

**Exploratory fishing and population
biology of greenlip abalone
(*Haliotis laevis*) off Cowell**

Report to PIRSA

March 2006

Carlson, I. J., Mayfield, S., McGarvey, R. and C.D. Dixon



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TABLE OF CONTENTS

| | |
|--|-----------|
| LIST OF ACRONYMS | i |
| EXECUTIVE SUMMARY | ii |
| ACKNOWLEDGEMENTS | iv |
| 1. GENERAL INTRODUCTION | 1 |
| Project Overview | 2 |
| 2. DISTRIBUTION OF GREENLIP OFF COWELL | 6 |
| 2.1 Introduction | 6 |
| 2.2 Methods | 6 |
| 2.2.1 Catch | 6 |
| 2.2.2 Catch-per-unit effort (CPUE) | 7 |
| 2.2.3 Mapping commercial CPUE | 7 |
| 2.2.4 Length frequency distribution of the commercial catch | 7 |
| 2.3 Results..... | 7 |
| 2.3.1 Catch | 7 |
| 2.3.2 Catch-per-unit effort (CPUE) | 11 |
| 2.3.3 Length frequency distribution of the commercial catch | 11 |
| 3. ABUNDANCE OF GREENLIP OFF COWELL..... | 15 |
| 3.1 Introduction | 15 |
| 3.2 Methods | 15 |
| 3.2.1 Transect surveys to estimate density and length-frequency distribution ... | 15 |
| 3.2.2 Bootstrap confidence intervals..... | 17 |
| 3.3 Results..... | 18 |
| 3.3.1 Estimate of greenlip density in the survey area | 18 |
| 3.3.2 Estimate of greenlip population size in the survey area | 19 |
| 3.3.3 Estimate of greenlip biomass in the survey area..... | 19 |
| 3.3.3 Length-frequency distribution of the sample | 21 |
| 4. BIOLOGY OF GREENLIP OFF COWELL..... | 22 |
| 4.1 Introduction | 22 |
| 4.2 Methods | 22 |
| 4.2.1 Relationship between shell length and whole weight..... | 22 |
| 4.2.2 Relationship between whole weight and meat weight..... | 23 |
| 4.2.3 Relationship between shell length and bled meat weight | 23 |
| 4.2.4 Size at sexual maturity | 23 |
| 4.2.5 Sex ratio | 24 |
| 4.2.6 Rate of growth..... | 24 |
| 4.3 Results..... | 24 |
| 4.3.1 Relationship between shell length and whole weight..... | 24 |
| 4.3.2 Relationship between whole weight and meat weight..... | 25 |
| 4.3.3 Relationship between shell length and bled meat weight | 27 |
| 4.3.4 Size at sexual maturity | 27 |
| 4.3.5 Sex ratio | 28 |
| 4.3.6 Rate of growth..... | 28 |
| 5. GENERAL DISCUSSION | 29 |
| 6. REFERENCES | 33 |

LIST OF ACRONYMS

| | |
|-------|--|
| AIASA | Abalone Industry Association of South Australia |
| BMW | Bled meat weight |
| CI | Confidence interval |
| CZ | Central Zone of the South Australian abalone fishery |
| CPUE | Catch-per-unit effort |
| GPS | Global positioning system |
| MLL | Minimum legal length |
| MW | Meat weight |
| PIRSA | Primary Industries and Resources SA |
| SAAF | South Australian abalone fishery |
| SARDI | South Australian Research and Development Institute |
| SE | Standard error |
| SL | Shell length |
| TACC | Total allowable commercial catch |
| WW | Whole weight |
| WZ | Western Zone of the South Australian abalone fishery |

EXECUTIVE SUMMARY

1. This is the second report on the distribution, abundance and biology of greenlip abalone (*Haliotis laevis*) off Cowell in NW Spencer Gulf. It documents exploratory fishing, fishery-independent surveys and biology of this species in this area during 2004 and 2005.
2. The aim of the project was to determine the distribution, abundance and biology of *H. laevis* off Cowell to address the potential for these stocks to support a commercial fishery.
3. Greenlip abalone were first harvested from the Cowell area in 1989. Since then, catches from this area have been low and sporadic (cumulatively <10 t whole weight).
4. This is the first project to effectively link exploratory fishing for abalone with fishery-independent surveys estimating absolute biomass and population number within a defined survey area.
5. Specifically, commercial abalone fishers undertaking directed exploratory fishing within designated areas for specified periods of time provided data on the distribution and abundance of greenlip abalone. These data were used to identify the area of highest greenlip abalone density which was then surveyed by SARDI using the leaded-line survey method.
6. In 2004 and 2005, exploratory fishing was undertaken in 595 of 1143 (52%) one-square-km blocks, distributed among seven regions. Greenlip abalone were harvested from 66 blocks distributed among four regions. The total catch was 3.10 t (8,390 individuals). Catches of >200 individuals were obtained from 16 blocks, 13 of which were in Region D.
7. In 2005, similar exploratory fishing was targeted in Regions C and D into the area of highest abundance from 2004. In total, 174 of 380 (46%) ¼-square-km blocks were surveyed. Greenlip abalone were harvested from 47 blocks and the total catch was 2.47 t (6,265 individuals). Large catches (>150 individuals), that collectively accounted for 69% of the total catch, were obtained from 18 blocks.
8. The data from the exploratory fishing suggest that greenlip abalone were not widely distributed off Cowell and that there is one large 'aggregation', located in a narrow band (~2 km wide by 16 km long) running east-west between 3 km and 8 km offshore.
9. Fishery-independent surveys, using the leaded-line transect method, were used to estimate the density, total number and legal-sized, bled-meat-weight biomass of greenlip abalone within a defined and stratified survey area of highest exploratory-fishing CPUE.

10. No abalone were observed on 46% of fishery-independent, leaded-line transects – even in areas within which the commercial CPUE was high. This confirmed the patchy distribution of this species in this area.
11. A high percentage of the total (78%) and sub-legal-sized (85%) greenlip were observed in the high-CPUE stratum – despite this stratum covering less than half (40%; 6.8 km²) of the survey area.
12. The confidence ratio (SE/mean) was 32.5%. This represented a substantial improvement in the precision of the survey estimate over that in 2004 (41%).
13. The mean survey estimates of density, total number and legal-sized bled-meat-weight (BMW) biomass inside the survey area were 0.047 greenlip abalone.m⁻², 800,000 individuals and 77 t, respectively.
14. In combination, the high commercial CPUE in Region D and the large estimates of legal-sized, bled-meat-weight biomass in the survey area, suggest that there is a strong potential for the greenlip abalone stocks off Cowell to support a commercial fishery with conservative catch limits.
15. Several significant advances in knowledge on the South Australian abalone fishery would accrue if harvesting greenlip off Cowell was undertaken alongside an appropriate long-term research program.

ACKNOWLEDGEMENTS

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We are grateful to Mr Brian Foureur, Mr Rowan Chick and Mr Nick Turich for diving, fieldwork and logistic support. Mr Rowan Chick also provided useful comments on earlier drafts of this report that substantially improved the document. Mr Chris Isso assisted with shell measuring and data entry. Ms Annette Doonan created the maps and GIS information. Mr John Feenstra undertook the interpolations on the catch and effort data. Mr Michael Tokley provided the cover photograph. The divers and deckhands of the Central Zone abalone fishery are thanked for their co-operation in conducting the exploratory fishing. We are grateful to Mr Chris Rooyens (Hot Dog Fisheries) and Mr David Pickles (Dover Fisheries) for collection of the catch-weight data.

This report was formally reviewed by Dr Adrian Linnane (SARDI Aquatic Sciences), Mr Paul Rogers (SARDI Aquatic Sciences), Mr Sean Sloan (PIRSA Fisheries), Mr Bob Pennington (AIASA) and Mr Michael Tokley (AIASA). Dr Tony Fowler (Sub-Program Leader: Marine Scalefish, SARDI Aquatic Sciences) formally approved the report for release.

1. GENERAL INTRODUCTION

This is the second report to PIRSA on the project “Exploratory fishing for and biology of greenlip abalone (*Haliotis laevis*) off Cowell”. The report updates the 2004 report (Dixon *et al.* 2004) and is divided into five sections.

The first section is the general introduction that outlines the structure of the report and provides an overview of the project. Section two describes the distribution and abundance of greenlip abalone (hereafter referred to as greenlip) off Cowell. This was inferred from catch and effort data provided by commercial fishers undertaking directed exploratory fishing within 1,143 one-square-km blocks (during 2004 and 2005) distributed among seven Regions (A-G) and 380 ¼-square-km blocks (during 2005). Analyses presented include spatial patterns in (1) catch (by numbers and weight); (2) catch-per-unit effort (CPUE, kg.hr⁻¹); and (3) size-frequency distribution of the catch. Data were compared to that from other fished areas of the South Australian Abalone Fishery (SAAF) from which large catches of greenlip have been obtained over the last five years.

Section three describes the fishery-independent survey design, with surveys conducted in the areas of highest greenlip density identified by exploratory fishing (42 km² in 2004; 16.9 km² in 2005). They employed the recently developed leaded-line survey method, which was used to estimate absolute density and legal-size, bled-meat-weight biomass in the bounded survey area. The results of the survey, including estimates of the greenlip legal biomass and associated confidence levels of these estimates are also presented.

Details of the collection and analysis of biological data on greenlip off Cowell in 2004 (May and June) and 2005 (June and August) are provided in Section four. Data presented include the relationships between shell length and rate of growth, total weight, shell length and bled meat weight, meat weight and total weight, the size at which 50% of the individuals observed were sexually mature and the sex ratio of the samples. The rate of weight loss by the harvested greenlip meats was also examined.

Section five, the general discussion, summarises information from the previous sections, draws conclusions and highlights the cost-effective use of coordinating the collection of commercial fishery data in concert with developing and refining fishery-independent methods for stock assessment. Both uncertainty in the current knowledge and future options are also identified.

Project Overview

The SAAF began in 1964. 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 (Zacharin 1997, Nobes *et al.* 2004). In 1971 the SAAF was divided into three Zones (Western, Central and Southern). The Central Zone (CZ) of the SAAF includes all coastal waters of South Australia between Longitude 136°30'E and Longitude 139°E. There are six commercial abalone licence holders in the CZ.

Quotas were imposed on the CZ from 1990. The larger proportion (85%) of the total allowable commercial catch (TACC) in the CZ comprises greenlip (2006 TACC: 143.1 t whole weight). The remainder, 15%, comprises blacklip abalone (2006 TACC: 24.3 t whole weight). Minimum legal lengths (MLL; 130 mm shell length (SL)) were imposed on both species in 1971 (Mayfield *et al.* 2004).

Since the introduction of TACC in 1990, the spatial distribution of the CZ catch has contracted, and substantially so over the last decade. Thus, small catches of greenlip are currently being harvested from many fishing areas in the CZ.

Prior to 1989 no catch was reported from the Cowell area (SARDI Aquatic Sciences, unpublished data). During 1989 >18 t (whole weight) was harvested from this area. However, since 1989 effort in and catches from the Cowell area have been sporadic. The cumulative catch from 1990 to 2003 was <10 t (whole weight). Reasons for the low fishing effort in, and small catches from, the Cowell area are unclear. Hence, the extent of the greenlip stocks in the Cowell area are unknown.

To address the potential for the greenlip stocks off Cowell to support a commercial fishery, a project was developed collaboratively among SARDI Aquatic Sciences, PIRSA and the AIASA. The aim of the project was to determine the distribution, abundance and biology of greenlip off Cowell. The primary objectives were:

1. To determine the spatial distribution of greenlip;
2. To evaluate the catch rates on greenlip by commercial divers, and to compare those with catch rates observed in other fishing areas of the CZ and WZ;
3. To determine the size-frequency distribution of the commercial catch;
4. To use fishery-independent surveys to estimate the density and abundance of greenlip in a bounded survey area;
5. To obtain biological data relevant to developing harvest strategies for greenlip off Cowell; and
6. To ascertain the potential for sustainable commercial exploitation of greenlip off Cowell.

To facilitate this research the CZ mapcodes 21J and 20C (referred to collectively as the Cowell area, hereafter) were divided into seven Regions (Regions A-G; Figure 1.1). Each of the seven Regions was divided into blocks 1 km in length and width, from the shore seawards to about the 20-m depth contour. A sub-set of the blocks within Regions C and D that encompassed the extent of the area with harvestable biomass levels were subdivided into ¼-square-km blocks (*i.e.* 500 m by 500 m) to permit analysis of greenlip distribution and abundance at a finer spatial scale (Figure 1.2).

The research plan comprised (1) the collection, collation and analysis of comprehensive catch and effort data from exploratory fishing undertaken by CZ licence holders; (2) fishery-independent surveys; and (3) the collection and analysis of relevant biological information from the greenlip population.

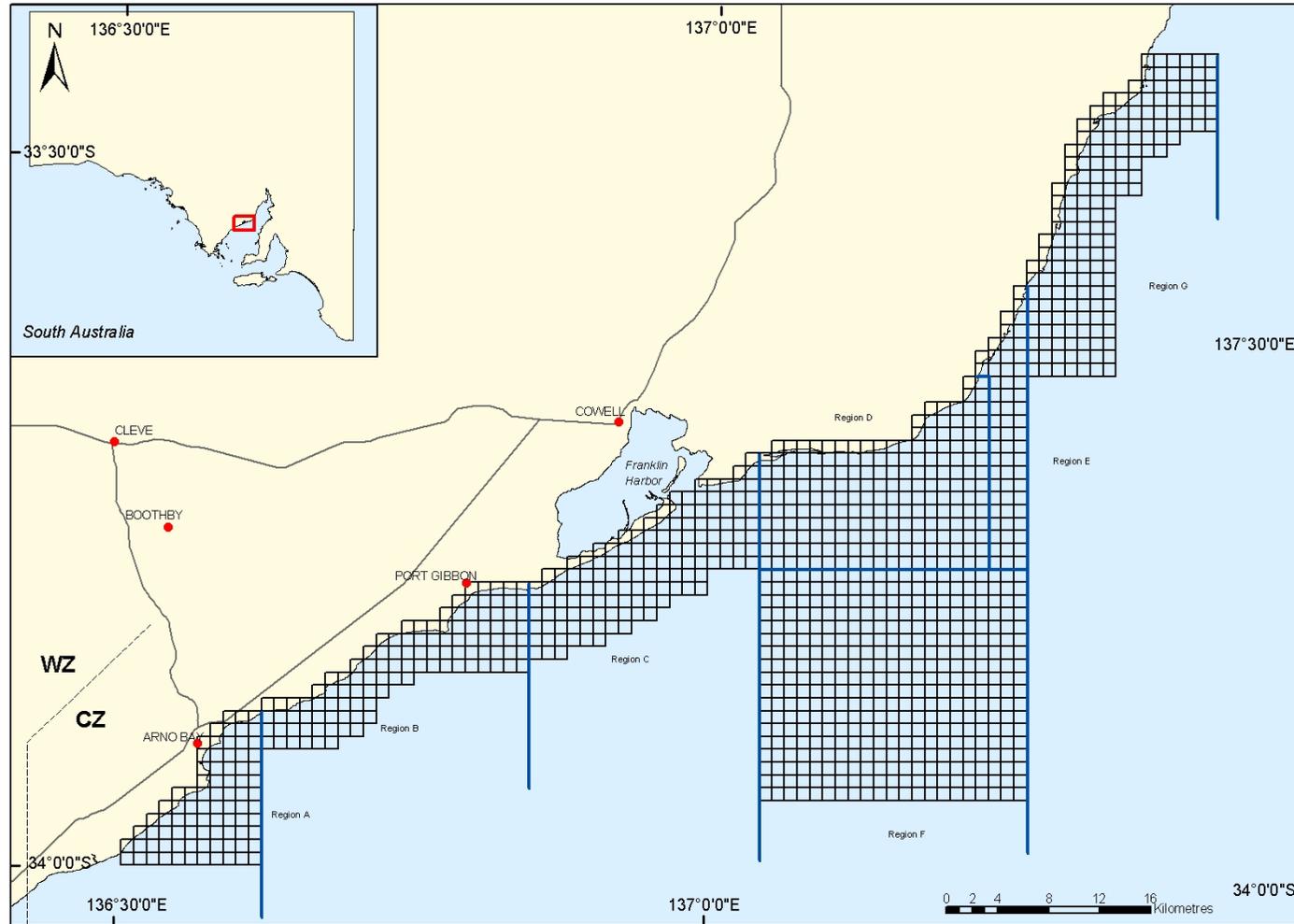


Figure 1.1: Location of Regions and one-square-km blocks used in the exploratory fishing for greenlip off Cowell in 2004 and 2005.

2. DISTRIBUTION OF GREENLIP OFF COWELL

2.1 Introduction

Prior to this project, there were no data on the distribution or abundance of greenlip off Cowell. Information about their spatial distribution (*i.e.* both patchiness and area with fishable densities) was required to evaluate the potential for a fishery on greenlip in this region. To obtain these data, commercial abalone divers harvested greenlip during controlled fishing within 589 one-square-km blocks in May 2004, and in both 554 one-square-km blocks and 380 ¼-square-km blocks in June 2005 (after Groeneveld & Cockcroft 1997).

The detailed catch and effort data provided by the fishers enabled the distribution and abundance of greenlip off Cowell to be determined. Information on the abundance of greenlip was inferred from catch rates (catch-per-unit-effort, CPUE). These data also aided the selection of sites for fishery-independent surveys, hence increasing their precision (Section 3), and the identification of sites for collection of biological data (Section 4).

2.2 Methods

Broad scale: Over 110 km of coastline, east of Longitude 136°50'E was divided into seven arbitrarily defined regions (A-G; Figure 1.1). Each region was further sub-divided into one-square-km blocks (based on Eastings and Northings) from the shore seaward to the 20-m depth contour.

Fine scale: A sub-set of the blocks within Regions C and D that encompassed the extent of the area with harvestable biomass levels were subdivided into ¼-square-km blocks (Figure 1.2) to permit analysis of greenlip distribution and abundance at a finer spatial scale.

GPS positions of the corner and centre points of each block were provided to divers prior to fishing. Each vessel was designated a series of survey blocks on each fishing day. Each block was first searched with an echo sounder. Thereafter, divers entered the water and harvested all greenlip >120 mm SL. Diving within each block was restricted to one hour. Comprehensive catch and effort data were recorded for each block (see Appendix 1). This included the location (GPS position) at the start and end point of each dive, catch number, estimated catch weight and time taken to harvest each bag of greenlip.

2.2.1 Catch

All greenlip >120 mm shell length (SL) were harvested and 'shucked' at sea. Meats were kept in separately labelled bags for each block. Harvested meats were transported to the processor

at the conclusion of each days fishing. The processor recorded the catch information supplied for each bag and provided a total count and weight of greenlip meat from each block to SARDI. The whole weight of the catch was estimated at three times the meat weight (see Section 4).

2.2.2 Catch-per-unit effort (CPUE)

Catch rate (CPUE) was calculated, as the total whole weight divided by total diving time, for each block. Catch rates from each block were categorised based on the 5-year average raw CPUE from Tiparra Reef (CZ) from 1998 to 2004 (Mayfield *et.al.* 2005a). Catch rates were considered high when the average CPUE was exceeded ($>81 \text{ kg.hr}^{-1}$), medium when the catch rate was greater than half the average CPUE (range: $40.5\text{--}81 \text{ kg.hr}^{-1}$) and low when the catch rate was less than half the average CPUE ($<40.5 \text{ kg.hr}^{-1}$).

2.2.3 Mapping commercial CPUE

The systematically-spaced catch and effort data from the exploratory fishing within the 380 $\frac{1}{4}$ -square-km blocks across Regions C and D provided a spatial data set of 171 approximate-point measurements of CPUE. Distribution maps of CPUE were produced using the radial basis function (RBF) in ArcView GIS (version 8.3).

2.2.4 Length frequency distribution of the commercial catch

All shells from the commercial catch were measured where possible. The majority of shells ($>99\%$) from the commercial catch were brought ashore and measured by SARDI.

2.3 Results

During 57 days of effort, exploratory fishing was undertaken in 52% of the 1,143 one-square-km blocks off Cowell (Figure 2.1; Table 2.1). Exploratory fishing occurred in $>67\%$ of the blocks in Region D. A lower fraction of the blocks were fished in the other Regions (6-63%).

Twenty days of exploratory fishing effort resulted in 174 (46%) of the 380 $\frac{1}{4}$ -square-km blocks being surveyed (Figure 2.2; Table 2.2).

2.3.1 Catch

Broad scale: A total of 8,390 greenlip were harvested, representing a total whole weight of 3.10 t (Table 2.1). Most of the catch was obtained from Region D (2.1 t; 67% by number and by weight). Almost 20% of the catch (0.6 t) was obtained from Region B. Only small catches were obtained from Regions A (0.09 t), C (0.3 t) and E (0.05 t), and no greenlip were observed in, or harvested from Regions F and G.

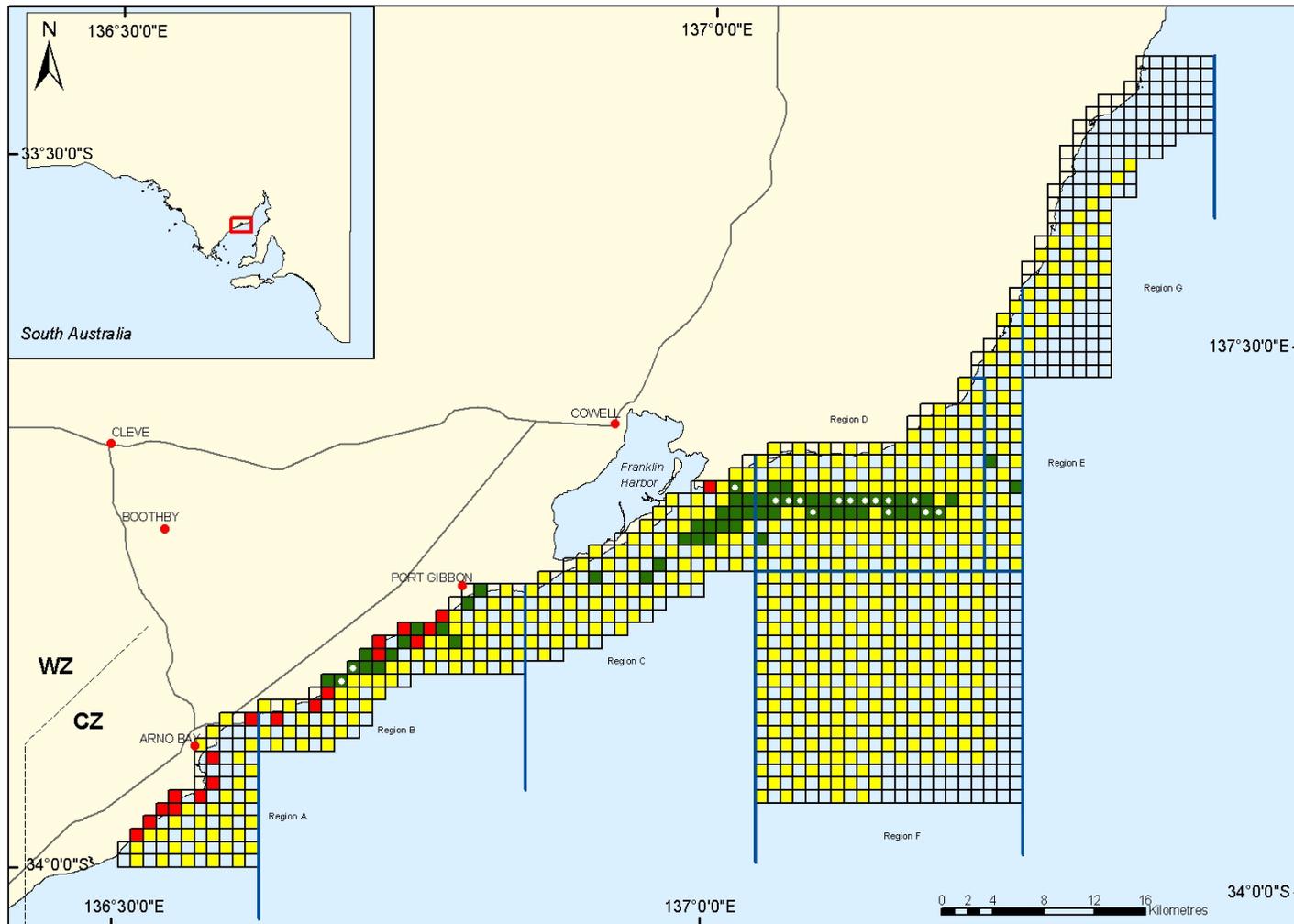


Figure 2.1: Surveyed one-square-km blocks within which the substrate comprised reef from which no greenlip were harvested (red shading), reef from which at least one greenlip was harvested (green shading), reef from which >200 greenlip were harvested (green shading with white dot) or sand/seagrass (yellow shading). Pale blue blocks were not surveyed.

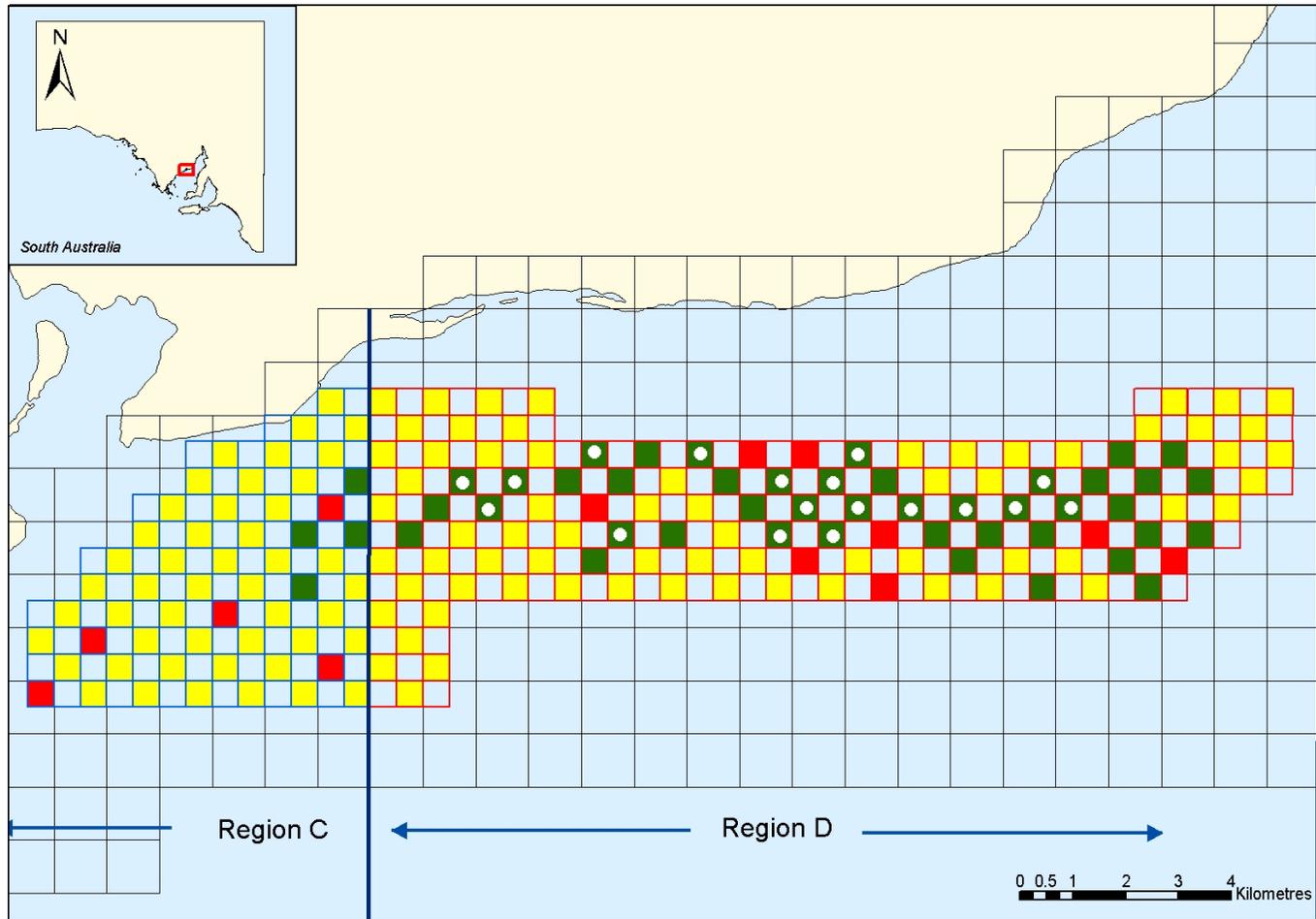


Figure 2.2: Surveyed 1/4-square-km blocks within which the substrate comprised reef from which no greenlip were harvested (red shading), reef from which at least one greenlip was harvested (green shading) reef from which >150 greenlip were harvested (green shading with white dot) or sand/seagrass/clay (yellow shading). Pale blue blocks were not surveyed.

Table 2.1: Summary catch, effort and CPUE data for the seven Regions within which exploratory fishing in one-square-km blocks was undertaken during 2004 (Regions A-E) and 2005 (Regions F and G).

| | Region | | | | | | | |
|---|--------|-----|------|-----|------|-----|-----|-----|
| | All | A | B | C | D | E | F | G |
| Total blocks | 1143 | 81 | 112 | 136 | 200 | 60 | 378 | 176 |
| Blocks within which exploratory fishing occurred | 595 | 50 | 70 | 77 | 134 | 30 | 204 | 30 |
| Percentage of blocks surveyed | 52 | 62 | 63 | 57 | 67 | 50 | 54 | 17 |
| Blocks from which no greenlip were harvested | 539 | 44 | 57 | 63 | 103 | 28 | 204 | 10 |
| Blocks from which at least one greenlip was harvested | 66 | 6 | 13 | 14 | 31 | 2 | 0 | 0 |
| Total catch (numbers) | 8390 | 302 | 1611 | 767 | 5602 | 108 | 0 | 0 |
| Total catch (kg, whole weight) | 3096 | 95 | 597 | 265 | 2085 | 54 | 0 | 0 |
| Mean CPUE (total catch/total effort; kg.hr ⁻¹) | 39 | 13 | 39 | 14 | 60 | 18 | - | - |
| Blocks where the CPUE was high (>81 kg.hr ⁻¹) | 15 | 0 | 2 | 0 | 13 | 0 | 0 | 0 |
| Blocks where the CPUE was medium (40.5–81 kg.hr ⁻¹) | 15 | 1 | 5 | 1 | 8 | 0 | 0 | 0 |
| Blocks where the CPUE was low (<40.5 kg.hr ⁻¹) | 35 | 5 | 6 | 12 | 10 | 2 | 0 | 0 |

Table 2.2: Summary catch, effort and CPUE data for the two Regions within which exploratory fishing in ¼-square-km blocks was undertaken during 2005.

| | Region | | |
|---|--------|-----|------|
| | All | C | D |
| Total blocks | 380 | 112 | 268 |
| Blocks within which exploratory fishing occurred | 174 | 56 | 118 |
| Percentage of blocks surveyed | 46 | 50 | 44 |
| Blocks from which no greenlip were harvested | 127 | 52 | 75 |
| Blocks from which at least one greenlip was harvested | 47 | 4 | 43 |
| Total catch (numbers) | 6265 | 59 | 6206 |
| Total catch (kg, whole weight) | 2470 | 15 | 2455 |
| Mean CPUE (total catch/total effort; kg.hr ⁻¹) | 67 | 4.9 | 73 |
| Blocks where the CPUE was high (>81 kg.hr ⁻¹) | 16 | 0 | 16 |
| Blocks where the CPUE was medium (40.5–81 kg.hr ⁻¹) | 14 | 0 | 14 |
| Blocks where the CPUE was low (<40.5 kg.hr ⁻¹) | 17 | 4 | 13 |

Large numbers of individuals (>200) were only obtained from 16 blocks (Figure 2.1), of which 13 were in Region D. All of these were located within a band that was two blocks high and 14 blocks long (*i.e.* 2 km wide by 14 km in length).

Fine scale: A total of 6,265 greenlip were harvested, representing a total whole weight of 2,470 kg (Table 2.2). Most of the catch was obtained from Region D (2.46 t; 99% by number and by weight) despite this Region containing ~70% of the blocks surveyed. Large catches (>150 individuals) were obtained from 18 blocks that collectively accounted for 69% of the total catch (Figure 2.2).

2.3.2 Catch-per-unit effort (CPUE)

Broad scale: On average, 54 kg whole weight (~18 kg meat weight) was harvested during each fishing day. The mean CPUE (total catch/total effort) was 39 kg hr⁻¹ (Table 2.1). Mean CPUE was highest in Region D (~60 kg hr⁻¹) and lowest in Region A (13 kg.hr⁻¹). Region D had the greatest number of blocks (13; 42%) within which the CPUE was high (Table 2.1). In Region B, the CPUE was only high in 2 (13%) blocks. High CPUE was not observed in any blocks from Regions A, C, E, F or G. Region C had the greatest number of blocks (12) within which the CPUE was low (92%). In general, the CPUE off Cowell was considerably lower than that observed at Tiparra Reef (CZ), or in fishing area 9 and 18 (WZ; range 13–52%; Table 2.2). However, the CPUE in Region D was higher than that observed in fishing areas 9 and 18, and just 10% lower than that at Tiparra Reef.

Fine scale: The mean CPUE was 67 kg.hr⁻¹. Mean CPUE was substantially greater in Region D (73 kg.hr⁻¹) when compared with the CPUE in Region C (4.9 kg.hr⁻¹; Table 2.2). There were no blocks within which the CPUE was medium or high in Region C (Table 2.2). In contrast, the CPUE within 30 blocks in Region D were categorised as high or medium. High catch rates (>81 kg.hr⁻¹) were concentrated in a narrow (<2 km) band approximately 8 km in length, located in the eastern third of the fine-scale survey area (Figure 2.3). The mean CPUE during 2005 in the ¼-square-km blocks distributed in the sub-area of Region D, within which catches were obtained in 2004, was 73 kg.hr⁻¹. As above, this was higher than that observed in fishing areas 9 and 18, and just 10% lower than that at Tiparra Reef.

2.3.3 Length frequency distribution of the commercial catch

Broad scale: The mean size of the commercial catch was 137.9 mm SL and the modal size class was 130–134 mm SL (Figure 2.4). A small percentage of the catch (<1%) was smaller than 120 mm SL. Just over 23% of the catch was between 120 and 129 mm SL; 58% of the catch was larger than 134 mm SL. The maximum size observed was 190 mm SL.

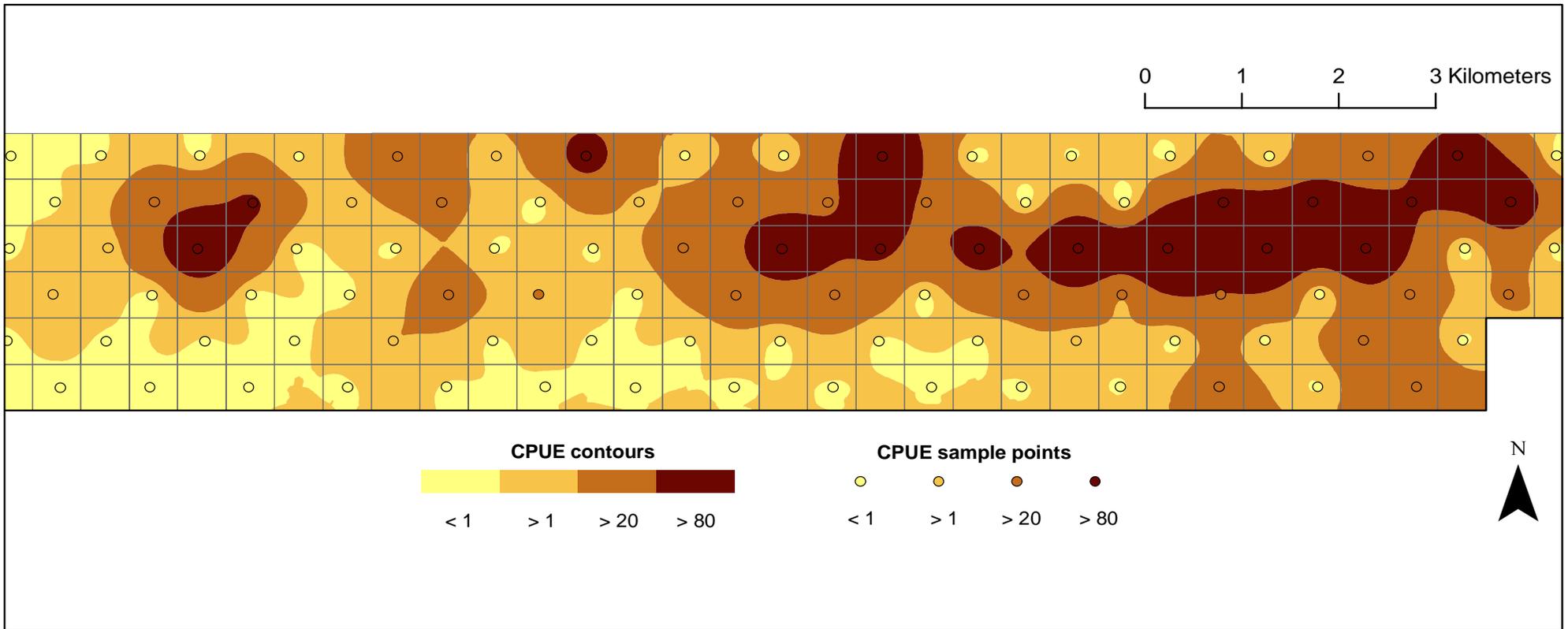


Figure 2.3: Distribution of CPUE on greenlip (kg.hr⁻¹) within the eastern portion of the fine-scale survey area. Circles show the midpoint of each surveyed block.

Table 2.3: Observed (raw) CPUE (kg.hr⁻¹) on greenlip off Cowell during 2004 and 2005, at Tiparra Reef (CZ) and in fishing areas 9 and 18 (WZ; all 5-year average (2000-2004)).

| Location | CPUE (kg.hr ⁻¹) |
|--|-----------------------------|
| Tiparra Reef (CZ; Mayfield <i>et al.</i> 2005a) | 93 |
| Fishing area 9 (WZ; Mayfield <i>et al.</i> 2005b) | 73 |
| Fishing area 18 (WZ; Mayfield <i>et al.</i> 2005b) | 70 |
| Cowell (total catch / total effort) | 37 |
| Cowell (all one-square-km blocks from which catches were obtained) | 40 |
| Cowell (all one-square-km blocks within which the CPUE was medium or high) | 75 |
| Region D (all one-square-km blocks from which catches were obtained) | 73 |
| Region D – ¼-square-km blocks (total catch / total effort) | 73 |

There was substantial spatial variation in the length-frequency distribution of the commercial catch. Notably, the mean size increased from west (130.4 mm SL in Region A) to east (154.1 mm SL in Region E; Figure 2.4). This pattern was also generally reflected in the modal size class. The modal size class was 125–129 mm, 130–134 mm, 135–139 mm, 130–134 mm and 155–159 in Regions A-E, respectively (Figure 2.4). The percentage of the catch larger than 130 mm SL increased from 49% in Region A to 99% in Region E. Similar trends were apparent in the percentage of the catch >135 mm SL.

Fine scale: The mean size of the commercial catch was 142.3 mm SL and the modal size class was 134-139 mm SL (Figure 2.5). A small percentage of the catch (<1%) was smaller than 120 mm SL. Just under 14% of the catch was between 120 and 129 mm SL; 57% of the catch was larger than 139 mm SL while 18% of the catch was larger than 154 mm SL. The maximum size observed was 186 mm SL.

There was substantial spatial variation in the length-frequency distribution of the commercial catch in Region D. Notably, the mean size increased from west (136.6 mm SL) to east (144.6 mm SL; Figure 2.5). This pattern was also reflected in the modal size class (western blocks: 135–139 mm; eastern blocks: 140-145 mm SL) and percentage of the catch larger than 135 mm SL (western blocks: 50%; eastern blocks: 79%).

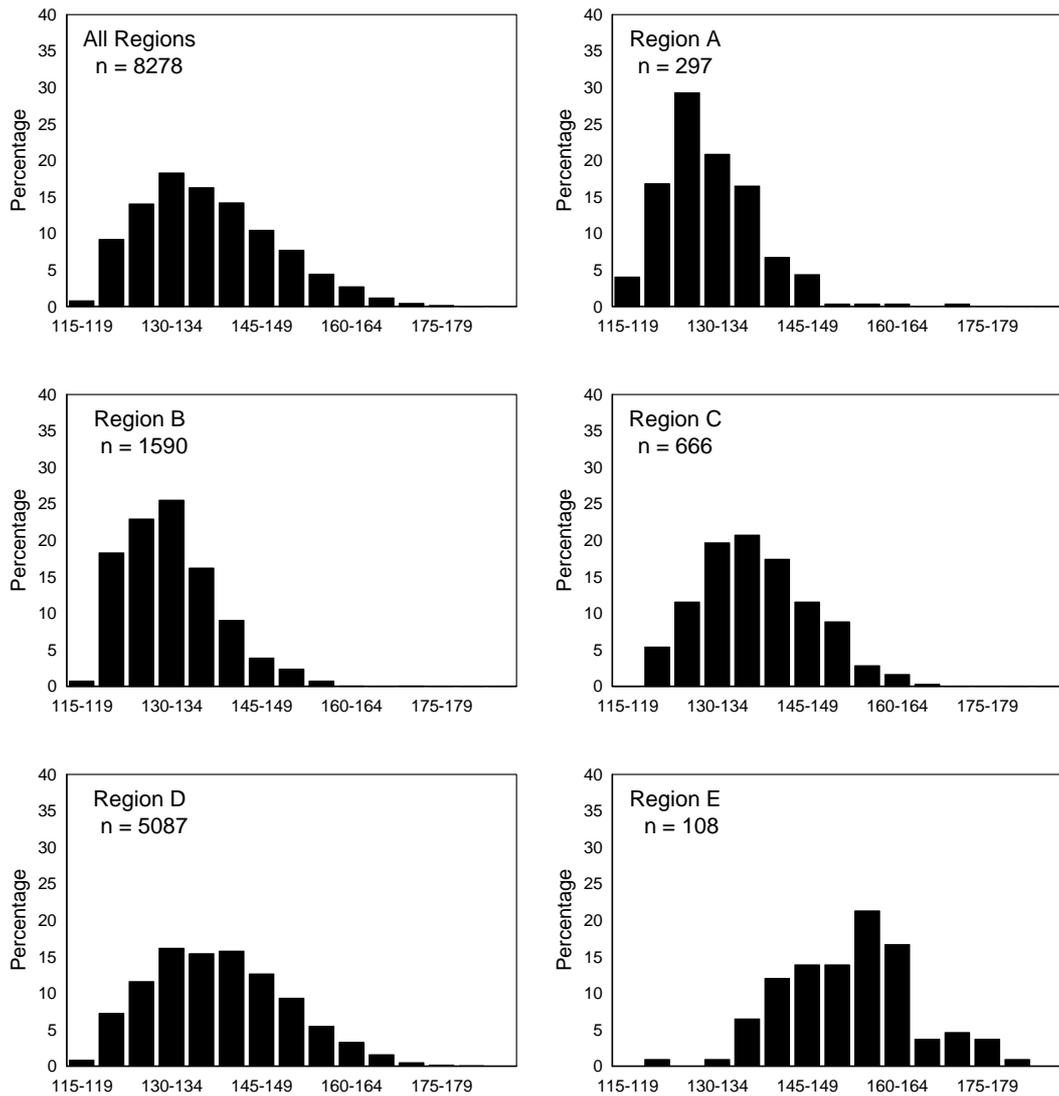


Figure 2.4: Length-frequency distribution of the commercial catch of greenlip from all Regions (combined) and Regions A-E (separately) within which exploratory fishing in one-square-km blocks was undertaken during 2004 (Regions A-E). Data are expressed as a percentage of the total. Size classes are mm SL.

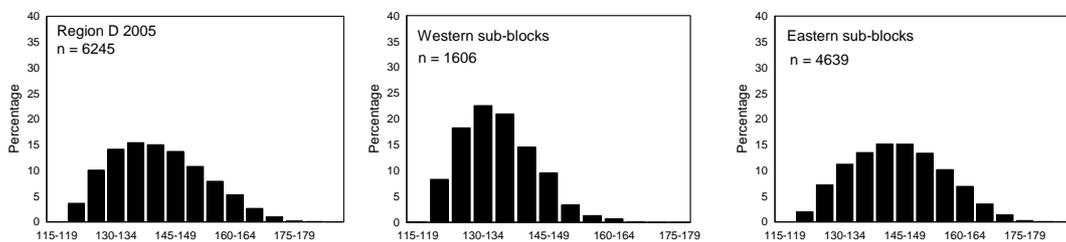


Figure 2.5: Length-frequency distribution of the commercial catch of greenlip from all ¼-square-km blocks, and the ¼-square-km blocks in the western and eastern halves of Region D within which exploratory fishing was undertaken during 2005. Data are expressed as a percentage of the total. Size classes are mm SL.

3. ABUNDANCE OF GREENLIP OFF COWELL

3.1 Introduction

The harvestable biomass was estimated by leaded-line survey inside a designated subregion (survey area) of high greenlip abundance off Cowell. This survey area was identified, and stratified into three strata (high, medium and low), using detailed maps based on catch and effort data provided by the commercial fishers undertaking exploratory fishing. Stratifying the survey area using exploratory fisher data permitted substantially higher precision of the survey biomass estimate.

The catch and effort data obtained from exploratory fishing off Cowell in 2004 were combined with that obtained from exploratory fishing within both one-square-km and ¼-square-km blocks in 2005. The four-fold increase in spatial resolution of exploratory fishing off Cowell, using the ¼-square-km blocks, permitted identification of a smaller survey area (16.9 km²) in 2005 than that surveyed in 2004 (42 km²; Dixon *et al.* 2004). Both areas were surveyed using the leaded-line transect method (McGarvey in press). Using this method (Dixon *et al.* 2004; McGarvey *et al.* 2005; McGarvey in press) enabled determination of the absolute density and biomass of greenlip inside the survey area.

3.2 Methods

To improve the precision of the estimate, the survey was constrained in three ways: (1) only the irregular 16.9 km² area from which the majority of the catch (>95%) had been harvested during fine-scale exploratory fishing in 2005, with the areas of zero or low catch excluded, was surveyed (Figure 3.1); (2) the area was stratified into 3 categories (blocks within which the commercial CPUE during the exploratory fishing was high (>80 kg.hr⁻¹), medium (20–80 kg.hr⁻¹) and low (<20 kg.hr⁻¹) and; (3) within each stratum, a subset of blocks was chosen randomly for survey. The survey design within each stratum followed the leaded-line method developed during an FRDC-funded project (2001/076; McGarvey in press). This survey method permitted estimation of the total number of greenlip, by shell length, in each stratum, and thus in the survey area.

3.2.1 Transect surveys to estimate density and length-frequency distribution

Each of two divers counted and measured (maximum shell length) all greenlip encountered within each of 64 transects, defined as the area one metre on either side of each 100-m leaded-line. Thus all greenlip observed along a total of 64 transect lines, arranged in 32 pairs (leaded lines) were counted and measured.

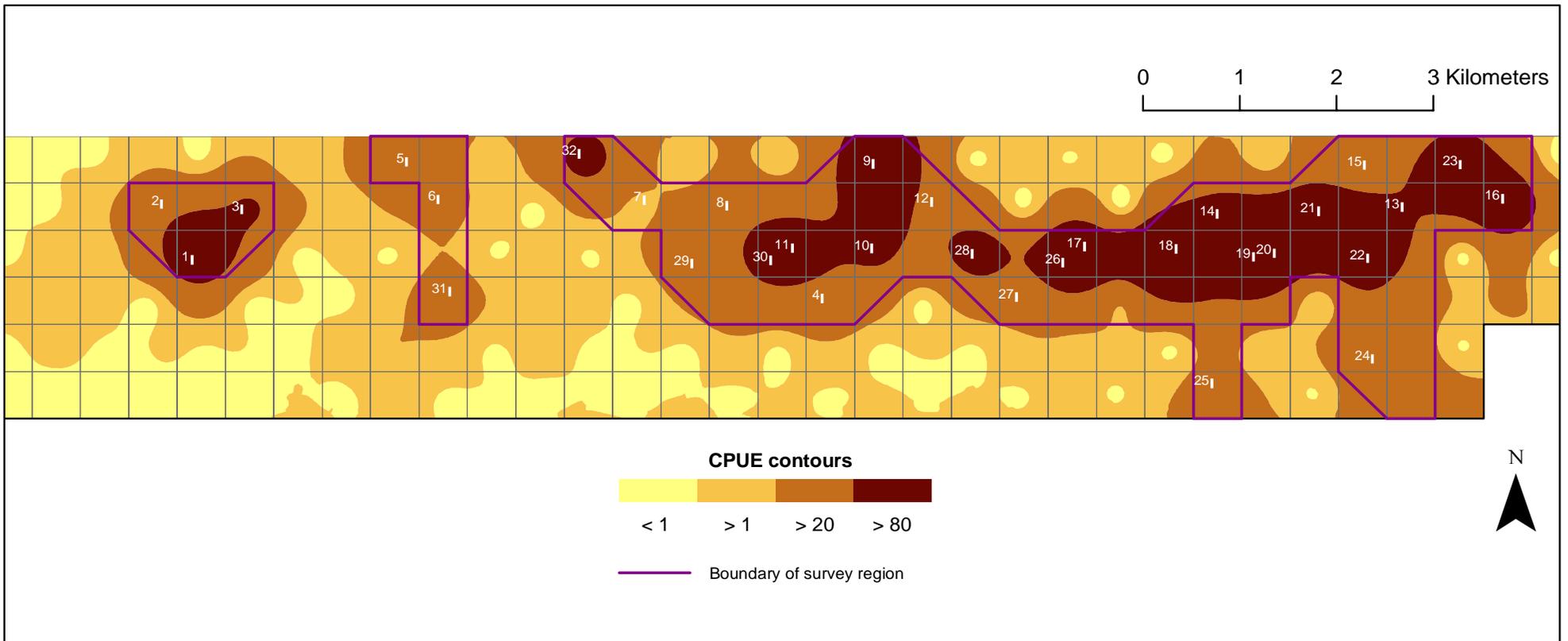


Figure 3.1: Bounded survey area showing the locations of the 32 numbered ledged lines. Two transects were surveyed at each ledged-line location.

The 32 leaded lines were distributed systematically throughout each stratum comprising the survey area (Figure 3.1). Nineteen, 12 and one leaded lines were laid in strata within which the CPUE was high (5.6 transects.km⁻²), medium (2.5 transects.km⁻²) and low (0.7 transects.km⁻²), respectively. All leaded-line transects were laid in a north-south direction.

Harvestable biomass was estimated by combining survey estimates of density in each stratum, with length-frequency samples, and a derived relationship of shell length to bled-meat-weight (BMW). The count of greenlip measured in each 100-m² transect provided an estimate of density. The length measurements provided a representative sample of the size-frequency distribution of the population. The BMW biomass of legal-sized (>130 mm SL) greenlip in each transect was calculated by summing the weight of each legal-sized greenlip counted, calculated from the BMW-length relationship (see Section 4). Total legal-sized population number and biomass in each stratum were calculated as the mean number or biomass density (per m²) multiplied by the survey area (m²). Total population size and total harvestable biomass in the survey area were calculated as the sum of the totals from all three strata covering the survey area.

3.2.2 Bootstrap confidence intervals

A stratified 3-level bootstrap (n = 10,000 iterations of re-sample with replacement) was used to determine the confidence range around the estimate of the BMW biomass of greenlip within each stratum. This adaptation of a standard bootstrap method accounted for random variation at all three levels of the sampling design: among blocks in each stratum, leaded-line transect locations within each block and the two transects along each leaded line.

These levels of sampling are nested, and the bootstrap re-samples in each bootstrap iteration were nested in the same fashion. First, the set of blocks were re-sampled from the full set of surveyed blocks. Second, a set of leaded-line transects was re-sampled from the leaded-lines surveyed in each re-sampled block. This was necessary in only three blocks where two leaded-lines were surveyed. Finally, for each leaded-line so chosen, re-sampling was done from the two possible transects (*i.e.* sides) of each leaded line.

The BMW legal biomasses in all re-sampled transects were then summed and divided by the total transect area searched in each stratum to obtain a bootstrapped mean legal-size BMW biomass density for each iteration. For each bootstrap iteration, the overall BMW legal-sized biomass in the survey area was obtained, as above, by multiplying the re-sampled biomass density from each stratum by the stratum area, and the three stratum totals were summed. The

10,000 bootstrap iterations of total BMW legal-sized biomass were ranked, and the 10%, 20%, . . . , 90% quantile confidence intervals (CI's) extracted.

3.3 Results

A total of 414 greenlip (size range 45-172 mm SL) were encountered and measured on the 64 transect lines. Sand/seagrass comprised large sections of nearly all transect lines. Consequently, there was a high proportion of transect lines (50%) along which no greenlip were observed (Figure 3.2). There was a weak relationship between the level of CPUE during exploratory fishing and the number of zero-count transects.

3.3.1 Estimate of greenlip density in the survey area

For the blocks in which the CPUE was high, medium and low the mean estimates of density were 0.092, 0.018 and 0.010 greenlip.m⁻², respectively. The mean estimate of legal-size density in the three strata was 0.058, 0.014 and 0.005 greenlip.m², respectively. The stratified mean estimate of total greenlip density in the survey area was 0.047 greenlip.m⁻².

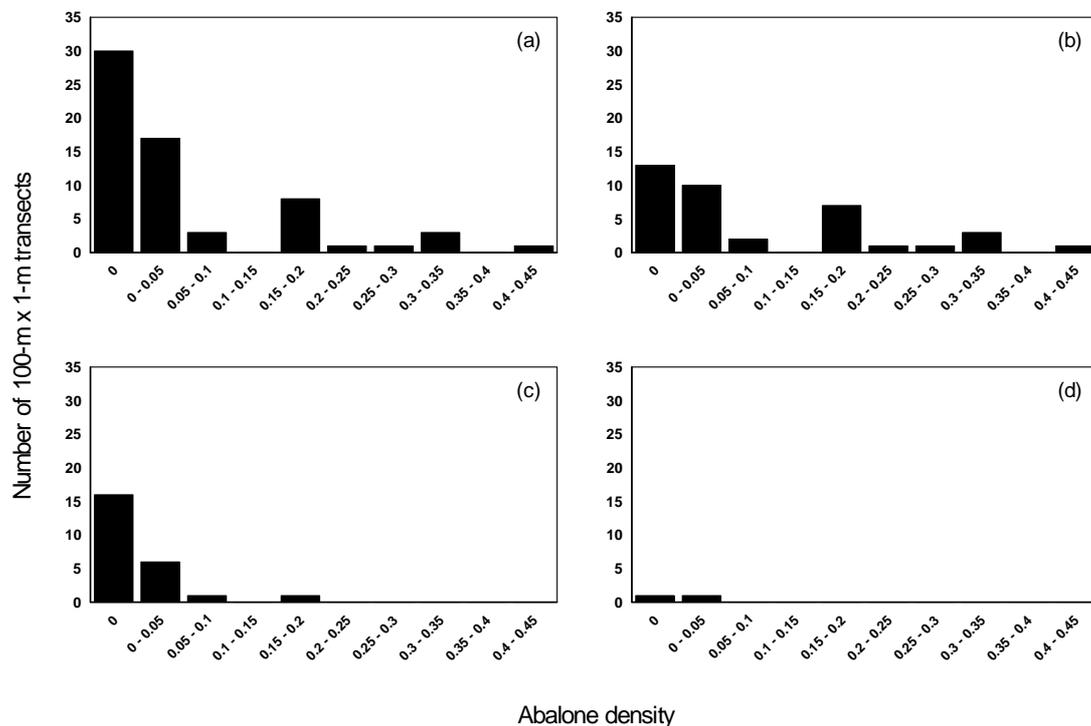


Figure 3.2: Number of transects yielding different observed greenlip densities (number.m⁻²) within all blocks surveyed (a) and blocks within which the CPUE during the experimental fishing were high (b), medium (c) or low (d). The number of zero-count transects is shown by the left-most bar in each graph.

3.3.2 Estimate of greenlip population size in the survey area

The stratified mean estimate of the total number of greenlip in the survey area was 800,000 individuals, of which 530,000 were of legal size. A high percentage of the total (78%) and sub-legal-sized (85%) greenlip were observed in the high-CPUE stratum – despite this stratum covering less than half (40%; 6.8 km²) of the survey area.

3.3.3 Estimate of greenlip biomass in the survey area

There was a strong association between the estimates of BMW biomass at each leaded-line and the commercial CPUE (Figure 3.3). The estimate of mean legal-size (≥ 130 mm SL) greenlip BMW biomass density in the survey area was 4.6 ± 1.5 g.m⁻². As the survey area was 16,876,500 m² in size, the mean estimate of total legal BMW biomass in the survey area was 77 ± 25 t. The confidence ratio (SE/mean) was 32.5%. This represented a substantial improvement in the precision of the survey estimate over that in 2004 (41%).

There was a 90% probability that total legal BMW biomass exceeded 46.3 t, but only a 10% probability that it was greater than 110.5 t (Table 3.1a; top row, parentheses). At assumed harvest fractions between 5% and 20% of the total BMW (0.05 to 0.2 in Table 3.1), and spanning the range of CI's for estimated biomass from 10% to 90%, potential levels of catch from the survey area ranged between 2.3 and 22.1 t BMW.

Table 3.1. Greenlip legal bled-meat-weight (kg) catches under various assumed levels of (1) 10%, 20%, . . . 90% confidence in legal-size biomass in the survey area, and (2) harvest fraction. The confidence-bound percentages (10%, 20%, . . . , 90%) are quantiles used to separate ordered values of legal-size BMW biomass estimates from 10,000 2-level bootstraps. Quantiles specify the probability that the true value of harvestable greenlip biomass is the given biomass-quantile value (e.g. 46,287 kg, 55,260 kg, etc.) or greater.

| Harvest fraction | Probability (of legal biomass estimate, kg) | | | | | | | | |
|------------------|--|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|------------------|
| | 90% (46,287) | 80% (55,260) | 70% (62,525) | 60% (69,379) | 50% (75,804) | 40% (81,970) | 30% (88,818) | 20% (97,522) | 10% (110,533) |
| 0.05 | 2314 | 2763 | 3126 | 3469 | 3790 | 4099 | 4441 | 4876 | 5527 |
| 0.075 | 3472 | 4145 | 4689 | 5203 | 5685 | 6148 | 6661 | 7314 | 8290 |
| 0.1 | 4629 | 5526 | 6253 | 6938 | 7580 | 8197 | 8882 | 9752 | 11053 |
| 0.125 | 5786 | 6908 | 7816 | 8672 | 9476 | 10246 | 11102 | 12190 | 13817 |
| 0.15 | 6943 | 8289 | 9379 | 10407 | 11371 | 12296 | 13323 | 14628 | 16580 |
| 0.175 | 8100 | 9671 | 10942 | 12141 | 13266 | 14345 | 15543 | 17066 | 19343 |
| 0.2 | 9257 | 11052 | 12505 | 13876 | 15161 | 16394 | 17764 | 19504 | 22107 |
| 0.225 | 10415 | 12434 | 14068 | 15610 | 17056 | 18443 | 19984 | 21942 | 24870 |

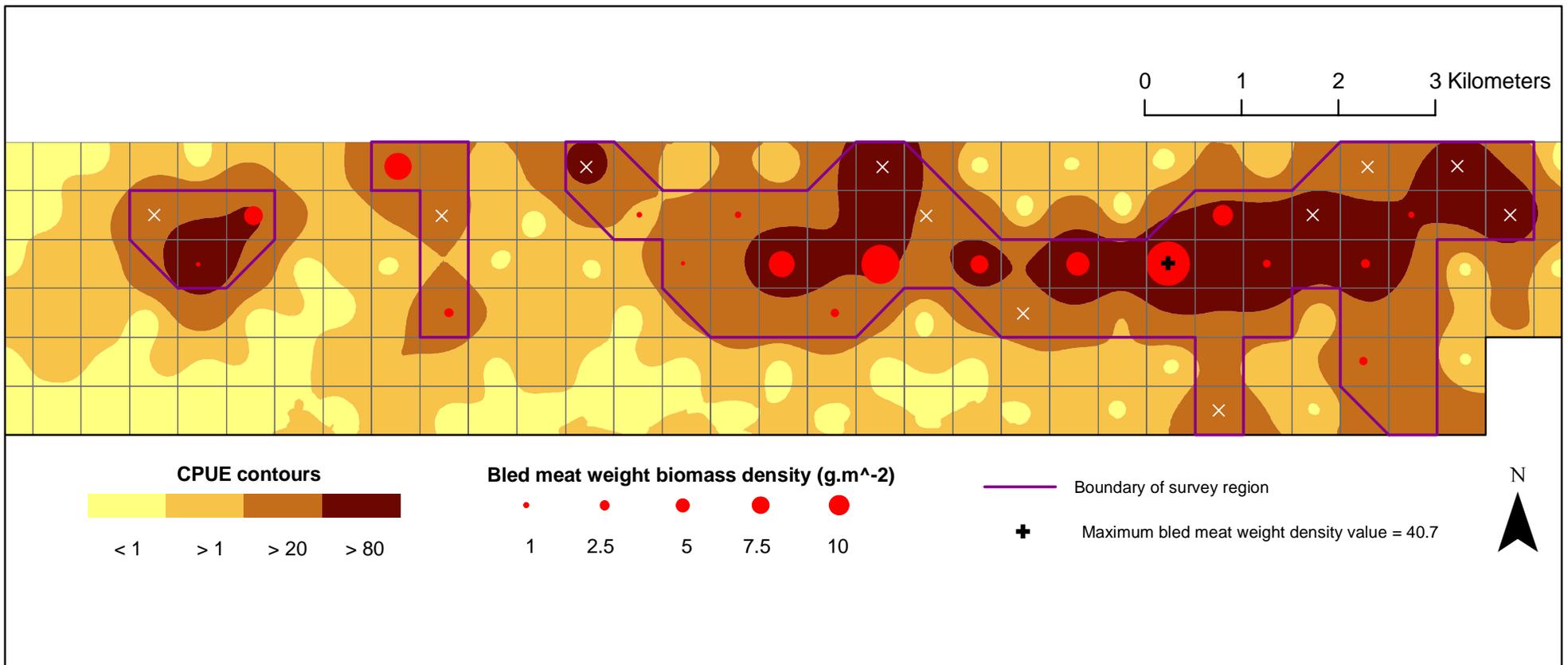


Figure 3.3: Spatial distributions of survey legal-size mean-bled-meat-weight biomass density (g.m⁻²) by surveyed block and commercial exploratory CPUE off Cowell in 2005. White crosses indicate leaded lines where no legal-sized greenlip were counted.

3.3.3 Length-frequency distribution of the sample

The size range of greenlip observed on the transects was 45 – 172 mm SL. The mean size was 130 mm SL and the modal size class 130–139 mm SL. Greater than two thirds of the greenlip measured exceeded 130 mm SL (Figure 3.4). More legal-sized greenlip were observed during 2005 than during 2004.

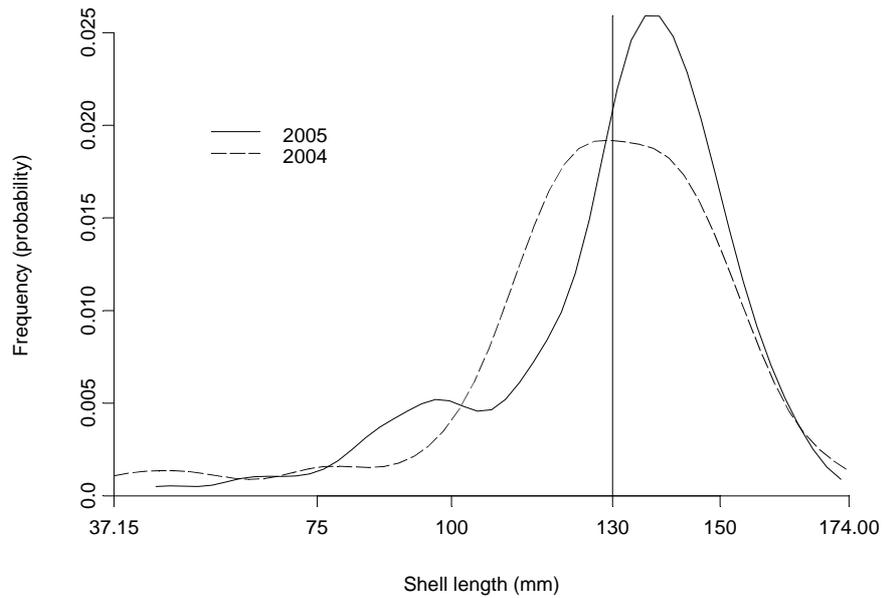


Figure 3.4: Length-frequency distribution of greenlip (n = 414) surveyed off Cowell in 2004 and 2005. Size was measured as mm SL.

4. BIOLOGY OF GREENLIP OFF COWELL

4.1 Introduction

Abalone (Family: Haliotidae; Genus: *Haliotis*) are marine gastropods inhabiting nearshore reefs (Day & Shepherd 1995) from the shallow subtidal zone to depths around 400 m (Geiger 1999). Greenlip are contiguous throughout southern Australia, with their distribution ranging from Corner Inlet (Victoria) to Cape Naturaliste (Western Australia). They inhabit water depths between 10 and 30 m and occur in clusters of local populations, separated from other similar clusters by tens of kilometres. This pattern is reflected in the population genetics with clusters representing putative 'metapopulations' (Shepherd & Brown 1993). Abalone have separate sexes. Spawning is seasonal and synchronised (*e.g.* Keesing *et al.* 1995, Rodda *et al.* 1997) as unfertilised eggs and sperm are released. Fertilisation success is strongly influenced by adult density (Babcock & Keesing 1999).

The spatial variability in abalone populations is well documented (*e.g.* McShane & Naylor 1995). There are few data on the biology of greenlip off Cowell. To ensure collection of biological data relevant to evaluating the potential for a fishery on this species off Cowell, that may encompass the development of harvest strategies, data on growth rate, relationship between shell length and whole weight, relationship between whole weight and meat weight and reproductive biology (size at sexual maturity, sex ratio) were collected during winter 2004 and 2005. These data were obtained from samples provided by commercial fishers and from samples collected by SARDI at three locations distributed throughout Region D during 2004 and 2005. These data are compared to that for other greenlip populations in the CZ and WZ.

4.2 Methods

4.2.1 Relationship between shell length and whole weight

Data on the relationship between shell length (SL, mm) and whole weight (WW, g) were obtained in May 2004 and June 2005 from the commercial catch (>120 mm SL) and samples (>45 mm SL) collected by SARDI at three sites (all in Region D). Each individual collected was measured (maximum SL, to the nearest mm) and weighed in shell (whole weight, g).

Whole weight was cube root transformed to obtain a linear relationship between whole weight and shell length. Differences in the relationship between whole weight and shell length among sites and between years (data truncated to exclude samples >160 mm SL) were tested using ANCOVA (after Quinn & Keough 2000).

4.2.2 Relationship between whole weight and meat weight

Data on the relationship between whole weight and meat weight (MW, g) were obtained from the commercial catch (>120 mm SL) and samples (>45 mm SL) collected by SARDI at three sites (all in Region D). Each individual collected, measured and weighed as described above (Section 4.2.1) was also shucked (*i.e.* meat removed from the shell and viscera) and the meat weighed separately (MW, g). A linear regression was fitted to the data to best describe the relationship. Differences in the relationship between whole weight and meat weight among the Regions (data truncated to exclude samples <220 and >500 g WW) and between sites (all data) were tested using ANCOVA (after Quinn & Keough 2000).

4.2.3 Relationship between shell length and bled meat weight

Data on the relationship between shell length and bled meat weight (BMW, g) were obtained from the commercial catch in June 2005. A total of 140 greenlip were landed whole by the commercial fishers. Each individual was measured (SL) and weighed (WW and MW) as described above. Thereafter, the meats were placed in individually sealed and labelled bags and returned to the commercial catch. The individual meats were re-weighed, prior to commercial processing, by Dover Fisheries between 19 and 21 hr thereafter. A power curve of the form $BMW = a(SL)^b$ was fitted to the data using a maximum likelihood method to estimate the weight-length parameters, a and b , of the sample. The model-fit residuals (differences of observed from predicted weight) increased with shell length. This heteroscedastic error structure was modelled in the maximum likelihood estimation by a power function model for the standard error of the weight estimate: $SE(SL) = \sigma_0(BMW)^{\sigma_1}$. Thus, standard error was assumed to increase with the power of model BMW. In turn, BMW is given as a power function of shell length: $BMW = a(SL)^b$.

4.2.4 Size at sexual maturity

Data on the relationship between shell length and sexual maturity were obtained by SARDI from three sites in Region D in July 2004 (two sites) and August 2005 (one site). The size at which 50% of greenlip were sexually mature (L_{50}) was determined by macroscopic examination of the gonad-hepatic glands of individuals collected, prior to the commencement of spawning (Shepherd & Laws 1974; Rodda *et al.* 1997). Individuals that exhibited only small amounts of gonad on the tip of the conical appendage and the spire were classed as immature. Estimates of L_{50} were determined using the logistic equation of the form:

$$y = a/(1+b.exp^{-cx})$$

where y is the percentage mature, x the shell length and a , b and c estimated parameters.

4.2.5 Sex ratio

Data on the ratio between the number of male and female greenlip were obtained by SARDI from macroscopic examination of the gonad-hepatic gland while determining the size-at-maturity. Individuals that exhibited only small amounts of gonad on the tip of the conical appendage and the spire, and could be clearly sexed, were included in the analyses. A 2x2 Chi-square (χ^2) contingency table (after Zar 1984) was used to test the null hypothesis that the male:female sex ratio was not significantly different from 1 male:1 female ($\alpha = 0.05$).

4.2.6 Rate of growth

During June 2004, a total of 507 greenlip between 44 and 167 mm SL were tagged at two sites. Individuals were collected using a standard abalone tool (abalone iron), tagged, onboard a vessel, by securing a uniquely numbered disk tag with a plastic snap rivet to the shell (after Prince 1991) and then returned to the substratum near to where they were obtained. Exposure times during tagging were minimised by placing the greenlip in mesh bags immersed in seawater before and after tagging. The location of each site at which tagged greenlip were released was recorded using GPS and by placing submerged floats close to the centre of the release site. This enabled effective searching for tagged greenlip ~15 months after tagging.

Tagged greenlip were recaptured in August 2005 from both sites. Each greenlip was re-measured and then returned to the substratum near where they were re-captured. Growth increments of all recaptured individuals at each site were adjusted to an annual growth rate (mm.yr^{-1}). Growth increment was regressed against shell length at tagging, and estimates of theoretical maximum length (L_∞) and growth rate (K) calculated. Spatial variability in growth rate (data truncated to exclude individuals <70 and >145 mm SL) was compared using an ANCOVA in Statistica (after Quinn & Keough 2000).

4.3 Results

4.3.1 Relationship between shell length and whole weight

WW increased significantly with SL in all Regions (see examples in Figure 4.1). In 2004, the relationships between SL and WW in Regions B ($\text{WW} = 0.00011\text{SL}^{3.02}$) and D ($\text{WW} = 0.0000034\text{SL}^{3.02}$) were significantly different over the size range 120–160 mm SL ($F_{1,268} = 7.60$; $p < 0.05$). Small sample sizes in Regions A, C and E prevented evaluation of significant differences in this relationship among all Regions. There was no significant difference in the relationship between SL and WW in Region D during 2004 and 2005 ($\text{WW} = 0.000135 \text{SL}^{2.99}$; $F_{1,482} = 4.068$; $p > 0.05$). The relationships between SL and WW at the

three sites were not significantly different ($F_{1,273} = 1.96$; $p > 0.05$; $WW = 0.000024SL^{3.37}$, $WW = 0.000029SL^{3.32}$ and $WW = 0.0000216SL^{3.39}$, respectively).

4.3.2 Relationship between whole weight and meat weight

A linear regression best described the relationship between WW and MW in Regions B and D (Figure 4.2). The relationships between WW and MW in Regions B ($MW = 0.49WW - 7.11$) and D ($MW = 0.38WW + 3.34$) differed significantly in 2004 ($F_{1,148} = 11.75$; $p < 0.01$). In Region D the relationship was not significantly different ($F_{1,325} = 0.52$; $p > 0.05$) between 2004 and 2005 ($MW = 0.47WW - 29.2761$). The relationships between WW and MW at the three sites were not significantly different ($F_{1,218} = 0.54$; $p > 0.05$; $MW = 0.36WW + 2.90$, $MW = 0.39WW + 2.41$ and $MW = 0.38MW - 1.62$, respectively).

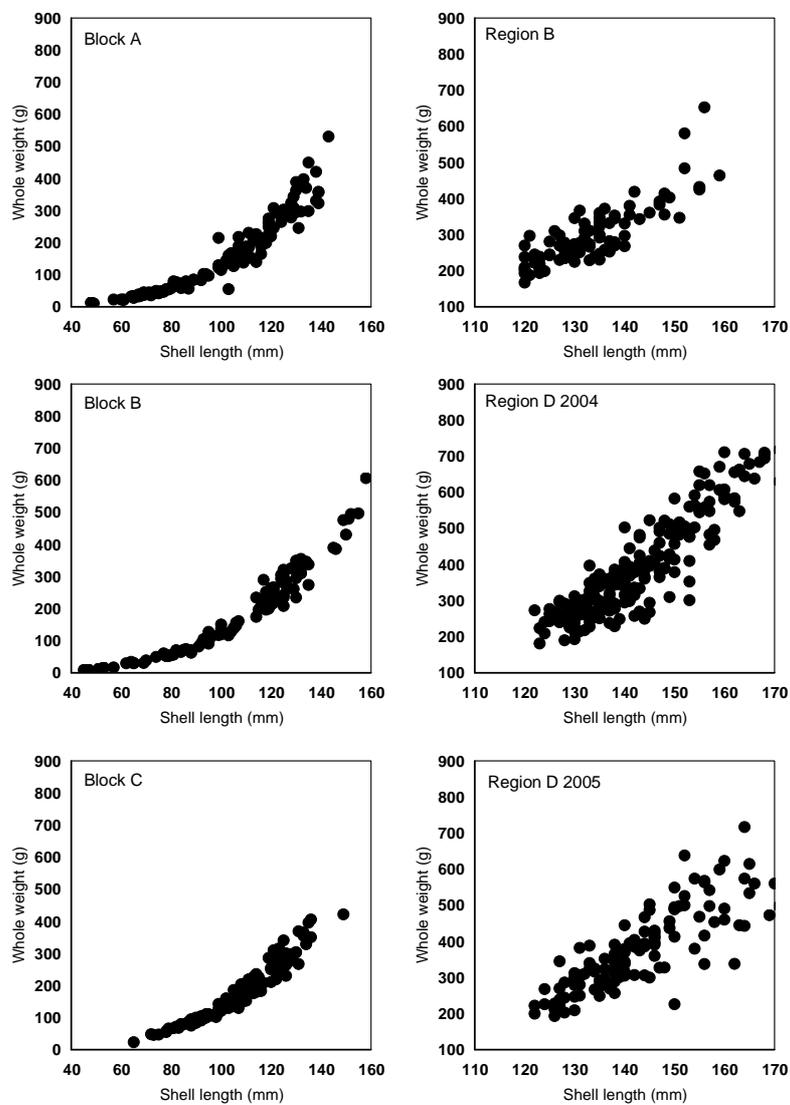


Figure 4.1: Relationships between whole weight (g) and shell length (mm) of greenlip at three sites (Blocks A and B (2004), Block C (2005)) in Region D and in Regions B (2004) and D (2004 and 2005) off Cowell.

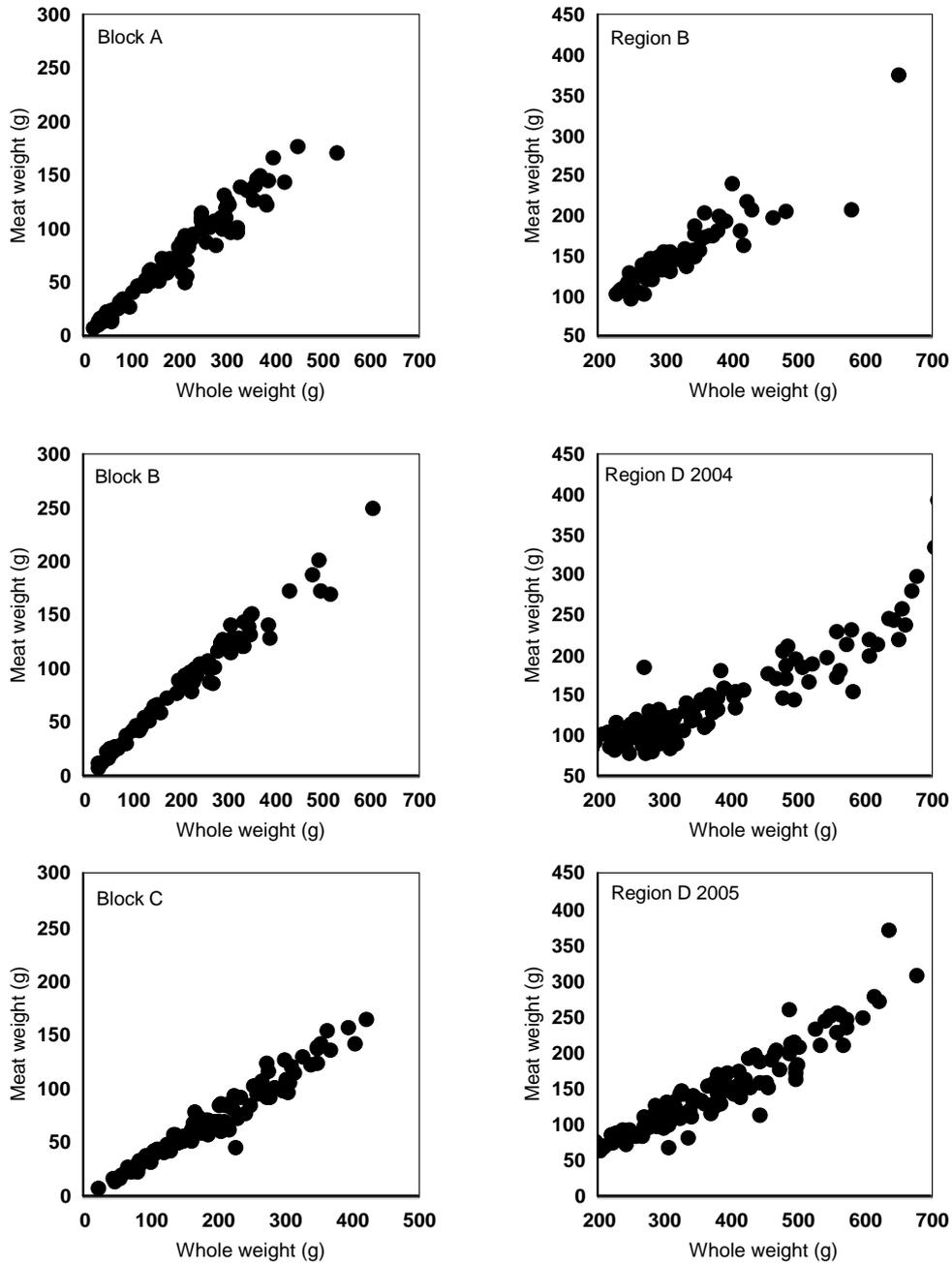


Figure 4.2: Relationships between meat weight (g) and whole weight (g) of greenlip at three sites (Blocks A and B (2004), Block C (2005)) in Region D and in Regions B (2004) and D (2004 and 2005) off Cowell.

4.3.3 Relationship between shell length and bled meat weight

BMW increased allometrically with shell length ($BMW = 0.000048SL^3$; Figure 4.3).

4.3.4 Size at sexual maturity

Estimates of the size at first maturity (L_{50} ; males and females combined) were 79 and 85 mm SL in 2004, and 77 mm SL in 2005 (Figure 4.4).

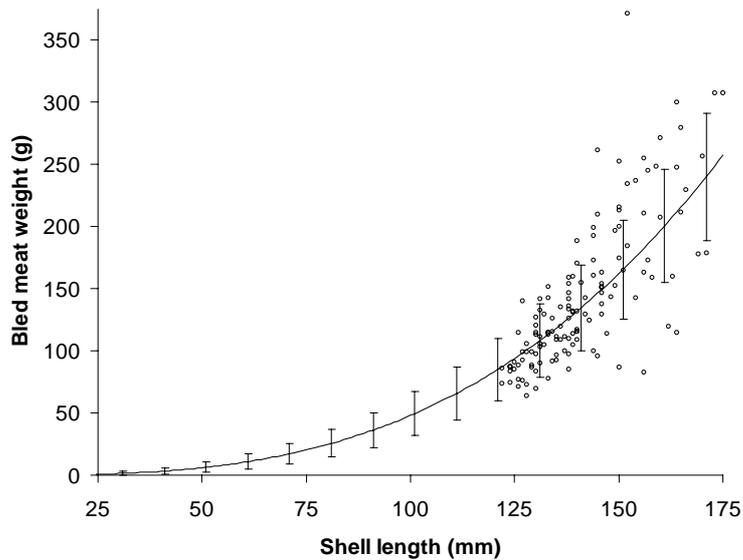


Figure 4.3: Power-model likelihood fits versus shell length of 19 to 21-hr bled meat weight for greenlip off Cowell in 2005. Likelihood-estimated SE's of the fit (used to estimate biomass – see section 3.2) are shown as error bars.

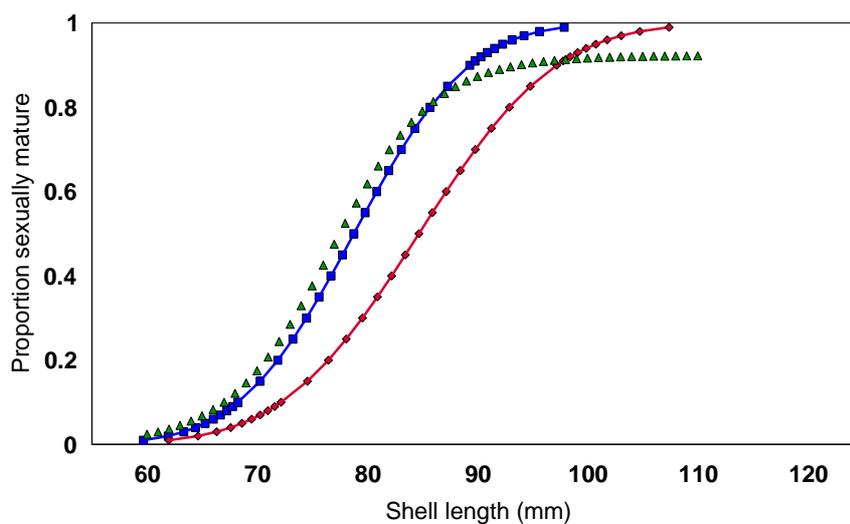


Figure 4.4: Fitted logistic curves describing the relationship between proportion of sexually mature individuals and shell length (mm) off Cowell during 2004 (red and blue lines) and 2005 (green line).

4.3.5 Sex ratio

The sex ratio was not significantly different from 1 male: 1 female in either 2004 ($\chi^2 = 3.24$; $df = 191$; $p > 0.05$) or 2005 ($\chi^2 = 1.064$; $df = 248$; $p > 0.05$), despite males comprising 56% and 55% of the sample respectively.

4.3.6 Rate of growth

A total of 175 (~35%) tagged greenlip were recaptured after ~410 days at liberty.

The rate of growth decreased significantly with increasing shell length at both sites (Linear Regression: $r^2 = 0.69$, $df = 61$, $p < 0.05$ and $r^2 = 0.50$, $df = 111$, $p < 0.05$, respectively; Figure 4.5). There were significant differences in the growth rate and estimate of L_∞ for greenlip at the two sites ($F_{1,152} = 56.96$, $p < 0.05$). This may reflect differences in the density of greenlip at these locations.

The mean rate of growth at each of the two sites was 2.65 and 3.11 $\text{mm}\cdot\text{yr}^{-1}$, respectively. However, almost 50% of individuals that were recaptured did not grow. Estimates of K and L_∞ for greenlip at each of the two sites were 0.164 $\cdot\text{yr}^{-1}$ and 130.4 mm SL (site 1) and 0.245 $\cdot\text{yr}^{-1}$ and 147.2 mm SL (site 2), respectively.

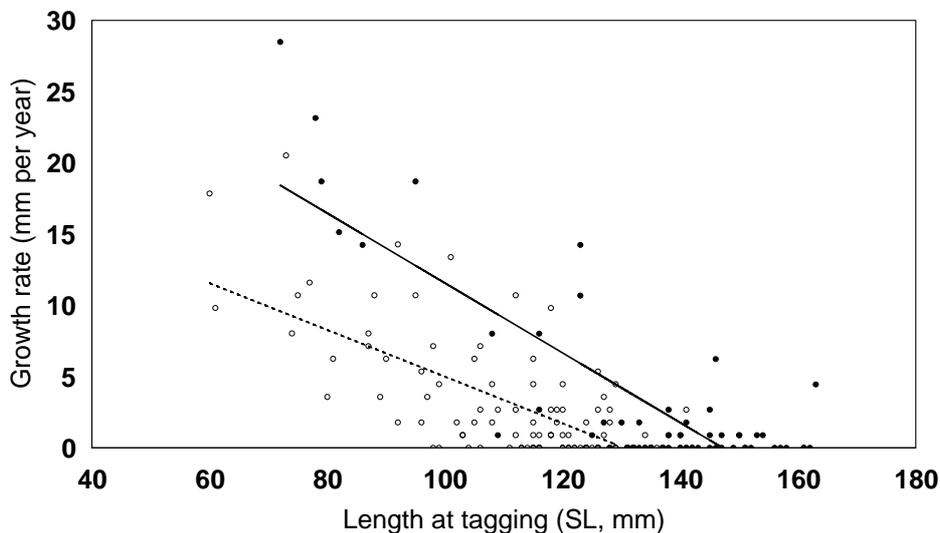


Figure 4.5: Relationship between growth rate ($\text{mm}\cdot\text{yr}^{-1}$) and size at tagging (SL, mm) for greenlip at two sites off Cowell.

5. GENERAL DISCUSSION

This is the first cooperative project anywhere, to our knowledge, to amalgamate exploratory commercial fishing for abalone with fishery-independent measures of absolute abundance, over any spatial scale, to estimate fishable biomass. Here, this was achieved through the cooperation of the AIASA, PIRSA and SARDI. This partnership achieved the rigorous and systematic sampling of an area of 1,143 km² off Cowell, along ~110 km of coastline.

Six commercial fishers undertaking directed fishing within designated areas for specified periods of time proved effective in providing data on the broad-scale distribution and abundance of greenlip over a large area (1,143 km²) in a relatively short period of time (*i.e.* < 2 weeks spread between 2004 and 2005). In both years, fishery-independent surveys targeted areas of high exploratory-fishing CPUE using the leaded-line approach (after McGarvey *in press*). The 2004 survey produced estimates of absolute abalone population number with associated CI inside a 42-km² survey area identified from exploratory fishing in one-square-km blocks. This is considerably larger than any other known survey on abalone. In 2005, fishery-independent estimates of legal-sized, bled-meat-weight biomass and associated CI were obtained inside a refined 16.9-km² survey area in a region of high greenlip density. Building on similar surveys at Waterloo Bay (McGarvey *et al.* 2005), to our knowledge, this was the first fishery-independent survey for which the aim was to estimate the absolute harvestable biomass in a defined and stratified survey area. The survey area was determined from commercial CPUE data during exploratory fishing in ¼-square-km blocks, that provided a four-fold increase in spatial resolution over that obtained in 2004. Leaded-line surveys required five days of field time in each year. The effectiveness and cost-efficient nature of this assessment and diver-survey method reflect its suitability for application in other areas of the SAAF and other fisheries, particularly those targeting relatively sedentary species.

The systematic exploratory catch and effort data collected off Cowell by commercial fishers informed maps of the broad-scale distribution and abundance of greenlip in this area. Catches were only obtained close to shore in Regions A and B (*i.e.* west of Franklin Harbour), and offshore in Regions C, D and E. No greenlip were observed in, or harvested from Regions F or G. Notably, most (67%) of the catch was obtained from Region D, with only small catches being harvested from any of the other six Regions. These data suggest that greenlip are not widely distributed off Cowell, but that there is principally one substantial ‘aggregation’ in a band (2 – 3 km wide by 16 km long) running east-west between 3 km and 8 km south of the coast in Region D.

Within this 'aggregation', greenlip were not ubiquitous. Catches of greenlip from the ¼-square-km blocks were again highly variable. A high percentage (73%) of blocks surveyed yielded no greenlip, and large catches, which cumulatively accounted for 69% of the catch, were obtained from just 18 of the 174 ¼-square-km blocks surveyed. In combination, these patterns confirm the previous conclusion that harvestable levels of greenlip are restricted to a narrow band and that large aggregations are rare.

There were also subtly consistent spatial patterns in CPUE and the length-frequency distribution of the catch. Both showed a general increase from west to east, not only across Regions A-D, but also within Region D. Approximately 80% of the catch harvested from Region D in both years exceeded the minimum legal limit (MLL, 130 mm SL).

The improved spatial resolution and focus in the areas in Regions C and D known to contain high densities of greenlip permitted a substantial reduction in the proportion of transects within which no greenlip were observed – from 66% in 2004 to 46% in 2005. The direct consequence of this was a 20% increase in the precision of the estimate of greenlip density, and hence the estimates of biomass. The estimates of greenlip density (0.047 greenlip.m⁻²) and total number (~800,000 individuals) of greenlip in the survey area in 2005 were similar to those observed in 2004 (0.025 greenlip.m⁻² and ~1,057,000 individuals, respectively). Both a higher density and smaller total number were expected because a smaller survey area (16.9 km²) targeting the areas of highest abundance was surveyed in 2005, compared with 42 km² in 2004. More than 65% of greenlip observed in the survey area in 2005 were of legal size (*i.e.* >130 mm SL). Additionally, there was an association between the abundance of legal and sub-legal-sized greenlip, both of which were substantially more abundant in the high-CPUE stratum.

The self-consistent estimates of greenlip density and population number are encouraging for the power and usefulness of this leaded-line survey method, particularly for assessment and management of localised abalone populations. The data presented here, in combination with the outcomes of four fish-down experiments (McGarvey in press) and more recent surveys in Waterloo Bay (McGarvey *et al.* 2005), demonstrate that the leaded-line survey estimates and associated CI provide accurate measures of abundance, density and biomass in a range of the most appropriate units for setting catch limits. Hence, this approach constitutes a useful tool for abalone fishery management.

Application of a maximum likelihood estimation in analysing the weight-at-length data was significant because this approach avoids the potentially large bias that can be introduced by

the more common method of ‘transforming the data’ which is used in least squares estimation when the residuals of the model fit are not uniform. Here, we used a non-linear submodel for the error structure in fitting the weight-length power model, to explicitly model variation in the residuals. The ability to model error structure (residuals) is a principal advantage of maximum likelihood over a simple least squares fit. In the latter, transforming the data can sometimes cause more bias than it averts.

The surveys generally measured high greenlip densities in areas of highest commercial CPUE, indicating the capability of commercial fishers to identify regions with high abundances of the target species, over large areas. Despite the considerable level of spatial overlap between these two measures, numerous outliers (*i.e.* high CPUE in a block within which the BMW biomass on the leaded-line was low, and its converse) and the high proportion of transects along which no greenlip were observed confirm the contagious distribution (Elliott 1971) of this species throughout this area.

The estimate of mean legal-size greenlip BMW biomass density in the survey region was $4.6 \pm 1.5 \text{ g.m}^{-2}$, which, scaled to the size of the survey area, resulted in a mean total legal-sized BMW biomass of $77 \pm 25 \text{ t}$ in the survey area. At assumed harvest fractions between 5% and 20% of the total BMW (0.05 to 0.2 in Table 3.1), and spanning the range of CI’s for the minimum estimated biomass from 10% to 90%, potential levels of total catch from the survey area ranged between 2.3 and 22.1 t BMW.

It is evident, from the high commercial CPUE in Region D and the large estimates of legal-sized BMW biomass in the survey area, that there is a strong potential for the greenlip stocks off Cowell to support a commercially viable fishery. However, determining the fraction of the available biomass that can be harvested sustainably is challenging, and there is little guidance in the scientific literature. Risk levels of stock collapse increase with increasing harvest fraction and increasing risk of overestimating current stock biomass.

In the South Australian sardine fishery, the annual harvestable fraction of the spawning biomass estimate ranges between 10 and 17.5% (Shanks 2005). In direct contrast with abalone, sardines are short lived and fast growing (Ward *et al.* 2005a), have a high fecundity (Ward *et al.* 2005b) and natural mortality rate (Ward *et al.* 2005a), and, perhaps most importantly, have shown the ability to rapidly recover from low biomass levels resulting from mass mortality events (Ward *et al.* 2001).

Furthermore, abalone fisheries around the world have shown a higher risk of collapse than any other commonly exploited group of species, with most contemporary fisheries having either collapsed (*e.g.* Davis *et al.* 1996, 1998; Parker *et al.* 1992; Haaker *et al.* 1996; Hobday *et al.* 2000; Tegner 2000; Farlinger & Campbell 1992; Sloan & Breen 1988) or demonstrating substantial declines (*e.g.* Tarr 2000).

Stock-recruitment relationships for abalone are typically poorly understood. However, local oceanographic patterns and reef topography suggest larval retention may be limited off Cowell. These factors include (1) the east-west orientation of the 'aggregation' that is at 45° to the strong long-shore tidal currents (Bills & Noye 1986), (2) local strong wind-forced currents (Bills & Noye 1986), (3) the low relief of the reef preventing tidal rectification (Dr John Middleton, SARDI Aquatic Sciences, personal communication), (4) the patchy and heterogeneous nature of the reef, and (5) the low and sparse algal canopy (Prince *et al.* 1987).

The differences in the life history strategies between abalone (slow growing, long-lived, low mortality, sedentary) and sardines (fast growing, short-lived, high mortality, high mobility), in combination with (1) historical abalone fishery collapses around the world, (2) the patchy distribution of greenlip off Cowell, (3) the likelihood of limited larval retention, and (4) an absence of data on the fecundity, mortality rate and productivity of greenlip off Cowell, suggests the need for conservative catch limits.

Several significant advances in knowledge on the South Australian abalone fishery would accrue if harvesting greenlip off Cowell was undertaken alongside an appropriate long-term research program. This is because the greenlip population in this area has only been fished sporadically since 1989 and hence is probably the closest representation of a 'virgin' population of abalone in Australia. For example, exploitation of greenlip from this area provides an ideal opportunity to begin addressing the pressing need to evaluate the ecosystem effects of abalone fishing which could be achieved through selection of reference (*i.e.* unfished) and fished areas and a suite of manipulative field experiments and ecosystem-based surveys. Moreover, combining detailed catch and effort data (similar to that acquired during the course of the project) with highly representative catch sampling, annual fishery-independent surveys and accumulated biological data would be particularly beneficial for testing and assessing the sensitivity and general performance of the abalone fishery models currently being developed, and for potentially providing insight into determining annual sustainable harvest fractions for abalone fisheries.

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APPENDIX 1

*** This form to be filled in using **PENCIL** only ***

South Australian Research and Development Institute

PO Box 120, Henley Beach, 5022, SA

2005 Cowell Project - greenlip Catch and Effort Return Form

This daily log does not replace, but rather is in addition to, the current logbook

| | | |
|------------------------|----------------------------|----------------------------------|
| Licence number: | <input type="text"/> | |
| Diver: | <input type="text"/> | Date: <input type="text"/> |
| Dive Number: | <input type="text"/> | |
| Area Fished: | Grid reference | |
| | <input type="text"/> | |
| | GPS Position-start | GPS Position-end |
| | <input type="text"/> S | <input type="text"/> S |
| | <input type="text"/> E | <input type="text"/> E |
| Cage used? | <input type="text"/> Y / N | |
| Time in water: | <input type="text"/> | |
| Time of first bag: | <input type="text"/> | No. abalone <input type="text"/> |
| Time of second bag: | <input type="text"/> | No. abalone <input type="text"/> |
| Time of third bag: | <input type="text"/> | No. abalone <input type="text"/> |
| Time of fourth bag: | <input type="text"/> | No. abalone <input type="text"/> |
| Time out of water: | <input type="text"/> | |
| Total abalone on dive: | <input type="text"/> | |
| Total weight: | <input type="text"/> | |

On completion, this form should be returned to:

SARDI, PO Box 120, Henley Beach, 5022, SA