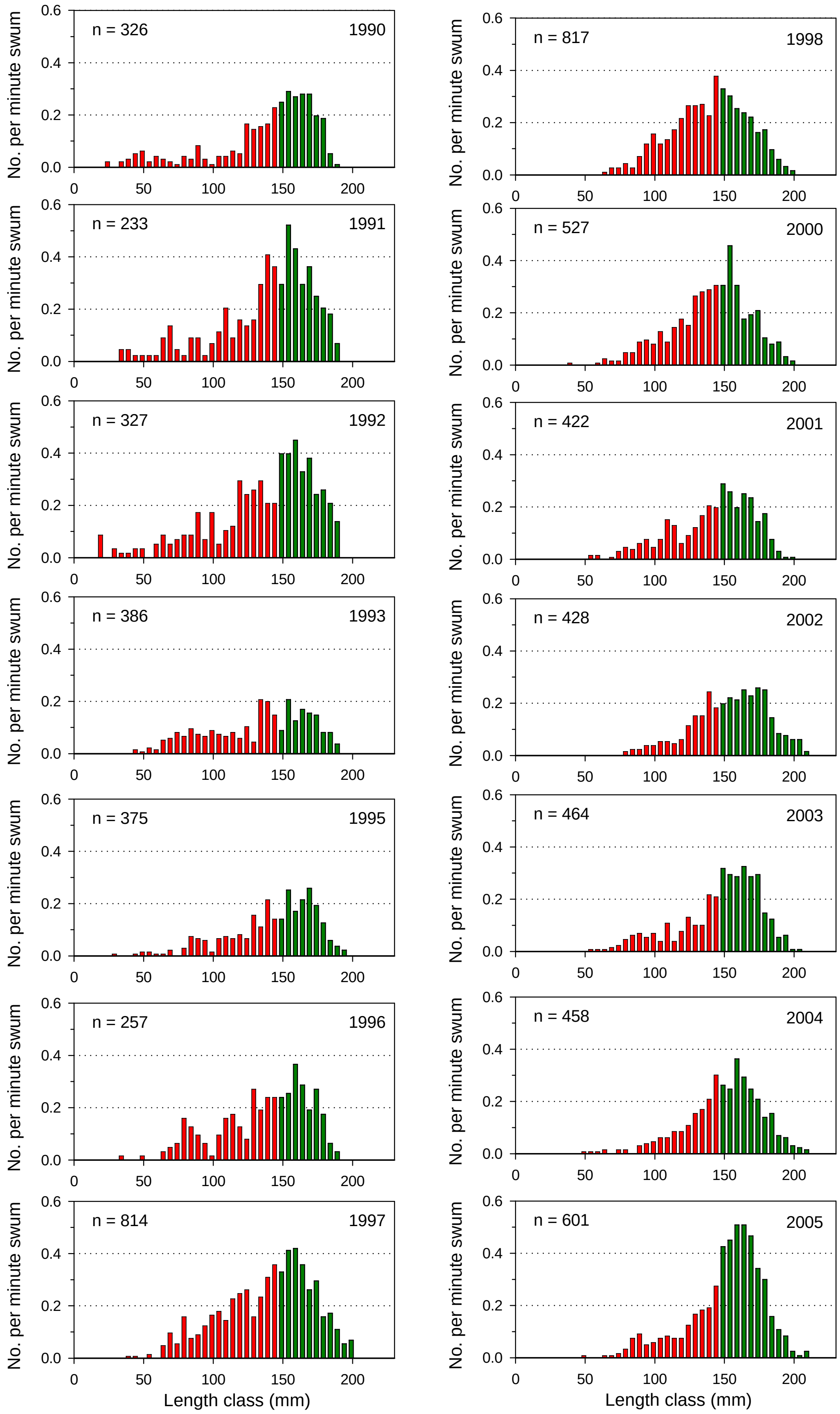

Figure 2.12 Length-frequency distribution of legal-sized (≥145 mm SL, green bars) and sub-legal-sized (<145 mm SL, red bars) greenlip surveyed per-minute-swum at Ward Island on fishery-independent surveys between 1990 and 2005. Length classes are 5 mm SL.

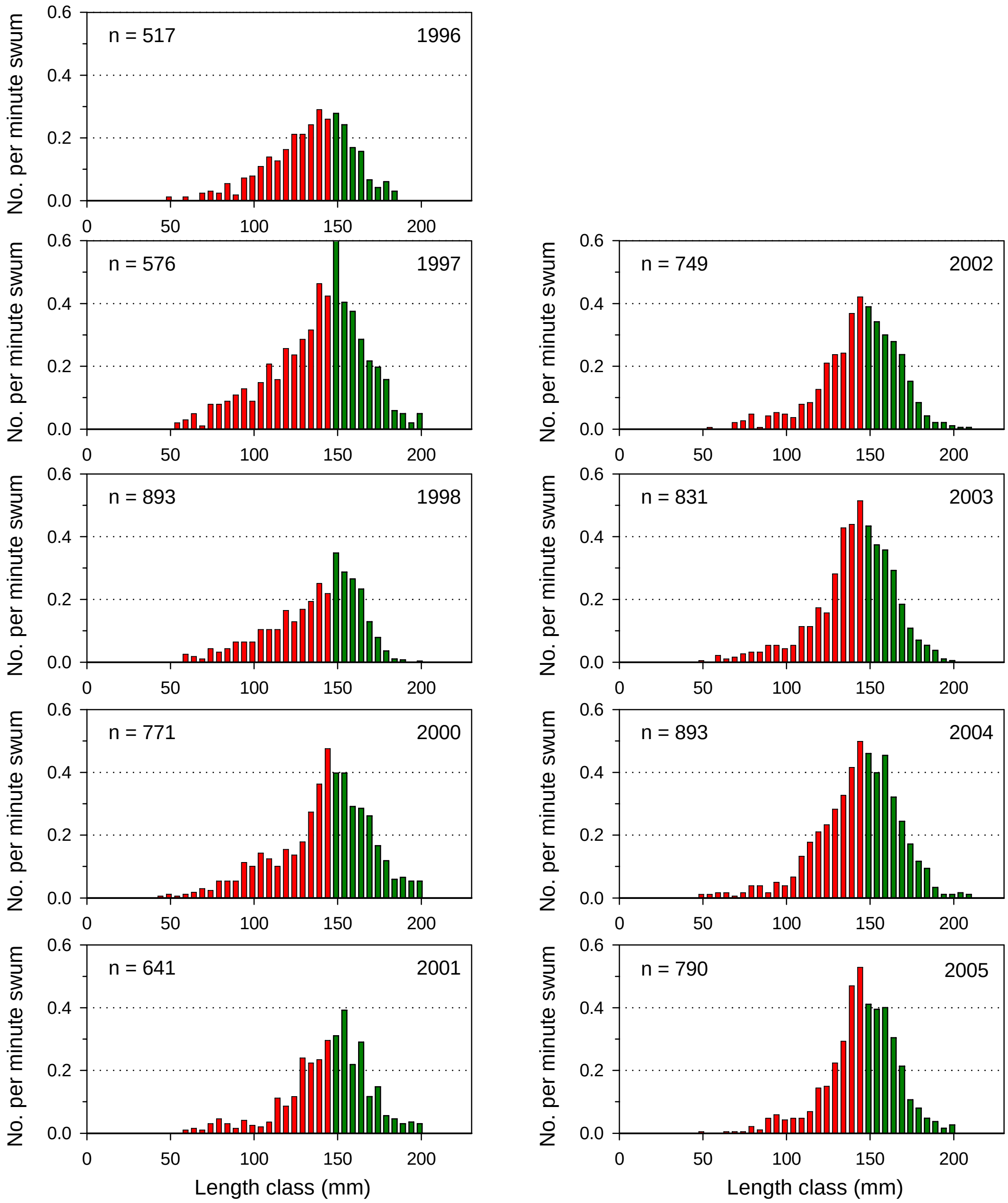

Figure 2.13 Length-frequency distribution of legal-sized (≥145 mm SL, green bars) and sub-legal-sized (<145 mm SL, red bars) greenlip surveyed per-minute-swum at Flinders Island on fishery-independent surveys between 1996 and 2005. Length classes are 5 mm SL.

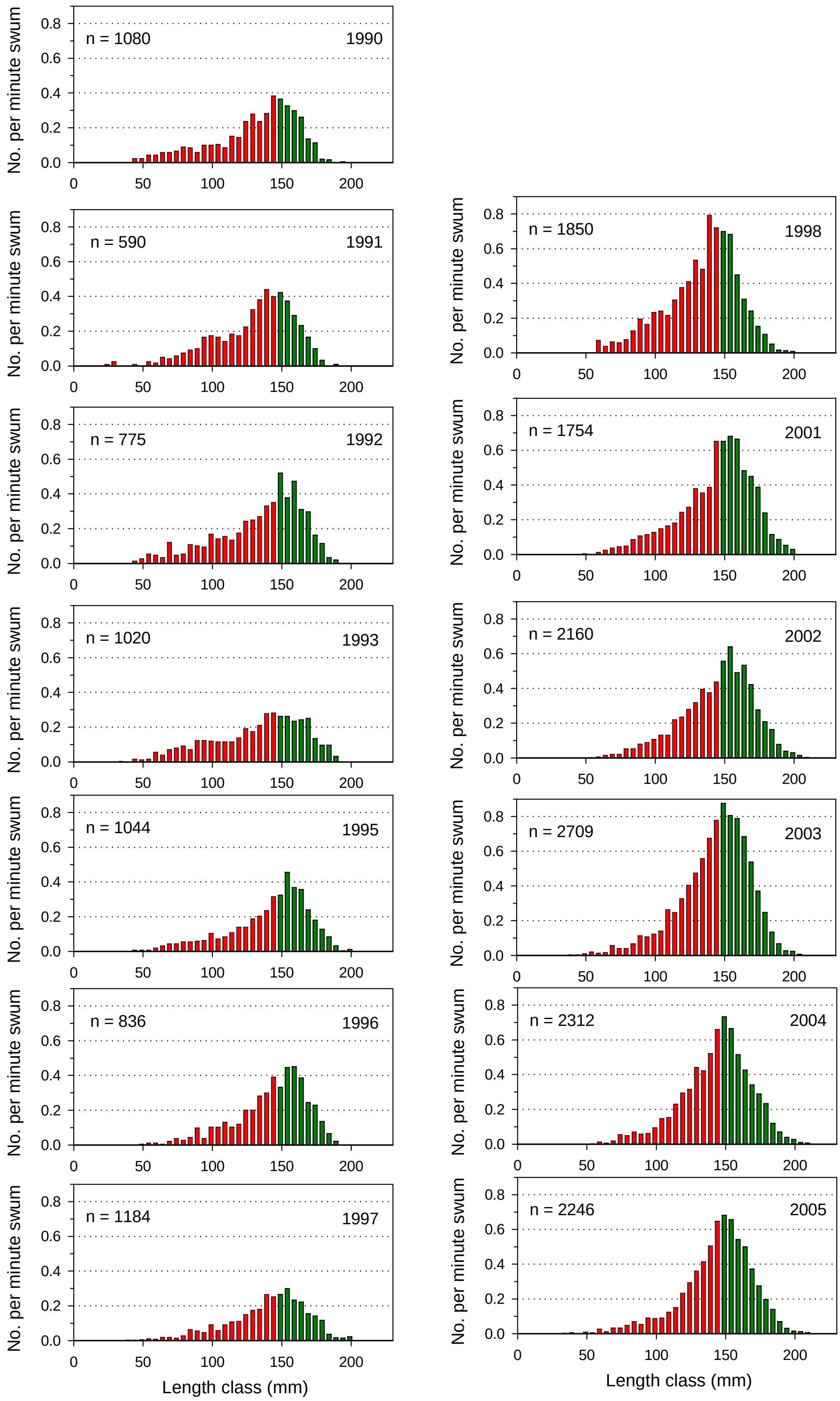

Figure 2.14 Length-frequency distribution of legal-sized (≥145 mm SL, green bars) and sub-legal-sized (<145 mm SL, red bars) greenlip surveyed per-minute-swum at Hotspot on fishery-independent surveys between 1990 and 2005. Length classes are 5 mm SL.

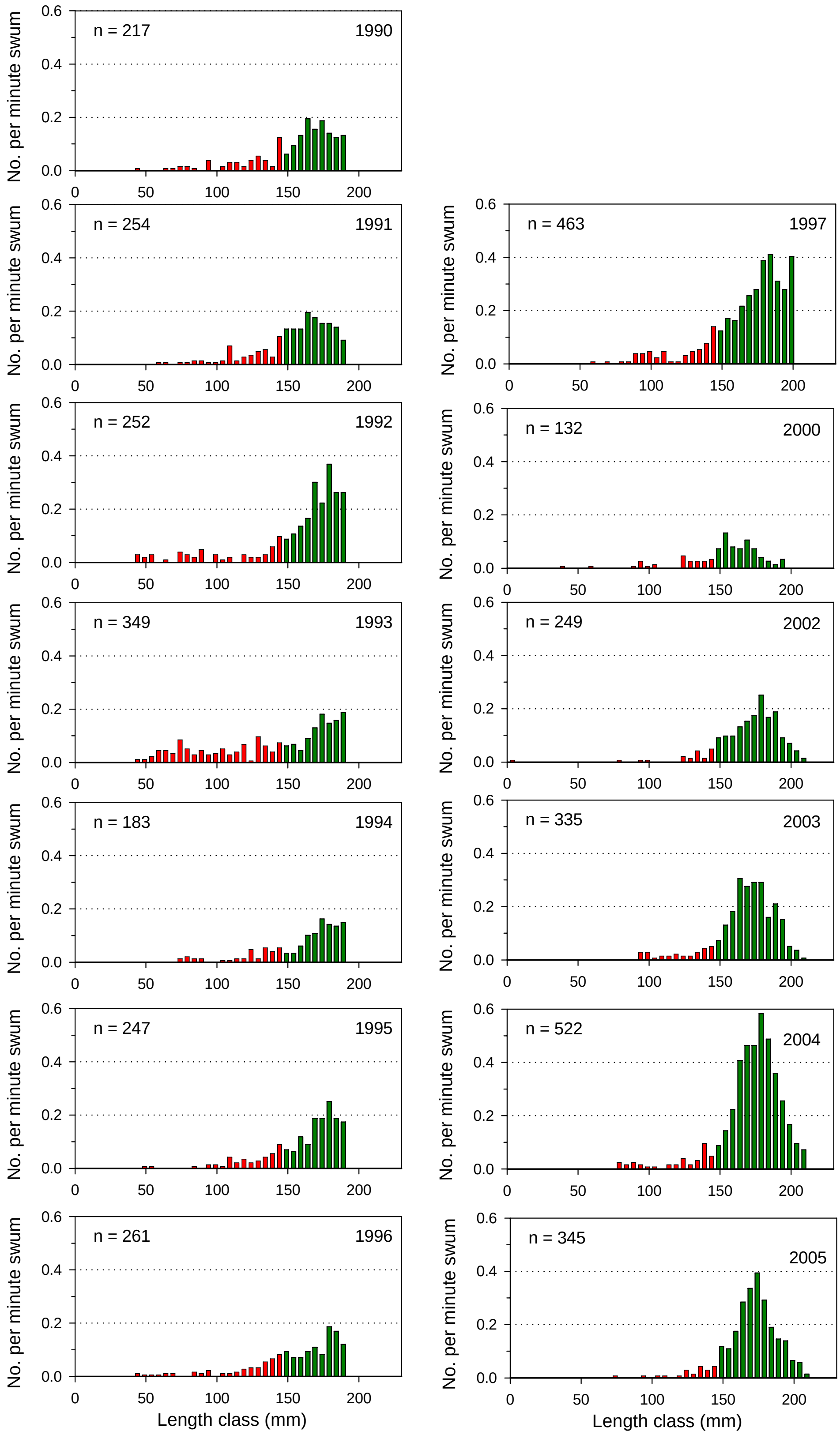

Figure 2.15 Length-frequency distribution of legal-sized (≥145 mm SL, green bars) and sub-legal-sized (<145 mm SL, red bars) greenlip surveyed per-minute-swum at Pearson Island on fishery-independent surveys between 1990 and 2005. Length classes are 5 mm SL.

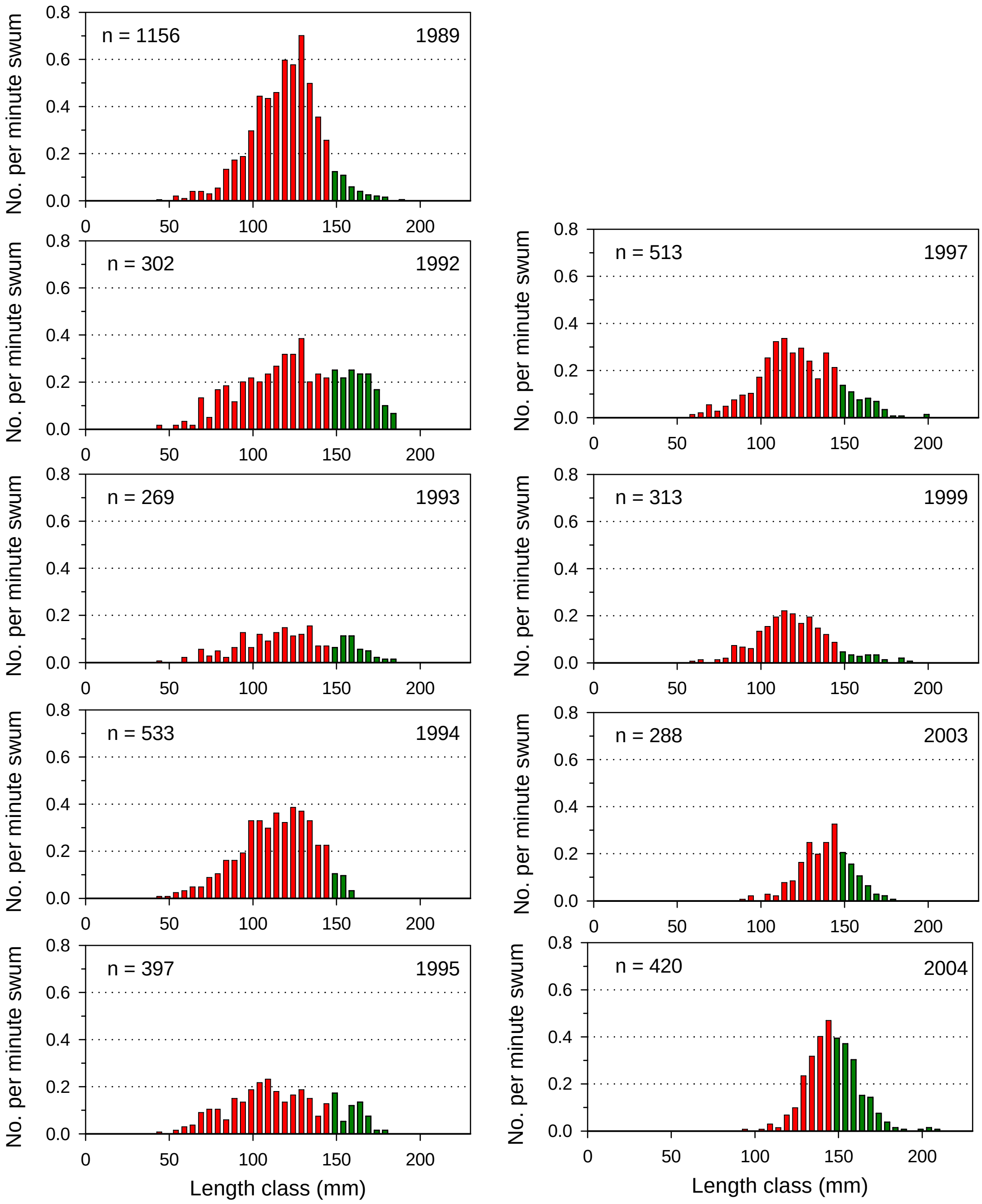

Figure 2.16 Length-frequency distribution of legal-sized (≥145 mm SL, green bars) and sub-legal-sized (<145 mm SL, red bars) greenlip surveyed per-minute-swum at Point Avoid on fishery-independent surveys between 1989 and 2004. Length classes are 5 mm SL.

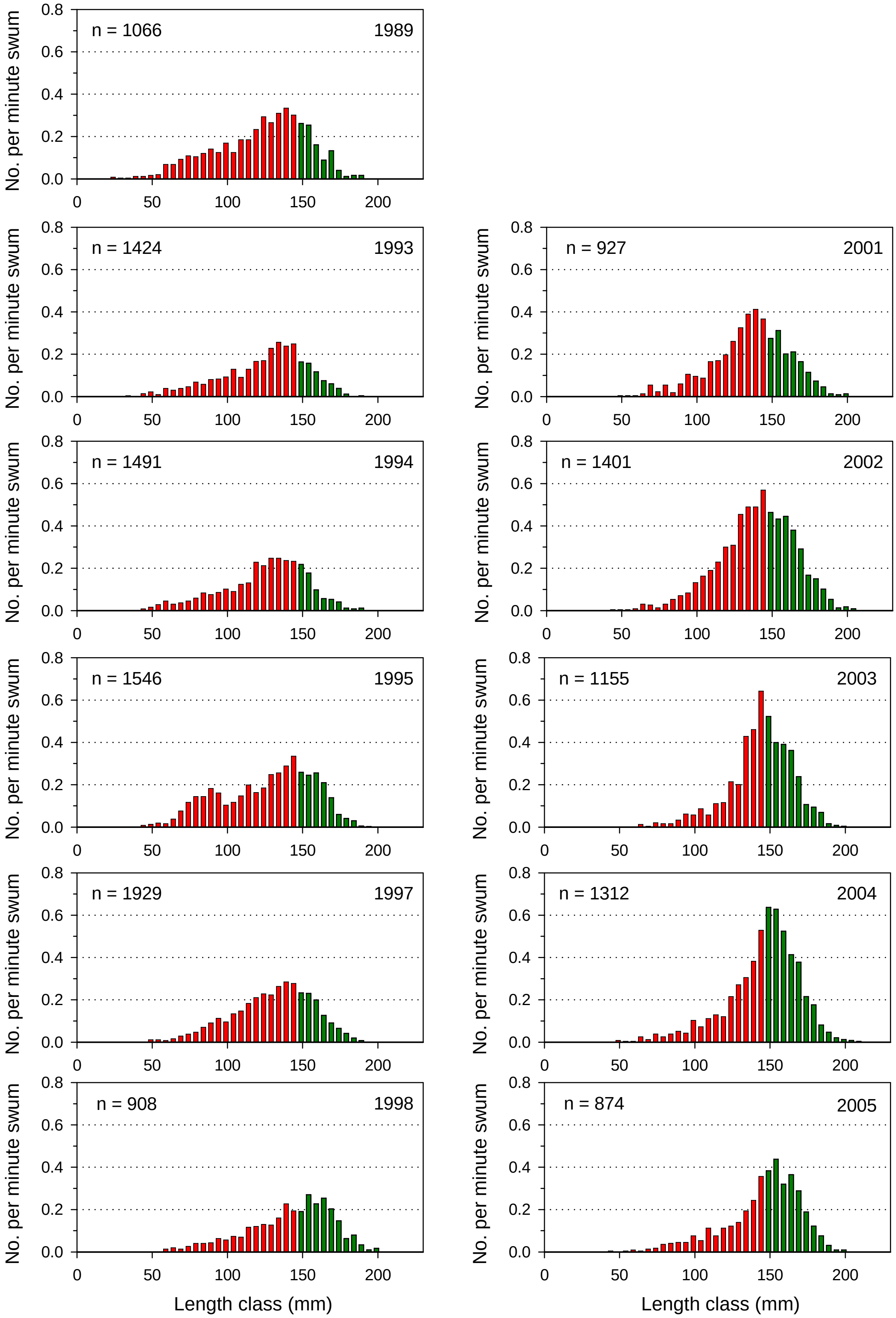

Figure 2.17 Length-frequency distribution of legal-sized (≥145 mm SL, green bars) and sub-legal-sized (<145 mm SL, red bars) greenlip surveyed per-minute-swum at 'The Gap' on fishery-independent surveys between 1989 and 2004. Length classes are 5 mm SL.

3. BLACKLIP ABALONE

Commercial catch and effort data on this fishery have been collected since 1968. Fishers complete a research logbook for each fishing day which is submitted 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 and catch-per-unit-effort (CPUE), from 1 January 1968 to 31 December 2005, presented in this section of the report. Due to low levels of accurate reporting and extraction of commercial fishery data from historical data sources for the year 1978 previous Fishery Assessment Reports have under reported commercial catches of blacklip in Region A for that year. CPUE was computed using the mean ratio estimator (after Rice 1995). Data on the length-frequency distribution of the commercial catch were obtained from samples provided by commercial fishers. The CPUE was standardised, and estimates of egg production, relative to those in an unfished (virgin) population, determined using models developed by SARDI Aquatic Sciences. Estimates of the mature and legal biomass of blacklip in Region A were made using the National abalone stock assessment and risk analysis model (Gorfine *et al.* 2005).

Fishery statistics in this section are provided at two spatial scales. These are (1) the whole blacklip fishery (*i.e.* all fishing areas of region A combined) and (2) individual fishing areas. Data are presented as mean ± 1 standard error (SE) unless otherwise stated.

3.1 Catch

The catch of blacklip in Region A declined significantly from 247 t in 1968 to 103 t in 1977 (LR: $r^2 = 0.61$, df = 8, $p < 0.01$; Figure 3.1). Catches increased substantially over the next three years, with 357 t harvested in 1981. From 1982 to 1984 catches fluctuated inter-annually (range: 281-346 $t.yr^{-1}$). Since 1985, blacklip abalone catches in Region A have been limited by TACCs that have remained almost unchanged at 293.25 t (Table 1.2; Figure 3.1).

The blacklip catch is typically harvested from several of the fishing areas in Region A (Tables 3.1a-c). From 2001 to 2005, >5% of the average annual catch was harvested from each of nine of the eighteen fishing areas comprising Region A (Table 3.1c). However, almost 20% of the TACC was harvested from fishing area 9 over the same period. This is substantially greater than the proportion harvested from this area during 1981 - 1985 (3.6%) or 1991 - 1995 (10.1%). From 2001 to 2005, >90% of the blacklip TACC was harvested from 10 of the 18 fishing areas in this region (Table 3.1c). Since 1981, the number of fishing areas utilised to obtain >60% of the blacklip abalone catch has not changed substantially (five (1981 - 1985); six (1991 - 1995) and five (2001 – 2005); Table 3.1c and Figure 3.2). However the specific fishing areas from which this catch has been taken have changed (Tables 3.1a-c).

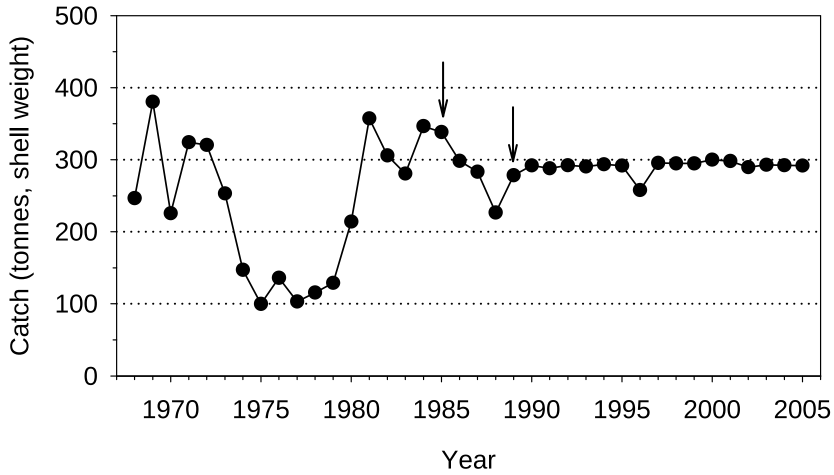

Figure 3.1 Catch (tonnes) of blacklip in Region A from 1968 to 2005. ↓ indicate the implementation (1985) and amendment (1989) of TACCs.

Similar patterns were also apparent when the spatial distribution of the catch was examined at a finer temporal scale (Figure 3.2). Since 1980 (*i.e.* 25 fishing seasons), no more than 28% of the catch has been landed from a single fishing area in one year, with the blacklip catch typically distributed among the available fishing areas (Figure 3.2) throughout Region A.

Levels of catch have fluctuated inter-annually within the fishing areas comprising Region A (Figure 3.3a,b). Notably, blacklip have been harvested from some fishing areas (e.g. 7 and 20) on an intermittent basis only.

Between 1979 and the mid 1980s, catches generally increased in each fishing area. This trend was strongest in fishing areas 6, 10, 11, 12 and 13. Since a TACC was implemented in 1985, the catch of blacklip has increased in fishing areas 5 (from ~20 to ~40 $t.yr^{-1}$), 9 (from ~15 to >50 $t.yr^{-1}$) and 14 (from ~10 to >15 $t.yr^{-1}$), declined in fishing areas 12 (from ~40 to ~15 $t.yr^{-1}$) and 16 (from >7 to <3 $t.yr^{-1}$) and fluctuated among years with no indication of a long-term trend in many fishing areas (*i.e.* 4, 6, 8, 10, 11, 13 and 15). Notably, current catches of blacklip from fishing area 9 are among the highest in the history of the fishery – the catch in 2005 was 63.8 t, the largest since 1999 (68.7 t).

More recently, catches from fishing areas 6, 10, 15 and 18 have declined, while those from fishing areas 5, and 9 have increased. In several cases these changes are substantial. For example, catch from fishing area 5 has increased from an average of 23.5 $t.yr^{-1}$ (2000 – 2001) to 37.9 $t.yr^{-1}$ (2003 - 2005), and in fishing area 9 catch has increased from 50.6 t in 2002 to 63.8 t in 2005. In contrast, levels of catch have declined sharply in fishing areas 10 (from 12.2 t in 2001 to 4.8 t in 2005), 15 (from 12.7 t in 2001 to 5.5 t in 2005) and 18 (from >25 $t.yr^{-1}$ in 1997 - 1999 to 10.9 t in 2005). The reasons causing these substantial changes over relatively short periods of time are unknown. Consequently, the reasons for these changes should be investigated, and documented.

Table 3.1a Average catch (t, shell weight) of blacklip, percent of annual catch and cumulative percent of average annual catch for the top 15 fishing areas (by catch) for the period 1981-1985.

Fishing Area	Average catch (t)	% of annual catch	Cumulative %
11	62.7	20.9	20.9
12	61.0	18.0	38.9
8	32.7	9.4	48.4
13	30.2	9.8	58.2
4	18.5	6.5	64.6
18	15.0	4.8	69.5
6	14.0	5.4	74.9
15	13.0	3.7	78.6
9	11.2	3.6	82.2
14	10.5	3.2	85.3
5	10.4	6.6	91.9
16	9.1	2.7	94.7
10	7.3	3.7	98.4
19	2.7	0.9	99.3
17	1.1	0.3	99.6

Table 3.1b Average catch (t, shell weight) of blacklip, percent of annual catch and cumulative percent of average annual catch for the top 15 fishing areas (by catch) for the period 1991-1995.

Fishing Area	Average catch (t)	% of annual catch	Cumulative %
11	38.9	13.4	13.4
6	33.2	11.4	24.8
4	31.2	10.7	35.5
9	29.3	10.1	45.6
5	25.3	8.7	54.3
13	25.0	8.6	62.9
12	23.2	8.0	70.8
18	21.5	7.4	78.2
8	15.4	5.3	83.5
14	14.8	5.1	88.6
15	10.4	3.6	92.2
10	9.0	3.1	95.2
3	4.4	1.5	96.7
19	3.7	1.3	98.0
16	3.4	1.2	99.2

Table 3.1c Average catch (t, shell weight) of blacklip, percent of annual catch and cumulative percent of average annual catch for the top 15 fishing areas (by catch) for the period 2001-2005.

Fishing Area	Average catch (t)	% of annual catch	Cumulative %
9	56.2	19.2	19.2
11	35.5	12.1	31.3
5	32.4	11.1	42.4
4	26.4	9.0	51.4
6	25.8	8.8	60.2
8	22.2	7.6	67.8
13	21.0	7.2	75.0
14	16.4	5.6	80.6
12	16.2	5.6	86.2
18	13.6	4.7	90.8
15	9.5	3.2	94.1
10	7.5	2.6	96.6
3	4.4	1.5	98.1
16	3.3	1.1	99.3
7	1.1	0.4	99.6

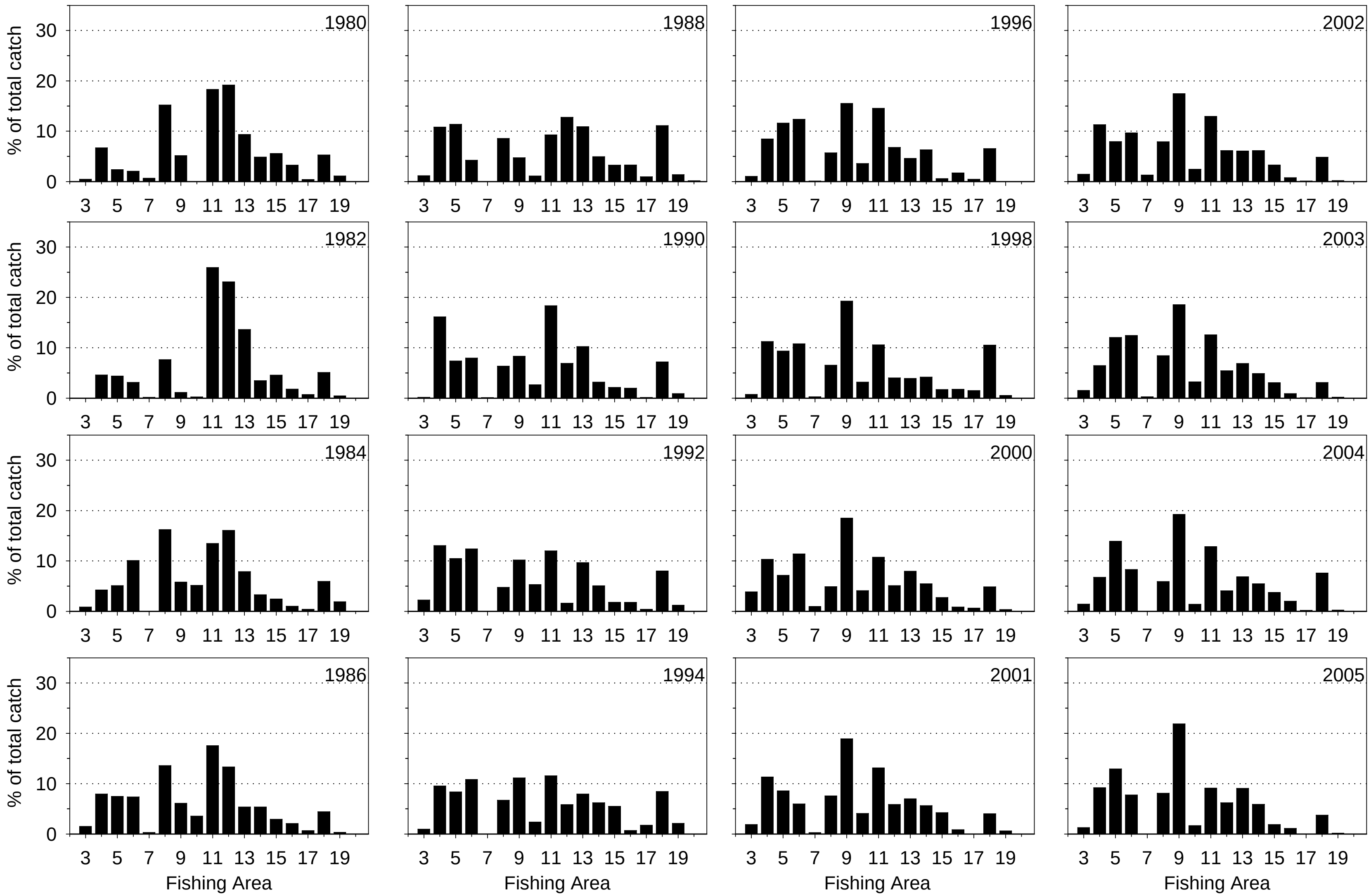

Figure 3.2. Spatial distribution of the blacklip catch (% of total catch) among each of the fishing areas in Region A of the Western Zone in alternate years from 1980 until 2000 and annually to 2005.

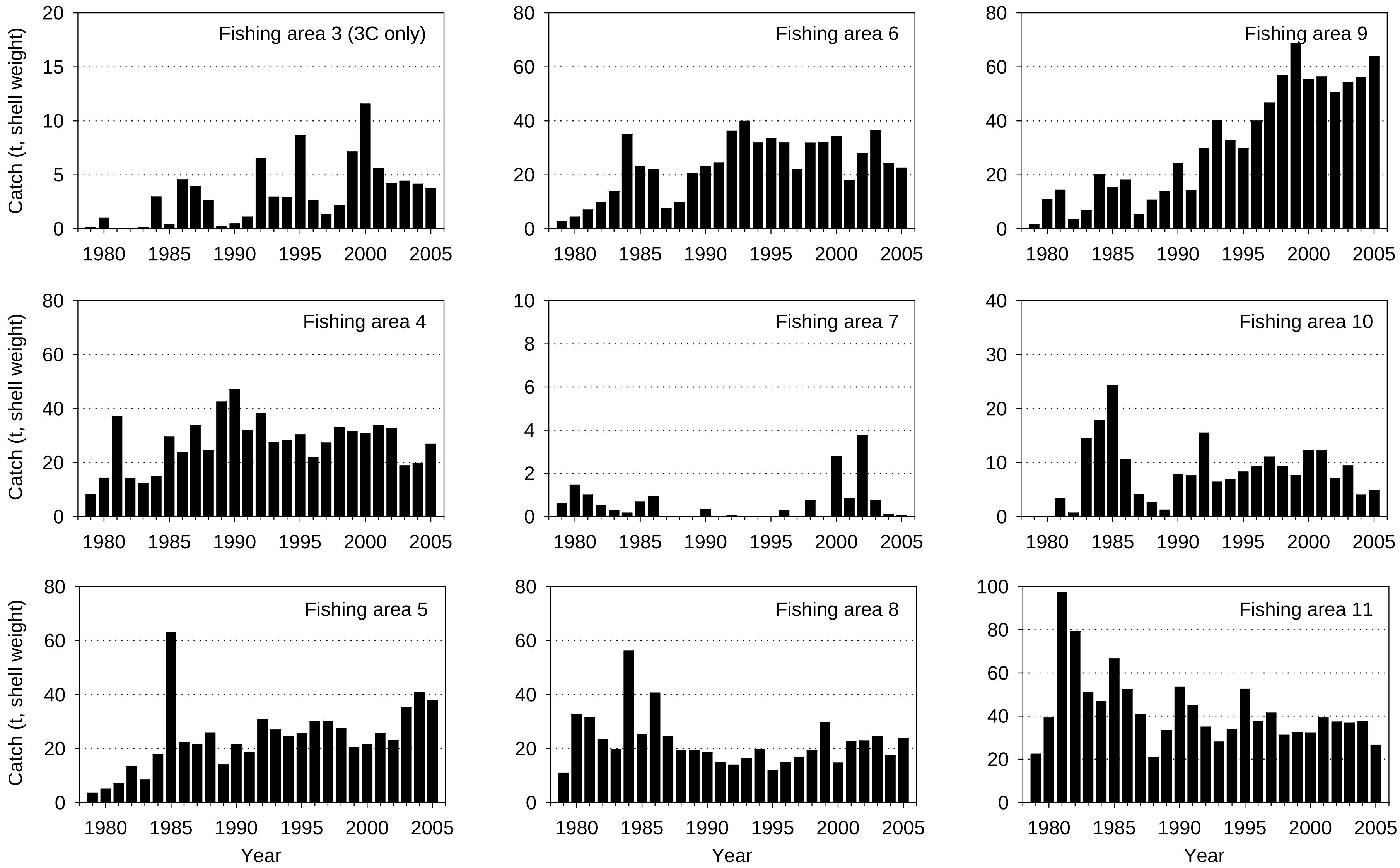

Figure 3.3a Catch of blacklip (tonnes, shell weight) in each of the fishing areas comprising Region A of the Western Zone from 1979 to 2005.

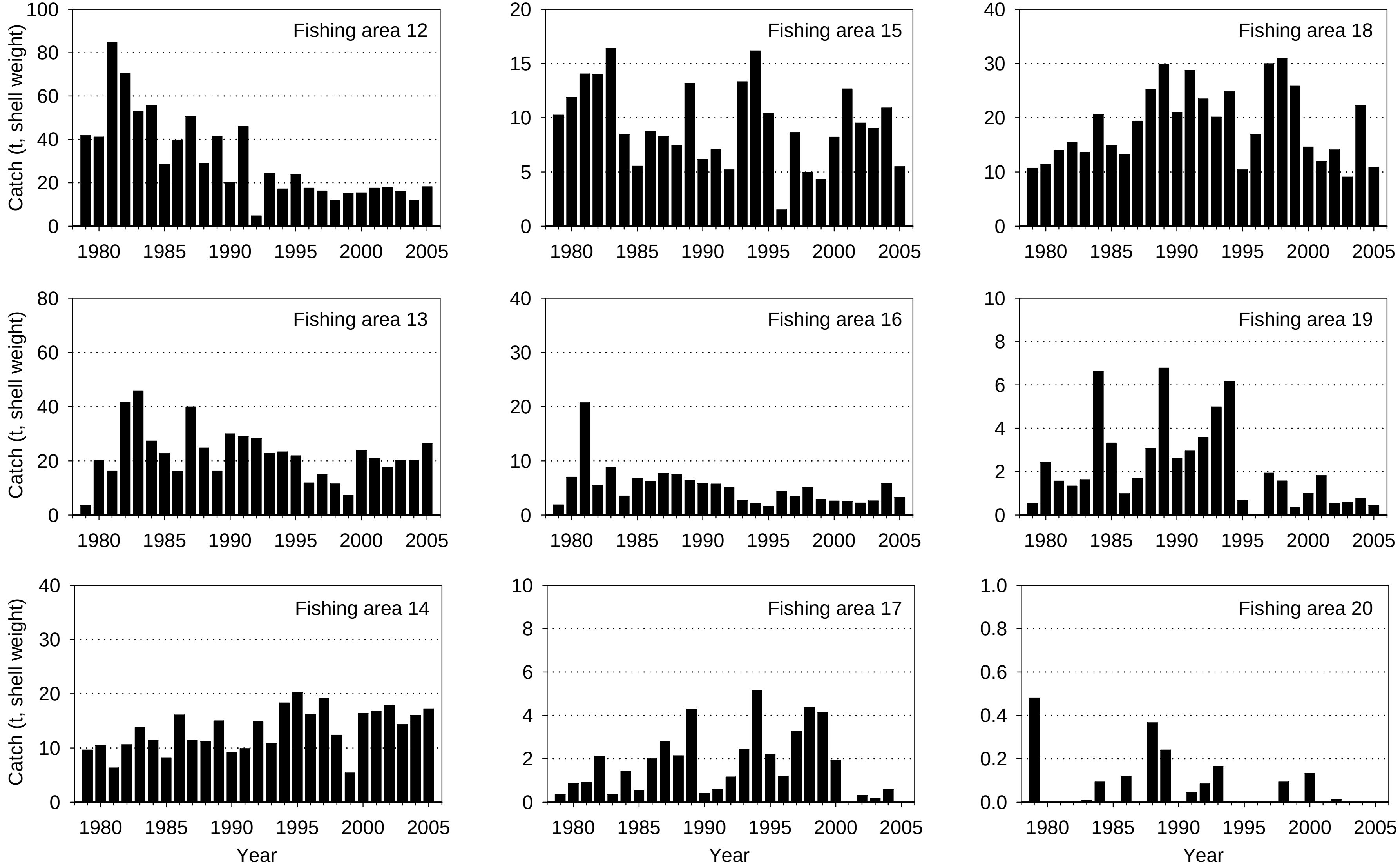

Figure 3.3b Catch of blacklip (tonnes, shell weight) in each of the fishing areas comprising Region A of the Western Zone from 1979 to 2005.

3.2 Catch-per-unit-effort (CPUE)

The CPUE on blacklip was defined as blacklip catch (kg) / total effort (hours) computed from only those daily records where the blacklip catch was greater than or equal to 50% of the total catch. This was justified for three reasons: (1) few fishing records between 1978 and 2005 report a blacklip catch of zero; (2) only between 12 and 26% of the blacklip catch in Region A is obtained on fishing days when no greenlip are harvested and; (3) using daily records where the blacklip catch is less than 50% of the total catch is likely to be inappropriate as blacklip were probably not being targeted on those days.

The mean CPUE on blacklip, in all fishing areas of Region A combined, increased significantly from 56 ± 1.6 kg.hr^{-1} in 1979 to 83.1 ± 3.8 kg.hr^{-1} in 2005 (LR: r^2 = 0.73, df = 25, $p < 0.01$; Figure 3.4), and in 2005 was at the highest level recorded in the history of the fishery. Similar temporal patterns in mean CPUE, to that observed for Region A, were observed in fishing areas 4, 5, 6, 9 and 11 (Figure 3.4). In each of these areas, the CPUE in 2005 was at (fishing areas 6 and 9) or near (fishing areas 4, 5 and 11) the highest observed CPUE levels for these areas.

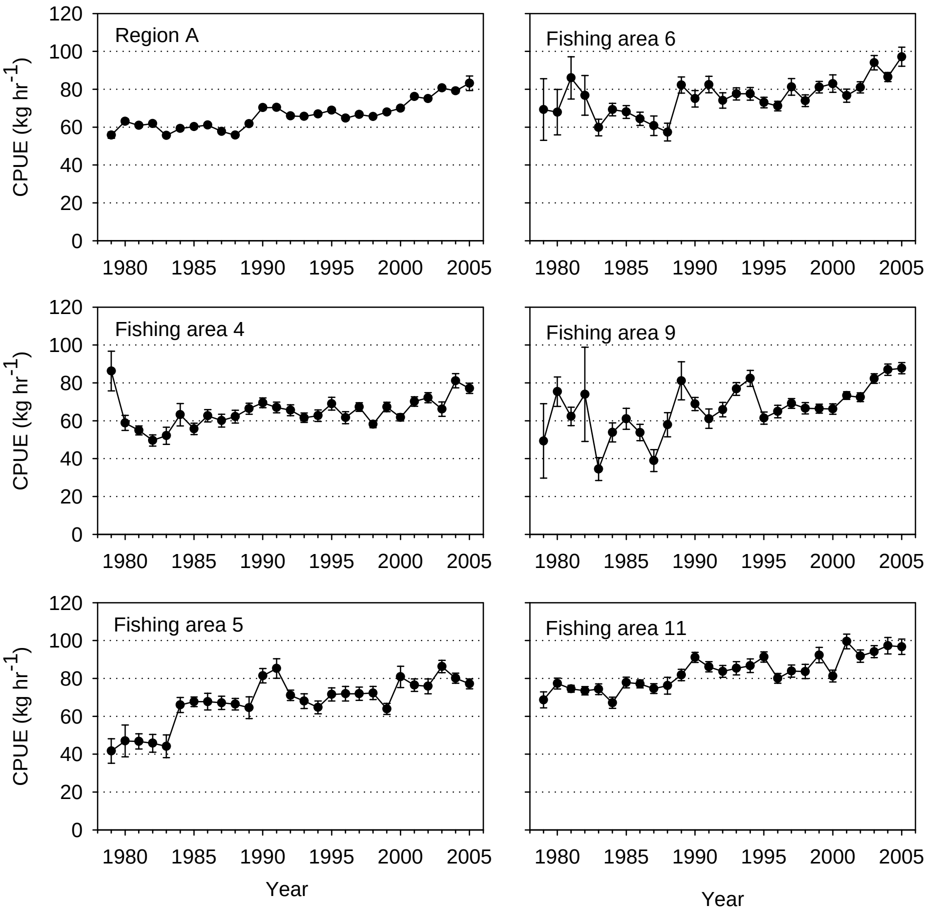

Figure 3.4 Mean catch-per-unit-effort (CPUE (kg.hr^{-1}) (± SE) on blacklip for all fishing areas of Region A combined, and for fishing areas 4, 5, 6, 9 and 11 from 1979 to 2005.

3.3 Standardised CPUE

To account for changes in effective fishing effort (*i.e.* technological advancement, diver behaviour and diver efficiency), historical catch and effort data were standardised (Mayfield *et al.* 2003, Mayfield *et al.* 2004) by year (from 1978 to 2005), using information from licence holders on their fishing practices using a generalised linear model (GLM) described in section 2.3.

For all fishing areas of Region A combined, raw (observed) and standardised CPUE show similar temporal patterns between 1980 and 2005. Of notable difference are the rates of declines in standardised CPUE between 1980 and 1987, and between 1990 and 2000 that are substantially greater than declines in the observed CPUE over the same time periods. In addition, standardised CPUE has declined from 2003, in contrast with raw (observed) CPUE. Both measures in 2005 were at or among the highest levels since 1980 (Figure 3.5).

In fishing area 9, the observed and standardised CPUE have similar temporal patterns: both were variable but generally declined between 1980 and the mid 1980s, increased rapidly to the early 1990s and were stable until 2000 where they have increased up to 2005. In contrast, the standardised CPUE in fishing area 11 declined between 1993 and 2000 and from 2001 to 2005. Observed CPUE remained relative stable throughout the same periods.

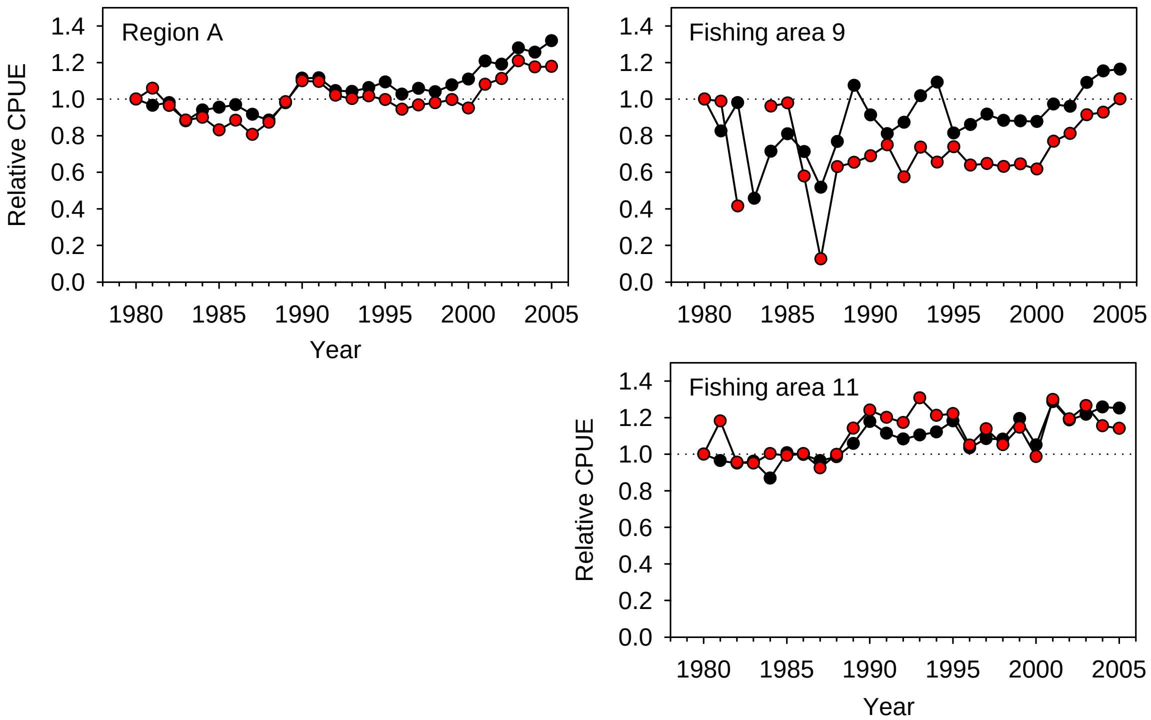

Figure 3.5 Relative (to that in 1980) raw (black) and standardised (red) CPUE on blacklip in all the fishing areas of Region A combined, and in fishing areas 9 and 11 separately.

3.4 Length-frequency distribution of the catch

Estimates of individual lengths of abalone in the commercial blacklip catch have been obtained from shell samples since 1999. During that year, 390 shells were sampled. More recent samples, for example those obtained in 2004 (n = 6 967) and 2005 (n = 8 073), have been larger.

In all years for which data were available, both the modal length class and the mean length of the commercial catch in Region A were substantially greater than the MLL (130 mm SL; Figure 3.6). In each year, the frequency distribution was generally normal, although slightly left skewed as large (≥165 mm SL) blacklip comprised a small proportion of the samples (range: 6.3 – 10.9%)

Similarly, the differences in modal length class and mean length vary minimally among years. The mean length of the commercial catch has varied by <5 mm SL since 1999, ranging between 146.7 ± 0.2 (2000) and 151.5 ± 0.5 mm SL (1999). Thus, in all years for which there are data, the mean length exceeded the MLL by >15 mm SL. The modal length class has varied between 140 - 144 mm SL (2000 and 2004) and 150 - 154 mm SL (1999).

During 2005, the mean length of the commercial catch exceeded 150 mm SL in fishing areas 5 (151.2 ± 0.5 mm SL), 6 (153.1 ± 0.5 mm SL), 9 (152.7 ± 0.3 mm SL) and 14 (150.1 ± 0.7 mm SL; Figure 3.7). The mean length did not vary substantially among fishing areas 4, 8, 10, 11, 13, 15 and 18, ranging between 144.1 ± 0.5 mm SL (fishing area 18) and 149.97 ± 0.3 mm SL (fishing areas 10 and 11). The modal length classes in these areas were also substantially greater than the MLL (Figure 3.7). However, in fishing area 12, the mean length (143.3 ± 0.2 mm SL) and modal length class (135 - 139 mm SL) were substantially lower than corresponding values for the other fishing areas. This difference was also evident in the shape of the distribution, that was more left-skewed in fishing area 12 and more normally distributed in the other fishing areas.

Cumulatively ~30% of the blacklip TACC was harvested from fishing areas 9 and 11 during 2005 (see section 3.1). In fishing area 9, both the mean length and modal length class has decreased ~3 and 5 mm respectively: the mean length declined from 155.0 ± 0.5 mm SL in 2002 to 152.7 ± 0.3 mm SL in 2005 and the modal length class decreased from 150 - 154 mm SL in 2002 to 145 – 149 mm SL in 2005 (Figure 3.8). In contrast, the mean length has increased from 148.5 ± 0.6 mm SL (2002) to 149.97 ± 0.3 mm SL (2005) in fishing area 11 and the modal length class has remained unchanged at 150 – 154 mm SL from 2002 to 2005, despite declining to 135 – 139 mm SL in 2004 (Figure 3.8).

The only possible evidence of ‘knife-edge’ fishing on blacklip abalone in Region A during 2004 was in fishing area 12 (Figure 3.7).

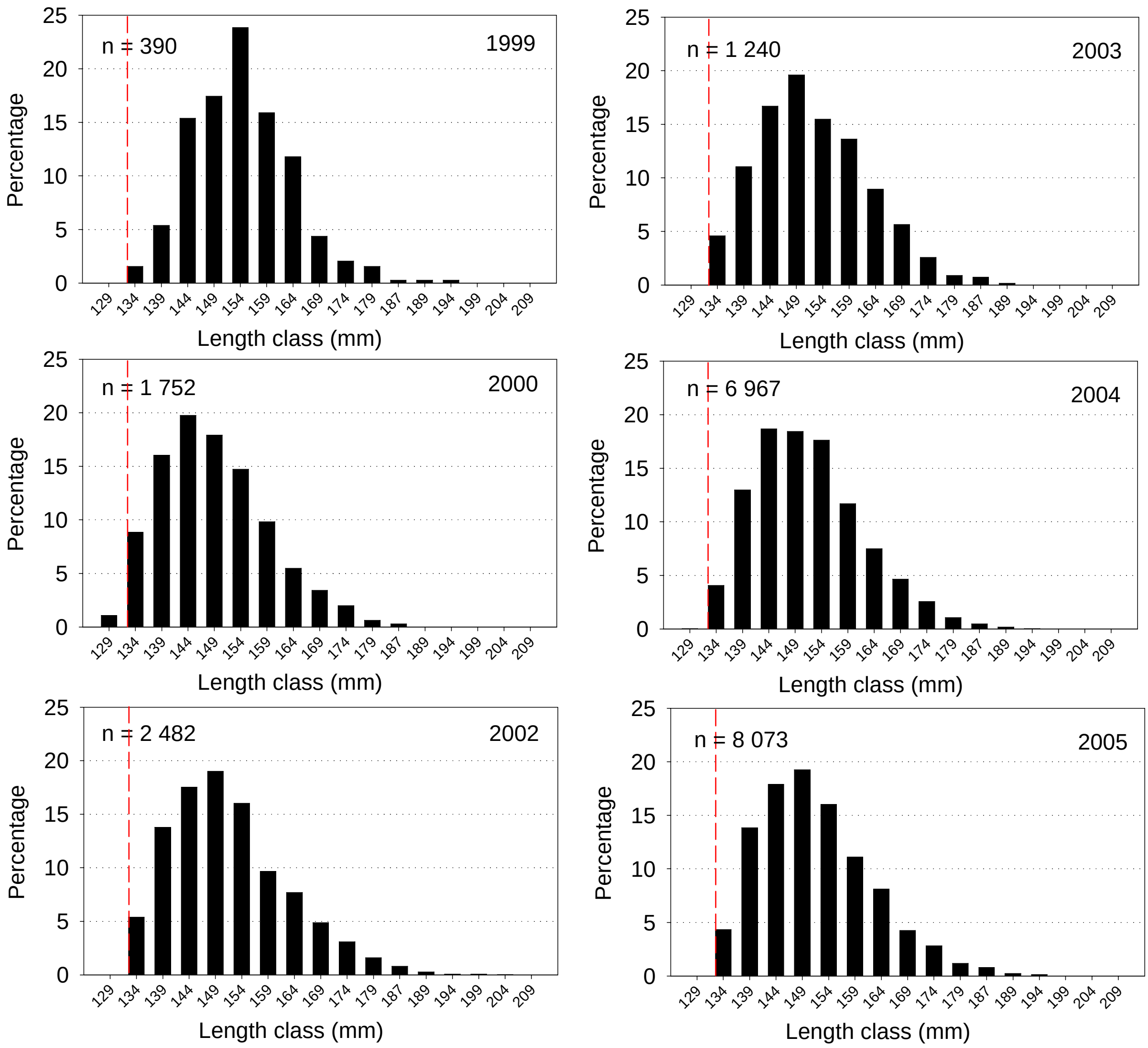

Figure 3.6 Length-frequency distribution obtained from measuring blacklip shells from the commercial fishery from Region A during the years 1999, 2000 and 2002-2005. Vertical red line indicates MLL (130 mm SL).

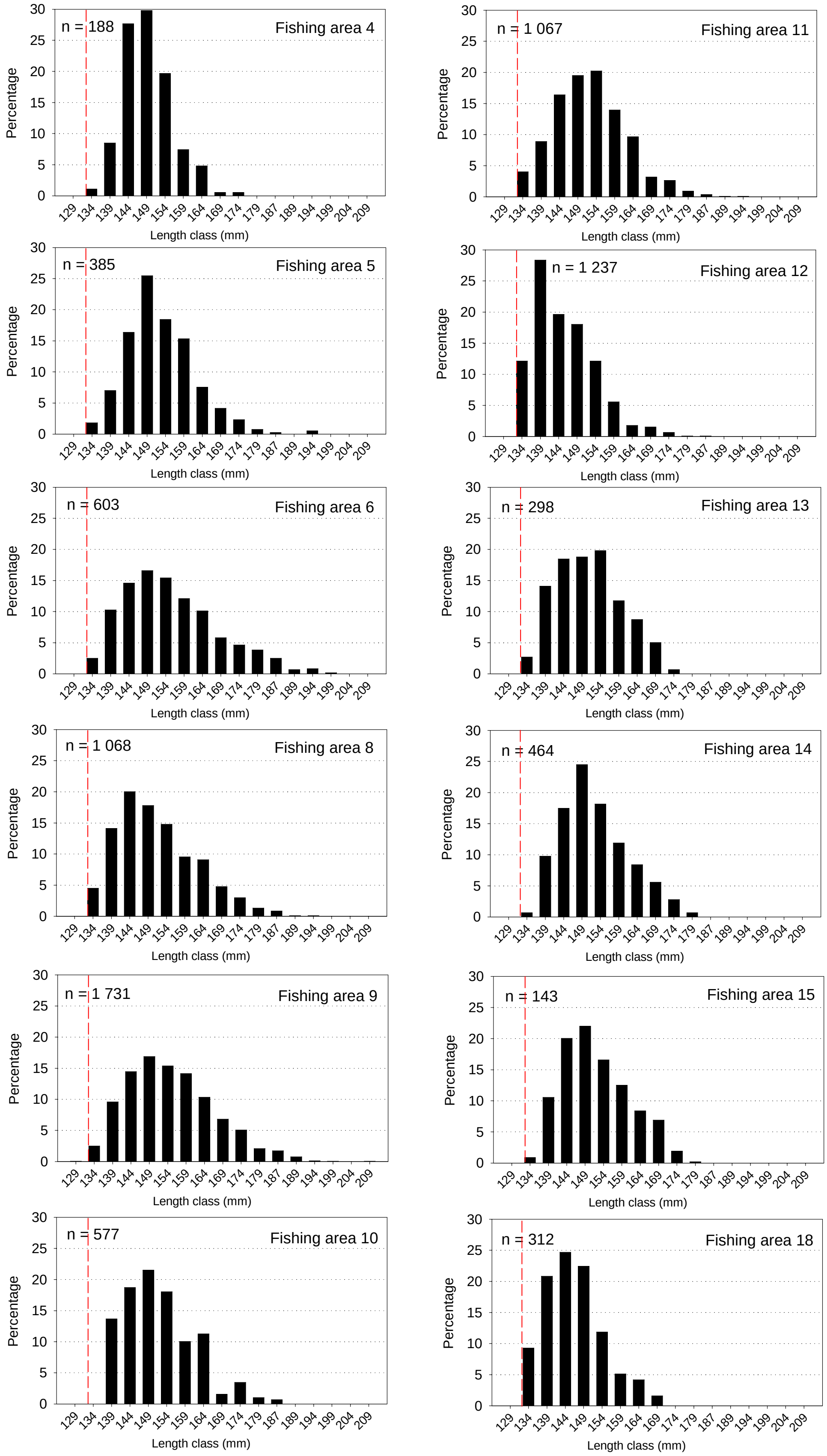

Figure 3.7 Length-frequency distribution obtained from measuring blacklip shells from the commercial fishery in fishing areas 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15 and 18 during 2005. Vertical red line indicates MLL (130 mm SL).

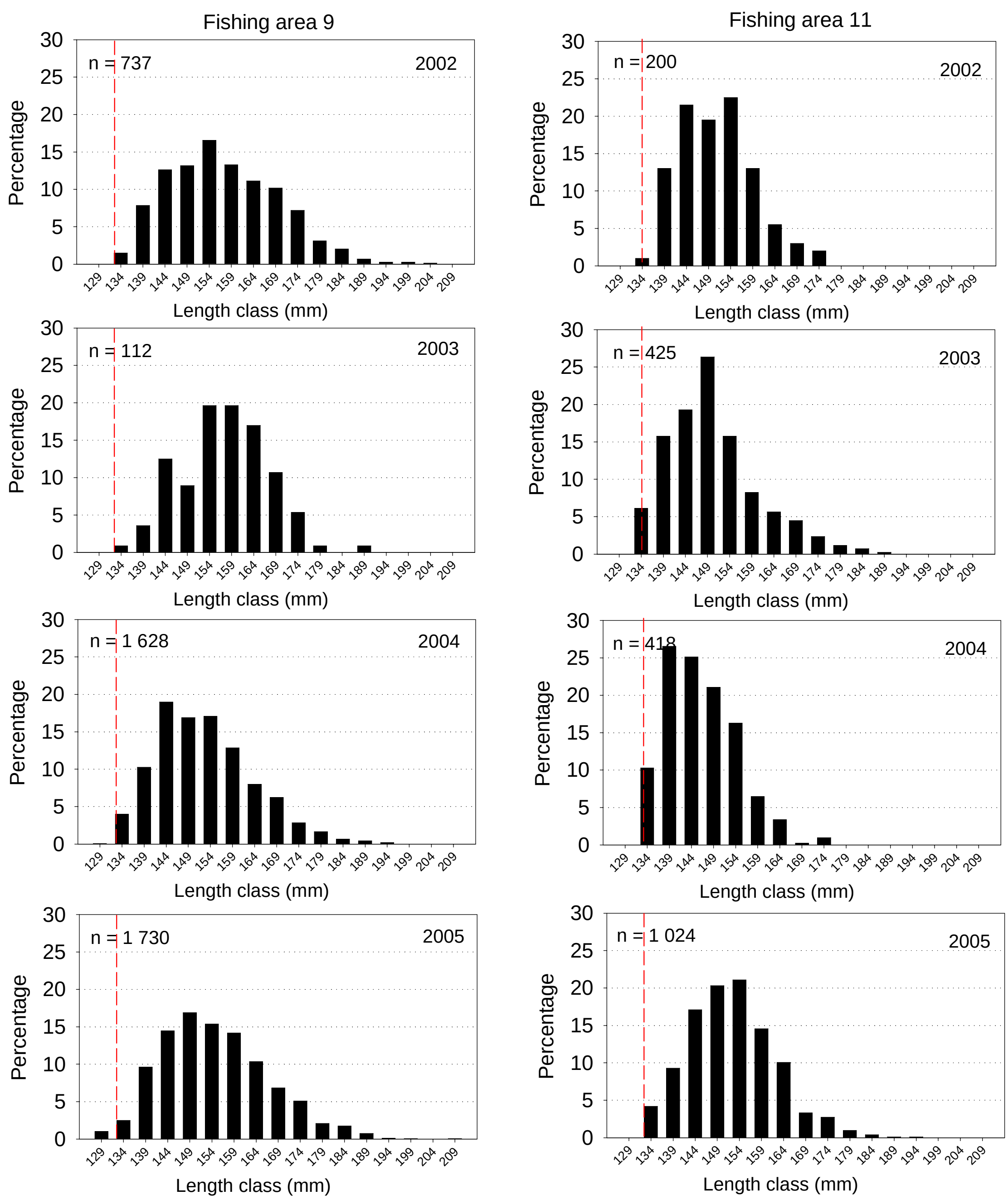

Figure 3.8 Length-frequency distribution obtained from measuring blacklip shells from the commercial fishery in fishing areas 9 and 11 from 2002 to 2005. Vertical red line indicates MLL (130 mm SL).

3.5 Estimates of egg production

A simple egg-production model, based on the (Beverton & Holt 1957) yield-per-recruit model (after King 1995) that considers the dependence of egg production on growth, age at first capture and fishing mortality (F), was used to estimate the proportion of pristine egg production conserved under the current management arrangements for the blacklip in fishing areas 9 and 11. Full details of the biological data used in the model, and the model assumptions are provided in Appendix 3.

The estimates of the percentage of pristine egg production conserved in fishing areas 9 and 11 were 65.2% and 60.4%, respectively. These figures represent an increase of 26.9% in the percentage of pristine egg production in fishing area 9 and a reduction of 7% from fishing area 11 from that estimated in 2004 (Mayfield *et al.* 2005b).

3.6 Fishery-independent abalone surveys

3.6.1 Introduction

Prior to 2005, there have been no regular fishery-independent measures of the abundance or population length structure of blacklip populations in this Region. During 2005, SARDI began fishery-independent surveys to assess the abundance and length-structure of blacklip populations at 5 locations in Region A. Initial sites were selected to (1) enable monitoring of blacklip populations in key fishing areas; and (2) obtain sites along the coast representative of the fishery. A number of these sites correspond to those described in the Management Plan. Sites that differ from those in the Management Plan have done so as the survey method has developed at more accessible sites and as patterns of catch and perceptions of stock status have differed between the development of the Management Plan and that of the surveys.

3.6.2 Methods

General aim & survey strategy

The aim of the survey strategy was to (1) obtain representative measures of the abundance and length structure of blacklip stocks in Region A that support substantial commercial catches (*i.e.* annual catches in excess of 7 t for each of the 5 years prior to 2005); (2) to allow performance indicators regarding blacklip abundance, described in the Management Plan, to be formally addressed; (3) permit additional locations and sites within locations to be surveyed through time; and (4) allow modifications to be made to the sampling design at existing sites to enable more accurate measures of abundance in future years if required.

Five locations were chosen for survey in 2005. The number of locations was determined in consideration of the research effort available and the estimated number of days required to survey each location. Four of the five locations were within the ten map codes from which there had been the highest average annual commercial catch of blacklip for the five years prior to 2005. This included Sheringa (11A), Ward Island (9A), Drummond Point (12B) and Hotspot (9D). The remaining location, Highcliff (4B), was within the top 15 map codes (by catch) and was selected such that a location in the far north of the fishery was sampled. In subsequent years existing locations will be surveyed and new locations added (*e.g*. Reef Head and Talia).

Site identification and stratification

At each location, large areas of reef (sites) were defined using a depth sounder (<15 m) and further stratified into 1 of 3 strata. Stratum 1 consisted of reef with observed 'higher than average abundance' of blacklip than the surrounding area, as determined either by direct observation by a research diver or as identified on 'mud maps' by commercial fishers. Stratum 2 consisted of poor habitat or habitat unable to be sampled (e.g. 100% sand or reef inaccessible to divers). Stratum 3 consisted of the area remaining within the site not conforming to definitions of strata 1 or 2 (*i.e.* area not regularly commercially fished). The boundaries of the site and strata were defined using a depth sounder, GPS and direct observation of the habitat type from a vessel or by a diver systematically swimming through the site and sending up floats to denote strata boundaries, with the location of the floats marked using a GPS. The area of each stratum and hence site was calculated using GIS software (ArcGIS 9.1).

Sampling methodology

At each site the number of small (<90 mm), medium (90<130 mm) and large (>130 mm) blacklip was sampled within strata 1 and 3, using 1 of 2 survey methods. Within stratum 1 a variable number (6-18) of GPS points were systematically distributed. At each of these points weights with sub-surface floats were dropped (hereafter referred to as a 'drop'). At each 'drop' the three length classes of blacklip were counted along four, 10 x 1 m transect lines laid at bearings of 0^o 90^o 180^o and $270\ ^o$, starting ~2 m from each 'drop'. The transects were surveyed by 2 divers descending to each 'drop', each with a ~12 m transect line consisting of ~2 m of light rope attached to 10 m of leaded-line (12 mm nylon rope with a core of lead wire). The transect area was defined by a diver clipping the end of the ~2 m line to the 'drop' and laying the leaded-line on the defined bearing (see Figure 3.9). The number of abalone within each length class (determined visually and with the aide of a marked rule) was counted within 1 m of the transect (determined by divers carrying a 1 m length of thin aluminium rod) without disturbance to the substrate. Each transect was done on the right hand side of the transect line as the diver swam from the end of the line towards the 'drop'. In addition, to obtain estimates of the variation in the number of blacklip counted in each length class among divers, the first two transects (commonly 0^o and 180^o) at each 'drop' were counted by both divers. Where new divers or complex habitat was encountered, divers compared their counts for each replicate. Where counts of the total number of abalone varied by more than ~20% a diver would recount the transect. After completion of the first two transects, the lines were pulled in and the remaining 2 transects were completed for that 'drop', without replicated counts being made. Any abalone that fell within the plane above or below the 1 m rod when touching the transect line was counted.

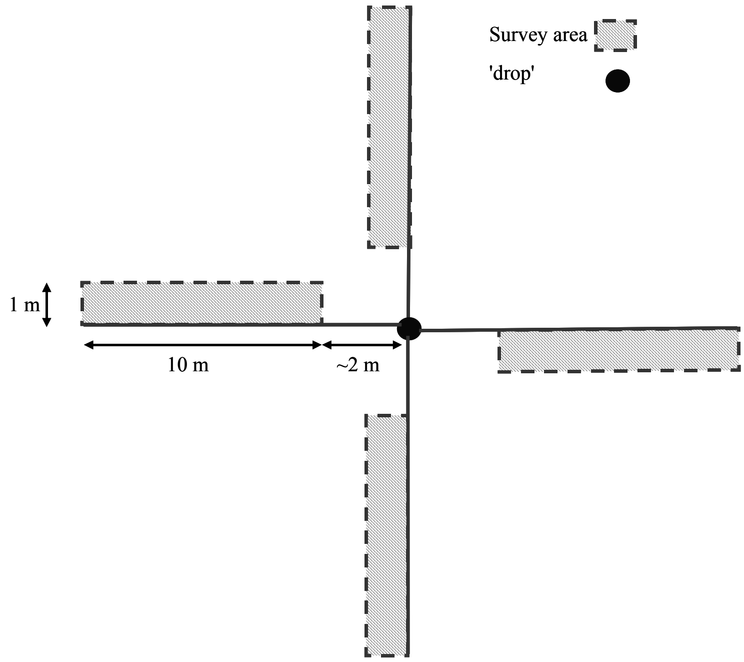

Figure 3.9 Design of the sampling strategy to measure the density of blacklip at each 'Drop' within strata 1 (defined in the text) at each site (not to scale).

Within stratum 3 the start points for a variable number (4-8) of 50 m leaded-lines (LL) were systematically determined and the LL was set from the vessel (using methods described in McGarvey (in press). The number of each size class of blacklip was counted within 1 m of each side of the line by separate divers (using aides described above for the 10 m transects). Each 50 x 1 m transect was treated as an independent measure of density.

Areas defined as poor habitat (stratum 2) were not surveyed and the area of this stratum was subtracted from the total area of the site prior to calculations of absolute abundance being made.

In addition to fishery-independent measures of the abundance, blacklip were collected from a defined area within 200-300 m of the survey site to obtain fishery-independent measures of the population length-structure. At the collection site all blacklip observed on a dive were collected, their lengths measured and then returned to the substrate. At each site approximately 120 individuals were sampled.

As only one year (2005) of data were available, changes in absolute abundance (density (no. $10m^{-2}$) x survey area) and measures of population length structure of blacklip at each location will be presented in subsequent reports, after analysis of subsequent survey data.

3.7 Length-based stock assessment model

3.7.1 Introduction

This is the second year in which the integrated, length-structured national abalone stock assessment and risk analysis model (Gorfine *et al.* 2005) was used to assess the status of blacklip abalone stocks in Region A of the Western Zone. The assessment used Bayesian techniques to estimate (1) model parameters; (2) determine the sensitivity of the model outputs to alternative CPUE time series, the magnitude of the CPUE and commercial length-frequency observation error; change in growth description (*i.e.* use of Shnute growth parameters) and variation in growth rate (3) determine current stock status relative to that in 1968 (*i.e.* B_0); and (4) determine the uncertainty of those estimates.

Four substantial changes were made to improve the application of the model over the previous assessment. Firstly, there was a broader evaluation of the appropriateness of the priors (and their associated distributions) that was extended to the use of both 'exploratory' (*i.e.* diffuse) and 'driving' (*i.e.* informative) prior distributions. That is, while exploratory priors can allow the model and observations to provide more broad ranging outputs these outputs are often associated with high levels of uncertainty. The uncertainty of the model outputs can be significantly reduced by using supporting data (such as empirical estimates of natural mortality) to estimate informative priors that can reduce the uncertainty of model outputs. Secondly, we employed a more rigorous use of a suite of diagnostic tools for assessing model performance. Thirdly, the time series of CPUE used to fit the model was extended back to 1985 (the first year in which a TACC was implemented). Finally, strengths of the relationships between the data used to fit the model and the model outputs were more critically evaluated. Other, more minor changes, including a re-evaluation of the data used within the model were also implemented.

Despite these changes, the level of precision in the outputs is limited by the short time series of the data being fitted, and the absence of data from fishery-independent surveys. Reliability of the outputs is also strongly influenced by growth rate (particularly the degree to which the growth parameters reflect the magnitude and variability of growth in the Zone), the model's reliance on CPUE, the degree to which the biological data reflect blacklip abalone populations in the Zone and the spatial scale at which the model was applied. Notably, estimates of growth rates developed for the growth matrix by 'Estimatrix' based on a probabilistic Gompertz model (Bardos 2005) appear overly optimistic. Thus, model outputs are likely to be overestimating the productivity of the stock while underestimating the level of depletion. Alternative (length-transition) models for fitting the growth data, such as the inverse logistic (A/Professor Malcolm Haddon, Tasmanian Aquaculture and Fisheries Institute, personal communication) and polynomial (McGarvey & Feenstra 2001) functions, are available and need to be evaluated.

Consequently, current outputs from the model may not be representative of the status of the stock - with refinement of the model, and the data used in future years possibly changing the model outputs considerably.

3.7.2 Methods

Model description

A detailed description of the model can be found in Gorfine *et al.* (2005). The formulae and parameter priors underpinning the model are provided in Appendix 3. Briefly, the model considers the population divided into small (2 mm) length-classes with the number of abalone in each length-class calculated through time. The numbers of abalone in each length class are calculated by applying growth, fishing mortality, natural mortality and recruitment to each length class each year. Biomass estimates are derived from a length-weight relationship. These calculations provide estimates of model-based catch rates and length-frequencies that are compared to real observations. Modelling occurs in two stages: (1) model parameters are estimated using maximum likelihood to provide a good fit to observed data, and (2) Bayesian posteriors for these parameters are derived using Markov chain-Monte Carlo simulation (*McMC*).

Base-case model

A variety of data is required to fit the base case model to observed data. These include the catch and selectivity from each sector of the fishery and a range of biological data. This information then allows the model to provide estimates to fit the observed data.

Commercial, recreational and illegal catches

Commercial catch data for the period 1968 - 2005 were obtained from research logbooks completed for each fishing day and submitted to SARDI Aquatic Sciences. Recreational catch was set at 1 t from 1968 – 1979 and 1.5 t (1980-2005; after Mayfield *et al.* 2004). Illegal catches were fixed for all years at 1.05 $t.yr^{-1}$ (after Mayfield *et al.* 2004).

Length-frequency distribution of the commercial catch

Data on the length-frequency distribution of the commercial catch are available from 1999, 2000 and 2002 to 2005. There are no data on the length-frequency distribution of either the recreational or illegal catch.

Fishing selectivity

The fishing selectivity relationship for the commercial sector was determined from commercial shell samples obtained from 1999, 2000 and from 2002 to 2005 (n = 20 098) and was assumed to be constant during all years from 1971. Prior to 1971 the fishing selectivity relationship for the commercial fishing sector was set such that all blacklip ≥ 110 mm SL were fully recruited. The fishing selectivity relationship for the recreational and illegal fishing sectors was set such that all blacklip ≥ 132 mm SL and 115 mm SL were fully recruited each sector respectively.

Biological data

Growth was assumed to be constant over time and the same for both sexes. It was incorporated in the model as a transition matrix, where abalone from each 2-mm length class at the start of each season grow into a range of larger (2-mm) length classes during each season. The growth transition matrix was determined from tag-recapture data for blacklip abalone at Reef Head, Venus Bay and Sheringa (after Bardos 2005). This growth transition matrix varied from that used in the previous assessment (Mayfield *et al.* 2005b) in that the maximum length class was reduced from 210 mm to 182 mm to better reflect maximum lengths from tag recapture data. Moreover, growth data were not scaled to account for potential reduced growth due to handling. Individual abalone with negative growth were omitted from the data used to calculate the transition matrix.

The proportion of sexually mature individuals within each length class was determined from data obtained from West Bay, Reef Head, Sheringa, Tungketta, Hotspot and Ward Island. A logistic function was fitted to the data (SPSS Inc., Sigma Plot) and used to determine the proportion of sexually mature individuals within each 2-mm length class. The allometric relationship between shell length and whole weight was determined from data obtained at West Bay, Avoid Bay, Point Drummond, Sheringa, Tungketta, Waldergrave Island, Flinders Island, Hotspot and Ward Island.

Fitting the observed data

The base-case model was fitted to two data sets. Model estimates of the biomass of abalone selected by the fishery were fitted to the observed (*i.e.* raw and unstandardised) mean CPUE from 1985 to 2005. Model estimates of the proportion of abalone in each length class selected by the fishery were fitted to the observed commercial length-frequency data from 1999, 2000 and 2002 to 2005.

Markov chain - Monte Carlo simulation (*McMC*)

Uncertainty in the mature and exploitable biomass estimates during each year (1968 - 2005) were determined using a *McMC* simulation of 1 200 000 model runs from which the first 200 000 runs were discarded and 5 000 (0.5%) observations systematically sampled thereafter. Mature and exploitable biomass estimates for each season were converted to a proportion of respective biomass in 1968 (B_0). For the 'Base Case', the 5 000 values for B/B_0 for each year were ranked and the median, 5% and 95% values obtained to provide an estimate of the proportion of mature and exploitable biomass in each year relative to B_0, with a 90% confidence interval (CI). For sensitivity analyses, estimates of mean mature and exploitable biomass for each year were determined from the 5000 samples.

Model Outputs

Outputs from the model included (1) fits to each year of commercial-catch-sampling data and observed CPUE; (2) estimates and posterior distributions of the 42 parameters (including, as presented below, initial recruitment (R_{init}), steepness of the Beverton-Holt stock-recruit relationship (h), natural mortality (M), and annual recruitment deviations (the difference between predicted recruitment and model-estimated recruitment for each of the 38 years; R_{devs})) estimated by the model and (3) median (and 90% CI) values of mature and exploitable biomass from the base case.

Sensitivity analyses

The sensitivity of the base-case model outputs to (1) an alternative CPUE time series; the magnitude of (2) the CPUE and (3) commercial length-frequency observation error; and alternative growth descriptions including; (4) the use of Shnute growth parameters and (5) a 30% increase in growth (as described in the previous assessment (Mayfield *et al.* 2005b), were examined. This was achieved by (1) fitting the model to raw CPUE from 1999 to 2005 as in the previous assessment (rather than 1985 to 2005); (2) setting the observation error on CPUE at zero, as in the previous assessment (rather than at 0.15); (3) setting the effective sample size for commercial length-frequency data to 25 (rather than to 50); (4) describing alternative growth parameter priors (range) (Shape = 3 (1 - 5); β_g = 1 (0.4 – 2); g_1 = 15 (10 - 25) and g_2 = 4 (1 – 8) at Y_1 = 90 mm and Y_2 = 150 mm, respectively); and (5) increasing the growth rate by 30%, as in the previous assessment. In each case, variability in the mature and exploitable biomass estimates during each year (1968 - 2005) were determined using a *McMC* simulation of 1 200 000 model runs from which the first 200 000 runs were discarded and 5 000 (0.5%) observations systematically sampled thereafter. Estimates of mean mature and exploitable biomass for each year were determined from the 5 000 samples, and compared to those estimates obtained from the base-case model.

3.7.3 Model Outputs

Base-case model fits to observed data

The model outputs closely fitted the proportions-at-length from the commercial catch samples (Figure 3.10) and the observed CPUE (Figure 3.11). These fits are of similar quality to those in other abalone fishery models (Worthington *et al.* 2001, Breen *et al.* 2003, Mayfield *et al.* 2005b).

Parameter estimates and posterior distributions

Median estimates of R_{init}, *h* and M were 5 953 293, 0.60 and 0.20, respectively. The base-case model provided information useful to estimation of R_{init}, but was less informative for estimating *h* and M with the estimated median of the posterior very similar to the prior. Despite the general similarity of the medians among the prior posterior, the base-case model did provide information that suggested the reduced probability of high and low values for both *h* and M as described by the prior (Figure 3.12).

The base-case model was also informative in determining the R_{devs}. This was evident both in the temporal patterns in recruitment and in the posterior distributions (relative to the prior) of R_{dev} within years (Figure 3.13). These outputs suggest that annual recruitment was consistently below predicted levels described by the prior during the mid 1970's, with recruitment above average between 1979 – 1991 and 1994 – 1998 and consistently below average from 1999 to 2005.

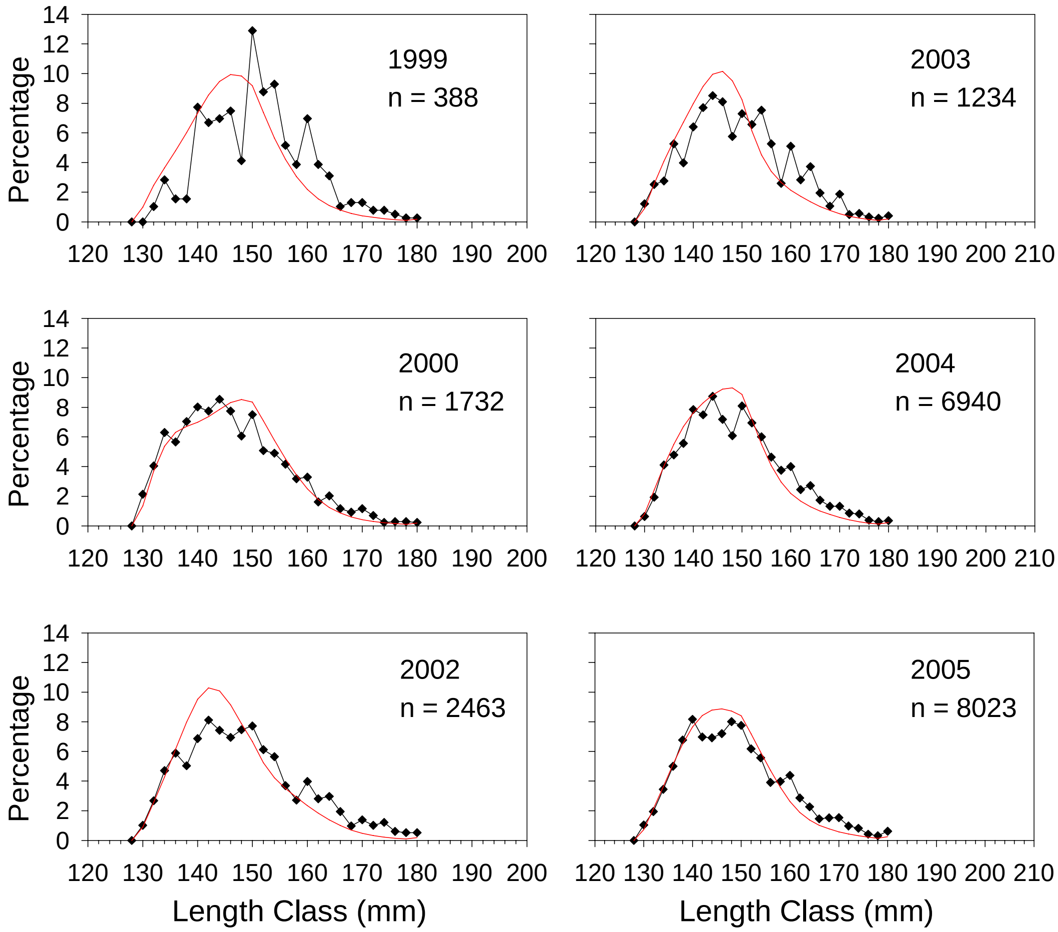

Figure 3.10 Model fit (red lines) to the proportion-at-length observed (black lines) in the commercial catch from 1999 to 2005.

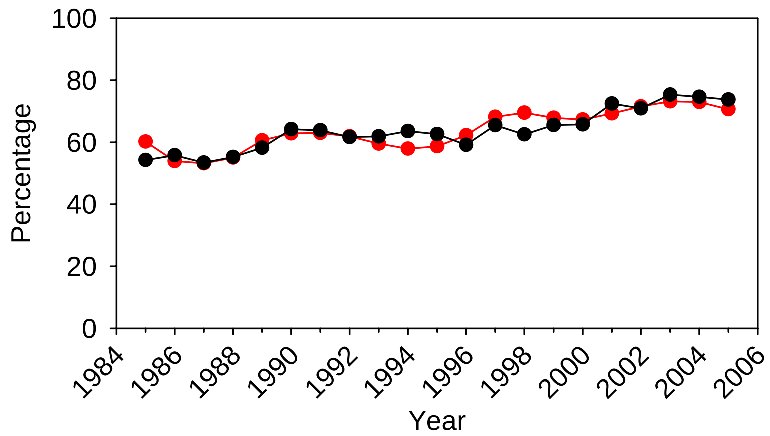

Figure 3.11 Model fit (red line) to raw (observed) (black line) CPUE from 1985 to 2005.

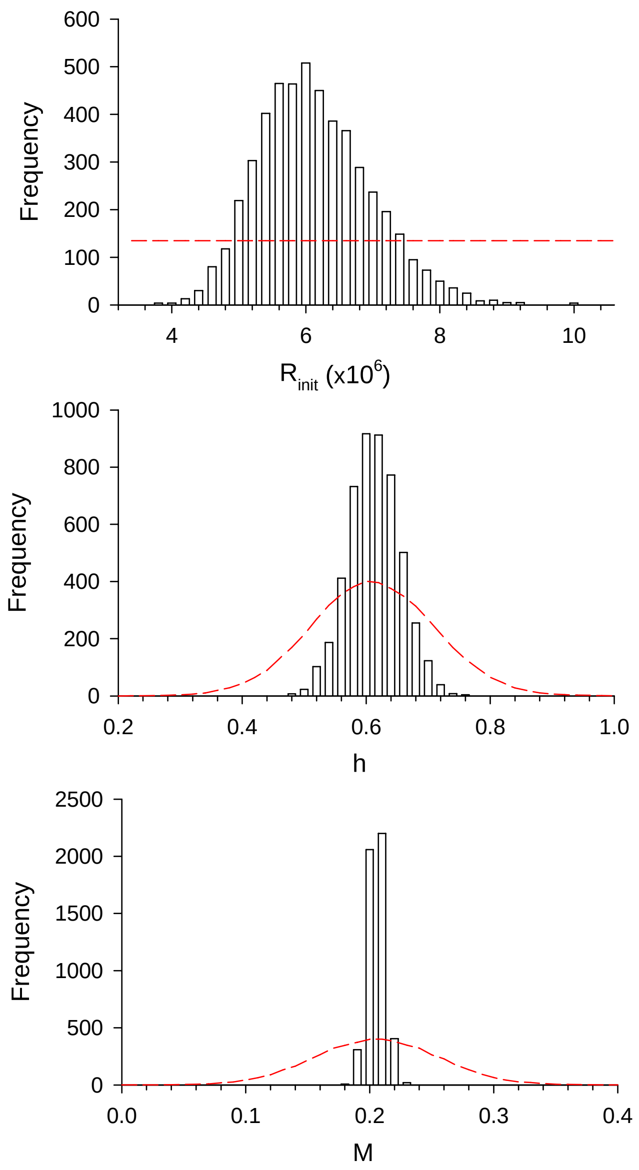

Figure 3.12 Posterior distributions (histograms) of Rinit, h and M, relative to the prior distribution (red lines) obtained from the base-case model.

Temporal patterns in mature and exploitable biomass

Base-case model outputs suggest that mature and exploitable biomass of blacklip declined each year from 1968 (B_0) until 1983 and 1987 respectively, to a point where each had been depleted to 54% and 16% of B_0 (Figure 3.14). The most substantial decline in exploitable biomass occurred between 1970 (86%) and 1971 (49%) as a consequence of the implementation of a 130 mm MLL effectively reducing the biomass available to the commercial fishery by ~30%.

Since the implementation of a TACC (1985) the level of depletion of both mature and exploitable biomass has steadied, relative to rates of depletion prior to 1985. From 1985 to 1999 mature biomass generally increased, whereafter it has declined ~8% to be at 51% of B_0 in 2005 (Figure 3.14, see insert A). Exploitable biomass generally increased since the implementation of a TACC (1985) to 21% of B_0 in 2003. In 2005 exploitable biomass is estimated to be among the highest levels for 20 years (Figure 3.14, see insert B).

Contemporary changes in mature and exploitable biomass are considerably more optimistic and likely to be more indicative of changes in the managed stock (Table 3.2). For example, estimates of mature and exploitable biomass in 2005, relative to B_{1985}, were 96% and 124%, respectively. This illustrates that biomass changes since the introduction of a TACC (1985) have been significantly less than prior to implementation of a TACC, and highlights the need to select an appropriate reference year(s) as a 'benchmark' for assessment of this fishery.

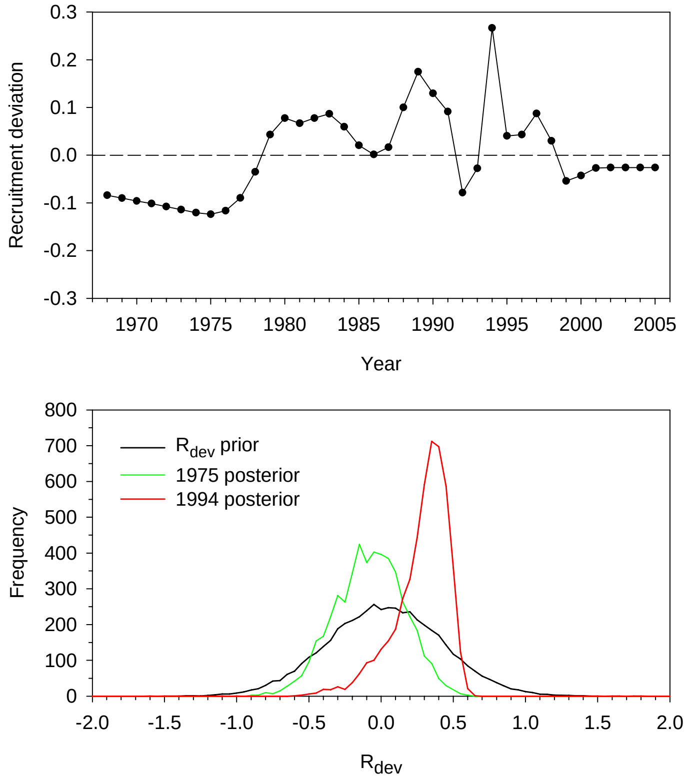

Figure 3.13 Estimated recruitment deviation (R_{devs}) between 1968 and 2005 (top) and posterior distributions (bottom) of R_{devs} in 1975 (green line) and 1994 (red line), relative to the prior distribution (black line), obtained from the base-case model.

Sensitivity analyses

Deviations from the level of depletion of mature biomass described in the base-case model for 2005 ranged from -12 to +27% for the five sensitivity analyses considered (Figure 3.15) and for exploitable biomass, the range was smaller (3 to 18%). When the model was fitted to the shorter CPUE time series and when the observation error on CPUE was reduced, the level of depletion of mature and exploitable biomass in 2005, relative to B_0 (B_{1968}) was 1 – 2% smaller than the base case model. Substantially lower depletion levels (27 – 18%) in mature and exploitable biomass were estimated when alternative (Shnute) growth parameters were used to describe growth. In contrast, reducing the observation error on the commercial length-frequency data and increasing the rate of growth by 30% resulted in a 12% increase in the level of depletion of mature biomass and a 10% and 3% increase in the level of depletion of exploitable biomass, respectively.

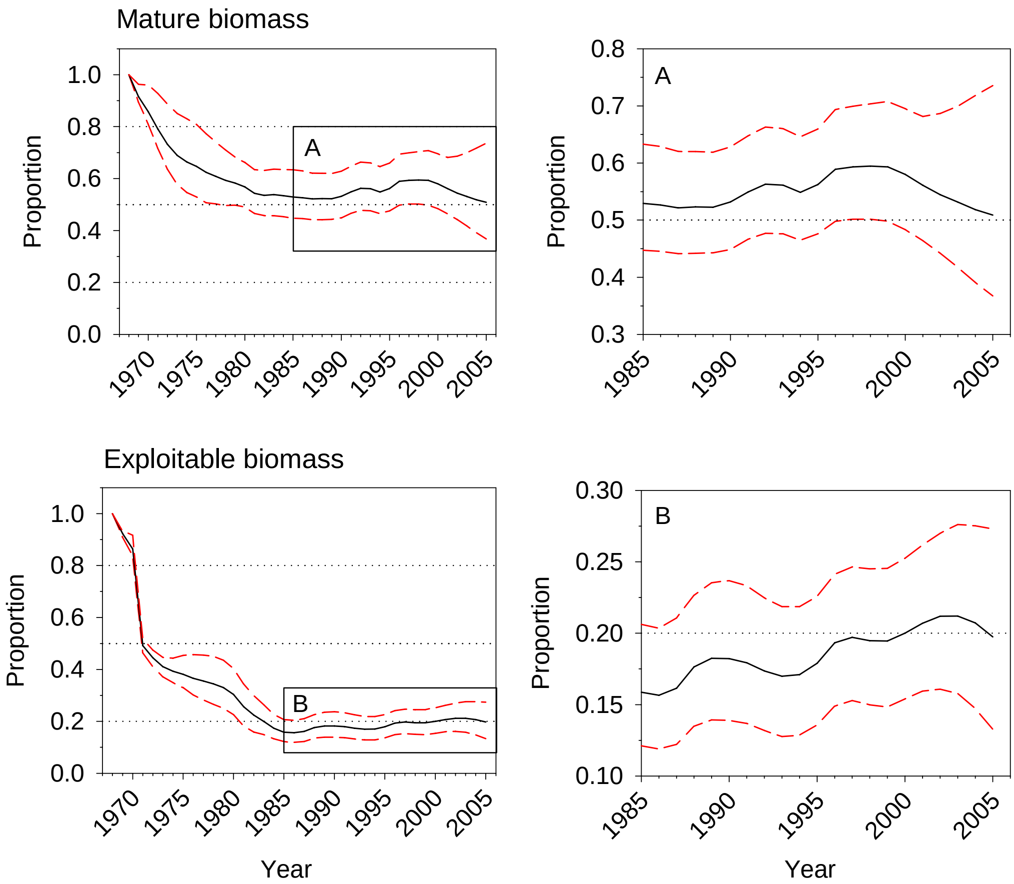

Figure 3.14 Trajectories of mature and exploitable (continuous black line) biomass ± 90% CI (dashed red lines), relative to B_0, obtained from the base-case model from 1968 to 2005. Boxes A and B (from insets) show the last 20 years for each trajectory.

Table 3.2 Median estimates of mature and exploitable biomass, relative to B_0 and B_{1985} obtained from the base-case model from 2000 to 2005.

Fishing season	Mature biomass		Exploitable biomass	
	Median B_t/B_0	Median B_t/B_{1985}	Median B_t/B_0	Median B_t/B_{1985}
2000	0.58	1.10	0.20	1.26
2001	0.56	1.06	0.21	1.30
2002	0.54	1.03	0.21	1.34
2003	0.53	1.00	0.21	1.34
2004	0.52	0.98	0.21	1.31
2005	0.51	0.96	0.20	1.24

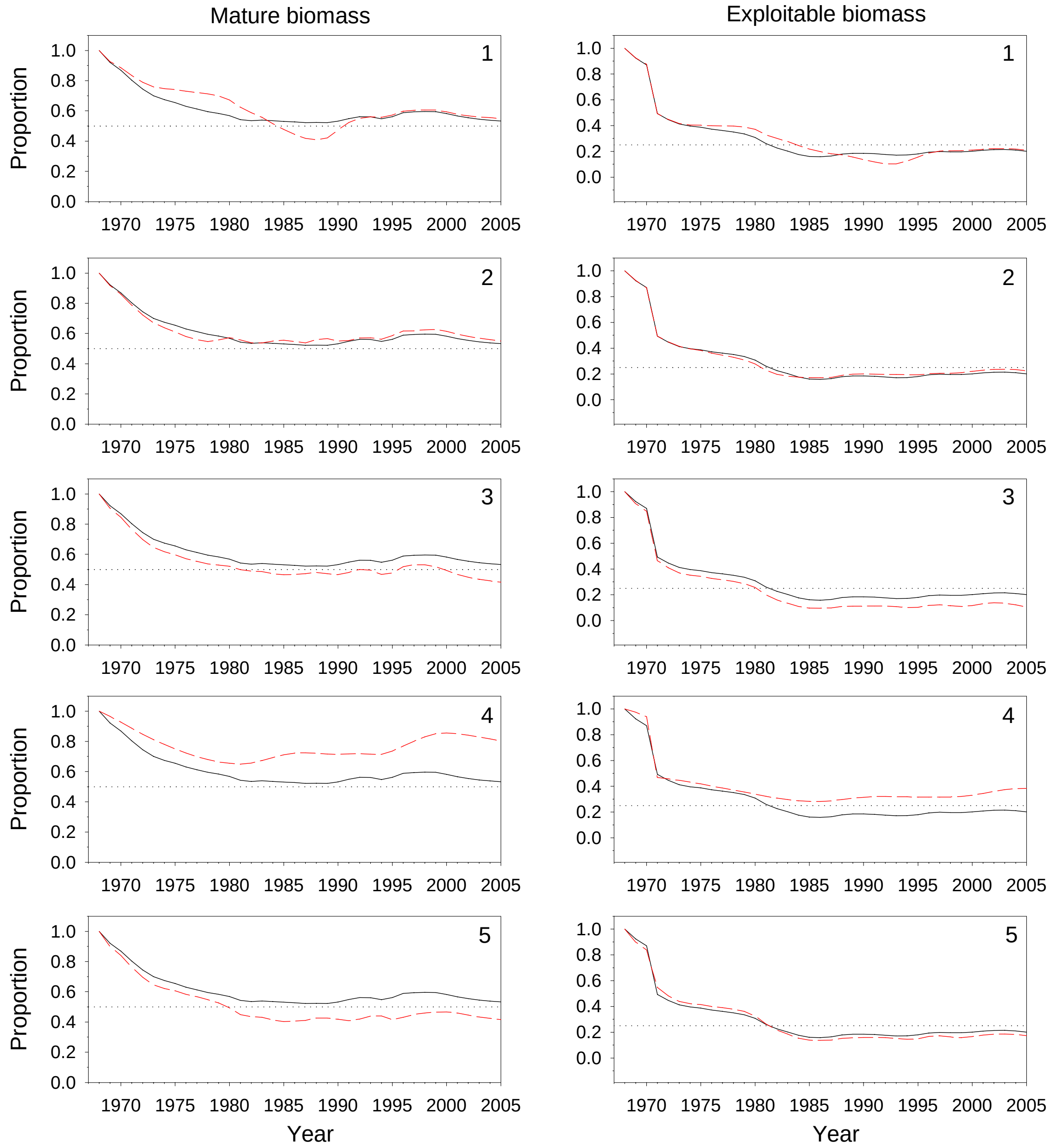

Figure 3.15 Sensitivity (red lines) of the mean mature and exploitable biomass outputs from the base-case model (black lines) to (1) fitting the model to raw CPUE from 1999 to 2005 (rather than 1985 to 2005); (2) setting the observation error on CPUE at zero (rather than at 0.15); (3) setting the observation error on commercial length-frequency data to 25 (rather than to 50); (4) change to alternative growth parameters (Shnute) and (5) increasing the growth rate by 30%. Dotted lines are for reference and set at 50% for mature biomass and 25% for exploitable biomass.

4. PERFORMANCE INDICATORS

This section provides a report on the performance of the fishery against the performance indicators (PI) for Region A as defined in the Management Plan and documented in Tables 1.4 and 1.5 (Section 1.3). Significant difference in inter-annual change was determined using *t*-tests ($\alpha = 0.05$ or 0.01). Significant difference over the last 5 years was determined by ANOVA of regression ($\alpha = 0.05$) as described in the Management Plan (Nobes *et al.* 2004).

Commercial logbooks from all licence holders for the period ending 31 December 2005 were received and the data entered into the database.

4.1 Greenlip abalone

There are 112 biological PI specified for greenlip abalone in Region A. Of these, 102 are addressed in this report. The remaining ten PI (diver assessment of stock status (in fishing areas 4, 5, 8, 9, 14, 18 and 19); harvest discard; illegal catch; and recreational catch) are addressed in other reports submitted to PIRSA Fisheries.

Data are available to assess fishery performance against 81 of the 102 (79%) PI to be addressed in this report. Thirty six of these 81 PI (44%) have triggered (Table 4.1; Appendix 5). Of these, 18 (50%) may be considered positive for the fishery.

Fishing effort on greenlip has decreased significantly from 2 608 hr (2001) to 2 138 hr (2005) over the last five years.

Mean daily catch increased significantly in fishing areas 5 and 9 between 2004 and 2005, and in fishing areas 9, 14, 18 and 19 over the last five years (2001 – 2005). In contrast, mean daily catch decreased significantly in fishing area 8 between 2004 and 2005, and in fishing area 4 over the last five years (2001 – 2005).

In fishing areas 5 and 9 the mean daily effort increased significantly between 2004 and 2005. Mean daily effort has decreased significantly in fishing area 4 since 2001, but increased significantly in fishing areas 8, 9 and 18 over the same period.

CPUE increased significantly in fishing area 18 and decreased significantly in fishing area 8 between 2004 and 2005. CPUE increased significantly in five fishing areas between 2001 and 2005 (5, 9, 14, 18 and 19).

The mean size of greenlip in the commercial catch decreased significantly in fishing area 5, 8 and 18 between 2004 and 2005.

Estimates of egg production in fishing area 9 and 18 were 27.8% and 46.5% of ‘unfished’ levels respectively. The trigger point was exceeded for both areas as the level was less than 50%.

The abundance of greenlip abalone larger than L_{50}, the length at which 50% of individuals were sexually mature decreased significantly between 2004 and 2005 at Pearson Island and 'The Gap'. However the abundance of greenlip larger than L_{50} increased significantly at Ward Island between 2001 and 2005.

Legal-sized greenlip abundance increased significantly between 2004 and 2005 at Ward Island, but decreased significantly at Pearson Island and 'The Gap' over the same time period. Between 2001 and 2005, legal-sized greenlip abundance increased significantly at Ward Island and 'The Gap'. Sub-legal-sized greenlip abundance declined significantly between 2001 and 2005 at 'The Gap'.

4.2 Blacklip abalone

There are 125 biological PI specified for blacklip in Region A. Of these, 114 are addressed in this report. The remaining eleven PI (diver assessment of stock status (in fishing areas 4, 5, 6, 8, 9, 11, 12, 13, and 14); harvest discard; illegal catch; and recreational catch) are addressed in other reports submitted to PIRSA Fisheries.

Data are available to assess fishery performance against 69 of the 114 (61%) PI to be addressed in this report. Twenty-two of these 69 PI (32%) have triggered (Table 4.2; Appendix 6). Of these, twelve (57%) may be considered positive for the fishery.

The proportion of the TACC harvested from fishing areas 6 and 18 declined from 8.3 and 7.6% (2004) to 7.7 and 3.7% (2005), respectively. In addition, the proportion harvested from fishing areas 4 and 13 increased from 6.7 and 6.8% (2004) to 9.1 and 9.0% (2005), respectively. This resulted in a change to the order and composition of the five most important fishing areas, by catch, between 2004 and 2005.Fishing effort on blacklip has decreased significantly from 3 436 hr (2001) to 3 189 hr (2005) over the last five years.

Mean daily catch increased significantly in fishing areas 9 and 12 between 2004 and 2005, and in fishing areas 6, 8, and 9 over the last five years (2001 – 2005).

In fishing areas 5, 9 and 12 mean daily effort increased significantly between 2004 and 2005. Mean daily effort has also increased significantly in fishing areas 6 and 9 since 2001.

CPUE increased significantly between 2001 and 2005 in fishing areas 8 and 9.

The mean size of blacklip abalone in the commercial catch increased significantly in fishing areas 5, 9, 11 and 14 between 2004 and 2005. However, it declined significantly in fishing areas 4, 6, 8 and 12 over the same time period.

Table 4.1 Assessment of the performance of the greenlip fishery in Region A and fishing areas 4, 5, 8, 9, 14, 18 and 19 against the performance indicators prescribed in the management plan (inter-annual: 2004 – 2005; 5-year trend: 2001 – 2005).

Performance indicator	Temporal scale	Region A	4	5	8	9	14	18	19
Commercial catch	Annual								
Spatial distribution of catch	Inter-annual								
Commercial effort	5-year trend								
Mean daily catch	Inter-annual								
	5-year trend								
Mean daily effort	Inter-annual								
	5-year trend								
CPUE	Inter-annual								
	5-year trend								
Mean size	Inter-annual								
	5-year trend								
Egg production/pristine	Annual								

Performance indicator	Temporal scale	Ward Island	Flinders Island	Hotspot	Pearson Island	Point Avoid	The Gap
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

Table 4.2 Assessment of the performance of the blacklip fishery in Region A of the Western Zone and fishing areas 4, 5, 6, 8, 9, 11, 12, 13 and 14 against the performance indicators prescribed in the Management Plan (inter-annual: 2004 – 2005; 5-year trend: 2001 – 2005).

Performance indicator	Temporal scale	Region A	4	5	6	8	9	11	12	13	14
Commercial catch	Annual										
Spatial distribution of catch	Inter-annual										
Commercial effort	5-year trend										
Mean daily catch	Inter-annual										
	5-year trend										
Mean daily effort	Inter-annual										
	5-year trend										
CPUE	Inter-annual										
	5-year trend										
Mean size	Inter-annual										
	5-year trend										
Egg production/pristine	Annual										

Performance indicator	Temporal scale	Reef Head	Talia	Sheringa	Ward Island	Point Labatt
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 Data available to assess the fishery

Extensive information and data are available to aid assessment of the abalone stocks in Region A. This includes (1) a well documented history and management of the fishery, (2) a broad suite of performance indicators, (3) fine-scale catch and effort data from 1968 to 2005, (4) data from commercial-catch sampling, (5) long-term, fishery-independent surveys on greenlip at six sites, and (6) outputs from three models: a GLM to standardise CPUE, a simple egg-production model and a length-based, Bayesian stock assessment model for blacklip. In addition, the expansion of fishery-independent surveys to areas supporting relatively low levels of greenlip catch and to areas supporting high levels of blacklip catch will continue to support robust assessment of abalone stocks in this fishery.

As in all fishery assessment reports, the available data and information are used within the limitations governed by their level of uncertainty. The quality of the catch and effort data for the abalone fishery in Region A is poorly understood. In addition, there are few data on the magnitude of the illegal and recreational catches from this Region. This prevents reliable estimation of the total catch and, hence, impedes assessment of the fishery.

Data and information for assessment of greenlip are well balanced among those provided by commercial fishers (*e.g.* catch and effort and catch-sampling data), that collected by SARDI Aquatic Sciences (*i.e.* biological and fishery-independent survey data) and outputs from two models. In contrast, assessment of blacklip is heavily weighted by the interpretation of commercial catch and effort data. Data from fishery-independent surveys implemented at five sites (Point Drummond, Sheringa, Hotspot, Ward Island and Highcliff), ongoing collection of relevant biological data and outputs from a range of developing numerical models will augment future assessments for this species.

Analyses on the catch data provide useful information on the spatial and temporal distribution of catch within individual fishing areas within fishing zones (Mayfield *et al.* 2005b, 2005c), and hence their catch histories. Changing patterns in the spatial and temporal distribution of catch and effort are often difficult to interpret because fishers may move among areas to maintain, or increase, their expected levels of catch in response to changes in abalone abundance, or through a change in diver behaviour that is unrelated to fluctuations in stock abundance. Such behaviour could include responses to technological changes in the fishing fleet (*e.g.* the trend to larger vessels) that could restrict the number of access points along the coast. This could be reflected through increased and decreased levels of catch in 'more accessible' and 'less accessible' fishing areas, respectively.

Here, we have also used CPUE to assess stock status. The use of CPUE is based on the assumption that change in CPUE reflects changes in the size of the fishable stock (Tarbath *et al.* 2002, 2003, 2005). CPUE can be strongly influenced by numerous factors, including changes in abalone abundance, diver behaviour and technology, and is often viewed as a biased index of changes in abalone abundance (Harrison 1983, Breen 1992, Prince & Shepherd 1992, Gorfine *et al.* 2002). For example, catch rates may remain high as a result of re-aggregation of abalone, thereby masking fluctuations in population size arising from local depletion (Officer *et al.* 2001a, 2001b).

In this assessment, the difficulties in interpreting the effort and CPUE data are further complicated by the necessity to apply a decision rule when calculating the level of 'directed effort' and, hence, CPUE on each species. While this approach has been used in both Regions of this Zone for several years, the appropriateness of this decision rule requires scrutiny. For example, this approach assumes that no effort is expended on the alternative species for each day where the target species consists of at least 50% of the total catch. This approach needs review, not only for interpreting the CPUE but also because temporal patterns in CPUE have significant influence on the outputs of the integrated, length-based stock assessment model (section 3.7). An alternative approach may be to apportion daily effort in direct proportion to the catch of each species on a day, although this necessitates the assumption that equal fishing effort is required to catch each species.

Less than 2% of the commercial catch was measured during 2005. These data are unlikely to be representative of either the catch from the major fishing areas or the abalone populations in this Region. The lack of robust, commercial length-frequency data to reliably detect and quantify significant temporal changes in the mean length, modal length class and the length-frequency distribution of commercially fished abalone, substantially increases the uncertainty and limits the assessment of stock status in this Region. This is because these data are important given the difficulties associated with using CPUE as a relative index of abundance that were described above.

Changes in the length structure of abalone in the commercial catch can provide information to assess the status of the stock. For example, initial reductions in the length structure over a short number of years followed by progressively larger abalone may indicate that there has been a strong pulse of recruitment to the fishery. However, more long-term reductions in the mean length or modal length class combined with the absence of large abalone contributing to the commercial catch may indicate that the fishery is becoming more reliant on smaller individuals and is moving towards a less sustainable position (Andrew *et al.* 1997). Moreover, the length-frequency distribution of the commercial catch varies among areas, divers and diving days for individual divers. Thus, sampling at spatial and temporal scales representative of the fishery is required to reliably detect and quantify changes. To determine a representative sampling regime (*i.e.* the number of abalone to measure from different divers at different times of year for each fishing area) requires a robust cost-benefit analysis. Andrew *et al.* (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 relevance of this approach to developing a more robust commercial-catch sampling program in Region A should be evaluated.

Three models were used to aid assessment of the stocks. These were (1) a generalised linear model (GLM; (Mayfield *et al.* 2003) that standardised the catch and effort data, (2) a simple egg-production model that estimates egg production each year, and (3) an integrated, length-based, stock assessment model (Gorfine *et al.* 2005), for blacklip abalone. Each model combines multiple data sets from a variety of sources. However, like most models, the outputs have considerable levels of uncertainty.

Uncertainty in the outputs of the GLM and egg production model are well documented and arise primarily from the absence of information on historical changes in technology or diver behaviour (Mayfield *et al.* 2005b) and (1) the wide range of biological data required to run the models (including growth rates and their representation of population dynamics of exploited stocks) and (2) estimating fishing mortality (F) from shell samples (Parrack & Cummings 2003).

This is the second year in which an integrated, length-based stock assessment model (Gorfine *et al.* 2005) has been used to aid assessment of blacklip stocks in Region A. This model, that has been developed specifically for the assessment of abalone populations, provides significant potential to assess the blacklip stocks in this region. Moreover, variations to this model have been developed and applied to aid assessment of blacklip stocks in the South Australian Southern (Mayfield *et al.* 2005d) and Central (Mayfield *et al.* 2005a) Zone abalone fisheries. However, this model is still being developed and initial sensitivity analyses suggest estimates of current levels of biomass depletion are sensitive to moderate alterations to defining parameters. and to the limited series of many of the input data sets. Improvements to the application of the model in this Region in 2006 include a review of the prior distributions for a number of parameters, improved diagnostics to determine model fit, the re-evaluation of input data defining some parameters and fitting the model to a longer time series of available CPUE data.

Despite these changes, the level of precision in the outputs is limited not only by the short time series of the data being fitted but also the absence of data from fishery-independent surveys. Reliability of the outputs is also strongly influenced by growth rate, the model's reliance on

CPUE, the degree to which the biological data reflect blacklip abalone populations in the Zone and the spatial scale at which the model was applied. Hence, current outputs from the model may not be representative of the status of the stock – with refinement of the model, and the data used in future years possibly changing the model outputs considerably.

5.2 Status of the fishery in Region A

5.2.1 Greenlip abalone

The assessment of greenlip stocks in 2005 (Mayfield *et al.* 2005b) suggested that they were in one of the strongest positions for several years. The greenlip TACC was increased from 207 t to 227.7 t from 2006 (*i.e.* 2006 calendar year). As this report only considers data to the end of the 2005 fishing season, data to assess the potential impacts of the change in the TACC for greenlip in 2006 are not yet available.

Current assessment of the stocks is more equivocal. Much of the data continue to support the conclusion that the stocks are being fished within sustainable limits Mayfield *et al.* (2005b). These are: (1) stable total catch, with the TACC being caught in each year since it's implementation; (2) significant increases in mean daily catch since 2001 in fishing areas 9, 14, 18 and 19, coinciding with (3) significant increases in CPUE in these areas; (4) long-term reductions in 'directed effort' including a decline of >40% from 1986-1990 to 2001-2005 to the lowest level since the TACC was implemented; (5) a significant decline in 'directed effort' since 2001; (6) raw CPUE in 2005 was the highest since at least 1979; (7) raw CPUE in fishing areas 4, 5, 8, 9, 14, 18 and 19, that contribute >85% of the TACC, were at or among the highest levels since 1979; (8) standardised CPUE in Region A was among the highest levels since 1979 and, in fishing areas 9 and 18, was at the highest levels since 1979; (9) large mean length and modal length class of commercial shells in the Region that exceeded the MLL by >20 and >15 mm SL, respectively; (10) large mean lengths and model length classes in many fishing areas; (11) no indication of 'knife edge' fishing in any of the fishing areas sampled; (12) a significant increase in the abundance of legal-sized greenlip at Ward Island between 2004 and 2005 and since 2001; and (13) a significant increase in the abundance of legal-sized greenlip at 'The Gap' since 2001.

In contrast, information from other data that includes: (1) the continued high concentration of fishing effort within few fishing areas; (2) significant declines in the mean length of commercial shell samples in 3 fishing areas (5, 8 and 18) between 2004 and 2005; (3) recent decreases in CPUE in fishing areas 4, 8 and 14; (4) estimates of retained egg production in fishing areas 9 and 18 at < 50%; (5) declines in the abundance of legal-sized greenlip at Pearson Island and 'The Gap'; and (6) a decrease in the abundance of sub-legal-sized greenlip at 'The Gap' suggest that the resource may have weakened in some fishing areas between 2004 and 2005.

Total catch of greenlip was at its highest level in 1968, declined significantly into the early 1970's and fluctuated substantially over periods of 4-5 years until the mid 1980's. Since the introduction of a TACC in 1985 the total catch of greenlip has been stable. The TACC in 2005 was 207 t (shell weight), and less than half the mean catch from 1968 to 1984.

Prior to, and immediately after the increase in the MLL (1984) and the introduction of a TACC (1985), catches of greenlip were more evenly obtained from throughout Region A, with <20% being harvested from any one fishing area. Over the subsequent 20-year period, the spatial distribution of the catch has changed substantially, to the extent that since 2001, >70% of the TACC has been harvested from four fishing areas (5, 8, 9 and 18). Since 1985, catches have declined in twelve, remained stable in four and increased in two fishing areas. Catches from eight of the twelve fishing areas have declined to almost the lowest levels on record. In contrast, the catch from fishing area 9 has doubled over the last 20 years with current catches among the highest since 1984. Insufficient data are available to determine if the current level of catch from fishing area 9 is sustainable.

Long-term temporal changes in the level of catch from individual fishing areas may be explained by each of at least two hypotheses: (1) changing patterns of catch may reflect altered fisher behaviour unrelated to the abundance of greenlip or; (2) that the (i) uneven distribution of catch among the 18 fishing areas and approximately 120 map codes comprising Region A, and (ii) substantial declines in catches in several previously-productive areas reflect a reduction in the abundance of greenlip in this Region (Shepherd & Rodda 2001, Shepherd *et al.* 2001). Fishery-independent data to begin to address the dichotomy between these hypotheses are a high priority because the current status of the greenlip abalone stocks in the 'lightly-fished' areas is poorly understood.

Since 1991 the majority of the catch has been harvested in January. This trend has continued and increased through to 2005. In combination, (1) the lower meat weights from individual abalone (Rodda & Mayfield 2002) and (2) the high level of catch harvested in January requires an estimated additional catch of ~10 500 individuals (4%) and represents a considerable reduction in the potential productivity of the fishery.

The five year average 'directed effort' from 1989 – 1993 to 2001 – 2005 has declined by 23% and by 18% between 2001 and 2005, with the level of 'directed effort' in 2005 (2 138 hrs) being the lowest since 1979. These reductions in 'directed effort' suggest that greenlip abalone abundance has increased.

Stable catches, in conjunction with decreases in effort, result in increases in CPUE. The CPUE on greenlip has increased significantly since 1996, and in 2005 was at the highest level since 1979. Similar patterns were observed in most of the main fishing areas, although small declines were observed in fishing areas 4, 8 and 14, between 2004 and 2005. Despite this reduction, levels of CPUE in these areas is still among the highest since 1979. These data, and in particular their spatial and temporal consistency, suggest that stock abundance has increased during recent years.

This conclusion was also supported by the temporal patterns in standardised CPUE which, having increased significantly since 1996, generally imitate those of the raw CPUE. Similar increases in standardised CPUE were also evident in fishing areas 9 and 18, from which >50% of the greenlip abalone TACC has been harvested over the last five years. These patterns suggest that (1) substantial increases in effective fishing effort have not occurred in this fishery over the last decade, and (2) that the densities of abalone in local populations being fished has increased.

There was no evidence of ‘knife-edged’ fishing during 2005. The mean length of the samples from each fishing area was >10 mm above than the MLL (145 mm SL). A similar pattern was observed in the modal length classes where it was >5 mm above than the MLL. However, the mean length of commercial shells in 2005 was significantly smaller in fishing areas 5, 8 and 18, when compared with those in 2004.

In 2005, the legal size structure of greenlip populations is not reliably represented in the majority of fishing areas due to the low sample size obtained from the commercial catch. Moreover, the methodology used to obtain estimates of the length frequency distribution from the commercial catch requires improvement as regular, unbiased estimates of length structures, through time, is essential for the reliable assessment of greenlip stocks in all fished areas. For example, commercial fishers could aim to measure each abalone from the first bag harvested on each day of fishing in each area fished.

Data from fishery-independent surveys indicate that fluctuations in the abundance of greenlip are not consistent among sites and reinforce the need to maintain spatially representative sampling. Surveys at Hotspot, Pearson Island and ‘The Gap’ over the last decade show that the abundances of all and legal-sized greenlip have increased substantially. Similar levels of increase in the abundance of sub-legal-sized greenlip at Hotspot and legal-sized greenlip at Ward Island were also evident. More recently (2001 – 2005) the abundance of sub-legal-sized greenlip at Ward Island and legal-sized greenlip at Ward Island and 'The Gap' and have increased significantly, with that at Ward Island increasing by more than 50%.

In contrast, the abundance of sub-legal-sized greenlip has declined significantly at Point Avoid since 1989, and were low, relative to historical levels, at Ward Island, Pearson Island and ‘The Gap’ during more recent surveys. Moreover, within the last year (2004 – 2005) the abundance of all, legal-sized and sub-legal-sized greenlip has declined at all sites with the exception of Ward Island.

Of the 81 performance indicators assessed for greenlip, 36 triggered, of which 18 (50%) did so in a positive direction. In addition, a substantial percentage (47%) of the performance indicators that triggered indicated significant changes between 2004 and 2005, rather than over the last five years (*i.e.* 2001-2005). This highlights the challenge of interpreting performance indicators at multiple temporal scales that are not hierarchically structured.

In summary, while much of the data continue to support the conclusion that greenlip stocks are in a generally healthy state and being fished within sustainable limits, some data do not support the persistence of this trend. Thus, the continued concentration of effort, the length structure of the population described from commercial shell samples, changes in CPUE and fishery-independent measures of abundance warrant careful monitoring over future years.

5.2.2 Blacklip abalone

Assessment of blacklip stocks in 2005 is more challenging than for greenlip because, despite blacklip comprising ~60% of the total abalone TACC, data and information are more limited. For example, there are no data from commercial catch sampling prior to 1999 and there is insufficient information from fishery-independent surveys (*i.e.* one year of available data) to reliably contribute to the current assessment.

The data available generally suggest that blacklip stocks are being fished within sustainable limits, providing numerous lines of evidence to support the conclusion that these stocks have remained stable, or have increased over recent years. These are: (1) stable total catch with the TACC being caught in each year since it's implementation; (2) increases in mean daily catch since 2001 in fishing areas 6, 8, and 9, (3) 'directed effort' has declined each year since 1998 and significantly since 2001; (4) 'directed effort' in 2005 (3 189 hrs) was at the lowest level since 1981; (5) raw CPUE in the Region and in 5 major fishing areas (4, 5, 6, 9 and 11) was at or among the highest levels since 1985; (6) increases in CPUE in fishing areas 8 and 9 since 2001; (7) increases in standardised CPUE in Region A and fishing area 9 between 2001 and 2005; (8) large mean length and model length class of the commercial catch, that both exceeded the MLL (130 mm SL) by >15 mm SL, (9) significant increases in mean length between 2004 and 2005 in fishing areas 5, 9, 11 and 14; (10) the relatively high estimates of retained egg production in fishing areas 9 and 11; and (11) the triggering of 12 of the 22 (55%) PI that triggered in a positive direction.

In contrast, data supporting the alternative conclusion (*i.e.* that the stocks may have declined in some areas) include (1) sharp declines in catch from fishing areas 10, 15 and 18 in recent years; (2) decreases in standardised CPUE between 1993 and 2000 and since 2001 in fishing area 11 and since 2003 in the Region; (3) a significant reduction in the mean length of the commercial catch in fishing areas 4, 6, 8 and 12 between 2004 and 2005; (4) evidence of ‘knife-edged’ fishing in fishing area 12 in 2005; and (5) the triggering of 10 of the 22 (45%) PI that triggered in a negative direction.

Total catch of blacklip declined significantly from 1968 to 1977 and increased substantially from the mid 1970's to the early 1980's. Since the introduction of a TACC in 1985 the total catch of blacklip has been stable. The TACC in 2005 was 293 t (shell weight). This is about 30% greater than the mean catch from 1968 to 1984. However, the catch is obtained from a broad range of fishing areas distributed throughout the Region. Notably, since 2001, an average of >5% of the TACC was harvested from each of nine fishing areas.

Since the implementation of a TACC, catches have generally increased in three, decreased in two and varied among years without indication of any long-term trend in 13 fishing areas. The catch from fishing area 9 has more than doubled over this period, with current catches among the highest since at least 1979. Insufficient data are available with which to determine if the current level of catch from fishing area 9 is sustainable. More recently, catches from fishing areas 10, 15 and 18 have declined substantially, while catch from fishing area 5 has increased markedly. The reasons for these large changes over relatively short periods of time are poorly understood, and should be investigated and documented.

Total ‘directed effort’ has declined by 20% since 1989 and by 7% between 2001 and 2005. In 2005 the level of 'directed effort' (3 189 hrs) was the lowest since 1981. These reductions in ‘directed effort’, in concert with a constant TACC, and assumed unchanged catchability, suggest that blacklip abundance has increased, particularly more recently.

Stable catches associated with decreasing effort result in increases in CPUE. The CPUE on blacklip has increased significantly since 1979, and was at its highest level in 2005. Similar patterns were observed in most of the main fishing areas. Small reductions in CPUE have, however, been observed in fishing areas 4 and 5 over recent years. Despite these declines, the CPUE in 2005 in these areas was near the maximum observed levels. These data suggest that stock abundance has increased during recent years.

The inference that abundance has increased was also supported by the temporal patterns in standardised CPUE, which increased substantially between 2000 and 2005. This was also evident in fishing area 9. In contrast, the standardised CPUE in fishing area 11 declined between 1993 and 2000 and from 2001 to 2005, suggesting that the abundance of blacklip abalone in this fishing area has declined over recent years.

The only evidence of knife-edged fishing on blacklip abalone during 2005 was in fishing area 12. This was evidenced by the right-skewed length-frequency distribution of the commercial catch sample – indicating a reliance on harvesting abalone close to the MLL, and the small mean length and modal length class in comparison with other fishing areas. The mean length of samples from each remaining fishing area was >10 mm above than the MLL (130 mm SL) and, in four fishing areas was >20 mm above the MLL. A similar pattern was observed in the modal length classes that were >10 mm greater than the MLL. Despite these broad patterns, the mean length of commercial shells in 2005 was significantly smaller in fishing areas 4, 6 8 and 12 when compared with those in 2004.

Of the 114 performance indicators assessed for blacklip 22 triggered, of which 12 (55%) did so in a direction that would be considered positive for the fishery. As with greenlip, the majority (59%) of the performance indicators that triggered indicated significant changes between 2004 and 2005, rather than over the last five years (*i.e.* 2001-2005). Again, the triggering of substantial proportions of these inter-annual performance indicators increases the difficulties in providing unambiguous assessment of these stocks.

Despite the limited series of data to assess the stocks of blacklip, general patterns in much of the data presented support the conclusion that they are being fished within sustainable limits. This conclusion was supported by multiple lines of evidence. However, other data, that do not support the persistence of this trend, notably in fishing areas 11 and 12, warrant careful monitoring over future years. Additional commercial shell samples, in conjunction with fishery-independent surveys and ongoing development of numerical models for this fishery, will provide additional information with which to assess blacklip stocks in future years.

5.3 Future research needs

The two most important research objectives in Region A are to (1) examine, expand and regularly undertake fishery-independent surveys of blacklip populations and (2) address the dichotomy between the two hypotheses for the observed changes in the spatial and temporal distribution of the greenlip catch.

Fishery-independent surveys of blacklip populations were initiated in 2005. The methodology developed to obtain estimates of absolute abundance need to be tested and expanded, and then conducted on a regular basis (Andrew 1996). This will provide fishery-independent data to determine changes in the abundance and population structure of blacklip in the Western Zone and permit assessment of the performance of the fishery against several of the performance indicators that are specified in the Management Plan, that is currently not possible.

Addressing the dichotomy between the hypotheses proposed for the observed changes in the distribution of greenlip catch is central to understanding the status of the greenlip stocks in the 'lightly-fished' areas, the appropriate level of the greenlip TACC and concerns (Shepherd & Rodda 2001, Shepherd *et al.* 2001) regarding the potentially poor status of this resource. Four approaches, including examination of catch, effort and CPUE data at different spatial scales, acquisition of information on changes in fishing practices, ‘test-fishing’ (after Dixon *et al.* 2004, Carlson *et al.* 2006) and fishery-independent surveys are processes by which this issue can be addressed.

Future assessment of this fishery will be enhanced by (1) reviewing the decision rule used in determining CPUE on each of the two species, (2) expanding the collection of commercial shell samples to ensure they are representative of the scale of the fishery, (3) refining the biological data, including their representation of population dynamics of exploited stocks, and model parameters, and thus the estimates of egg production, and mature and legal biomass from the egg production model and the stock assessment model, respectively and (4) refining the performance indicators and defining stock status target levels and reference points for future years.

Subsequent assessments would also benefit from (1) improved estimates of the recreational and illegal catch, and (2) assessing the direct and indirect effects on the ecosystem arising from the harvest of abalone in this Zone. These issues could be addressed by (1) undertaking regular (*e.g.* biennial) creel surveys, (2) improving estimates of illegal catch obtained from illegal detection and obtaining length-frequency measurements from seized illegal catch, and (3) ecosystem-based surveys in fished and un-fished areas coupled with manipulative field experiments to test hypotheses regarding the potential effects of abalone fishing. The latter issue is central to the development of environmental and ecological performance indicators that can be reported against in future stock assessment reports

6. REFERENCES

Andrew N, Worthington D, Brett P (1997) Size-structure and growth of individuals suggest high exploitation rates in the fishery for blacklip abalone, *Haliotis rubra*, in New South Wales, Australia. Molluscan Research 18:275-287

Andrew NL (1996) Review of the South Australian Abalone Research and Management Plan., Report to PISA.

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

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

Beverton RJH, Holt SJ (1957) On the dynamics of exploited fish populations. Ministry of Agriculture, Fisheries and Food, Fisheries Investigations, UK Series 2:19

Breen PA (1992) A review of models used for stock assessment in abalone fisheries. In: Shepherd SA, Tegner MJ, Guzmán Del Próo SA (eds) Abalone of the world: biology, fisheries and culture. Blackwell, Oxford, p 253-275

Breen PA, Kim SW, Andrew NL (2003) A length-based Bayesian stock assessment model for the New Zealand abalone *Haliotis iris*. Marine and Freshwater Research 54:619

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

Brown LD, Murray ND (1992) Genetic relationships within the genus Haliotis. In: Shepherd SA, Tegner MJ, Guzmán Del Próo SA (eds) Abalone of the World, Biology, Fisheries and Culture

Carlson IJ, Mayfield S, McGarvey R, Dixon CD (2006) Exploratory fishing and population biology of greenlip abalone (*Haliotis laevigata*) off Cowell, Report for PIRSA. SARDI Aquatic Sciences Publication No. RD04/0223-2. SARDI Research Report Series No. 127

Day RW, Shepherd SA (1995) Fisheries biology and ecology of abalone: An introduction. Australian Journal Marine Freshwater Research 46:3-5

Dixon CD, Mayfield S, McGarvey R (2004) Exploratory fishing and population biology of green lip abalone (*Haliotis laevigata*) off Cowell. Report No. RD04/0166, Report to PIRSA. SARDI Aquatic Sciences Report Series No. RD04/0166

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

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

Geiger DL (1999) Distribution and biography of the recent Haliotidae (Gastropoda: Vetigastropoda) world-wide. Bolletino Malacologico 35:57-120

Gorfine H, Taylor B, Cleland M, Haddon M, Punt A, Worthington D, Montgomery I (2005) Development of a spatially-structured model for stock assessment and TAC decision analysis for Australian Abalone Fisheries. Report No. 1999-116, Final Report to Fisheries Research and Development Corporation. Project No. 1999-116. Primary Industries Victoria, Queenscliff.

Gorfine HK, Taylor BT, Smith DC (2002) Abalone - 2001. Report No. 43, Fisheries Victoria Assessment Report No. 43 (MAFRI, Queenscliff).

Hancock B (2000) Genetic subdivision of Roe's abalone, *Haliotis roei* Grey (Mollusca: Gastropoda) in south-western Australia. Marine and Freshwater Research 51:679-687

Harrison AJ (1983) The Tasmanian abalone fishery. Tasmanian Fisheries Research 26:1-42

Henry GW, Lyle JM (2003) The National Recreational and Indigenous Fishing Survey. Report No. 99/158, Final Report to FRDC (Project 99/158)

Keesing JK, Baker JL (1998) The benefits of catch and effort data at a fine spatial scale in the South Australian abalone (*Haliotis laevigata* and *Haliotis rubra*) fishery. Canadian Special Publication of Fisheries Aquatic Sciences 125:179-186

Keesing JK, Grove-Jones R, Tagg P (1995) Measuring settlement intensity of abalone: results of a pilot study. Marine and Freshwater Research 46:539-544

King M (1995) Fisheries Biology, Assessment and Management. Fishing News Books, p 342pp

Lewis RK, Shepherd SA, Sluczanowski P, Rohan G (1984) An assessment of the South Australian abalone resource., South Australian Department of Fisheries.

Mayfield S, Carlson IJ, Ward TM (2005a) Central Zone Abalone (*Haliotis laevigata* and *H. rubra*) fishery. Report No. RC05/0022, Fishery assessment report to PIRSA. South Australian Fisheries Assessment Series. Publication No. RD05/0022.

Mayfield S, Chick RC, Carlson IJ, Turich N, Foureur BL, Ward TM (2005b) Western zone Abalone (*Haliotis laevigata* and *H. rubra*) Fishery 1. Region A., Fishery assessment report to PIRSA. South Australian Fisheries Assessment Series. Publication No. RD05/0017-1.

Mayfield S, Chick RC, Ward TM (2005c) Western zone Abalone (*Haliotis laevigata* and *H. rubra*) Fishery 2. Region B., Fishery assessment report to PIRSA. South Australian Fisheries Assessment Series. Publication No. RD05/0017-2.

Mayfield S, Foureur BL, Ward TM (2004) Western Zone Abalone (*Haliotis laevigata* and *H. rubra*) Fishery 1. Region A., Fishery assessment report to PIRSA. South Australian Fisheries Assessment Series. Publication No. RD04/0157.

Mayfield S, Rodda KR, Preece PAG, Foureur BL, Ward TM (2001) Abalone., Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Assessment Series 01/02.

Mayfield S, Rodda KR, Ward TM (2002a) Abalone (Western Zone). Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 02/02c.

Mayfield S, Saunders T, Hogg A, Ward TM (2005d) Southern Zone Abalone (*Haliotis rubra* and *H. laevigata*) Fishery., Fishery assessment report to PIRSA Fisheries. South Australian Fisheries Assessment Series. Publication No. RD04/0091-2. SARDI Report Series No. 86.

Mayfield S, Saunders T, Jones A, Ward TM (2002b) Abalone (Southern Zone). Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 02/02a.

Mayfield S, Saunders T, Ward TM (2003) Abalone (Southern Zone). Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 03/02a.

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

McGarvey R (in press) Assessing survey methods for greenlip abalone in South Australia, Final report to the Fisheries Research and Development Corporation: Project 2001/076

McGarvey R, Feenstra JE (2001) Estimating length-transition probabilities as polynomial functions of premoult length. Marine and Freshwater Research 52:1517-1526

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

McShane PE, Smith MG (1988) Measuring abundance of juvenile abalone. *Haliotis rubra* Leach (Gastropoda : Haliotidae); Comparison of a novel method with two other methods. Australian Journal Marine Freshwater Research 39:331-336

McShane PE, Smith MG (1991) Recruitment variation in sympatric populations of *Haliotis rubra* (Mollusca: Gastropoda). Marine Ecology Progress Series 73:203-210

Nobes M, Casement D, Mayfield S (2004) Management Plan for the South Australian Abalone Fishery., South Australian Fisheries Management Series No. 42

Officer RA, Dixon CD, Gorfine HK (2001a) Movement and re-aggregation of the blacklip abalone, *Haliotis rubra* Leach, after fishing. Journal of Shellfish Research 20:771-779

Officer RA, Haddon M, Gorfine HK (2001b) Distance-based abundance estimation for abalone. Journal of Shellfish Research 20:781-786

Parrack ML, Cummings NJ (2003) Errors in transforming length samples to age frequencies without age samples. Fisheries Research 63:235-243

Preece PA, Shepherd SA, Clarke SM, Keesing JK (1997) Abalone stock enhancement by larval seeding: effect of larval density on settlement and survival. Molluscan Research 18:265-273

Prince JD, Sellers TL, Ford WB, Talbot SR (1988) Confirmation of a relationship between the localised abundance of breeding stock and recruitment for *Haliotis rubra* (Mollusca: Gastropoda). Journal of Experimental Marine Biology and Ecology 122:91-104

Prince JD, Shepherd SA (1992) Australian abalone fisheries and their management. In: Shepherd SA, Tegner MJ, Guzmán Del Próo SA (eds) Abalone of the World, Biology, Fisheries and Culture, p 407-427

Rice JA (1995) Mathematical Statistics and Data Analysis. In. Duxbury Press, Belmont, California, p 594pp

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

Rodda KR, Keesing JK, Foureur BL (1997) Variability in abalone settlement using artificial collectors. Molluscan Research 18:253-264

Rodda KR, Mayfield S (2002) Determination of an appropriate meat-weight: shell-weight ratio., Report to PIRSA Fisheries Policy Group.

Rodda KR, Mayfield S, Shepherd SA (2002) Translocation of greenlip abalone in South Australia., Report to PIRSA Fisheries.

Rodda KR, Styan C, Shepherd SA, McShane P (1998) Abalone., Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 98/02.

Shepherd SA (1973) Studies on southern Australian abalone (genus Haliotis). I. Ecology of five sympatric species. Australian Journal Marine Freshwater Research 24:217

Shepherd SA (1988) Studies on Southern Australian abalone (Genus *Haliotis*). VIII. Growth of juvenile *H. laevigata*. . Australian Journal Marine Freshwater Research 39:177-183

Shepherd SA (1990) Studies on the southern Australian abalone (genus Haliotis). XII. Long-term recruitment and morality dynamics of an unfished population. Australian Journal Marine Freshwater Research 41:475-492

Shepherd SA, Baker JL (1998) Biological reference points in an abalone (*Haliotis laevigata*) fishery. Canadian Journal of Fisheries and Aquatic Sciences 125:235-245

Shepherd SA, Breen PA (1992) Mortality in abalone: its estimation, variability and causes. In: Shepherd SA, Tegner MJ, Guzmán Del Próo SA (eds) Abalone of the World: Biology, Fisheries and Culture. Blackwell Scientific Publications Ltd., Oxford, p 276-304

Shepherd SA, Brown LD (1993) What is an abalone stock: Implications for the role of refugia in conservation. Canadian Journal of Fisheries and Aquatic Sciences 50:2001-2009

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

Shepherd SA, Clarke SM, Dalgetty A (1992a) Studies on southern Australian abalone (genus *Haliotis*) XIV. Growth of *H. laevigata* on Eyre Peninsula. Journal of the Malacological Society of Australia 13:99-113

Shepherd SA, Daume S (1996) Ecology and survival of juvenile abalone in a crustose coralline habitat in South Australia. In: Watanabe Y, Yamashita Y, Oozeki Y (eds) Survival strategies in early life stages of marine resources, Vol 50. Balkema, Rotterdam., p 2001-

Shepherd SA, Godoy C, Clarke SM (1992b) Studies on southern Australian abalone (genus *Haliotis*) XV. Fecundity of *H. laevigata.* Journal of the Malacological Society of Australia 13:115-121

Shepherd SA, Hearn WS (1983) Studies on Southern Australian abalone (genus *Haliotis*). IV. Growth of *H. laevigata* and *H. ruber.* Australian Journal Marine Freshwater Research 34:461-475

Shepherd SA, Laws HM (1974) Studies on southern Australian abalone (genus Haliotis) II. Reproduction of five species. Australian Journal Marine Freshwater Research 25:49-62

Shepherd SA, Rodda KR (2001) Sustainability demands vigilance: Evidence for serial decline of the greenlip abalone fishery and review of management. Journal of Shellfish Research 20:829-841

Shepherd SA, Rodda KR, Karlov T, Preece PA, Williams H (1999) Abalone, Fishery assessment report to PIRSA Fisheries Policy Group. South Australian Fisheries Assessment Series 99/02.

Shepherd SA, Rodda KR, Vargas KM (2001) A chronicle of collapse on two abalone stocks with proposals for precautionary management. Journal of Shellfish Research 20:843-856

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

Shepherd SA, Turner JA (1985) Studies on southern Australian abalone (genus Haliotis). VI. Habitat preference, abundance and predators of juveniles. Journal of Experimental Marine Biology and Ecology 93:285

Tarbath D, Hodgson K, Mundy C, Haddon M (2002) Tasmanian abalone fishery 2001., Fishery Assessment Report. TAFI.

Tarbath D, Mundy C, Haddon M (2003) Tasmanian abalone fishery 2002., Fishery Assessment Report. TAFI.

Tarbath D, Mundy C, Haddon M (2005) Tasmanian abalone fishery 2004., Fishery Assessment Report. TAFI.

Worthington D, Blount C, Chick RC, Gibson PT, Stewart BR (2001) An assessment of the performance indicators of the Abalone Share Management Plan in 2000., NSW Fisheries' Fishery Resource Assessment series No.11.

Zacharin W (1997) Management plan for the South Australian Abalone Fishery. In: Internal document PF (ed), p 33pp.

Appendix 1: Abalone biology

Table A1.1 Size at 50% maturity (mm, shell length) for greenlip at different sites in the Western Zone. Parameters (a and b) describe the proportion of greenlip abalone mature. The equation is of the form ($f_{(x)} = a/(1+\exp(-((x-L_{50})/b))$).

Site	Year	a	b	L_{50}	*n*	Reference
Anxious Bay	2005	0.9826	7.312	76.6	119	SARDI unpublished data
The Gap	2003	1.0182	4.441	94.0	96	SARDI unpublished data
The Gap	2004	0.9846	1.952	93.8	124	SARDI unpublished data
Waterloo Bay	1974	-	-	102	34	(Shepherd & Laws 1974)

Table A1.2 Relationships between shell length (SL, mm) and fecundity (F, millions of eggs) for greenlip at different sites in the Western Zone. The equation is of the form $F = aSL^b$.

Site	a	b±SE	*r*	*n*	Reference
Maclaren Point	$1.93\text{x}10^{-6}$	5.61±0.42	0.97	14	(Shepherd *et al.* 1992b)
Taylor Island	$7.55\text{x}10^{-6}$	5.33±0.54	0.94	15	(Shepherd *et al.* 1992b)
Sceale Bay	$6.19\text{x}10^{-10}$	7.24±0.91	0.90	17	(Shepherd *et al.* 1992b)
Yanerbie	$1.11\text{x}10^{-2}$	3.87±0.65	0.87	14	(Shepherd *et al.* 1992b)
Waterloo Bay	$6.40\text{x}10^{-3}$	3.85±0.91	0.76	15	(Shepherd *et al.* 1992b)
Anxious Bay	$2.94\text{x}10^{-2}$	3.70±0.93	0.74	15	(Shepherd *et al.* 1992b)

Table A1.3 Relationships between fecundity (F, millions of eggs) and whole weight (W, g) for greenlip at different sites in the Western Zone. The equation is of the form $F = c + dW$.

Site	c	d	Reference
Waterloo Bay	-0.36	0.004	(Shepherd & Baker 1998)
Ward Island	-1.87	0.008	(Shepherd & Baker 1998)
Thorny Passage	-1.57	0.014	(Shepherd & Baker 1998)
Sceale Bay	-1.13	0.011	(Shepherd & Baker 1998)

Table A1.4 Relationships between shell length (SL, mm) and total weight (TW, g) for greenlip at different sites in the Western Zone. The equation is of the form TW = aSL^b.

Site	Year	a	b±SE	*r*	*n*	Reference
Anxious Bay	1992	1×10^{-4}	3.07±0.07	0.99	46	(Shepherd *et al.* 1992b)
Anxious Bay	2004	4×10^{-4}	2.79	0.97	52	SARDI unpublished data
Anxious Bay	2005	2.9×10^{-5}	3.30	0.99	110	SARDI unpublished data
Flinders Island	1998	4×10^{-4}	2.80	0.94	69	SARDI unpublished data
Flinders Island	1999	5.3×10^{-2}	1.84	0.63	47	SARDI unpublished data
Flinders Island (Flind. Bay)	2004	3.5×10^{-5}	3.26	0.98	53	SARDI unpublished data
Hotspot	1998	3.9×10^{-5}	3.26	0.94	80	SARDI unpublished data
Hotspot	1999	1.8×10^{-1}	1.60	0.78	35	SARDI unpublished data
Hotspot	2004	5×10^{-4}	2.78	0.93	53	SARDI unpublished data
Maclaren Point	1992	5.8×10^{-5}	3.12±0.05	0.99	47	(Shepherd *et al.* 1992b)
Price Is	1997	6.1×10^{-5}	3.16	0.97	47	SARDI unpublished data
Price Is	1999	3×10^{-4}	2.86	0.90	43	SARDI unpublished data
Rowly Bay	1991	7×10^{-5}	3.10	0.97	65	SARDI unpublished data
Sceale Bay	1992	1.2×10^{-4}	3.00±0.03	0.99	59	(Shepherd *et al.* 1992b)
Searcy Bay	1999	1×10^{-4}	3.07	0.97	127	SARDI unpublished data
Taylor Island	1992	4.7×10^{-5}	3.16±0.06	0.99	45	(Shepherd *et al.* 1992b)
The Gap	1998	2×10^{-4}	3.00	0.96	88	SARDI unpublished data
The Gap	2000	2.8×10^{-3}	2.38	0.77	43	SARDI unpublished data
The Gap	2003	4×10^{-5}	3.22	0.98	27	SARDI unpublished data
The Gap	2004	1×10^{-4}	3.14	0.95	87	SARDI unpublished data
Ward Island	1998	7×10^{-5}	3.13	0.94	75	SARDI unpublished data
Ward Island	2004	1×10^{-4}	3.05	0.97	72	SARDI unpublished data
Waterloo Bay	1992	2×10^{-4}	2.92±0.06	0.99	57	(Shepherd *et al.* 1992b)
Waterloo Bay	1999	2.9×10^{-3}	2.38	0.73	152	SARDI unpublished data
Waterloo Bay	2005	2.8×10^{-5}	3.33	0.97	150	SARDI unpublished data
Yanerbie	1992	4.6×10^{-5}	3.20±0.08	0.98	53	(Shepherd *et al.* 1992b)

Table A1.5 Growth rate (mm yr^{-1}) (± SE) of sub-adult greenlip at different sites in the Western Zone.

Site	Size range (mm)	Growth rate	Reference
Taylor Island	15-145	39.6 ± 0.9	(Shepherd *et al.* 1992b)
Ward Island	60-125	25.7 ± 1.5	(Shepherd *et al.* 1992b)
Sceale Bay	45-110	20.4 ± 1.8	(Shepherd *et al.* 1992b)
Anxious Bay	25-95	20.4 ± 1.5	(Shepherd *et al.* 1992b)
Maclaren Point	20-140	20.3 ± 0.4	(Shepherd *et al.* 1992b)
Avoid Bay	45-115	19.7 ± 2.4	(Shepherd & Triantafillos 1997)
Yanerbie	15-110	15.3 ± 0.9	(Shepherd *et al.* 1992b)

Table A1.6 Natural mortality rates (yr^{-1}) for adult (emergent) greenlip at different sites in the Western Zone.

Site	M (yr^{-1})	Reference
Waterloo Bay	0.4	(Shepherd & Baker 1998)
Thorny Passage	0.25	(Shepherd & Baker 1998)
Sceale Bay	0.25	(Shepherd & Baker 1998)
Ward Island	0.13	(Shepherd & Baker 1998)

Table A1.7 Growth rate, K (yr^{-1}) and L_∞ (mm SL) for greenlip tagged and recaptured at different sites in the Western Zone. Errors are standard errors. Size ranges are shell length (mm).

Site	Year	*r*	*p*	k (± SE)	L_∞ (± SE)	*n*	Reference
Anxious Bay	1988	0.744	<0.05	0.385	119.5 (5.3)	26	(Shepherd *et al.* 1992a)
Anxious Bay	2001	-	-	0.293	155.2	65	(Rodda *et al.* 2002)
Flinders Is (Flind. Bay)	2004	0.768	<0.05	0.211	170.1	37	SARDI unpublished data
Flinders Is (Windmill)	2004	0.832	<0.05	0.365	162.8	153	SARDI unpublished data
Hotspot (2003)	2002	0.691	<0.05	0.255	214.0	122	SARDI unpublished data
Hotspot (2004)	2002	0.812	<0.05	0.306	181.7	53	SARDI unpublished data
Maclaren Point	1988	0.534	<0.05	0.368	178.3 (7.7)	35	(Shepherd *et al.* 1992a)
Sceale Bay	1988	0.856	<0.05	0.186	186.3 (28.2)	9	(Shepherd *et al.* 1992a)
Speeds Point	2001	-	-	0.023	191.0	27	(Rodda *et al.* 2002)
Taylor Island	1988	0.713	<0.05	0.552	180.4 (10.3)	41	(Shepherd *et al.* 1992a)
The Gap (2004)	2002	0.805	<0.05	0.276	157.0	175	SARDI unpublished data
Ward Island	1988	0.81	<0.05	0.413	167.2 (5.2)	36	(Shepherd *et al.* 1992a)
Waterloo Bay	1969	0.921	<0.05	0.595	147.8 (1.8)	126	(Shepherd & Hearn 1983)
Yanerbie	1988	0.642	<0.05	0.268	140.4 (8.6)	19	(Shepherd *et al.* 1992a)

Table A1.8 Size at 50% maturity (mm, shell length) for blacklip at different sites in the Western Zone. Parameters (a and b) describe the proportion of blacklip abalone mature. The equation is of the form $f_{(x)} = a/(1+\exp(-(x-L_{50})/b))$.

Site	Year	a	b	L_{50}	*n*	Reference
Hotspot	2004	1.0042	7.495	82.3	124	SARDI unpublished data
Hotspot	2005	1.0094	5.359	94.3	192	SARDI unpublished data
Reef Head	2001	0.9979	6.784	87.7	189	SARDI unpublished data
Sheringa	2004	1.0022	5.369	97.3	130	SARDI unpublished data
Tungketta	2004	0.9942	8.135	103.0	88	SARDI unpublished data
Waldegrave Island	2005	1.0173	6.060	120.1	94	SARDI unpublished data
Ward Island	2001	1.0353	10.720	92.0	65	SARDI unpublished data
Ward Island	2005	1.000	0.322	91.8	94	SARDI unpublished data
Waterloo Bay	1974	-	-	100	28	(Shepherd & Laws 1974)
West Bay	2001	0.9917	7.040	96.1	222	SARDI unpublished data

Table A1.9 Growth rate, K (yr^{-1}) and L_∞ (mm SL), for blacklip tagged and recaptured at different sites in the Western Zone.

Site	Year	*r*	*p*	k	L_∞	*n*	Reference
Reef Head	2001	0.185	>0.05	0.050	219.4	48	SARDI unpublished data
Reef Head	2002	0.644	<0.05	0.193	131.2	59	SARDI unpublished data
Sheringa	2002	0.664	<0.05	0.246	147.9	97	SARDI unpublished data
Venus Bay	2000	0.719	<0.05	0.312	132.7	25	SARDI unpublished data
Venus Bay	2001	0.560	<0.05	0.231	156.6	70	SARDI unpublished data
Ward Island	2005	0.602	<0.05	0.172	167.3	24	SARDI unpublished data

Table A1.10 Relationships between shell length (SL, mm) and total weight (TW, g) for blacklip at different sites in the Western Zone. The equation is of the form $TW = aSL^b$.

Site	Year	a	b	*r*	*n*	Reference
Avoid Bay		4×10^{-4}	2.81	0.97	99	SARDI unpublished data
Flinders Island	1998	3×10^{-5}	3.11	0.96	85	SARDI unpublished data
Hotspot	2004	1×10^{-4}	3.19	0.98	124	SARDI unpublished data
Hotspot	2005	1×10^{-4}	3.14	0.98	192	SARDI unpublished data
Kiana	1999	8×10^{-2}	1.74	0.73	46	SARDI unpublished data
Point Drummond		1×10^{-4}	3.07	0.96	100	SARDI unpublished data
Point Drummond	1998	1×10^{-4}	3.19	0.94	54	SARDI unpublished data
Point Labatt	1999	1×10^{-3}	2.53	0.85	102	SARDI unpublished data
Point Whidbey	1998	1×10^{-4}	3.12	0.97	49	SARDI unpublished data
Price Island	1999	5×10^{-4}	2.75	0.68	50	SARDI unpublished data
Reef Head	1999	1×10^{-2}	2.09	0.79	44	SARDI unpublished data
Reef Head	2004	6×10^{-4}	2.72	0.94	63	SARDI unpublished data
Sheringa	2004	$\sim 2 \times 10^{-5}$	3.44	0.98	130	SARDI unpublished data
Smoothpool	1999	2×10^{-4}	2.91	0.94	127	SARDI unpublished data
Tungketta	2004	1×10^{-4}	3.12	0.98	88	SARDI unpublished data
Waldegrave Island	1998	7×10^{-5}	3.15	0.96	100	SARDI unpublished data
Waldegrave Island	2005	1×10^{-4}	3.06	0.98	94	SARDI unpublished data
Waterloo Bay	2005	7×10^{-4}	2.72	0.94	162	SARDI unpublished data
Ward Island	1998	1×10^{-4}	3.10	0.96	100	SARDI unpublished data
Ward Island	2005	3×10^{-4}	2.86	0.98	145	SARDI unpublished data
West Bay	1998	2×10^{-4}	2.93	0.95	99	SARDI unpublished data
West Bay	1999	8×10^{-3}	2.20	0.86	50	SARDI unpublished data

Appendix 2: Greenlip 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 = aSL^b) were determined from parameters estimated at each site.

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

6. Selectivity increased linearly from zero to the MLL (145 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} coming into contact with the 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

Data	Parameter	Size / age	9	18
Growth rate	L_∞	-	211.77 [a]	200.00 [b]
	K	-	0.2481 [a]	0.2756 [c]
[d]Size at maturity	a	-	0.9899	0.9899
	b	-	2.8001	2.8001
	L_{50}	-	93.8292	93.8292
[e]Fecundity	a	-	-0.36	-1.57
	b	-	0.004	0.014
[f]Natural Mortality	M	0 – 12 months	3	3
		13 – 24 months	0.9	0.9
		25 – 36 months	0.45	0.45
		>36 months	0.13	0.25
Length fully selected	L_{msc}	-	161	171
Fishing mortality	F	-	0.47	0.41

[a] Mean value obtained from individuals tagged and recaptured at Hotspot from 2002/03 to 2004/05.
[b] Estimate derived from commercial catch samples.
[c] Mean value obtained from individuals tagged and recaptured at 'The Gap' from 2002/03 to 2004/05.
[d] Parameter estimates for the logistic function describing the relationship between shell length and proportion mature for greenlip at 'The Gap'.
[e] Published data (Shepherd & Baker 1998).
[f] Published data from Shepherd and Breen (1992) and Shepherd and Baker (1998).

Appendix 3: Blacklip egg-production model

3.1 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 = aSL^b) were determined from parameters estimated at each site.

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

6. Selectivity increased linearly from zero to 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} coming into contact with the 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.

3.2 Biological data

Data	Parameter	Size / age	9	11
Growth rate	L_∞	-	180 [a]	172 [a]
	K	-	0.2831 [b]	0.3147 [c]
[d]Size at maturity	a	-	1.0108	1.0022
	b	-	8.1876	5.3686
	L_{50}	-	89.32	97.34
[e]Fecundity	a	-	4×10^{-5}	4×10^{-5}
	b	-	5.0334	5.0334
[f]Natural Mortality	M	0 – 12 months	3	3
		13 – 24 months	0.9	0.9
		25 – 36 months	0.45	0.45
		>36 months	0.25	0.25
Length fully selected	L_{msc}	-	155	151
Fishing mortality	F	-	0.15	0.19

[a] Derived from commercial catch samples.
[b] Published data (Mayfield *et al.* 2004).
[c] Mean value obtained from individuals tagged and recaptured at Sheringa from 2001/02 to 2002/03.
[d] Parameter estimates for the logistic function describing the relationship between shell length and proportion mature for blacklip at Ward Island and Hotspot (fishing area 9) and Sheringa (fishing area 11).
[e] Published data (Mayfield *et al.* 2005b).
[f] Published data from Shepherd and Breen (1992) and Shepherd and Baker (1998).

Appendix 4: Length-based stock assessment model

4.1 Model description

The model was developed in AD Model Builder (Otter Research Ltd). It is length based. The lower size limit is 52 mm SL. There are 66, 2 mm SL length classes. Sexes are not distinguished. The model runs on an annual time step. Catches from commercial, recreational and illegal fishers were used in the model, each with their own fishing selectivity.

The model operates by estimating the numbers of abalone in each length class at the start of each season by applying growth, natural mortality, fishing mortality and recruitment to each length class each year. This process is numerically represented by:

$$N^{c}_{t,l,m} = \alpha_{t,l,m\text{-}1}(\sum_{l'\le l} N^{c}_{t,l',m\text{-}1}\, e^{-M^{c}_{l'}}[1-\sum_{i} F^{i}_{t,m\text{-}1}\, S^{i}_{t,l',m\text{-}1}]X^{c}_{l,l',m\text{-}1} + \sum_{l'\le l} N^{\tilde{c}}_{t,l',m\text{-}1}\, e^{-M^{\tilde{c}}_{l'}}\, X^{\tilde{c}}_{l,l',m\text{-}1})$$

$$N^{\tilde{c}}_{t,l,m} = (1-\alpha_{t,l,m\text{-}1})(\sum_{l'\le l} N^{c}_{t,l',m\text{-}1}\, e^{-M^{c}_{l'}}[1-\sum_{i} F^{i}_{t,m\text{-}1}\, S^{i}_{t,l',m\text{-}1}]X^{c}_{l,l',m\text{-}1} + \sum_{l'\le l} N^{\tilde{c}}_{t,l',m\text{-}1}\, e^{-M^{\tilde{c}}_{l'}}\, X^{\tilde{c}}_{l,l',m\text{-}1} + R_{t,l,m\text{-}1})$$

where $N^{c}_{t,l,m}$ is the number of abalone in size-class *l* in non-cryptic habitat at the start of season *m* of year *t*

$N^{\tilde{c}}_{t,l,m}$ is the number of abalone in size-class *l* in cryptic habitat at the start of season *m* of year *t*

$\alpha_{t,l,m\text{-}1}$ is the probability that an animal in size-class *l* is in the non-cryptic habitat at the end of season *m-1*of year *t*

$M^{c/\tilde{c}}_{l}$ is the instantaneous rate of natural mortality on animals in size-class *l* in the non-cryptic / cryptic habitat

$X^{c/\tilde{c}}_{l,l',m\text{-}1}$ is the probability that an animal in the non-cryptic / cryptic habitat and size-class *l'* grows into size-class *l* at the end of season *m-1* (the size-transition matrix)

$F^{i}_{t,m\text{-}1}$ is the fully-selected exploitation rate by sector *i* (commercial, recreational, and illegal) during season *m-1* of year *t*

$S^{i}_{t,l,m\text{-}1}$ is the selectivity of sector *i* on animals in size-class *l* during season *m-1* of year *t*

$R_{t,l,m\text{-}1}$ is the recruitment to size-class *l* at the end of season *m'* of year *t*

4.1.1. *Exploitation rate*

The fully-selected exploitation rate for each sector, $F^{i}_{t,m}$, is defined as the ratio of the catch to the exploitable biomass:

$$F^{i}_{t,m} = \frac{C^{i}_{t,m}}{B^{e,i}_{t,m}} = \frac{C^{i}_{t,m}}{\sum_{l} w_{l}\, S^{i}_{t,l,m}\, N^{c}_{t,l,m}\, e^{-M^{c}_{l}\Delta t}}$$

where $C^{i}_{t,m}$ is the catch by sector *i* at the end of season *m* of year *t*

$B^{e,i}_{t,m}$ is the exploitable biomass corresponding to sector *i* during season *m* of year *t*,

w_l is the mean weight of an animal in length-class *l*

Δt is one year

4.1.2. *Growth*

Growth parameters are specified by a growth matrix derived from tag-recapture data from Lipson Reef (2002/03 to 2004/05) generated using Estimatrix (after Bardos in review).

4.1.3. *Length-weight relationship*

Weight, as a function of length, is given by:

$$w_l = a\bar{l}^{\,b}$$

where $\bar{l}$ is the maximum shell length.

a, b are the parameters of the weight-length relationship.

4.1.4. *Fishing selectivity*

Fishing selectivity, as a function of length-class is given by the proportion selected:

$$S^{i}_{t,l,m} = \begin{cases} 0, l < l_{\min,i} \\ p^{i}_{t,m} + (1 - p^{i}_{t,m})(l - l_{\min})/(l_{\max} - l_{\min}), l_{\min,i} > l > l_{\max,i} \\ 1, l \geq l_{\max,i} \end{cases}$$

where $l^{i}_{50,t}$ is the length of 50% selectivity for sector *i* during season *m* and year *t*

$l_{min,i}$ is the minimum length fished for sector i during season *m* and year *t*

$l_{max,i}$ is the first length fully fished for sector i during season *m* and year *t*

$p^{i}_{t,m}$ is the proportion of animals selected for sector *i* at $l_{min,t}$ during season *m* and year *t*

4.1.5. *Transition from cryptic to non-cryptic habitat*

Emergence, as a function of length-class, is given by:

$$\alpha_{t,l,m} = (1 + \exp(-\ell n19(\bar{l} - l_{50,t,m})/\phi_{t,m}))^{-1}$$

where $\alpha_{t,l,m}$ is the probability of an animal in size-class *l* being in non-cryptic habitat at the end of season *m* of year *t*

$\phi_{t,m}$ is the width of the emergence ogive during season *m* of year *t*

$l_{50,t,m}$ is the size-at-50%- emergence during season *m* of year *t*

4.1.6. *Maturity*

Maturity, as a function of length class is described by an ogive where 50% of individuals at 90 mm are mature, with the width of the ogive set at 20 mm.

4.1.7. *Recruitment*

The recruitment by size-class, year and season is given by:

$$R_{t,l,m} = \omega_{l,m} \sum_{t' \le t} \theta_{(t-t')} \frac{(B^S_{t'} / B^S_{-\infty}) e^{\varepsilon_{t'}}}{\tilde{\alpha} + \tilde{\beta}(B^S_{t'} / B^S_{-\infty})}$$

where $\omega_{l,m}$ is the fraction of the recruitment that occurs to size-class *l* during season *m*

$\theta_{(t-t')}$ is the weighting from spawning in year *t'* to recruitment in year *t* (user specified); $\sum_{t' \le t} \theta_{(t-t')} = 1$

$\tilde{\alpha}$, $\tilde{\beta}$ are the parameters of the stock-recruitment relationship (defined in terms of the "steepness" of the relationship, *h*, and the virgin recruitment, $R_{-\infty}$)

$$\tilde{\alpha} = \frac{(1-h)}{4hR_{-\infty}} \quad and \quad \tilde{\beta} = \frac{(5h-1)}{4hR_{-\infty}}$$

h is the steepness of the stock-recruitment relation so that

$$hR = \frac{0.2}{\alpha + 0.2\beta} \text{ and } R = \frac{1}{\alpha + \beta}$$

B^S_t is the mature biomass corresponding to the recruitment during year *t*:

$$B^S_t = \sum_l w_l \, f_l \, (N^c_{t',l,m(S)} + N^{\tilde{c}}_{t',l,m(S)})$$

f_l is the fraction of animals in size-class *l* that are mature

w_l is the weight at length *l*

$m(S)$ denotes the season of spawning

ε_t is the 'recruitment residual' for year *t*

4.2 Likelihood (estimation) functions

4.2.1. *Catch-per-unit-effort (CPUE)*

$$-\ln L = \sum_t [\ln \sigma_i + \frac{1}{2\sigma_i^2} (\ln A_t - \ln(\hat{q} \sum_l (S^i_l N_{l,t}))^\gamma)^2]$$

where Nl,t is the estimated number

A_t is the observed CPUE

S^i_l is the selectivity of the fishing on animals in the commercial sector I

σ_i is the either a given standard deviation or the standard error from the data

$$\hat{q} = \exp[\frac{1}{n} \sum_y (\ln A_t - \ln(\sum_l (S^r_l N_{l,t}))^\gamma)]$$

4.2.2. *Commercial and fishery-independent proportion-at-length*

The robust likelihood function of Fournier et al (1998) is used:

$$-\log L = -0.5\sum_t\sum_l \log[2\pi(\xi_{l,t} + 0.1/I)] - \sum_t I\log(\tau_t) + \sum_t\sum_l \log[\exp\{-\frac{(\rho_{l,t}^{obs} - \rho_{l,t}^{pred})^2}{2(\xi_{l,t} + 0.1/I)\tau_t^{\,2}}\} + 0.01]$$

where $\rho_{l,t}^{obs}$ is the observed proportion of animals in length class l and year t

$\rho_{l,t}^{pred}$ is the predicted proportion of animals in length class l and year t

$\xi_{l,t} = (1-\rho_{l,t}^{obs})\rho_{l,t}^{obs}$

$\tau_t^{\,2} = 1/\min(S_t, N_{eff})$

S_t is the sample size for the length frequency data for year t

N_{eff} is the effective sample size

I is the number of length classes in the sample

4.2.3. *Recruitment*

Recruitment has a log-normal prior and σ_{Rec} is specified in:

$$-\ln L = -\sum_t (\sigma_t^r)^2 / \sigma_{\mathrm{Rec}}^2 .$$

Priors, parameter values and parameter posterior distributions

Parameter	Description	**Prior** / Fixed value	Parameter bounds	Estimate Median, 90%CI
R_{init}	Initial Recruitment (millions)	**U(0.1, 80)**		5.95, 4.80-7.53
h	Steepness of the Beverton Holt recruitment relationship	**N(0.6, 0.15)**	0.1 – 0.9	0.60, 0.53-0.67
R_{dev}	Recruitment deviations	**N(0, 0.4)**	-2.3 – 2.3	-0.03, -0.02-0.05
M	Natural mortality	**N(0.2, 0.05)**	0.1 – 0.3	0.20, 0.19-0.21
q	Power of the relationship between CPUE and biomass	1.0		
a	Coefficient of the relationship between weight and length	0.0001		
b	Power of the relationship between weight and length	3.09		
l_{min}	Minimum size harvested (commercial)	$90_{\leq 1971}130_{>1971}$		
p	% of minimum size retained (commercial)	5%		
l_{max}	Size at which 100% are retained (commercial)	$110_{\leq 1971}150_{>1971}$		
$Neff_{comm}$	Effective sample size of the commercial length frequency	50		
$Neff_{CPUE}$	Effective sample size of the CPUE series	0.15		
$Neff_{ind}$	Effective sample size of the independent length frequency	NA – no data		

Appendix 5: Assessment of the greenlip fishery in Region A of the Western Zone of the South Australian abalone fishery against the biological performance indicators in the Management Plan. Values are mean ± SE. Red indicates statistical significance.

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Commercial effort	hr	Region A	2608	2382	2371	2254	2138	-	$r^2 = 0.93$, df = 3, $p < 0.05$
Mean daily catch	$kg.day^{-1}$	Area 4	278.0±21.5	262.0±19.3	231.8±23.7	235.0±18.4	198.1±15.1	$t = 1.56$, df = 73, $p > 0.05$	$F_{1,197} = 9.52$, $p < 0.01$
		Area 5	263.3±19.3	229.2±17.3	215.4±26.9	204.9±14.2	284.8±23.0	$t = 2.80$, df = 78, $p < 0.01$	$F_{1,196} = 0.14$, $p > 0.05$
		Area 8	328.4±40.5	407.2±26.2	404.3±35.1	475.8±33.7	387.2±28.5	$t = 2.01$, df = 102, $p < 0.05$	$F_{1,286} = 2.72$, $p > 0.05$
		Area 9	326.3±11.0	378.6±12.6	334.2±12.8	382.3±14.3	466.7±15.2	$t = 3.99$, df = 237, $p < 0.01$	$F_{1,709} = 38.19$, $p < 0.01$
		Area 14	325.3±51.7	359.0±39.6	430.1±53.7	556.2±44.1	483.1±45.2	$t = 1.14$, df = 55, $p > 0.05$	$F_{1,105} = 10.48$, $p < 0.01$
		Area 18	311.9±14.1	330.5±15.2	362.0±14.1	414.4±12.7	432.7±13.3	$t = 0.99$, df = 220, $p > 0.05$	$F_{1,602} = 51.81$, $p < 0.01$
		Area 19	297.4±25.3	321.4±32.8	345.0±28.4	401.4±28.2	450.0±41.0	$t = 0.95$, df = 50, $p > 0.05$	$F_{1,177} = 14.51$, $p < 0.01$
Mean daily effort	$hr.day^{-1}$	Area 4	4.6±0.2	4.2±0.2	3.1±0.3	3.7±0.2	3.4±0.2	$t = 1.07$, df = 73, $p > 0.05$	$F_{1,197} = 18.35$, $p < 0.01$
		Area 5	4.1±0.2	4.1±0.2	3.3±0.3	3.2±0.2	4.1±0.3	$t = 2.72$, df = 78, $p < 0.01$	$F_{1,196} = 1.50$, $p > 0.05$
		Area 8	3.8±0.3	5.2±0.2	4.4±0.2	5.0±0.3	4.9±0.2	$t = 0.11$, df = 102, $p > 0.05$	$F_{1,286} = 5.12$, $p < 0.05$
		Area 9	4.9±0.1	5.1±0.1	4.2±0.1	5.1±0.1	5.7±0.1	$t = 3.42$, df = 237, $p < 0.01$	$F_{1,709} = 7.49$, $p < 0.01$
		Area 14	5.4±0.6	4.9±0.3	5.4±0.3	5.6±0.3	5.3±0.2	$t = 0.72$, df = 55, $p > 0.05$	$F_{1,105} = 0.33$, $p > 0.05$
		Area 18	4.7±0.2	4.7±0.2	4.7±0.2	5.6±0.1	5.4±0.1	$t = 0.83$, df = 220, $p > 0.05$	$F_{1,602} = 19.13$, $p < 0.01$
		Area 19	4.9±0.4	4.6±0.4	4.3±0.3	5.0±0.3	5.3±0.4	$t = 0.67$, df = 50, $p > 0.05$	$F_{1,177} = 0.39$, $p > 0.05$

Appendix 5. (continued)

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
CPUE	kg.hr^{-1}	Area 4	60.7±4.2	63.0±3.1	74.0±4.7	63.6±3.0	59.1±3.4	$t^1 = 1.00$, df = 73.0 $p > 0.05$	$F^2_{1,197} = 0.07$ $p > 0.05$
		Area 5	63.7±3.3	56.0±2.4	65.7±4.1	64.9±3.7	70.1±3.7	$t^1 = 1.01$, df = 76.9 $p > 0.05$	$F^2_{1,196} = 7.25$ $p < 0.01$
		Area 8	86.8±7.6	78.3±4.5	90.9±5.8	96.1±5.0	79.0±4.6	$t^1 = 2.53$, df = 101.0 $p < 0.05$	$F^2_{1,286} = 0.26$ $p > 0.05$
		Area 9	67.0±1.7	73.7±2.0	80.7±2.2	75.8±2.2	82.0±2.6	$t^1 = 1.84$, df = 216.0 $p > 0.05$	$F^2_{1,709} = 25.32$ $p < 0.01$
		Area 14	60.6±6.0	73.4±6.2	79.0±7.9	99.6± 6.4	91.0±7.7	$t^1 = 0.87$, df = 54.8 $p > 0.05$	$F^2_{1,105} = 20.01$ $p < 0.01$
		Area 18	65.8±2.0	70.2±2.0	76.4±1.6	74.7±1.8	80.2±1.9	$t^1 = 2.14$, df = 214.2 $p < 0.05$	$F^2_{1,602} = 51.03$ $p < 0.01$
		Area 19	60.6±3.9	70.0±3.8	80.0±3.5	80.3±5.4	84.5±4.7	$t^1 = 0.59$, df = 47.7 $p > 0.05$	$F^2_{1,177} = 32.64$ $p < 0.01$
Mean size	mm, SL	Area 4	No data	No data	No data	165.2±0.6	164.5±1.5	$t = 0.39$, df = 220 $p > 0.05$	-
		Area 5	No data	No data	164.1±0.6	167.7±0.6	163.5±0.9	$t = 3.86$, df = 509 $p < 0.01$	-
		Area 8	No data	No data	No data	170.7±1.0	160.0±0.6	$t = 9.84$, df = 518 $p < 0.01$	-
		Area 9	No data	165.1±0.3	165.4±0.4	168.6±0.3	169.1±0.3	$t = 1.33$, df = 3834 $p > 0.05$	-
		Area 14	No data	No data	No data	163.4±0.4	167.4±1.6	$t = 1.20$, df = 507 $p > 0.05$	-
		Area 18	No data	169.1±0.4	173.0±0.5	172.6±0.3	167.2±0.3	$t = 11.73$, df = 2389 $p < 0.01$	-
		Area 19	No data	170.0±0.6	No data	167.0±0.5	167.4±0.5	$t = 0.78$, df = 953 $p > 0.05$	-

1. Based on the ratio estimator (after Rice 1995)

2. Based on daily CPUE

Appendix 5. (continued)

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Egg production retained	%	Area 4	No data	No data	No data	No data	No data	NA	NA
		Area 5	No data	No data	No data	No data	No data	NA	NA
		Area 8	No data	No data	No data	No data	No data	NA	NA
		Area 9	No data	50.9	40.2	42.0	27.8	NA	NA
		Area 14	No data	No data	No data	No data	No data	NA	NA
		Area 18	No data	69.5	69.5	70.6	46.5	NA	NA
		Area 19	No data	No data	No data	No data	No data	NA	NA

Performance Indicator	Units	Survey site	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Abundance of abalone $>L_{50}$	no.m^{-2}	Ward Island	0.148±0.017	0.154±0.013	0.170±0.018	0.176±0.026	0.241±0.026	$t = 1.76$, df = 30 $p > 0.05$	$F^2_{1,78} = 10.18$ $p < 0.01$
		Flinders Island	0.184±0.038	0.207±0.035	0.265±0.065	0.272±0.046	0.210±0.020	$t = 1.24$, df = 46 $p > 0.05$	$F^2_{1,118} = 0.72$ $p > 0.05$
		Hotspot	0.361±0.025	0.318±0.026	0.458±0.021	0.391±0.047	0.342±0.031	$t = 0.88$, df = 94 $p > 0.05$	$F^2_{1,226} = 0.08$ $p > 0.05$
		Pearson Island	No data	0.090±0.017	0.122±0.018	0.205±0.026	0.124±0.013	$t = 2.80$, df = 30 $p < 0.01$	-
		Point Avoid	No data	No data	0.126±0.043	0.188±0.049	No data	-	-
		The Gap	0.224±0.036	0.323±0.042	0.244±0.025	0.290±0.035	0.200±0.025	$t = 2.05$, df = 58 $p < 0.05$	$F^2_{1,150} = 0.58$ $p > 0.05$

NA indicates not applicable

Appendix 5. (continued)

Performance Indicator	Units	Survey site	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Legal-sized abalone abundance	no.m^{-2}	Ward Island	0.086±0.012	0.101±0.010	0.115±0.014	0.110±0.018	0.171±0.017	$t = 2.53$, df = 30 $p < 0.05$	$F^2_{1,78} = 15.09$ $p < 0.01$
		Flinders Island	0.098±0.022	0.101±0.011	0.114±0.023	0.127±0.019	0.106±0.014	$t = 0.88$, df = 46 $p > 0.05$	$F^2_{1,118} = 0.54$ $p > 0.05$
		Hotspot	0.201±0.020	0.185±0.018	0.236±0.014	0.197±0.023	0.186±0.018	$t = 0.37$, df = 94 $p > 0.05$	$F^2_{1,226} = 0.10$ $p > 0.05$
		Pearson Island	No data	0.082±0.016	0.111±0.019	0.190±0.026	0.114±0.012	$t = 2.65$, df = 30 $p < 0.05$	-
		Point Avoid	No data	No data	0.038±0.018	0.084±0.020	No data	-	-
		The Gap	0.080±0.011	0.134±0.013	0.115±0.010	0.168±0.018	0.119±0.014	$t = 2.11$, df = 58 $p < 0.05$	$F^2_{1,150} = 5.84$ $p < 0.05$
Sub-legal-sized abalone abundance	no.m^{-2}	Ward Island	0.079±0.010	0.060±0.007	0.074±0.013	0.077±0.014	0.089±0.014	$t = 0.62$, df = 30 $p > 0.05$	$F^2_{1,78} = 0.96$ $p > 0.05$
		Flinders Island	0.100±0.030	0.119±0.026	0.166±0.045	0.160±0.035	0.114±0.012	$t = 1.26$, df = 46 $p > 0.05$	$F^2_{1,118} = 0.50$ $p > 0.05$
		Hotspot	0.195±0.018	0.162±0.014	0.259±0.013	0.224±0.034	0.185±0.017	$t = 1.01$, df = 94 $p > 0.05$	$F^2_{1,226} = 0.25$ $p > 0.05$
		Pearson Island	No data	0.009±0.003	0.014±0.005	0.019±0.004	0.011±0.003	$t = 1.65$, df = 30 $p > 0.05$	-
		Point Avoid	No data	No data	0.090±0.030	0.106±0.034	No data	-	-
		The Gap	0.170±0.035	0.219±0.042	0.145±0.021	0.146±0.023	0.099±0.015	$t = 1.70$, df = 58 $p > 0.05$	$F^2_{1,150} = 5.61$ $p < 0.05$

Appendix 6: Assessment of the blacklip fishery in Region A of the Western Zone of the South Australian abalone fishery against the biological performance indicators in the Management Plan. Values are mean ± SE. Red indicates statistical significance.

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Commercial effort	hr	Region A	3436	3386	3229	3215	3189	-	$r^2 = 0.88$, df = 3 $p < 0.05$
Mean daily catch	$kg.day^{-1}$	Area 4	310.1±15.2	303.1±14.7	241.2±16.6	331.9±22.2	346.7±22.1	$t = 0.46$, df = 123 $p > 0.05$	$F_{1,386} = 2.20$ $p > 0.05$
		Area 5	360.3±22.7	329.5±25.0	334.3±20.3	338.4±17.8	372.9±17.5	$t = 1.37$, df = 201 $p > 0.05$	$F_{1,418} = 0.40$ $p > 0.05$
		Area 6	297.6±24.7	394.4±21.7	470.9±28.0	412.8±23.1	496.3±41.0	$t = 1.87$, df = 100 $p > 0.05$	$F_{1,304} = 20.0$ $p < 0.01$
		Area 8	316.1±19.0	331.7±19.1	364.3±24.0	391.4±32.4	430.6±31.0	$t = 0.87$, df = 82 $p > 0.05$	$F_{1,264} = 14.01$ $p < 0.01$
		Area 9	387.8±16.2	357.0±18.4	367.0±18.3	489.8±21.9	577.1±25.5	$t = 2.58$, df = 170 $p < 0.05$	$F_{1,493} = 57.38$ $p < 0.01$
		Area 11	506.4±21.6	473.2±21.7	489.2±20.7	522.2±26.0	544.4±31.1	$t = 0.55$, df = 119 $p > 0.05$	$F_{1,350} = 2.10$ $p > 0.05$
		Area 12	395.7±27.5	383.0±14.4	351.5±22.4	370.2±29.9	437.6±23.9	$t = 1.78$, df = 71 $p < 0.05$	$F_{1,202} = 0.35$ $p > 0.05$
		Area 13	388.3±22.1	389.6±21.0	381.5±20.5	366.1±23.2	402.0±18.8	$t = 1.21$, df = 117 $p > 0.05$	$F_{1,264} = 0.03$ $p > 0.05$
		Area 14	451.4±27.5	402.3±22.5	365.0±27.3	378.8±21.2	413.0±25.6	$t = 1.04$, df = 66 $p > 0.05$	$F_{1,176} = 1.56$ $p > 0.05$

Appendix 6. (continued)

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Mean daily effort	$hr.day^{-1}$	Area 4	4.4±0.1	4.2±0.1	3.7±0.2	4.1±0.2	4.5±0.2	$t = 1.50$, df = 123 $p > 0.05$	$F_{1,386} = 0.03$ $p > 0.05$
		Area 5	4.7±0.2	4.3±0.2	3.9±0.2	4.2±0.2	4.8±0.2	$t = 2.89$, df = 201 $p < 0.01$	$F_{1,418} = 0.48$ $p > 0.05$
		Area 6	3.9±0.3	4.9±0.2	5.0±0.2	4.8±0.2	5.1±0.3	$t = 1.47$, df = 155 $p > 0.05$	$F_{1,304} = 9.20$ $p < 0.01$
		Area 8	4.6±0.2	4.9±0.2	4.4±0.2	4.6±0.2	5.2±0.3	$t = 1.63$, df = 82 $p > 0.05$	$F_{1,264} = 1.97$ $p > 0.05$
		Area 9	5.3±0.2	4.9±0.2	4.5±0.2	5.6±0.2	6.6±0.2	$t = 4.40$, df = 170 $p < 0.01$	$F_{1,493} = 29.08$ $p < 0.01$
		Area 11	5.1±0.1	5.2±0.2	5.2±0.2	5.4±0.2	5.6±0.2	$t = 1.01$, df = 119 $p > 0.05$	$F_{1,350} = 4.87$ $p > 0.05$
		Area 12	5.2±0.2	5.1±0.2	4.7±0.3	4.9±0.3	6.0±0.2	$t = 3.36$, df = 71 $p < 0.01$	$F_{1,202} = 3.34$ $p > 0.05$
		Area 13	5.6±0.2	5.6±0.2	6.0±0.2	5.5±0.2	5.8±0.2	$t = 1.06$, df = 117 $p > 0.05$	$F_{1,264} = 0.52$ $p > 0.05$
		Area 14	6.1±0.2	5.5±0.2	5.5±0.3	6.0±0.3	5.7±0.2	$t = 2.73$, df = 66 $p > 0.05$	$F_{1,176} = 0.06$ $p > 0.05$

Appendix 6. (continued)

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
CPUE	$kg.hr^{-1}$	Area 4	70.2±2.5	72.2±2.7	66.1±3.8	81.1±3.7	77.1±2.7	$t^1 = 0.87$, df = 101.9 $p > 0.05$	$F^2_{1,386} = 3.19$ $p > 0.05$
		Area 5	76.4±3.3	75.9±3.9	86.3±3.3	80.1±2.7	77.1±2.6	$t^1 = 0.79$, df = 199.8 $p > 0.05$	$F^2_{1,418} = 0.32$ $p > 0.05$
		Area 6	76.6±3.5	81.0±2.9	94.0±3.8	86.4±2.4	97.1±5.0	$t^1 = 1.91$, df = 63.8 $p > 0.05$	$F^2_{1,304} = 4.67$ $p > 0.05$
		Area 8	69.4±3.9	68.0±3.3	82.9±3.6	84.3±4.8	83.1±3.8	$t^1 = 0.31$, df = 71.6 $p > 0.05$	$F^2_{1,264} = 6.00$ $p < 0.05$
		Area 9	73.3±2.0	72.4±2.3	82.3±2.5	87.0±3.0	87.8±3.0	$t^1 = 0.19$, df = 169.4 $p > 0.05$	$F^2_{1,493} = 15.23$ $p < 0.01$
		Area 11	99.5±3.9	91.8±3.3	94.1±3.1	97.2±4.4	96.7±4.1	$t^1 = 0.09$, df = 117.0 $p > 0.05$	$F^2_{1,350} = 0.40$ $p > 0.05$
		Area 12	76.4±4.3	75.4±2.3	76.5±3.1	75.6±4.4	73.6±3.6	$t^1 = 0.36$, df = 63.6 $p > 0.05$	$F^2_{1,202} = 0.36$ $p > 0.05$
		Area 13	69.6±3.0	69.8±2.9	63.1±2.1	66.1±2.9	68.8±3.3	$t^1 = 0.74$, df = 106.1 $p > 0.05$	$F^2_{1,264} = 0.12$ $p > 0.05$
		Area 14	74.5±4.3	73.3±3.1	66.2±3.3	63.8±3.3	72.7±3.5	$t^1 = 1.86$, df = 64.8 $p > 0.05$	$F^2_{1,176} = 1.72$ $p > 0.05$

1. Based on the ratio estimator (after Rice 1995)

2. Based on daily CPUE

Appendix 6. (continued)

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Mean size	mm, SL	Area 4	No data	157.9±1.4	151.8±0.9	151.2±0.3	147.5±0.5	$t = 4.92$, df = 1033 $p < 0.01$	-
		Area 5	No data	151.6±0.7	152.8±0.8	147.8±0.3	151.3±0.5	$t = 6.32$, df = 1336 $p < 0.01$	-
		Area 6	No data	No data	No data	161.1±0.6	153.1±0.5	$t = 8.58$, df = 833 $p < 0.01$	-
		Area 8	No data	149.6±0.7	No data	151.3±0.7	149.1±0.4	$t = 14.1$, df = 1423 $p < 0.01$	-
		Area 9	No data	155.0±0.5	154.9±0.9	150.5±0.3	152.7±0.3	$t = 5.51$, df = 3359 $p < 0.01$	-
		Area 11	No data	147.8±0.5	No data	143.7±0.4	150.0±0.3	$t = 11.8$, df = 1527 $p < 0.01$	-
		Area 12	No data	No data	No data	146.6±0.4	143.3±0.2	$t = 7.2$, df = 1741 $p < 0.01$	
		Area 13	No data	142.9±0.3	146.7±0.4	149.1±0.4	148.2±0.7	$t = 1.31$, df = 937 $p > 0.05$	-
		Area 14	No data	147.2±0.5	150.4±0.9	145.3±0.4	150.1±0.8	$t = 5.52$, df = 535 $p < 0.01$	-

Appendix 6. (continued)

Performance Indicator	Units	Spatial Scale	2001	2002	2003	2004	2005	Inter-annual change	5-year trend
Egg production retained	%	Area 4	No data	No data	No data	No data	No data	NA	NA
		Area 5	No data	No data	No data	No data	No data	NA	NA
		Area 6	No data	No data	No data	No data	No data	NA	NA
		Area 8	No data	No data	No data	No data	No data	NA	NA
		Area 9	No data	37.3	35.5	38.3	65.2	NA	NA
		Area 11	No data	No data	No data	67.4	60.4	NA	NA
		Area 12	No data	No data	No data	No data	No data	NA	NA
		Area 13	No data	No data	No data	No data	No data	NA	NA
		Area 14	No data	No data	No data	No data	No data	NA	NA

NA indicates not applicable