FINAL REPORT

Stock Assessment And Modeling For Management Of The WA Greenlip Abalone Fishery

Anthony M. Hart
Norm Hall
Clinton Syers

Western Australian Marine Research Laboratories
PO Box 20, North Beach, WA 6020, Australia

FISHERIES
WESTERN AUSTRALIA

FISHERIES
RESEARCH &
DEVELOPMENT
CORPORATION

Project No. 95/143

ISBN No: 0 7309 8427 3
APRIL 1999

95/143 Stock Assessment And Modeling For Management Of The WA Greenlip Abalone Fishery

PRINCIPAL INVESTIGATOR: Dr Anthony Hart
ADDRESS: Western Australian Marine Research Laboratories
PO Box 20
North Beach
Western Australia 6020
Telephone: 08 9246 8444 Fax: 08 94473062

OBJECTIVES:
1. To improve the fishery database by providing data in catch and effort at a finer spatial scale.
2. To provide in-water estimates of stock abundance and status.
3. To improve the understanding of the biology of greenlip abalone (particularly the effects of high growth rates on size at maturity and egg production and the influence of seasonal condition changes on length-weight relationships.
4. To develop simulation models which can be used to assist in management decisions.

Non-technical Summary

The greenlip/brownlip abalone fishery on the south coast of Western Australia is the major commercial fishery in this area, with estimated earnings of about $8 million in 1997/98. The fishery is divided into 2 zones, with quota allocations in the 1997/98 season in Zone 1 (eastern zone) of 37.2 tonnes meat weight, and in Zone 2 of 40 tonnes, with 90% of the catch composed of greenlip abalone (*Haliotis laevigata*). This study focuses on Zone 2, which extends just west of Esperance to the Cape Naturaliste area and consists of three discrete areas of abalone habitat - Augusta, Windy Harbour and Hopetoun. Despite the Augusta area being near the limit of the distribution of *H. laevigata*, parts of the greenlip population in this area are thought to exhibit very rapid growth and mature at sizes above the current legal minimum. The Augusta area has also been highly productive, and has generally provided around 40% of the catch from the zone. However, heavy exploitation of the Augusta population during the 1980's caused concern about growth overfishing and the long-term viability of the stock in this area particularly with the large size of maturity. This lead to the area being closed for increasingly long periods in recent years. This project investigated the fishery and biological information needed to manage these stocks appropriately in the long term.

A detailed research dive by dive logbook was developed in conjunction with industry members. The logbook is designed to collect environmental data (swell, visibility), habitat information (type of bottom), population structure, and various other important information which will be located by GPS coordinates, in time building up a comprehensive map of the fishery. About 50% of the divers within Zone 2 are testing the

logbook, although the data has yet to be given to Fisheries WA. The official implementation of this logbook during this project was delayed due to political issues, which were eventually resolved. The industry has formally approved the trial and implementation of the research logbook during the 1999/2000 financial year and any logbook data available from previous trials will be collected.

Two independent surveys were undertaken to develop in-water stock assessment techniques. Two fixed monitoring sites were set-up around Augusta, the main producing area of the fishery. Mean density at one of these areas, "The Back", was 0.68 per m^2 (95% confidence limit: 0.35 - 1 per m^2) for all size classes sampled. In comparison, mean density at the Flinders Bay site was 7.25 m^2 (95% confidence limit: 4.65 - 9.85 per m^2); an order of magnitude greater. These sites will eventually form part of a network of fixed sites across the greenlip/ brownlip fishery in WA, similar to what currently exists in NSW and Victoria. Funding has been allocated by industry for further development of monitoring sites.

Haliotis laevigata from "The Back" near Augusta had growth parameters, K of 0.57 and L_∞ of 170 or 175mm, depending on method used. This suggested clearly that this was a fast growing population of greenlip abalone, giving biological validity for the voluntary higher size limit at which this area is fished (153 mm) compared to the legal minimum limit (LML) of 145mm. Size-at-maturity was 97mm (95% confidence limit: 91-103mm), which was considerably higher than populations at nearby Flinders Bay, which have a size-at-maturity of 80-85mm. Size-fecundity relationship was measured by the power equation ($Fec = aL^b$). For "The Back", $a = 1.00 \times 10^{-6}$; $b = 5.48$; $r^2 = 0.89$. For an earlier study (Wells, and Mulvay, 1992) in Flinders Bay, $a = 1.49 \times 10^{-3}$; $b = 4.29$; $r^2 = 0.83$. These equations show that, on average, a 150mm animal from Flinders Bay held 3 times as many eggs as a 150mm SL animal from "The Back". If reproductive capacity is age, rather than length-dependent, then these data support the hypothesis of considerably faster growth rates from "The Back". Between-site differences in morphology (length/width/height relationships) were detected between Augusta, Hopetoun, and Windy Harbour, with again the implication being different growth rates, although no comparative studies of growth between these sites has been undertaken.

Significant differences in condition (whole weight animal/bled weight meat) and blood loss (of meats 24 hours after shucking) between sites and seasons were detected for all size-classes. However in almost all cases, there was a significant interaction between sites and seasons, indicating that the seasonal differences vary between sites. Despite this, some general trends were evident from the data. Condition was higher during the May and August survey, and lower during February and November surveys. Hopetoun abalone show generally a lower mean condition compared to Augusta, although this was not consistent across all size-classes. Blood loss was significantly correlated with condition ($r = -0.66$; $p<0.05$), although other factors such as weight of visceral mass and gonad also influenced condition. As with condition, a general trend is that blood loss is higher during November in the legal sized animals (141mm+), and lowest in May and August. In the 141-160mm size range, which encompasses most of the legal catch, mean blood loss was higher at Hopetoun (25.4%), and similar at Augusta (19.0%) and Windy Harbour (19.8%). These data confirm that the opening season date of 1st April is the best time to optimise harvesting efficiency - the majority of the catch will be taken in the first 6 months when the animals are in peak condition and lessens the impact on the stock, as less animals need to be caught to obtain quotas.

The results of this study have demonstrated that between site differences in growth, fecundity, and condition do exist in the Zone 2 abalone fishery in WA. In order to fully understand the effect of these biological characteristics on the dynamics of the fishery, finer scale catch and effort data will need to be provided by the abalone diver research logbook. This will eventually result in accurate maps of the extent of the fishery, and the productivity of individual areas, as well as fully documenting the behaviour of the diver and influences on catch rates. The data will be invaluable in implementing proactive management strategies such as rotational fishing, and/or periodic closures to enhance stocks, as well as identifying areas which could be further explored. However, the success of such a program is contingent upon a high level of trust between the industry and Fisheries WA, as to the confidential nature of such information. Ultimately, all the available information will be incorporated into a formal stock assessment and decision analysis model, as is currently being developed via FRDC Project 99/116.

KEYWORDS: *Haliotis laevigata*, greenlip abalone, abalone fishery, growth, size-fecundity, condition, research logbook, independent surveys

Table Of Contents

		page
	Non technical Summary	i
1	BACKGROUND	2
2	NEED	2
3	OBJECTIVES	3
4	METHODS	3
	4.1 Study sites	3
	4.2 Finer scale catch and effort data	3
	4.3 In water stock abundance estimates	3
	4.4 Growth of a fast growing population	6
	4.5 Size-at-maturity and fecundity studies of a fast growing population	7
	4.6 Effect of site and season on morphometry, condition and blood loss	9
	4.7 Population modelling	10
5	RESULTS/DISCUSSION	11
	5.1 Finer scale catch and effort data	11
	5.2 In water stock abundance estimates	13
	5.3 Growth of a fast growing population	17
	5.4 Size-at-maturity of a fast growing population	20
	5.5 Size-fecundity relationship of a fast growing population	20
	5.6 Effect of site and season on the morphometry (length-width-height relationship)	22
	5.7 Effect of site and season on condition and blood loss	22
6	BENEFITS	27
7	FURTHER DEVELOPMENT	27
8	CONCLUSIONS	28
9	REFERENCES	28
10	APPENDIX 1: Intellectual Property	28
11	APPENDIX 2: Staff	29
12	APPENDIX 3: Distribution List	29
13	APPENDIX 4: Population Model	30
14	APPENDIX 5: Initial Survey Report - Dr Scoresby Shepherd, SARDI	33
15	APPENDIX 6: Analysis of Morphometry - Aaron Lee, Maritime College	39

1. Background

The greenlip/brownlip abalone fishery on the south coast of Western Australia is the major commercial fishery in this area, with estimated earnings of about $8 million in 1997/98. The fishery is divided up into 2 zones, with quota allocations in the 1997/98 season in Zone 1 (eastern zone) of 37.2 tonnes meat weight, and in Zone 2 of 40 tonnes, with 90% of the catch composed of *H. laevigata*, and 10% of *H. conicopora*. The fishery in Zone 1 area consists of several closely connected areas of abalone habitat between Esperance and Israelite Bay and a small area on the Nullabor near Cocklebiddy. Zone 2 covers the region from just west of Esperance to the Cape Naturaliste area and consists of three discrete areas of abalone habitat - Augusta, Windy Harbour and Hopetoun. In the Augusta/Cape Naturaliste area, both greenlip abalone (*Haliotis laevigata*) and brownlip abalone (*H. conicopora*) are at the western extreme of their distribution.

Despite the Augusta area being near the limit of the distribution of *H. laevigata*, parts of the greenlip population in this area are thought to exhibit very rapid growth and to mature at sizes above the current legal minimum. The Augusta area has also been highly productive, and has generally provided around 40% of the catch from the zone. However, heavy exploitation of the Augusta population during the 1980's caused concern about growth overfishing and the long-term viability of the stock in this area, leading to the area being closed for increasingly long periods in recent years. This in turn lead to higher levels of effort being directed into the other two major fishing areas of the zone, which were showing signs of over-exploitation during early 1990's. The outcome of these events has been a radical change to the quota arrangements for the 1995/96 year with the introduction of 4 sub-zones and a reduction in quota. These changes were reviewed mid-season and subsequently discarded for the 1996/97 season. This highlighted an urgent need for more accurate information on the state of the stock in each fishing area of the zone.

2. Need

Historically, the research effort on the Western Australian greenlip/brownlip abalone fisheries has focused on assessment of catch and effort. Quotas were originally set in conjunction with industry at levels which were believed to be conservative. Within abalone fisheries, the ability of divers to concentrate effort in specific regions and the use of a uniform size at first capture across the zone can lead to general over exploitation by a process of serial fishing. For this reason research and stock assessment needs to be conducted at an appropriate spatial scale to assess the state of the stocks so that management can set sustainable TAC's and more appropriate harvest strategies can be developed. This will require baseline data on the biology (particularly growth and size at maturity and the relative importance of stunted, normal and fast-growing abalone to egg production) and stock status in each sector of the zone.

3. Objectives:

1. To improve the fishery database by providing data in catch and effort at a finer spatial scale.
2. To provide in-water estimates of stock abundance and status.
3. To improve the understanding of the biology of greenlip abalone (particularly the effects of high growth rates on size at maturity and egg production and the influence of seasonal condition changes on length-weight relationships.
4. To develop simulation models which can be used to assist in management decisions.

4. Methods

4.1 Study Sites

Figure 1 shows the locations of sites where the field work and data collection for this project were carried out. Growth, maturity, and fecundity studies were carried out at "The Back", west of Augusta. In-water stock assessments sites were set-up at "The Back", and Flinders Bay, immediately south of Augusta. Seasonal morphometry, condition, and blood loss data were collected from waters near Augusta, Windy Harbour, and Hopetoun. The individual reefs from where the samples were collected were chosen after consultation with commercial abalone divers had identified these areas as representative of good abalone habitat.

4.2 Finer scale catch and effort data

Data collection of finer scale of catch and effort data by the industry involved lengthy discussions with abalone industry members over a number of issues. The main concern of the industry was the confidentiality of data collected at a fine scale, particularly in relation to generally unknown fishing grounds. This issue hampered progress on this particular objective for most of the project. We addressed this concern by providing a background paper which discussed the confidentiality issue and circulated it to industry members. Eventually, a research logbook was designed in consultation with industry.

4.3 In water stock abundance estimates

1996 Survey

Sites : The initial survey work was undertaken by South Australian researcher, Dr Scoresby Shepherd. The sites chosen for in-water stock abundance estimates were within 'The Back' and Flinders Bay areas of Augusta in Western Australia (Fig. 1). These highly productive areas consistently contribute a major portion of the Zone 2 abalone TAC. The distribution of abalone habitat was estimated during initial discussions with abalone divers familiar with the Augusta region.

Stock Assessment Techniques : A team of two divers using SCUBA connected one end of a spooled line to a stem of seaweed, then swam in a given direction with the 200m length of line unreeling behind them. The line was marked at 50m intervals, and it took approximately 12 minutes to swim each 100m. This procedure enabled 4 replicate transects of $100m^2$ to be completed in a single dive. Each diver swam along opposite sides of the line, measuring all abalone encountered within 1m of the line with an abalone measuring gauge. If the diver encountered a cluster of abalone (>5 individuals), those within the 1m transect were measured and those outside the transect were counted, but not measured. Data on shell length, cluster size and the distance between them for each $100m^2$ was recorded on waterproof paper backing onto the measuring gauge. A cluster was defined as including all individuals <1m from a neighbouring animal. The time between clusters was recorded in seconds by divers using a stopwatch, which was converted to distance (metres) using mean swimming speed.

1998 Survey

In May 1998, two permanent monitoring sites were set up near Augusta, in similar locations to which the initial surveys were carried out. These represent the first sites to be used in a long-term monitoring program for greenlip abalone in Western Australia. The sites were located in Flinders Bay (Fig 1), and in the area where the growth study was undertaken at "The Back" (Fig 1). The sites in Flinders Bay represented a typical, or "average" growing population, whereas the site at "The Back" is representative of a fast growing population.

Each site consisted of two star pickets, one at either end of the transect. Prior to counting, a length of rope was drawn taunt between each star picket. Abalone were counted systematically by two divers, one on either side of the transect. Each had a 1m length of PVC pipe which was attached to the transect rope. Divers swam in the same direction, counting and measuring all abalone seen within the 1m swath of the PVC pipe. Data were recorded on an underwater recording slate. At the end of each survey the rope was transferred to the next transect, and the procedure repeated in an iterative fashion until completion. The area of each transect was $40m^2$ at "The Back", and $20m^2$ in Flinders Bay. This was the result of much higher densities in Flinders Bay, which greatly increased dive time needed to measure the animals.

Data comparisons between sites were carried out with a non-parametric Mann-Whitney U - test due to the heteroskedascity of the variances between sites. Data were standardised to an area of $40m^2$ prior to analysis.

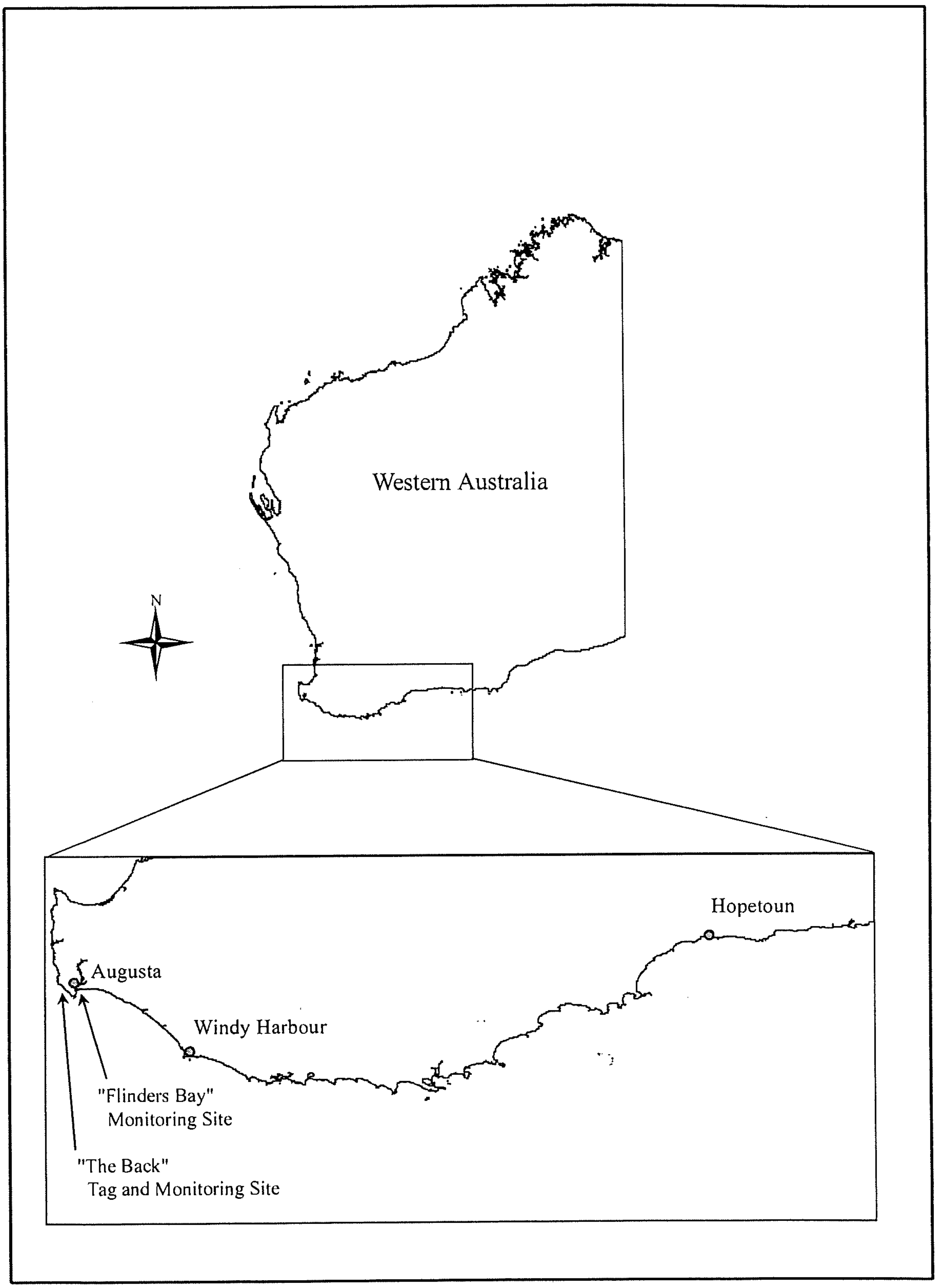


Figure 1. Greenlip abalone study sites - Western Australia

4.4 Growth studies of a fast growing population

Tag Line: The tag site at "The Back" was located in 18 metres of water, on an area identified by commercial abalone divers as a "fast" growing abalone reef. Approximately 150 metres of the reef's perimeter was cordoned off by a series of 4 moorings containing sub-surface buoys for easy identification by both research and commercial divers. GPS (Global Positioning System) fixes were taken for each of the moorings for future references.

Initial Tagging, Measurement and Release: A team of research divers using Surface Supply Breathing Apparatus (hookah) located, tagged and measured abalone 'in-situ'. An area on the shell of each abalone was scraped clean and a numbered plastic polyethylene tag set in a resin block was adhered to the shell's surface using a two part epoxy putty ('Emerkit') which sets under water. Care was taken to avoid obstructing the abalone's respiratory holes during the tagging procedure. The dorsal-ventral length (DVL) of each shell was measured using a set of callipers and recorded on the surface using an underwater communication system. A total of 405 abalone were tagged in March 1996. A summary of the growth study is described in Table 1.

Table 1. Summary of tagging experiment used for growth study

Year	Size-range released	n	$\bar{x}$ size at release	Size-range recaptured	n	$\bar{x}$ size at recapture
1996/1997	62 - 189mm	405	131 ± 1.7 s.e.	110-185 mm	265	150 ± 1.0 s.e.
1997/1998				122-188 mm	194	158 ± 0.9 s.e.

Recapture: The tag site was located using GPS and re-measurements of tagged abalone were made in-situ after 1 and 2 years at liberty. A total of 265 recaptures were made in 1997 and 194 recaptures in 1998. The tags were cleaned and the DVL of recaptured abalone measured using calipers. Each abalone was marked with surveyor's crayon to separate measured and unmeasured abalone to ensure efficient targeting of effort. Tag numbers and measurements were recorded using an underwater slate and transferred to record sheets on the surface.

Data Analysis

Faben's reformulation of the von Bertanffy growth curve was used to estimate the growth parameters K and L_∞ of the von Bertalanffy growth curve. The von Bertalanfy growth curve is as follows:

$$L(t) = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

where L_∞ is the expected maximum size, K is the growth rate, $L(t)$ is the expected length at time t, and t_0 is the initial age for adjustment.

If the age is unknown and the data come from capture-recapture experiments, as is the case for pearl oysters, Fabens method is used to estimate the growth parameters.

$$\Delta l_i = \left(L_\infty - l_i\right)\left(1 - e^{-K\Delta t_i}\right) + \varepsilon_i$$

where $\varepsilon_i \sim$ NID $(0,\sigma^2)$, Δl_i is the change in length from recapture of the ith animal, Δt_i is the change in time from recapture of the ith animal. Using non-linear regression techniques, K and L_∞ were estimated. Results from this method were then compared with results obtained using Francis's method (Francis, 1988).

4.5 Size-at-maturity and fecundity studies of a fast growing population

In November 1995, commercial abalone divers collected 108 greenlip abalone from "The Back". The sample consisted of abalone ranging in size from 60 to 180 mm. The meat was shucked and the remaining shell and contents were preserved in 10% formalin in seawater. The abalone samples were removed from the formalin solution in a fume cupboard, washed and placed in 70% ethanol. Each shell was measured, by length, width and height. The viscera was carefully removed and numbers of each sex determined by the presence and colour of gonad tissue. Females have a greenish gonad, while males have a creamy white gonad. Any doubtful samples were examined microscopically to determine sex. Viscera weight was recorded. The gonads were carefully dissected and placed in a container of known weight which was weighed to determine gonad weight. This was done as the gonad could not be dissected in one piece.

Gonad subsamples were removed from three locations along the gonad, weighed to 0.001 grams and placed in 70% ethanol. Fig 2 shows the locations from which subsamples were taken (A,B and C). These were the tip of the conical appendage, the whorl and a ventral anterior site.

Subsamples were placed in a petri dish and the eggs teased apart using a very fine dissecting needle and a small stiff paintbrush. The sample was carefully pipetted into a counting plate. The perspex counting plate consisted of twenty-five chambers each of a diameter entirely visible under 120 times magnification. The eyepiece was fitted with a 10 x 10 mm grid graticule to assist counting.

Numbers of eggs were recorded from two sites (A and B) of the three subsample sites and scaled up using gonad weight to determine total numbers of eggs in the gonad, as initially described by (Newman, 1967). The state of gametogenesis as far as possibly determined macroscopically was recorded. Differences in oocyte diameter from each of the three sites was not tested.

Mature gonads contained densely packed oocytes surrounded by a gelatinous matrix or large oocytes free in the lumen and free of the gelatinous matrix. Some pear shaped oocytes were attached to trabeculae with some samples containing oogonia attached to trabeculae. These mature gonads contained oocytes measuring 150 μm to 250 μm. Spent or developing gonads contained less densely packed trabeculae with numerous small oocytes (<50 μm). Some large oocytes were present in the lumen (due to the amount of tissue these samples proved difficult in terms of the time taken to separate eggs prior to counting). Different stages of gametogenesis were detected between sites from the same gonad. As a result only spawning or mature gonads were used in the final analysis.

Data Analysis

Size-at-maturity: Size at maturity was defined as the length at which 50% of animals were mature, as has been previously used for studies on *H. laevigata* in WA (Wells and Mulvay, 1992). Data were separated in to 10mm size classes, starting at 57mm, up to 187mm, with the proportion of mature abalone calculated for each size class. A logistical regression model was fitted to the data, and size-at-maturity calculated using the equation derived from the regression model. Bootstrapped confidence limits (95%) for size-at-maturity were calculated according to the procedures of Efron and Tibsherani (1993). The number of iterations used in the bootstrapping procedure was 300.

Size-fecundity: Number of eggs was plotted against the size of the animal, and the data fitted with an exponential regression model. Data were compared with previous studies from Western Australia (Wells and Mulvay, 1992).

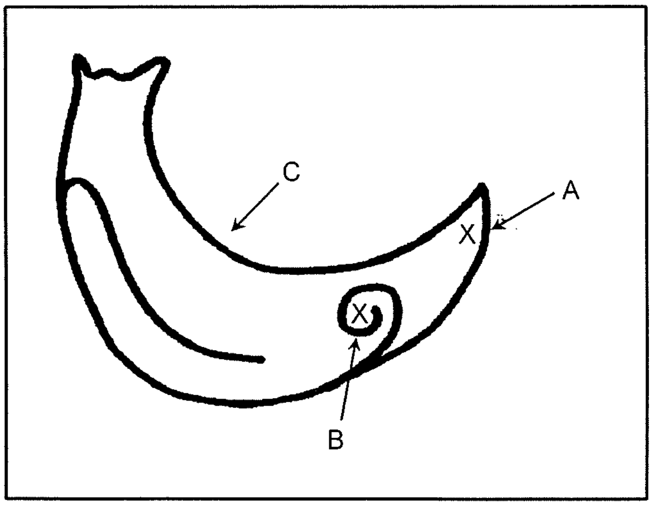


Figure 2. Gonad subsample locations; A - conical appendage; B - whorl; C - ventral anterior

4.6 Effect of sites and season on morphometry, condition and blood loss

Collection Of Samples : Samples at each site (Augusta, Hopetoun, Windy Harbour) were collected in February, May, August and November to represent the four main seasons. The abalone were collected at sea by a combination of research and commercial diving effort. All abalone were measured and sorted by research staff until the required size structure of the sample was obtained. This consisted of a maximum of 10 abalone for each 10mm size class above a minimum required size of 70mm length, to the maximum size available at each site. Once collected the samples were stored live on board in plastic tubs.

Measurement And Weighing : Abalone samples were brought ashore to an appropriate facility for processing. Each abalone was accurately measured for shell length, width and height, then weighed on a certified electronic balance to establish the animals whole weight. Each abalone was then 'shucked' (removal of the edible meat from the shell and viscera), and the meat weighed in order to establish the condition of the abalone before blood loss. The meat was then tagged with a plastic locked tag placed through the abalone's mouthpart, so it could be easily identified for reweighing after 24 hours. Each abalone was fully processed individually so that minimal blood loss occurred following shucking. All the individual tagged meats were then secured in a large plastic bag containing approximately 1-2 litres of clean seawater, which was stored overnight on ice. This procedure was designed to simulate the processing of commercially caught abalone. The tagged meats were re-weighed the following day in order to determine the percentage blood loss of each abalone over a period of time similar to that taken for commercially caught abalone meats to be transported to processing companies (approximately 18-24 hrs). In this study condition was defined as bled weight/whole weight. This is an appropriate measure for an animal fished under a TAC management regime, if animals are fished at times of highest condition, then less individuals are taken to meet quotas. Bled weight was defined as the weight of the meat 24 hours after shucking and being stored under ice.

Data Analysis

Morphometric analyses were undertaken via ANCOVA. Initial data examination found that condition and blood loss where significantly correlated with size. To account for this dependency, data were divided up into 6 size categories for which the relationship was not significant. These categories <80mm; 81-100mm; 101-120m; 121-140mm; 141-160mm; 160+mm. A 2-way ANOVA examining the effect of site, and season on condition and blood loss was used to analyze the data for individual size categories. Data were log transformed where necessary.

4.7 Population modeling

Initial trials of an abalone population model were reported in the FRDC progress report of 31st March 1998 (Appendix 4). The model is a length structured model based on a model developed for the NSW Abalone Fishery by Worthington et al. (1997). Progress on this particular model was paused as a result of a collaborative proposal by all abalone producing states to develop a national abalone population model (MacArthur Agribusiness, 1998). The model will be initially based on Worthington et al. (1997), but adapted to individual states need. This proposal was successfully approved by the FRDC (project No. 99/116) and has funding for 3 years. During this time it will be adapted to each individual state fishery including Western Australia.

5.0 Results/Discussion

5.1 Finer scale catch and effort data

The prototype research logbook is shown in Fig. 3. The logbook is far wider in scope and capacity than originally proposed, and will represents a considerable advance on data collected so far. It is designed to follow closely the daily working pattern of industry divers, with the deckhand doing most of the actual recording of information. Data gathered will fall into the following categories:

A) Swell, Cloud Cover (%), Underwater visibility, Bottom Type, Growth Area. These are categorical variables, and will require the industry member to the tick the appropriate category of the range presented to them. They also have a direct influence on diver catch rates.

B) GPS Position, Dive Details, Depth Range. Spatial position and time will be recorded at the beginning and end of the dives, so that accurate calculations of distance travelled and effort can be made.

C) Stock Data (% legal left and % undersize in stock). Percent legal left will be an estimate of the legal sized abalone seen, but not harvested. Percent undersize in stock is a measure of recruitment, as seen by the divers. In particular, this recruitment data will prove invaluable for future years providing an indication of next year's catch, once the method has been properly assessed and standardised.

D) Largest Harvested Abalone Harvested. The deckhand will measure, from each dive, the largest animal harvested. This will provide a measure of the status of the stock at each location, with the hypothesis being that small, but detectable changes in mean size of large animals will reflect the general 'health' of the stock.

E) Catch of abalone in terms of number, and estimates of meat weight.

At the completion of the project, no official system for collecting finer scale catch and effort data had been implemented, despite the industry recognizing the importance and value of this information. There were two main reasons for this: The first relates to the confidentiality of that information, industry felt that the information would not be able to be kept confidential to their satisfaction. The second reason relates to a political stand taken by the industry with respect to Fisheries WA on cost-recovery issues, a position outside the control of the Research Division. These issues were resolved in recent times, and the industry has now approved the development of the research diver logbook program to commence in 1999.

At present some industry divers have adopted the logbook on a confidentiality basis. They are using it on a daily basis and filling it out; however have yet to agree to hand information over to the Fisheries Agency to be assessed on account of the confidential nature of the data. In time it is anticipated that the data will be ready and available for analysis.

LEF License Name/No.:______________ Date:______________ Diver:____________ General area:______________

	DIVE 1	DIVE 2	DIVE 3	DIVE 4
Swell	☐ 0-2m ☐ 2-3m ☐ 3+m	☐ 0-2m ☐ 2-3m ☐ 3+m	☐ 0-2m ☐ 2-3m ☐ 3+m	☐ 0-2m ☐ 2-3m ☐ 3+m
Cloud cover (%)	☐ 0-30 ☐ 30-70 ☐ 70+	☐ 0-30 ☐ 30-70 ☐ 70+	☐ 0-30 ☐ 30-70 ☐ 70+	☐ 0-30 ☐ 30-70 ☐ 70+
GPS POSITION / Dive Details	START: Lat. / Long. / Time; FINISH: Lat. / Long. / Time	START: Lat. / Long. / Time; FINISH: Lat. / Long. / Time	START: Lat. / Long. / Time; FINISH: Lat. / Long. / Time	START: Lat. / Long. / Time; FINISH: Lat. / Long. / Time
Depth Range	(m)	(m)	(m)	(m)
Stock Data	% legal left (GL, BL); % undersize in stock	% legal left (GL, BL); % undersize in stock	% legal left (GL, BL); % undersize in stock	% legal left (GL, BL); % undersize in stock
Underwater Vizibility	☐ 0-3m ☐ 3-7m ☐ 7+m	☐ 0-3m ☐ 3-7m ☐ 7+m	☐ 0-3m ☐ 3-7m ☐ 7+m	☐ 0-3m ☐ 3-7m ☐ 7+m
Bottom Type	☐ Lime ☐ Gran ☐ Flat ☐ Bould ☐ Gutt ☐ Snd Edg	☐ Lime ☐ Gran ☐ Flat ☐ Bould ☐ Gutt ☐ Snd Edg	☐ Lime ☐ Gran ☐ Flat ☐ Bould ☐ Gutt ☐ Snd Edg	☐ Lime ☐ Gran ☐ Flat ☐ Bould ☐ Gutt ☐ Snd Edg
Growth area	☐ Fast ☐ Avrge ☐ Slow	☐ Fast ☐ Avrge ☐ Slow	☐ Fast ☐ Avrge ☐ Slow	☐ Fast ☐ Avrge ☐ Slow
Largest harvested: Green / Brown	Length(mm) / Width(mm)	Length(mm) / Width(mm)	Length(mm) / Width(mm)	Length(mm) / Width(mm)
G/L CATCH / B/L CATCH	Weight (kg) / Number caught	Weight (kg) / Number caught	Weight (kg) / Number caught	Weight (kg) / Number caught

COMMENTS: (e.g. Last time here?)

DAY TOTALS

	G/L	B/L
Weight (kg)		
Number caught		
DiveTime	mins	

Figure 3. Proposed research diver logbook

The most important future objective is to carry out a proper pilot study of the logbook. This will include: a) thorough briefing of industry on how to use the logbook; analysis of the effect of the environment/habitat variables on catch rates; evaluate spatial and diver differences in catch rate; largest size harvested; recruitment. It is likely that some variables will be discarded, and others kept. Eventually a standardised index of catch rate must be developed, taking into account these and other variables such as month, and year, as currently exists for the NSW fishery (Worthington et al. 1997).

5.2 In water stock abundance estimates

Initial surveys (1996)

A report by Dr Scoresby Shepherd on the initial surveys is attached as Appendix 5. The report provided some recommendations on appropriate sampling design for long-term monitoring sites. These were used as guides for the final setting up of monitoring sites. The length frequency data showed clear modes for 2+ and 3+ age classes. These can be used to derive recruitment indices. This survey also highlighted the potential to age greenlip abalone. Samples of tagged abalone will be aged after being at liberty for 3 years.

Long-term monitoring sites (1998+)

A significant difference in abundance between the two monitoring sites was detected for all size-classes examined (Table 2). Mean densities of greenlip abalone were between 4 and 33 times higher at "Flinders Bay", compared to "The Back" (Table 3). Larger differences were more evident at the smaller sizes. This data demonstrates the large variability in abalone abundance seen on productive fishing grounds. Figure 4 graphically illustrates the difference in abundance between the 2 sites.

Table 2. Results of Mann-Whitney U-tests comparing Site 1 and Site 2 (n = 8)

Size class	U	P
<140 mm	10	0.02
141-150 mm	11	0.02
>150 mm	10	0.04
All size classes	10	0.02

Table 3. Mean densities (per m^2) and 95% C.L. for density data at monitoring sites: TB - "The Back"; FB - "Flinders Bay".

	n	Mean	Std. Dev.	95% C.L.
<140 mm				
FB	4	4.18	1.68	2.5-5.85
TB	4	0.14	0.07	0.06-0.21
141-150mm				
FB	4	1.65	0.47	1.18-2.13
TB	4	0.18	0.10	0.08-0.28
150mm+				
FB	4	1.23	0.72	0.50-1.95
TB	4	0.34	0.21	0.13-0.54
Total Abundance				
FB	4	7.25	2.60	4.65-9.85
TB	4	0.68	0.33	0.35-1.0

Baseline size-frequency for the monitoring sites are presented in Fig. 5. The size-frequency is very different between the populations. At "The Back", the majority of the population surveyed appear to be legal-sized, and are generally larger (mean size = 148mm, s.e. = 1.9 mm; n = 109). At "Flinders Bay", most of the animals are below legal size (mean size = 128mm, s.e. = 1.0; n = 658).

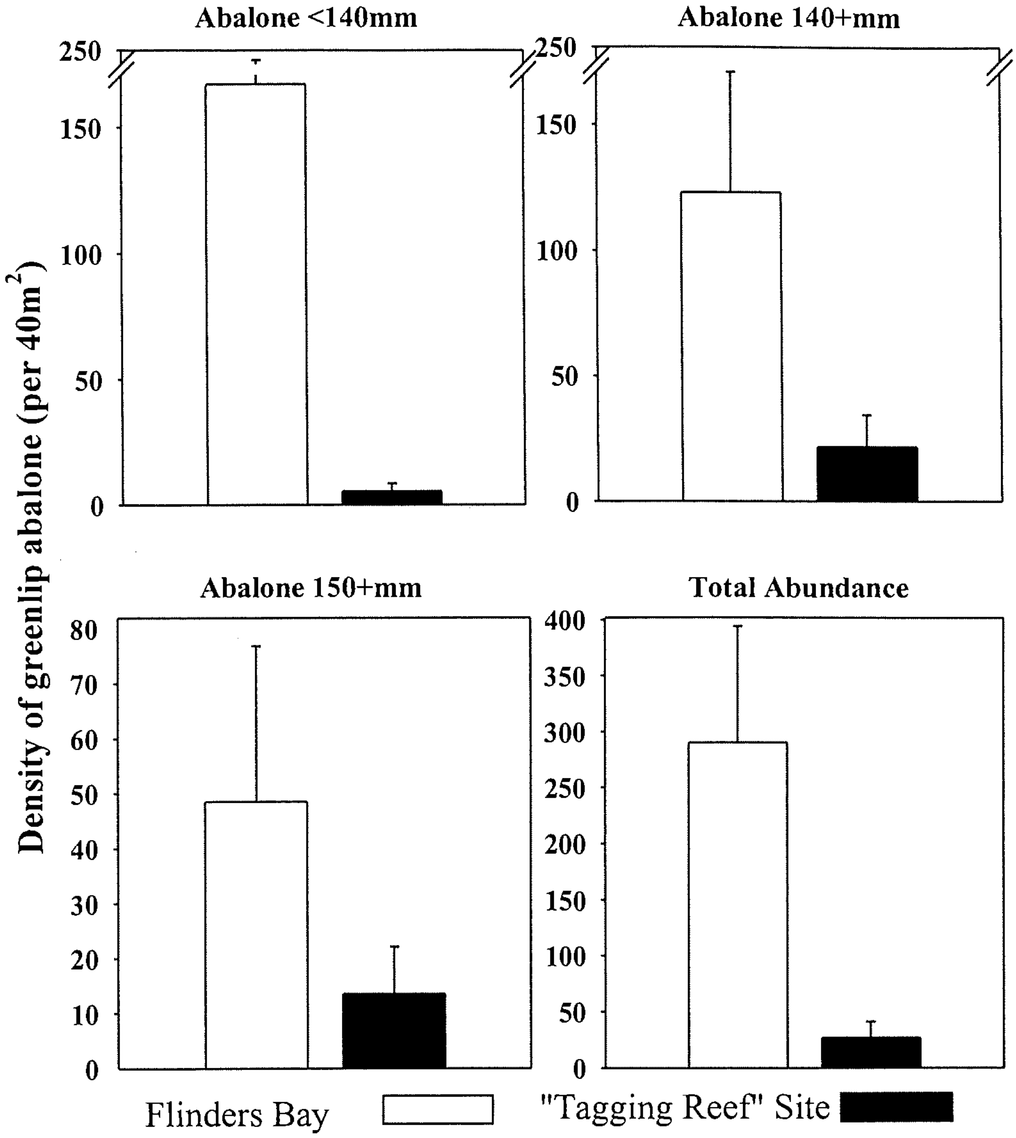


Figure 4. Greenlip abalone abundance from the Flinders Bay and "Tagging Reef" site.

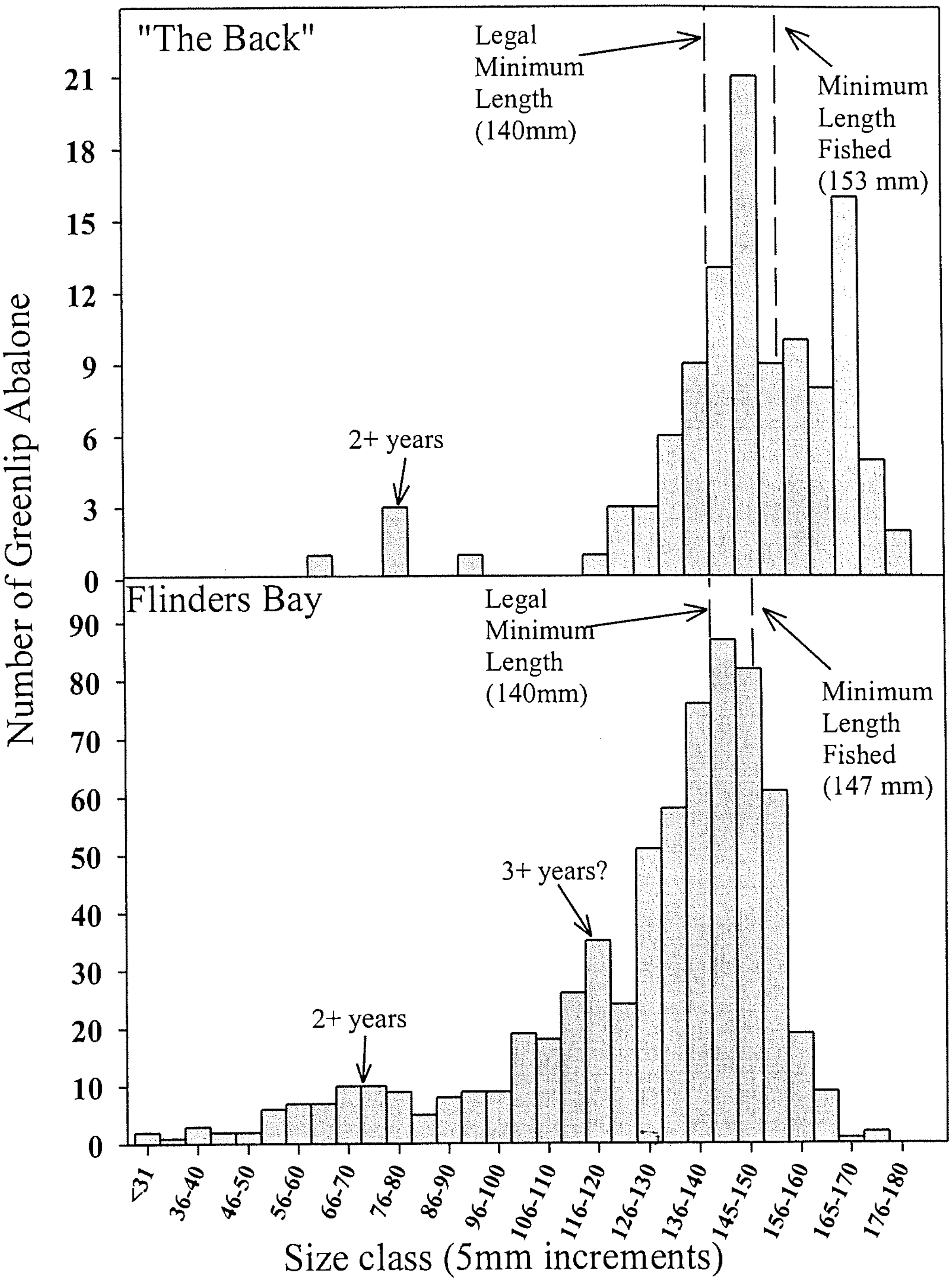


Figure 5. Baseline frequency of monitoring sites in Flinders Bay and "The Back"

5.3 Growth of a fast growing population

Size frequency data of greenlip abalone tagged and recaptured during the 2 year growth study are shown in Figure 6. Depending on the method used to analyse data, K ranged between 0.57 and 0.58, and L_∞ varied from 170 - 175mm (Table 4). Both growth analysis methods were close in agreement for the parameters of growth at this site. The K of 0.57 and L_∞ of 170-175mm are consistent with fast growth sites from South Australia (S. Shepherd, pers. comm.).

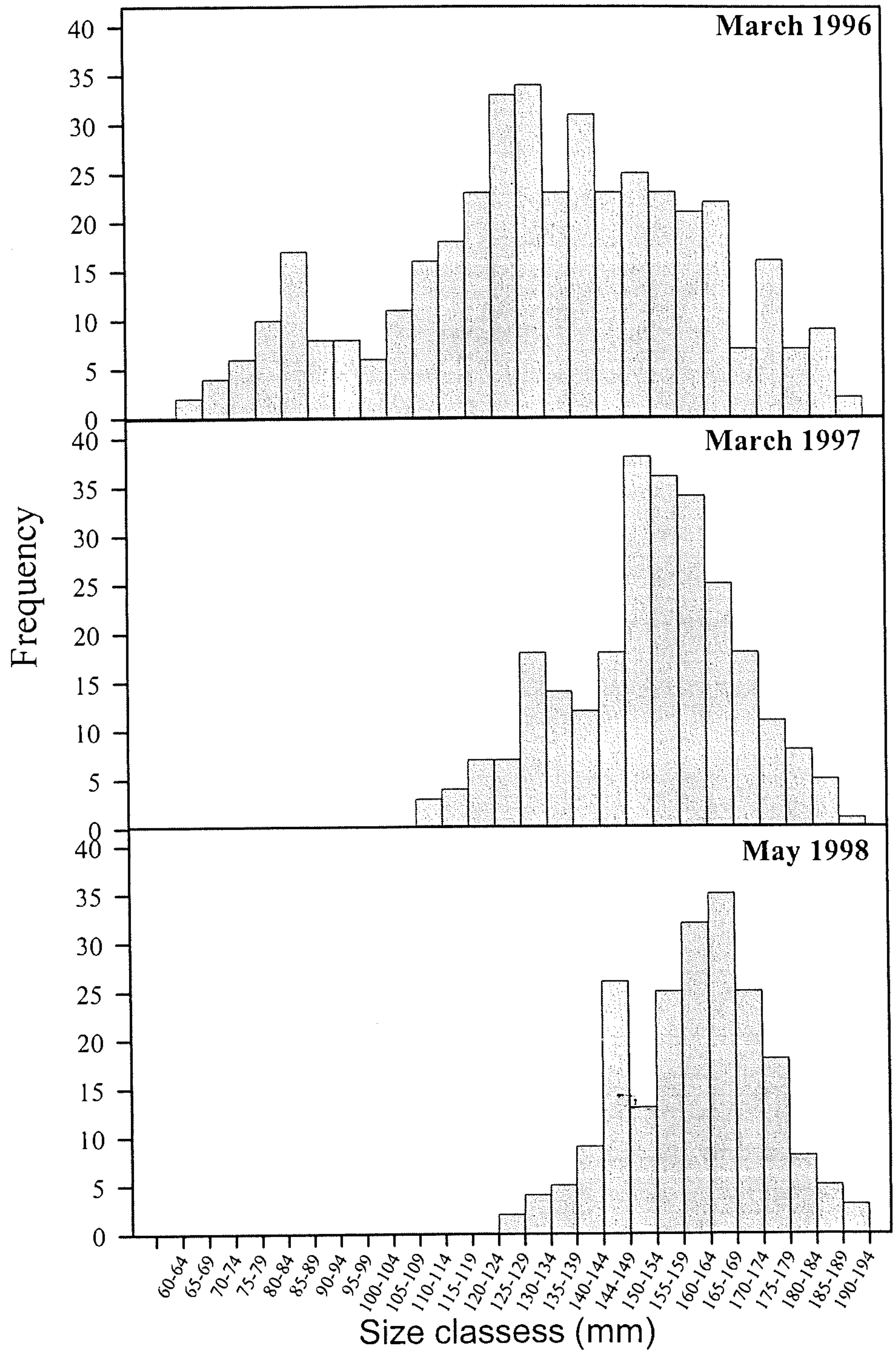


Figure 6. Size frequency of greenlip abalone tagged and recaptured during growth study.

Table 4. Summary of growth parameters for greenlip abalone at "The Back". The growth parameters relate to individuals released in 1996 and recaptured in 1997.

K	L_{∞}	Method
0.571	175 mm	Fabens
0.575	170 mm	Francis, 1988

To illustrate the differences in growth between the site used in this study ("The Back"), and a previous study (Wells and Mulvay, 1992) which was carried out at a location (Flinders Bay) quite close to this one, growth curves are plotted with Legal Minimum Lengths (Fig. 7). These results have important management implications.

The legal minimum length for the management zone in which the 2 sites are located is 147mm. Divers however, fish "The Back" at a voluntarily imposed level of 153mm, due to the higher growth rate. The graph shows quite clearly that an animal of 147mm in Flinders Bay may be a year older than an animal of 153mm from "The Back" This result illustrates the need for appropriate size-limits in appropriate places.

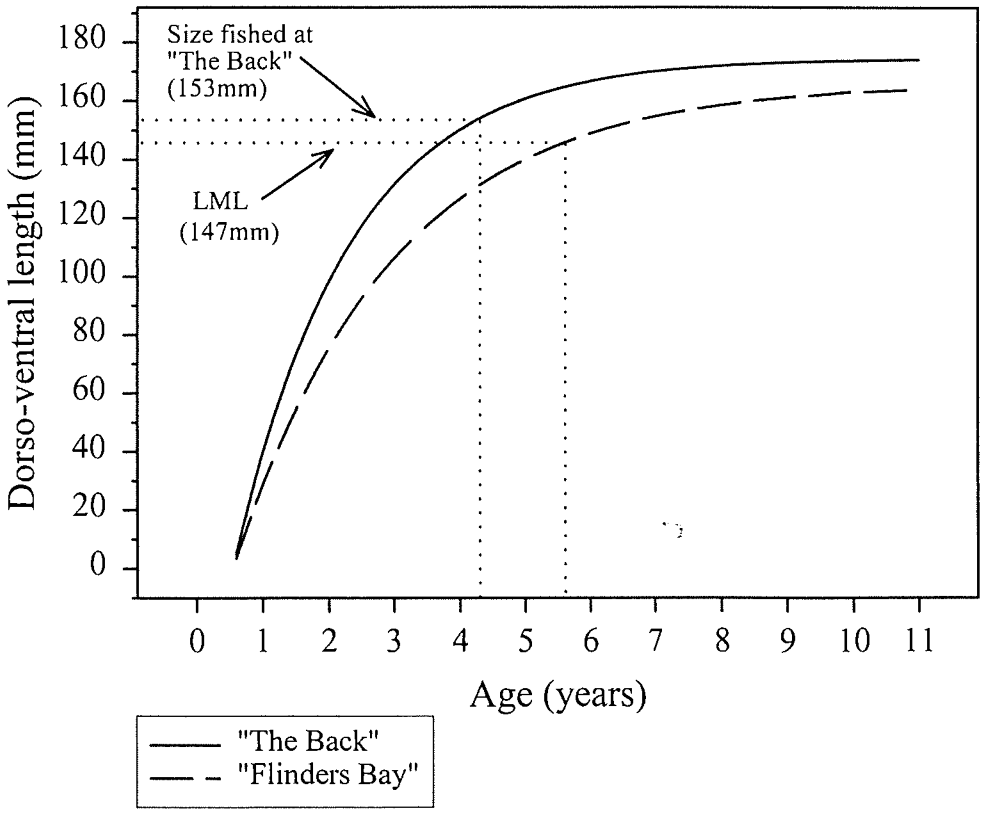


Figure 7. Greenlip abalone growth in Flinders Bay and "The Back"

5.4 Size-at-maturity of a fast growing population

Size at maturity was estimated to be 97 mm (95% C.L 91-100mm) for samples collected at "The Back". Figure 8 shows that, for females, size at maturity asymptotes very steeply. There is only a 10mm size range over which the % maturity changed from <10% to 100% (Figure 8). This size-at-maturity is high compared to other studies on greenlip in Western Australia. Wells and Mulvay (1992) found that size-at-maturity of greenlip abalone at "normal" and "stunted" populations ranged between 80 and 85mm. This is substantially smaller than 97mm as found in this study, however as no confidence limits are were established for these earlier estimates, any comparison can be qualitative only.

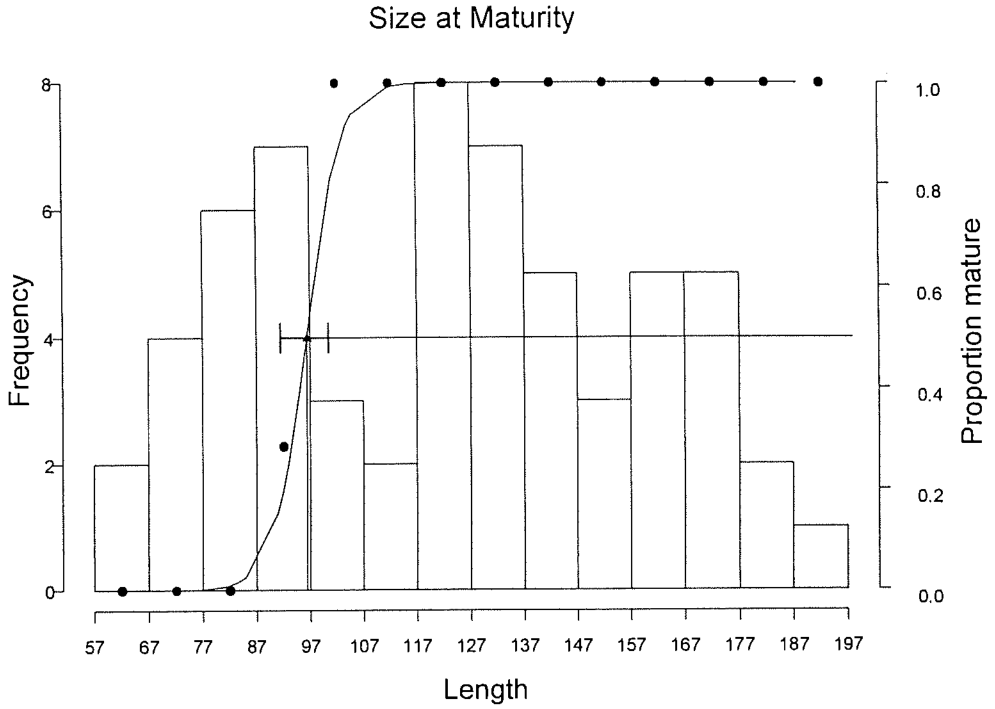


Figure 8. Size at maturity if greenlip abalone from "The Back".

5.5 Size-fecundity of a fast growing population

The sample of 108 abalone contained 65 male and 43 female abalone. Of the 43 females, 40 individuals ranging from 91 to 188 mm shell length contained gonad tissue that could be sampled.

Table 5 details a comparison of size-fecundity data from different populations which have been studied over the years at Augusta. While it was not possible to compare the results of the different studies in a statistical manner, it is quite evident that there seems to be a considerable difference in size-fecundity relationships between the different populations.

The Augusta "normal" (Flinders Bay) and Augusta "fast" (The Back) data are compared in Figure 9. The shell length axis indicates the range over which the data exists for each population. It is evident that the length-fecundity curve for "The Back" shows lower fecundity than Flinders Bay after taking size into account. This data is consistent with the growth data which demonstrates this to be a very fast growing population of *Haliotis laevigata*. The data shows that for sizes around the legal minimum length (145mm), fecundity is higher in greenlip from the more normal growing populations. Therefore the voluntary size limit of 153mm which is now used for the fast growing populations at Augusta has a good biological basis; i.e. egg production may be smaller for sizes around the legal minimum length. In fact Figure 9 suggests that fecundity of a 170mm animal from the fast growing site is equvalent to fecundity of a 145mm animal from the slower growing site. This data needs to be interpreted with caution however, as the sample size were small.

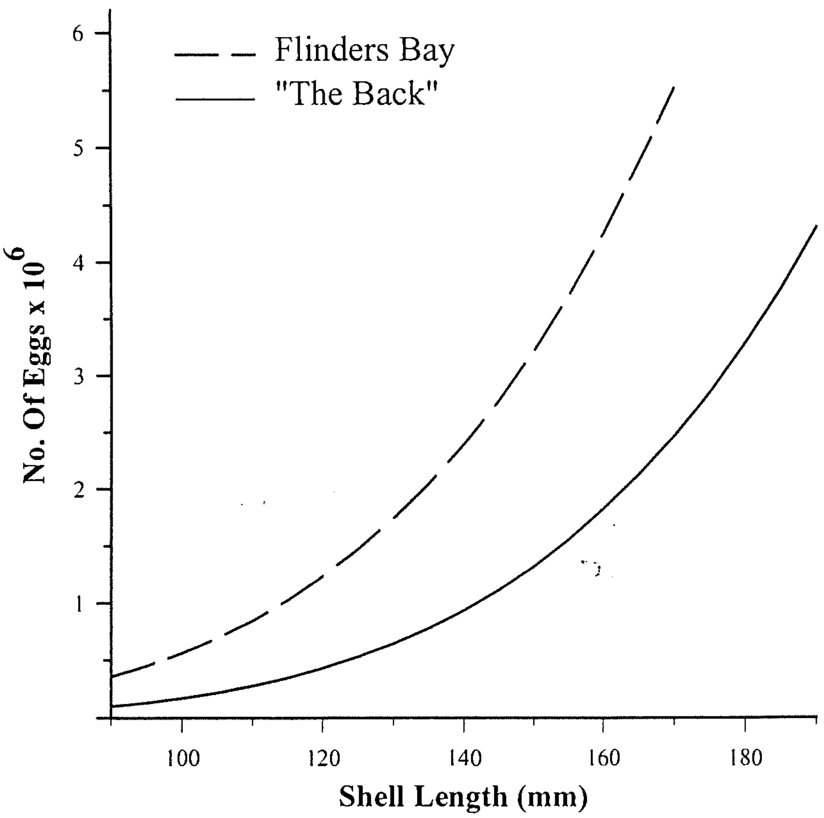


Figure 9. Size-fecundity of greenlip abalone from Flinders Bay and "The Back"

Table 5. Comparison of size-fecundity data from different studies on *Haliotis laevigata* in Augusta.

Population	n	a	b	r^2	Source
Augusta "normal"	29	1.49x10-3	4.29	0.83	Wells and Mulvay, 1992
Augusta "stunted"	30	1.39x10-4	4.70	0.59	Wells and Mulvay, 1992
Augusta "cage"	22	1.33x10-3	4.29	0.69	Wells and Mulvay, 1992
Augusta "fast"	23	1.00x10-6	5.48	0.89	This study

5.6 *Effect of site and season on the morphometry (length-width-height relationship)*

Appendix 6 provides a detailed report on the morphometry of *Haliotis laevigata* from the study sites. In summary, all morphological tests showed that significant differences existed between sites. The tests indicated that Hopetoun abalone had more individuals with a larger height for a given width. In general the shells from Hopetoun were more domed in shape than either at Augusta or Windy Harbour. These differences in morphology imply gross differences in growth rates between sites. To date however, the only data for growth rate of greenlip abalone come from Augusta, where differences have been found. There is a need for growth information from Windy Harbour and Hopetoun in order to examine this hypothesis.

5.7 *Effect of site and season on condition and blood loss*

Significant differences in condition and blood loss between sites and seasons were evident for all size-classes (Table 6 and 7). However in almost all cases, there was a significant interaction between sites and seasons, indicating that the seasonal differences vary between sites, and vice versa (Table 6; Table 7).

Figure 10 shows the mean condition of *H. laevigata* for each size class, separated into sites and seasons. A general trend is that condition is higher during May and August, and lower during February and November. Another general trend is that Hopetoun abalone show generally a lower mean condition compared to Augusta, although this is not consistent (e.g. see 160mm+ graph).

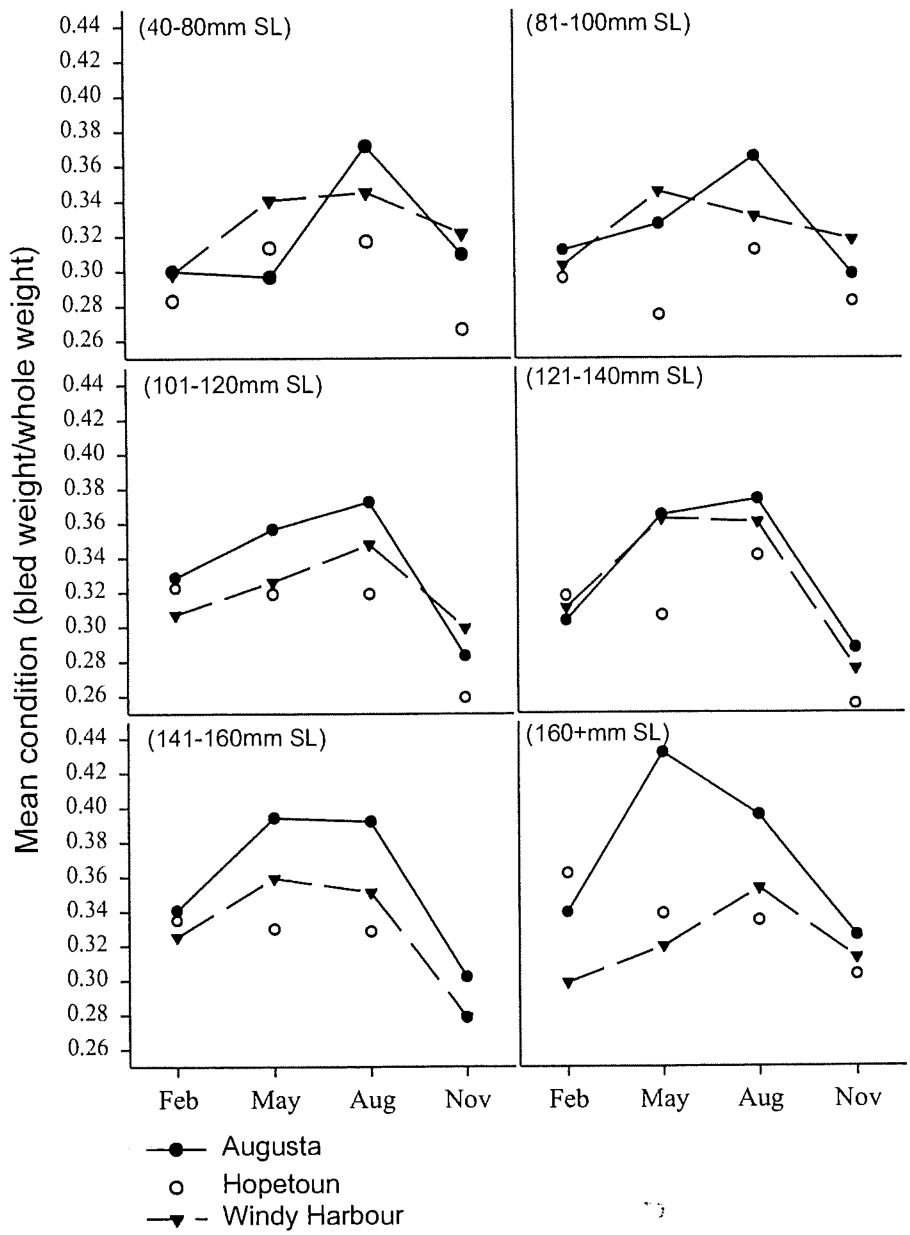


Figure 10. Mean condition of greenlip abalone separated by site and season.

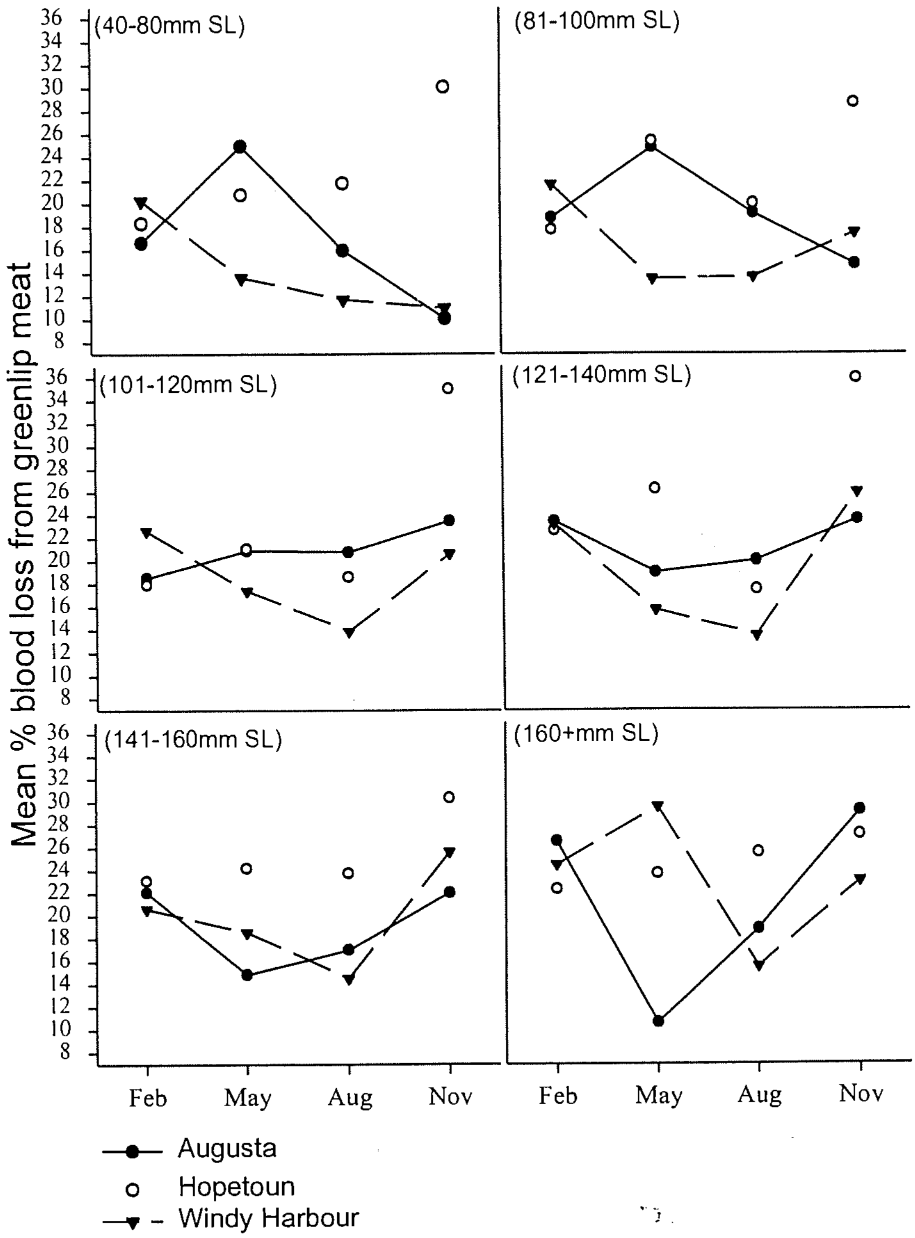


Figure 11. Blood loss comparison of greenlip abalone by site, size and season.

Blood loss is generally the main determinant of condition as measured here, although other factors such as weight of visceral mass and gonad can be significant. Figure 11 shows the blood loss of the abalone meats by size, season, and site. As with condition, a general trend is that blood loss is higher during November in the legal sized animals (141mm+), and lowest in May and August. In the 141-160mm size range, which encompasses most of the legal catch, mean blood loss was higher at Hopetoun, and similar at Augusta and Windy Harbour.

Table 6. ANOVA results for the effect of Site (Augusta, Hopetoun, Windy Harbour), and Season on condition (bled meat weight/whole weight) in *Haliotis laevigata*.

Effect of Site and Season on condition (bled meat weight/whole weight) of greenlip abalone

Source of variability	**d.f.**	**MS**	**F**	**P**
<80mm SL				
Site	2	0.0298	33.3	<0.001
Season	3	0.0178	19.9	<0.001
Site x Season	6	0.0022	2.45	0.03
Residual	157	0.0009		
81-100mm SL				
Site	2	0.0349	30.5	<0.001
Season	3	0.0185	16.2	<0.001
Site x Season	6	0.0067	5.8	<0.001
Residual	221	0.0011		
101-120mm SL				
Site	2	0.0111	11.8	<0.001
Season	3	0.0358	37.9	<0.001
Site x Season	6	0.0038	4.07	0.001
Residual	198	0.0009		
121-140mm SL				
Site	2	0.025	19.7	<0.001
Season	3	0.084	65.5	<0.001
Site x Season	6	0.005	3.91	0.001
Residual	213	0.001		
141-160mm SL				
Site	2	0.021	15.4	<0.001
Season	3	0.075	54.4	<0.001
Site x Season	6	0.005	3.70	0.001
Residual	264	0.001		
160+mm SL				
Site	2	0.077	83.7	<0.001
Season	3	0.036	39.1	<0.001
Site x Season	6	0.007	7.57	<0.001
Residual	143			

Table 7. ANOVA results for the effect of Site (Augusta, Hopetoun, Windy Harbour), and Season on % blood loss in *Haliotis laevigata*

Source of variability	**d.f.**	**MS**	**F**	**P**
<u><80mm SL</u>				
Site	2	0.055	11.9	<0.001
Season	3	0.003	0.74	0.53
Site x Season	6	0.050	10.8	<0.001
Residual	158			
<u>81-100mm SL</u>				
Site	2	0.083	15.2	<0.001
Season	3	0.012	2.15	0.09
Site x Season	6	0.041	7.70	<0.001
Residual	221	0.005		
<u>101-120mm SL</u>				
Site	2	0.036	8.58	<0.001
Season	3	0.066	15.7	<0.001
Site x Season	6	0.033	7.9	<0.001
Residual	198	0.004		
<u>121-140mm SL</u>				
Site	2	0.063	11.0	<0.001
Season	3	0.13	22.8	<0.001
Site x Season	6	0.026	4.51	<0.001
Residual	214	0.006		
<u>141-160mm SL</u>				
Site	2	0.107	20.3	<0.001
Season	3	0.074	14.0	<0.001
Site x Season	6	0.013	2.43	0.027
Residual	266	0.005		
<u>160+mm SL</u>				
Site	2	0.010	3.11	0.047
Season	3	0.031	9.27	<0.001
Site x Season	6	0.027	8.16	<0.001
Residual	143	0.003		

Summary of biological characteristics

In general the data was very much in support for the hypothesis that the area of greenlip abalone habitat from "The Back' at Augusta supports fast growing populations. The fast growth supports a higher size-at-maturity, and delayed development of fecundity (in terms of length) in comparison to other populations studied within this area. The fact that onset of sexual maturity appears to be primarily age-based rather than length-based in abalone means that at a given LML, slower growing populations are afforded better protection of egg production than faster growing ones (Nash, 1992). Clearly, populations of fast growing abalone, such as at "The Back" at Augusta, need to be managed at a higher size limit than that found in other areas in order to conserve egg production capacity. Furthermore, analysis of morphometry relationships between Hopetoun, Windy Harbour and Augusta also provided evidence of between-site differences in growth.

The other main conclusion relates to condition and blood loss in greenlip abalone, and the implications for harvesting. Although there was much variability, distinct seasonal differences, and distinct site differences were evident. Quite obviously, recovery rates of meat will be greater from animals fished from Augusta during May, compared to animals fished from Hopetoun during November. This is important for the exploitation rate, as less animals need to be taken to achieve quota when they are in good condition. At present the opening of the season on April 1st takes advantage of this seasonal change in condition.

6. Benefits

This study has highlighted clearly the importance of fine scale differences in demographic characteristics of *Haliotis laevigata* to the dynamics of the greenlip fishery in WA. There is now mounting biological evidence for the advantage of different size-limits for different parts of the fishery in order to conserve egg production. The benefits of this will be more robust management of the valuable abalone resource.

7. Further Development

Areas of further development have been identified as a result of this study. These are: 1. Establishment of a detailed industry research logbook; 2. Establishment of fishery independent, in-water monitoring sites; 3. Development of a standardised catch rate index; 4. Better understanding of spatial variation in growth; 5. Development of a formal stock assessment and decision analysis model.

8. Conclusions

The results of this study have demonstrated that between site differences in growth, fecundity, and condition do exist in the Zone 2 abalone fishery in WA. In order to fully understand the effect of these biological characteristics on the dynamics of the fishery, finer scale catch and effort data will need to be provided by the abalone diver research logbook. This will eventually result in accurate maps of the extent of the fishery, and the productivity of individual areas, as well as fully documenting the behaviour of the diver and influences on catch rates. The data will be invaluable in implementing proactive management strategies such as rotational fishing, and/or periodic closures to enhance stocks, as well as identifying potential areas of stock which could be further explored. However, the success of such a program is contingent upon a high level of trust between the industry and Fisheries WA, as to the confidential nature of such information. Ultimately, all the available information will be incorporated into a formal stock assessment and decision analysis model, as is currently being developed via FRDC Project 99/116.

9. References

Efron, B. and R. J. Tibshirani. (1993). An introduction to the bootstrap. Chapman and Hall, New York.

Francis, RICC (1988). Maximum likelihood estimation of growth and growth variability from tagging data. N.Z. J. Mar. Freshwater Res. 22: 42-51

MacArthur Agribusiness (1998). Wild Abalone Fisheries Research and Development Needs Review. Final Report to FRDC. Project No. 98/170

Newman, GG (1967). Reproduction of the South African abalone *Haliotis midae.* Investl. Rep. Div. Sea Fish. S. Afr. 64: 1-24.

Wells, FE, Mulvay, P (1992). Reproduction and growth of the greenlip abalone *Haliotis laevigata* on the south coast of Western Australia. A report to the WA Dept. of Fisheries.

Worthington, DG, Chick, RC, Blount, C, Brett, PA, Gibson, PT (1997). An assessment of the NSW abalone fishery in 1997. Fishery Resource Assessment Series No. 3. NSW Fisheries Research Institute. 56pp

10. Appendix 1: Intellectual Property

No saleable items were developed during this study.

11. Appendix 2: Staff

Staff that were employed on the project using FRDC funds were Mr Craig Skepper and Mr Clinton Syers. Staff who assisted on the project using non-FRDC funds were Dr Anthony Hart, Mr Boze Hancock, Ms Sally O'Connor, Mr Rod Pearn, Mr Frank Fabris, Mr James Murray, Mr Jamie Colquhoun, and Mr Michael Mackie. Dr Yuk Wing Cheng assisted with the statistical analysis for growth.

12. Appendix 3: Distribution List

Abalone Management Advisory Committee
C/- Fisheries WA
3rd Floor
SGIO Atrium
168-170 St Georges Tce
Perth WA 6000

Fisheries WA
WA Marine Research laboratories
PO Box 20
North Beach
WA 6020

South Australian Aquatic Sciences Centre
SARDI
PO Box 120
Henley Beach, SA 5022

Marine and Freshwater Resources Institute
PO Box 114
Queenscliffe, Vic, 3225

Department of Primary Industry and Fisheries
GPO Box 192B
Hobart, Tas, 7001

Queensland Dept. of Primary Industries
GPO Box 46
Brisbane, Qld, 4001

Fisheries WA
3rd Floor
SGIO Atrium
168-170 St Georges Tce
Perth WA 6000

Accessions Division
Library Board of Western Australia
102 Beaufort St
Perth WA 6000

NSW Fisheries Research Institute
PO Box 21
Cronulla, NSW 2230

The Librarian
CSIRO Division of Marine Research
GPO Box 1538
Hobart, Tas, 7001

West Australian Fishing Industry Council
PO Box 55
Mt. Hawthorn, WA, 6017

Department of Primary Industry and Fisheries
PO Box 79
Berrimah, NT, 0828

Fisheries Research and Development Corporation
PO Box 222
Deakin West, ACT, 2600

13. Appendix 4: Population Model

Draft Abalone Model for Western Australia

N. G. Hall and A. M. Hart

April 29, 1998

Worthington et al. (1997) have described the length stuctured model used for the blacklip (*Haliotis rubra*) abalone of NSW. A similar model was presented by Jon Schnute and Laura Richards in an abalone workshop in Adelaide in 1995(?). Length structured models of a similar nature are also being used to describe the rock lobster fisheries of Western Australia, Tasmania, South Africa and crab fisheries in Alaska (references to be inserted).

The controls available for management of the abalone fishery are regulation of the TAC and regulation of the legal minimum size. Accordingly, a length structured model appears to be the most useful for evaluating alternative harvest strategies.

The model below is based on the description provided by Worthington et al. (1997), after correcting several typographic errors and converting the model from one conditioned on effort to a model on catch. The description below is very much a draft at this time, but the computer model is well developed, has been tested, and is now being applied to actual data from one of the Western Australian abalone fisheries.

1 Parameters

$\Theta_D = (R^*, z, q, \{R_j\}_{t=1987}^{1997})$

2 Maturity, growth, weight-length and mortality

$$L_\ell = \begin{cases} 20 & : \ \ell = 1 \\ 20 + 10\ell & : \ 2 \le \ell \le L. \end{cases} \tag{1}$$

$$p_\ell^m = \begin{cases} 0 & : \ L_\ell \le (A^m - S^m) \\ \frac{1}{1+\exp\left(\frac{\ln(19)(A^m - L_\ell)}{S^m - A^m}\right)} & : \ (A^m - S^m) < L_\ell < (A^m + S^m) \\ 1 & : \ L_\ell \ge (A^m + S^m) \end{cases} \tag{2}$$

$$\alpha_\ell = \frac{1}{\beta}(L_\infty - L_\ell)(1 - \exp(-K)) \tag{3}$$

$$X = p^g_{\ell_1,\ell_2} = \int_{L_{\ell_2}-\delta L/2-L_{\ell_1}}^{L_{\ell_2}+\delta L/2-L_{\ell_1}} g(\alpha_{\ell_1},\beta)dx \tag{4}$$

$$W_L = aL^b \tag{5}$$

$$S = \{p^m_L \exp(-M_{\text{Mature}}\Delta T) + (1-p^m_L)\exp(-M_{\text{Immature}})\Delta T\}^L_{L=1} \tag{6}$$

3 Initial State and pre-virgin dynamics

$$N_t = 0 \tag{7}$$

$$N_{1,t} = R^* \tag{8}$$

$$N_t = XSN_{t-1} \tag{9}$$

for $-\frac{\ln(100)}{M_{\text{Mature}}} \geq t > 0$.

$$B^m_t = \sum_L p^m_L N_{L,t} W_L \tag{10}$$

$$b = (z-0.2)/(0.8zR^*) \tag{11}$$

$$a = \frac{B^m_0}{R^*}(1 - \frac{z-0.2}{0.8z}) \tag{12}$$

4 State Dynamics

$$N_t = XS(N_{t-1} - C_{t-1}) \tag{13}$$

where the catch is calculated from the proportion within each length class, the meat weight at each length, and the total meat weight landed. From this the average meat weight of the catch is calculated.

$$N_{1,t} = \frac{B^m_t}{a + bB^m_t} \tag{14}$$

5 Controls

$$p^r_{L,t} = \frac{1}{1+\exp\left(\frac{\ln(19)(A^r_t - L)}{S^r_t - A^r_t}\right)} \tag{15}$$

The catch is also used as a control.

6 Objective Function

The maximum likelihood is calculated where the two components of the likelihood function are the observed catch rates (meat weight per diver hour) and average meat weight, where both are assumed to be normally distributed around a mean of zero.

7 Results

The model has been fitted to the Western Australian zone 2 data using an estimate of the average size at first capture. This proved impossible to succesfully fit to the meat weight data as the estimated meat weights were always considerably larger than the observations, due to the distribution of lengths and the growth curve; the latter are reasonable estimates, so it appears that the average length of first capture must be closer to the minimum legal length. Further exploration is continuing to improve parameter estimates and model structure.

References

Worthington, D. G., R. C. Chick, C. Blount, P. A. Brett, and P. T. Gibson (1997). An assessment of the NSW abalone fishery in 1997. *Fisheries Resource Assessment Series 3*, 58 p.

14. Appendix 5: Initial Survey Report - Dr Scoresby Shepherd, SARDI

SUMMARY

A pilot survey of greenlip abalone stocks was undertaken at Augusta, W.A. in Nov. 1996. Abalone were dispersed at a scale of 10s to 100s of metres with mean cluster sizes of about 5 individuals per cluster. Mean survey densities were 18-25 per $100m^2$ with coefficients of variation of 11% for 6 transects with 4 replicates each of $100m^2$ per transect. Length frequency data show clear modes for the 2+ and/or 3+ age classes and can be used to derive recruitment indices. A tentative annual sampling strategy is proposed for Augusta on certain assumptions about precision and cost. Annual surveys can be used to provide the following indices for the fishery: density of recruits, density of total numbers and/or adults, cluster size, and distance between clusters. Preliminary aging studies of the shell at Augusta showed that 3 rings per year are deposited. Aging of commercial shell samples will enable estimation of total mortality.

INTRODUCTION

At the invitation of W.A. Dept of Fisheries I visited Augusta with a team of divers to suggest a monitoring protocol for the Augusta population of greenlip abalone. We visited the area on 6-8 Nov. 1996 and dived for two days, one in the Back area and the other in Flinders Bay (see Fig. 1) This report summarises the results of that study. I describe the pattern of distribution of greenlip abalone at two sites , and propose a protocol for deriving an index of abundance for both areas. Samples of shells were taken for aging, as well as commercial samples of shells and these will be described in a later report.

METHODS

The geographic extension of abalone beds were crudely estimated at Augusta after discussion with divers. Two sites were then selected where abalone were of "average" abundance, one at the "back" of Augusta, called Old Faithful, and the other in Flinders Bay called Dead Finish where previous growth studies by Wells & Mulvay (1995) had been done. A series of transects were done at each of these sites. In addition transects were done at the tagging site at the back of Augusta and near Seal I. in Flinders Bay.

At Old Faithful the habitat is a series of granitic ridges running roughly N-S, and 10-20 m across, and 1-2 m high, separated by sandy gullies 5-10 m across. The transects were transverse to the direction in which the ridges ran. Greenlip abalone were mostly at the base of the ridges where rock meets sand. Algal cover, mostly an upper storey of *Scytothalia*, *Ecklonia* and *Sargassum*, was 100%.

At Dead Finish the habitat is a series of reefs and boulders without obvious pattern interspersed with patches of sand. Algal cover is about 100% and is a diverse assemblage of upper storey species mainly of *Cystophora* and *Sargassum*.

We used a 200m line on a reel, and the diver attached one end to a piece of alga and then swam in the given direction allowing the line to unreel behind him. The line was marked at 50 m intervals and it took about 12 minutes to swim each 100 m, while measuring all abalone encountered *in situ* within a one metre swathe with an abalone measuring gauge (Shepherd 1985). When the diver encountered a large cluster (>5 abalone) he measured those within the 1 m strip and counted the others without measuring them. Data on the size of clusters and the distance between them were recorded in pencil on the plastic strip in the measuring gauge. The protocol for defining a cluster was to include all individuals which were < 1 m from a neighbour. Distance between clusters was estimated in seconds counted on a stop watch and converted to metres using mean swimming speed. Data for each 100 m^2 covered were recorded separately on each side of the plastic strip.

RESULTS

Pattern of dispersal

The distributions of cluster sizes and distances between clusters are given for two sites at Augusta (Fig. 2). At both sites cluster sizes appear to follow a truncated log normal distribution. Distances between clusters seems to be bimodal at Augusta and unimodal at Flinders Bay. These differences in distribution of clusters may be due to the different topographies at the two sites. Both sites show that the scale of the pattern is in the order of tens to hundreds of metres so that transect lines of 200 m are an appropriate length to span the observed pattern of distribution.

Cluster sizes (Fig. 2) are somewhat greater than those recorded by Shepherd & Partington (1995) in Waterloo Bay, even during the closure there and are not consistent with an over-exploited stock.

Mean densities (total numbers 100m^{-2}) at the two sites were:

Old Faithful	Dead Finish
17.9 (CV=35%)	25.2 (CV=36%)

At each site two divers each did two 100 m transects and there were three replicates of these transects about 100 m apart. So for each site the total coverage in area was 1200 m^2 (for N = 12).

To achieve a precision of 0.2 (which is probably an acceptable level) 4 replicates per site would be required using the formula given by Andrew & Mapstone (1987). This would be achieved by 2 divers each doing two 100 m transects which would take 30 minutes diving time per site.

It is possible that mean cluster size and mean distance between clusters could be useful indicators of the "health" of the fishery. This is currently being explored in South Australia. So it is important to collect these data as they potentially have greater use than simply to determine variability and sample size. I note in passing that the total numbers found were comparable with many sites surveyed in South Australia.

Length frequency data

Length frequency distributions for the Back of Augusta, and at Dead Finish (Fig. 3) are typical of sites with good, regular recruitment. Both sites appear to be intensely fished judging from the nearly knife- edge cut off of the distribution at about the legal minimum length (LML). The Back data show a clear mode at about 52 mm which is probably the 2+ age class. The density of this age class in surveys, and also the 3+ age class, once it is clearly identified, would be useful as recruitment indices for the fishery. At Dead Finish there is a mode at about 80 mm which is the 3+ age class. This also would be a useful recruitment index for that population.

SAMPLING STRATEGY

The following survey strategy for Augusta is proposed on the assumption that logistic and cost constraints are likely to require that an annual survey of Augusta for stock assessment purposes be completed within about a week by 4 divers (one of whom is also the boat handler) and that a precision of 0.2 is an acceptable level.
Diving depths are 15-20 m at the Back, and 5-12 m in Flinders Bay. Hence a research diver using DCIEM tables could doubtfully dive more than 3 -4 dives at the Back in a single day, but almost without limit in Flinders Bay. The Back of Augusta is also very exposed to weather and swell and the number of diving days restricted. Hence a realistic estimate is for 8-10 sampling sites at the Back and 6-8 in Flinders Bay. This should be achievable in about 4-5 diving day, especially if the daily plan is to do as many deeper sites as are possible at the Back followed by shallow sites in Flinders Bay. At each site 2 divers would each sample $200m^2$, so that over 18 sites a total of $7200m^2$ would be sampled. The total reef area is about 16 km^2 (of which some unknown proportion is unsuitable habitat), giving a sampling coverage of 0.04%. This is somewhat less than the optimum, but could be increased given more resources.

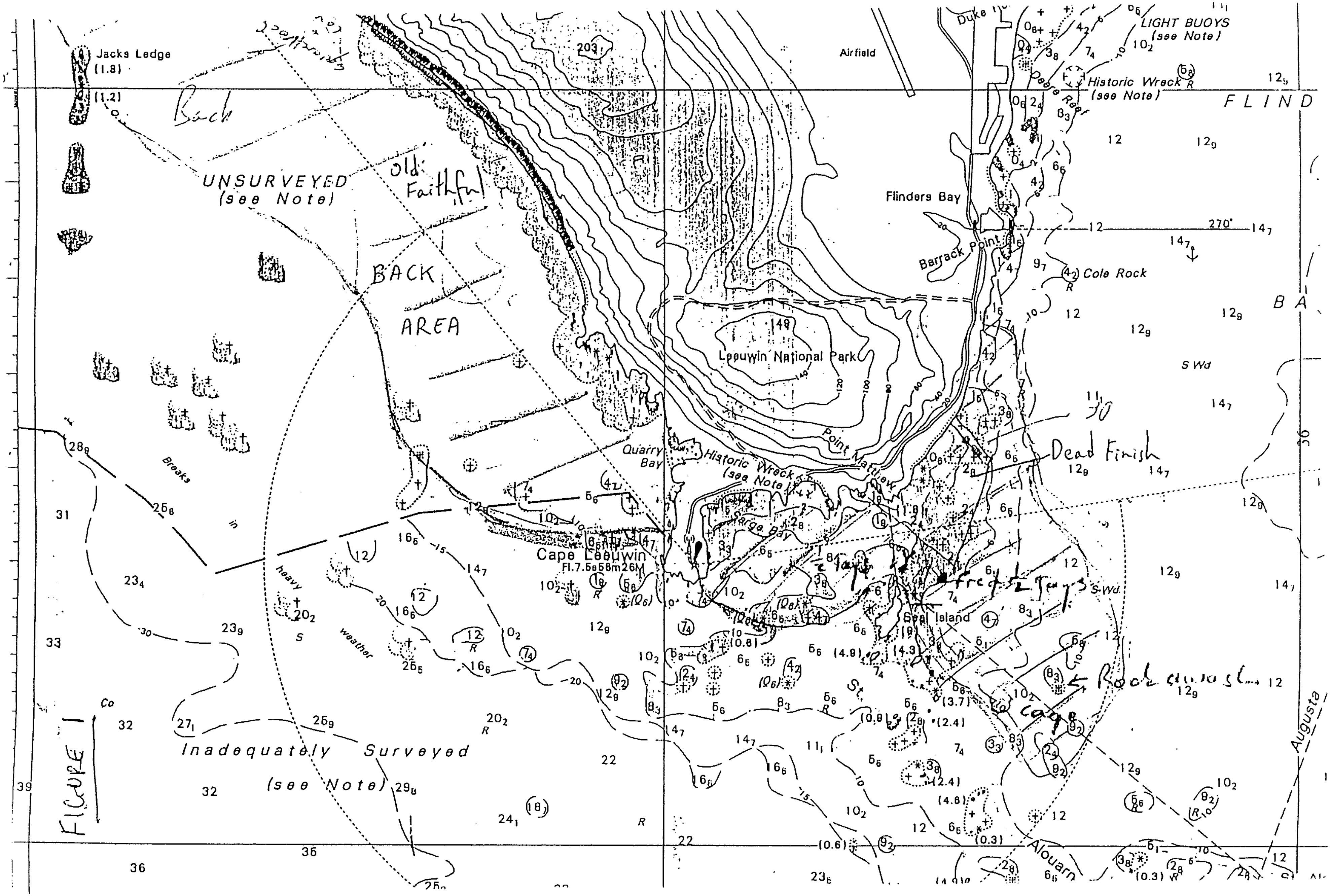
AGING SHELLS

Examination of a shell sample of 41 shells, 20-100 mm in length, taken from the tagging site of Wells & Mulvay (1995) showed by regression analysis that 3 (s.e.0.39) rings a year were laid down in the shell. Over this length range growth of the shell is linear so that length can be used to estimate age from the growth equation given by Wells & Mulvay (1995). Further validation is required for older age classes but from South Australian studies the results augur well for future aging studies of greenlip abalone in Western Australia. The great value of the technique is that estimates of total mortality (Z) can be readily derived from aging samples of commercial shells.

Acknowledgements
I am grateful to Boze Hancock for facilitating the visit to Augusta and to Craig Skepper and Clinton Syers for diving assistance. Brian McDonald prepared the figures. Terry Adams and David Moloney gave me much helpful advice and background information about the Augusta fishery.

References

Andrew NL & BD Mapstone (1987) Sampling and the description of spatial pattern in marine ecology Oceanogr. Mar.Biol.Ann.Rev. 25: 39-90.
Shepherd SA (1985) Power and efficiency of a research diver with a description of a rapid underwater measuring gauge. In *Diving for Science* pp263-272. Amer. Acad. Underwater Science, La Jolla.
Shepherd SA & D Partington (1995) Studies on Australian abalone XVI. Recruitment, habitat and stock relations. Mar. Freshw. Res. 46: 669-680.
Wells FE & P Mulvay (1992) Reproduction and growth of the greenlip abalone on the south coast of WA. A report to the WA Dept of Fisheries.



Jacks Ledge
UNSURVEYED
(see Note)
Back
Old Faithful
BACK AREA
Airfield
LIGHT BUOYS
(see Note)
Historic Wreck
(see Note)
Deere Reef
FLIND
Flinders Bay
Barrack Point
Cole Rock
Leeuwin National Park
Point Matthew
Quarry Bay
Historic Wreck
(see Note)
Cape Leeuwin
Fl.7.5s56m26M
Seal Island
Dead Finish
Breaks in heavy S weather
Inadequately Surveyed
(see Note)
Alouarn
Augusta

FIGURE 1

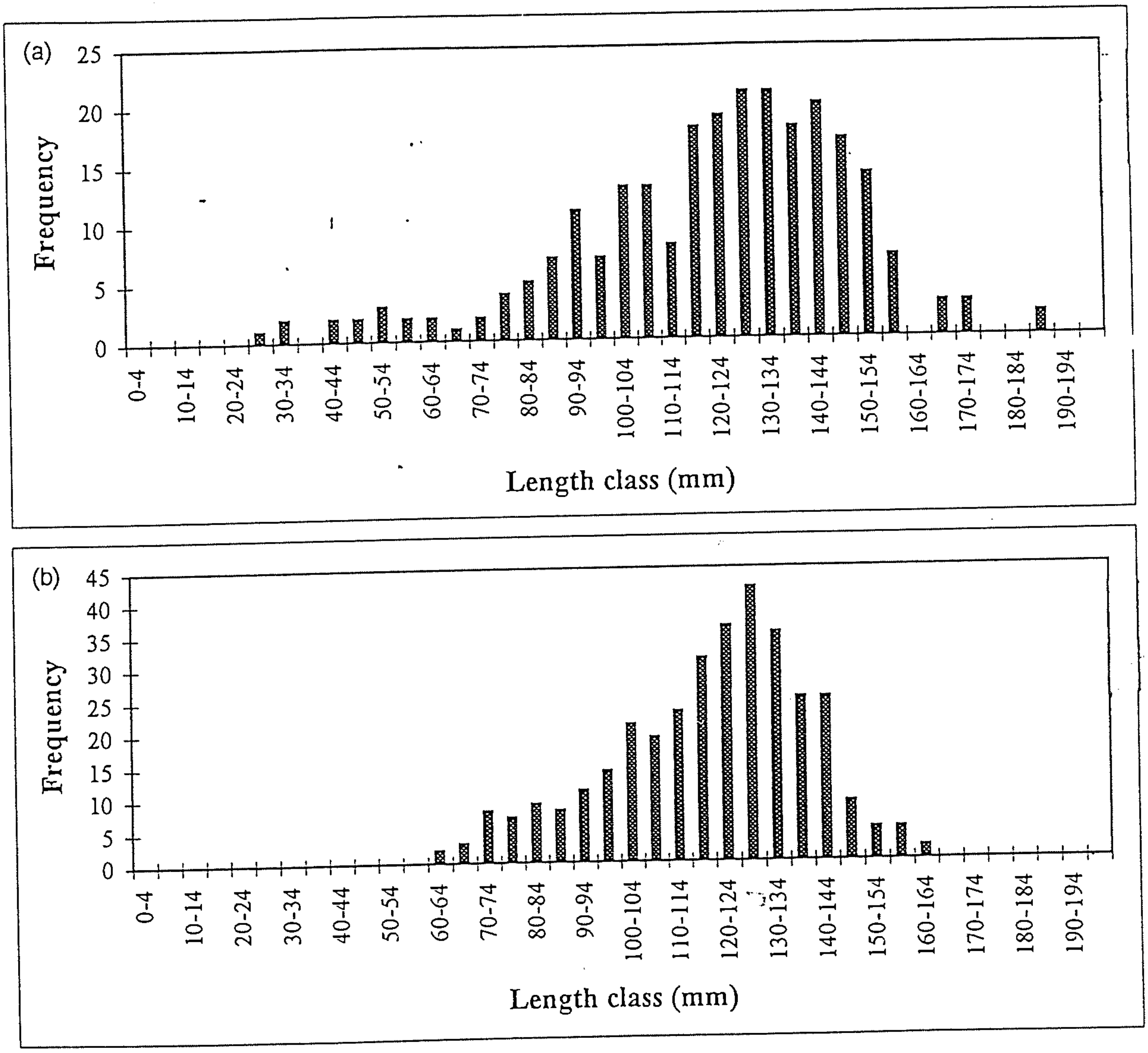


Figure 3 . Length frequency analyses for data recorded by reseqarch divers at Augusta (a) and Dead Finish (b), November 1996.

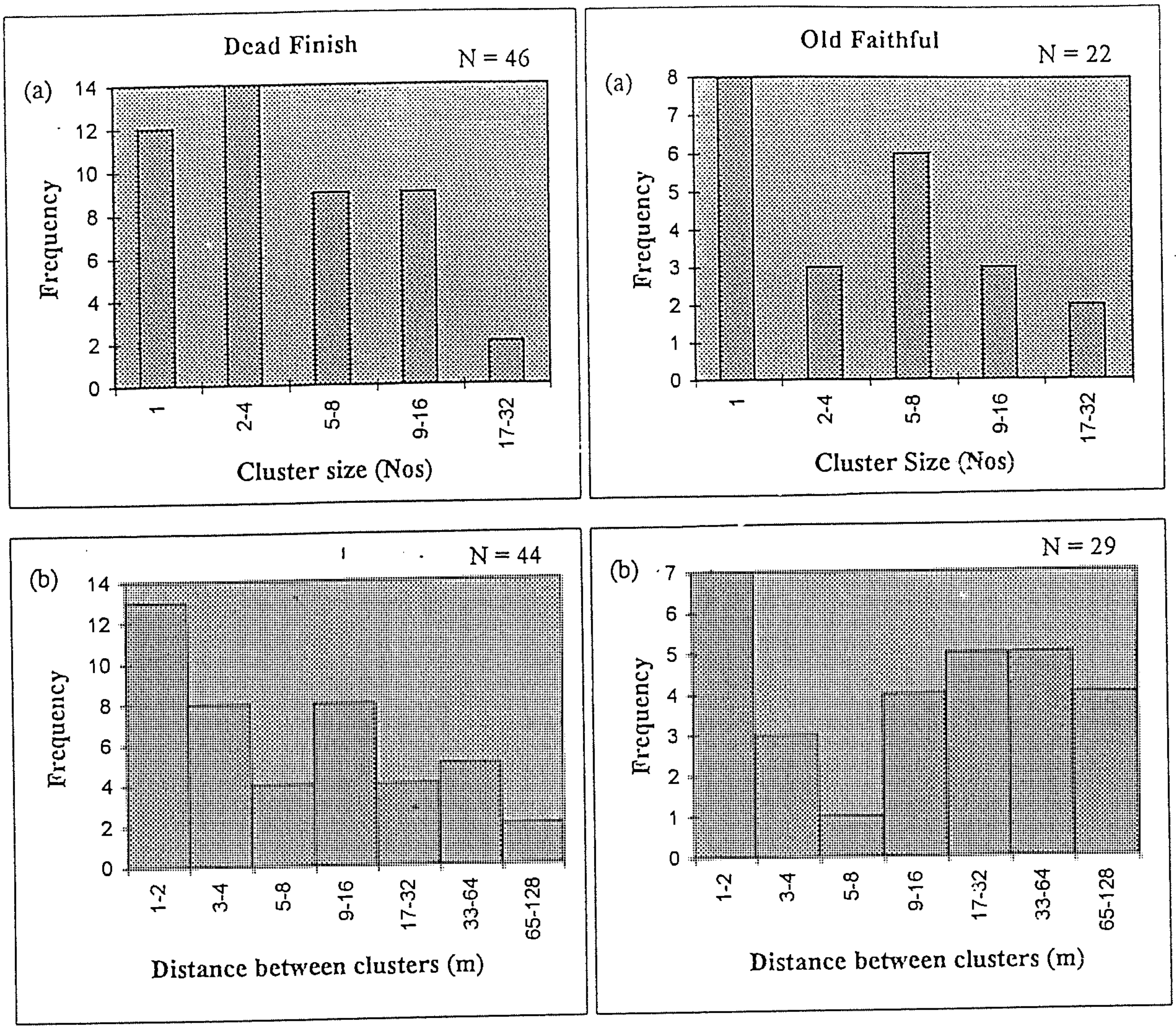
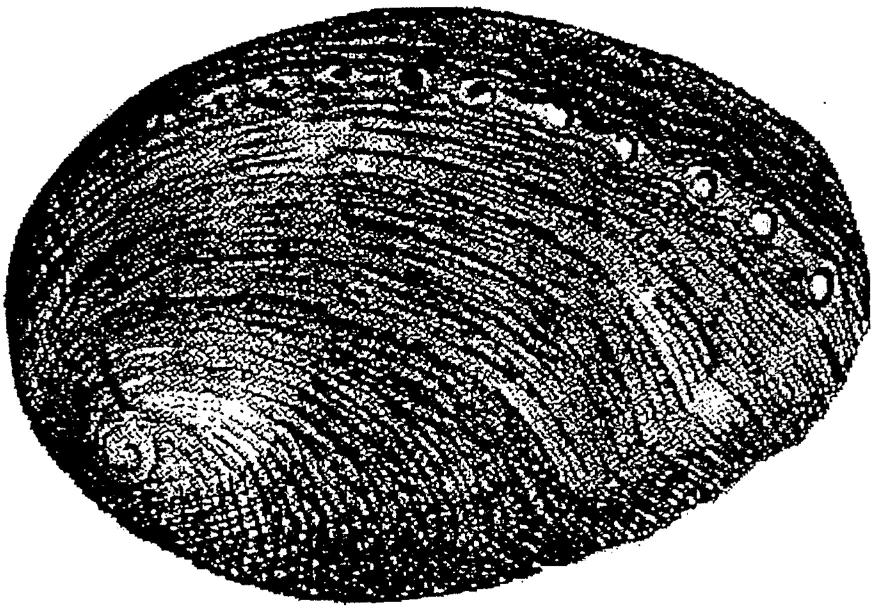


Figure 2: Distribution of cluster sizes (a) and distance between clusters (b) for Dead Finish and Old Faithful at Augusta.

15. Appendix 5: Analysis of Morphometry - Aaron Lee, Maritime Collage

Morphometrics of the Abalone *Haliotis laevigata* (Mollusca: Gastropoda) between the three major producing areas in south Western Australia



Submitted by Aaron Lee
In partial fulfilment of the degree: Bachelor of Applied Science-Fisheries
Australian Maritime College
1998

TABLE OF CONTENTS

		Page
TITLE PAGE		
TABLE OF CONTENTS		*ii*
ABSTRACT		*iii*
1	INTRODUCTION	1
	1.1 General introduction	1
	1.2 Management overview	1
	1.3 Minimum size limits	2
	1.4 Alternative size limits	2
	1.5 Morphometry	3
2	MATERIALS and METHODS	4
	2.1 Field Procedures	4
	2.1.1 Sites	4
	2.1.2 Sample Collection	5
	2.2 Laboratory & Analytical Procedures	6
	2.2.1 Morphometrics	6
	2.2.2 Statistical analysis	7
3	RESULTS	8
	3.1 Length frequency distribution	8
	3.2 Morphometrics	12
	3.3 Statistical analysis	
	14	
4	DISCUSSION	17
	4.1 Length frequency	17
	4.2 Morphometrics	18
	4.2.1 ANCOVA	18
	4.3 Alternative size limits	19
5	ACKNOWLEDGEMENTS	21
6	REFERENCES	22

40

ABSTRACT

Length-width, length-height and width-height relationships of greenlip abalone (*Haliotis laevigata*) were sampled from three sites in south Western Australia. All three morphological tests between sites showed that significant differences existed. *Haliotis laevigata* displays allometric growth, as measured by the parameters shell length, shell width and shell height. The implication of differences in shell morphometry between sites are discussed in relation to alternative size limits.

1 INTRODUCTION

1.1 General introduction

Abalone are sedentary marine gastropods they are long-lived, highly fecund animals which feed exclusively on algae and seagrass (Ward 1985).

There are about 15 species of abalone in Australian waters, of which three are harvested commercially: greenlip abalone (*Haliotis laevigata*), blacklip abalone (*Haliotis rubra*) and Roe's abalone (*Haliotis roei*) (Ward 1985). In 1992 abalone fisheries in Australia were valued at $100 million dollars annually (Prince and Shepherd 1992). The ever increasing pressure on the fisheries brings the need for a better understanding of abalone population dynamics to ensure sustainable management strategies.

1.2 Management overview

The West Australian abalone fishery has been divided into three zones, with *Haliotis laevigata* occurring in the lower south-west and south coast zones (Zones 1 and 2) of Western Australia. The value of this fishery, based on average prices in 1996, was estimated at $3.85 million from a production of 117 tonnes (Fisheries Report 1996-1997). Current management controls are limited entry, minimum legal shell sizes, area closures, individual quotas for each licensed diver and total allowable catches (TACs) for each zone (Fisheries Report 1996-1997).

The minimum legal size limit within Zone 2 is 140 mm, but fishers have agreed to a higher 'voluntary' size limit. The voluntary size limit, is 153 mm west of Black Point and 147 mm east of Black Point (Fisheries Report 1996-1997).

1.3 Minimum size limits

The reason for a minimum size limit is to conserve adequate levels of population egg production and optimise yield (Beverton and Holt, 1957). Size limits are determined by rates of growth, mortality and reproduction of the target species (King, 1995). Spatial variation within and among populations can complicate the purpose of size limits, as differences in growth, recruitment and survival often occur over smaller areas than those used to manage a fishery (McShane & Smith 1991; Day & Fleming 1992).

1.4 Alternative size limits

Variable growth rates are a common finding in abalone fisheries (Tegner *et al.*, 1989; Nash 1992) Shepherd (1988) used the term 'Stunted' which he describes as "populations in which individuals have both a slower growth rate and a smaller maximum size", (Fig. 1). Worthington *et al.* (1995) also point out the relationship between growth rate and maximum size: faster growing abalone will attain a larger maximum size than slower growing abalone (Fig. 1).

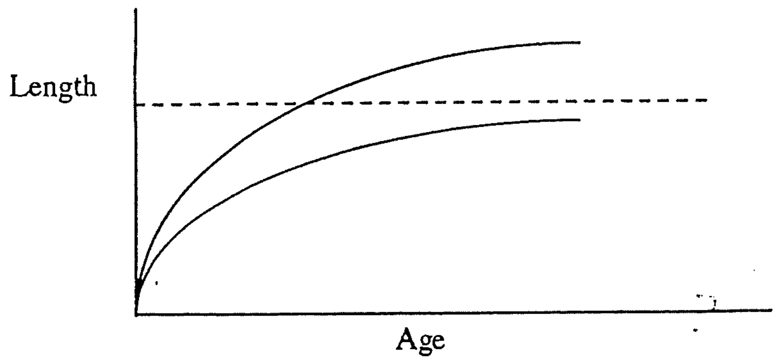


Figure 1. Growth plot for a fast growing abalone population (blue line) and a slow growing abalone population (red line), the dashed line represents the legal length limit.

The fact that onset of sexual maturity appears to be primarily age-based rather than length-based means that at a given minimum legal size limit, slower growing populations are afforded better protection of egg reproduction than faster growing ones (Nash 1992).

Faster growing populations may then be subjected to overexploitation and slower growing populations to underexploitation as the abalone would never (or barely) reach the minimum legal size (Fig. 1).

Size limits based on shell length alone seem to be inefficient, because of this variation in growth rates between and within abalone populations and the existence of 'stunted stocks' (Shepherd 1988). Variation in growth between regions can be dealt with by having a different size limit in different regions. However, fine-scale within-population variation precludes blanket protection for all individuals, yet multiple-length limit management is impossible. Numerous authors (Nash 1992; McShane *et al.*, 1994; Worthington *et al.*, 1995) have suggested alternative size limits and parameters for individual populations, in order to provide protection for slower growing abalone populations.

1.5 Morphometry

In molluscs, morphometrics (the study of form) has often centred around the structure of the shell. The subtidal and intertidal habitat of abalone generates a range of physical and biological factors which influence the morphological patterns in abalone (Tissot 1988). Wave shock, drag and accelerations generated by currents, rolling boulders, scouring effects of sand movement, water temperature, food availability, competition and predation were used by Tissot (1988) to describe morphological variation in a population of Californian black abalone *H. cracherodii*.

It is the aim of this study to examine the morphological parameters of length, width and height of *H. laevigata* between three Western Australian sites, Augusta, Hopetoun and Windy Harbour, to describe the general shell shape for each population and determine whether spatial variation exists in shell morphology, then to examine the feasibility of an alternative size limit.

2 MATERIALS and METHODS

2.1 Field Procedures

2.1.1 Sites

Samples of *Haliotis laevigata* $\geq$ 60 mm shell length (SL) were collected from three sites during the period May 1996 to May 1998. The three sites (Augusta, Hopetoun and Windy Harbour) represent the major greenlip abalone fishing areas in Zone 2 of the Western Australian abalone fishery (Fig. 2).

Individual reefs within the sites, were recognised as areas representative of good abalone habitat. The reefs were chosen for study after consultation with commercial abalone divers in the area.

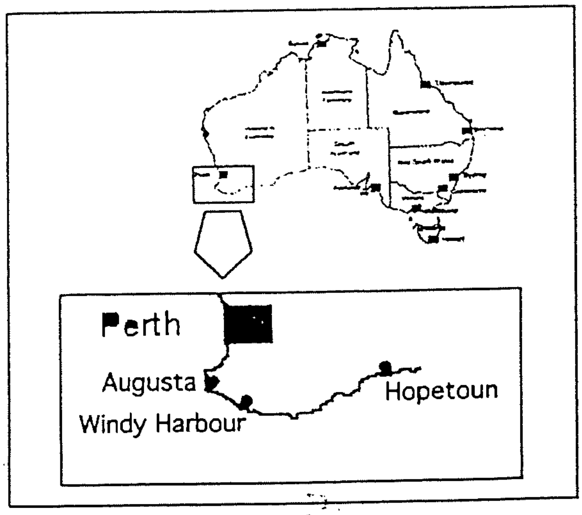


Figure 2. Map of Australia and south Western Australia, showing the position of the three major producing greenlip abalone areas.

2.1.2 Sample Collection

Samples were collected seasonally at each site: in Summer (February), Autumn (May), Winter (August) and Spring (November). The data were not collected in the four seasons within a single year, instead the data were collected over two or three years.

Collection of data was through a combined effort of research and commercial diving. Research staff measured and sorted all the abalone until the required size structure of the sample was obtained. A maximum of 10 abalone in each 10 mm size class was taken from each site, from 60 mm shell length upwards. These abalone were stored onboard in plastic tubs and kept alive until processing back in the laboratory.

2.2 Laboratory & Analytical Procedures

2.2.1 Morphometrics

Three morphological measurements were recorded ashore at an appropriate processing facility. Shell length, shell width and shell height for each abalone were accurately measured to the nearest millimeter (Fig. 3).

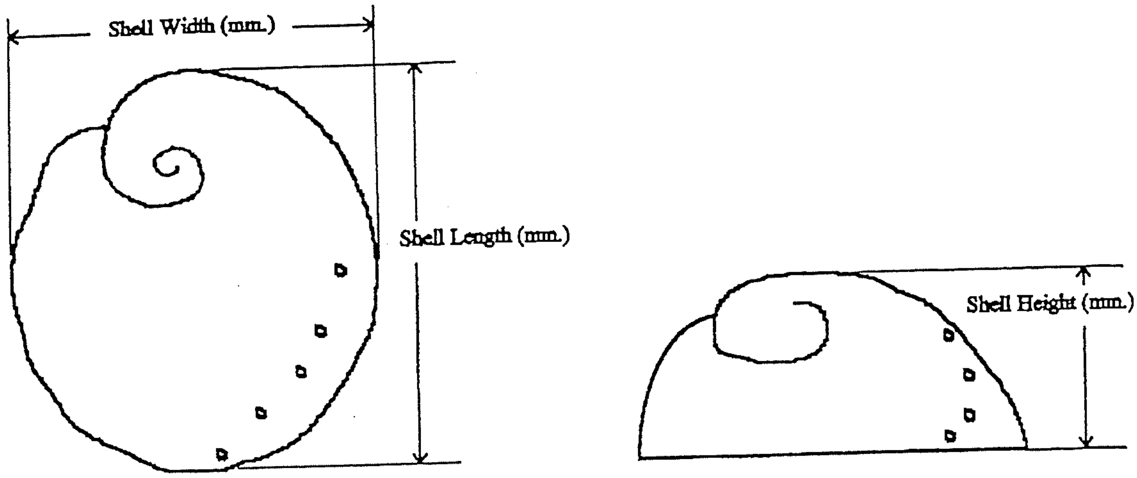


Figure 3. The morphological measurements taken to describe the shape of *H. laevigata*.

The relationship between shell length (L), shell width (W) and shell height (H) can be expressed as a power relationship:

$$\mathbf{W = a.L^b} \qquad \mathbf{H = a.L^b} \qquad \mathbf{H = a.W^b}$$

Where W = the shell width, H = shell height, L = shell length and a and b are constants. After logarithmic transformation, the power equation $y = a.x^b$ becomes $\ln(y) = \ln(a) + b.\log(x)$. The constants a and b were then estimated by least squares linear regression. For length-width, length-height or width-height relationships, growth is allometric (ie, the abalone change shape as they grow) if the exponent b is significantly different from 1.

Testing for differences in shell shape between sites, were made using fixed one-factor analysis of covariance.

2.2.2 Statistical analysis

Testing for morphological differences in length-width, length-height and width-height relationships between sites, was carried out using analysis of covariance (ANCOVA) following the procedure in Wilkinson *etal.*, (1992). Statistical tests were carried out on ln (shell length) with ln (shell width) (Table 2), ln (shell length) with ln (shell height) (Table 3) and ln (shell width) with ln (shell height) (Table 4). ln (length) was used as the covariate in Table 2 and 3, ln (width) was the covariate in Table 4. ANCOVA was used to adjust for differences in the independent variable between sites.

The first analysis tests that there is no interaction between the covariate and the dependent variable (ie tests for equality of slope of the regression lines). If the slopes differ significantly, then there is no valid basis to proceed with the comparison of intercepts (Underwood, 1981). Where this interaction term was nonsignificant $P > 0.05$ indicating similar slopes, the model was rerun. This second analysis provides a test for differences in elevation (y-intercept) of regressions among sites using a common regression slope.

The assumptions associated with the analysis of covariance are normality and homogenous variances.

3 RESULTS

A total of 1,304 abalone were caught from all three sites. Standard deviations of the raw data were plotted and data points that deviated more than three standard deviations from the mean were deleted from the data set. There were 23 such outliers.

3.1 Length frequency distribution

Individuals ranged from 42-215 mm shell length in Augusta, 41-183 mm in Hopetoun and 44-174 mm in Windy Harbour. In all three sites, length frequency for each separate month and all months combined are shown in Fig. 4.

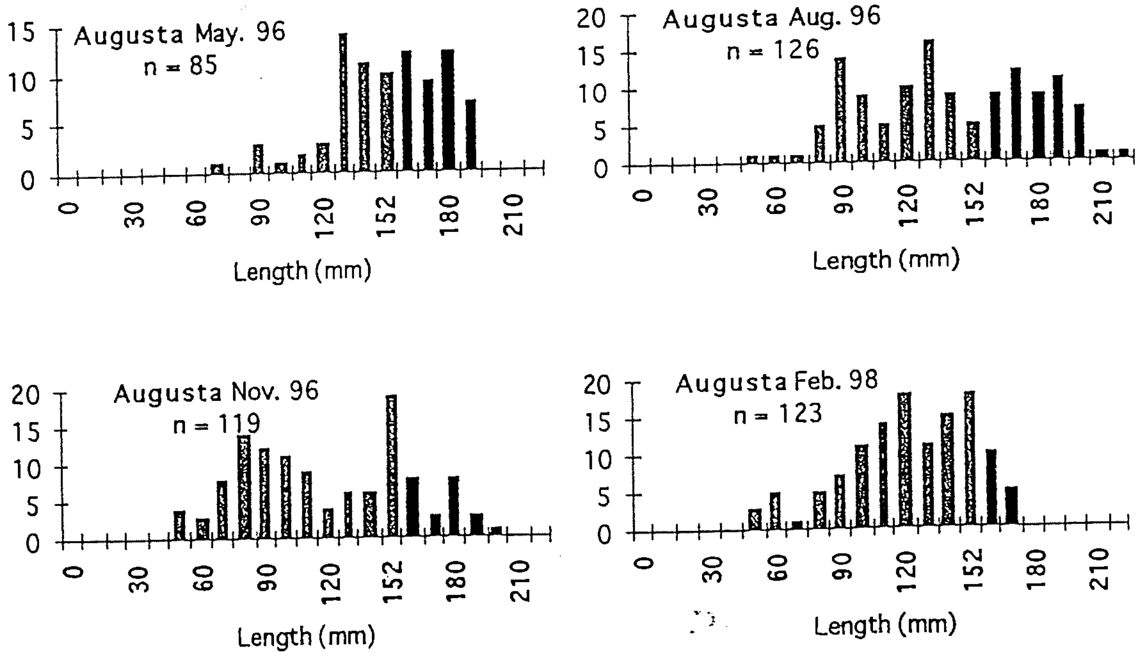


Figure 4a. Length frequency composition of *H. laevigata* from Augusta, expressed as a percentage. Collection dates and sample sizes are shown in the top left hand corner. The darker bars represent the number of abalone larger than the voluntary minimum size limit.

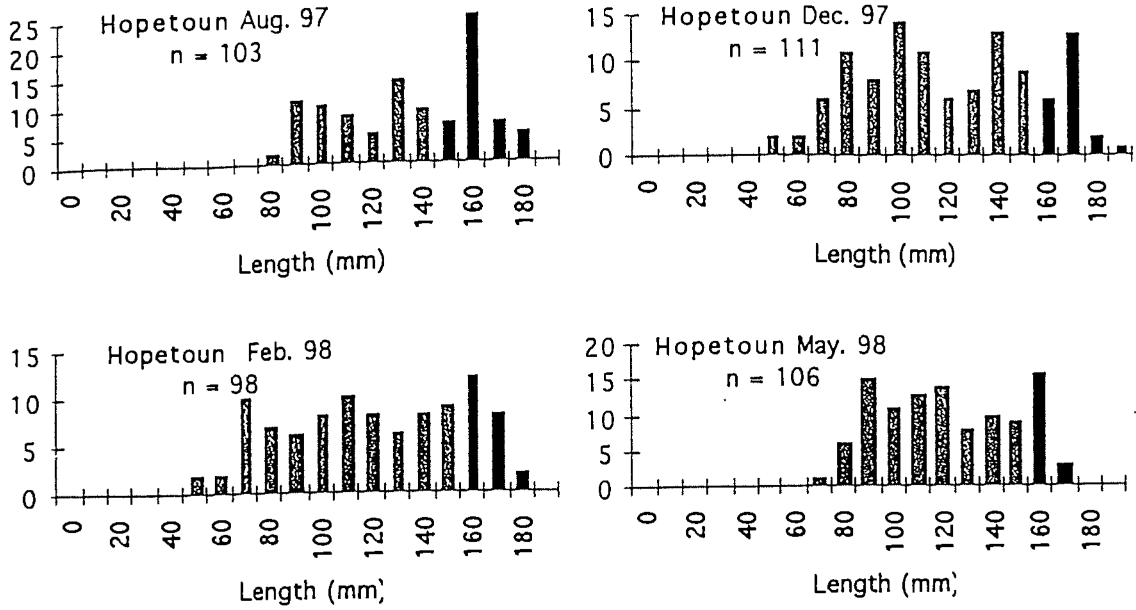


Figure 4b. Length frequency composition of *H. laevigata* from Hopetoun, expressed as a percentage. Collection dates and sample sizes are shown in the top left hand corner. The darker bars represent the number of abalone larger than the voluntary minimum size limit.

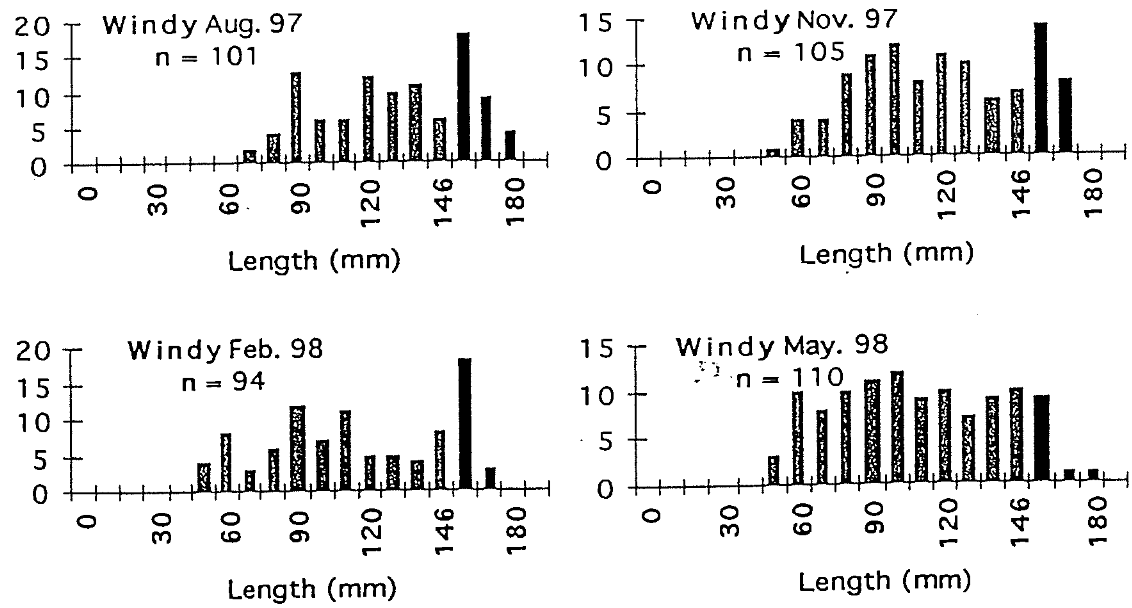


Figure 4c. Length frequency composition of *H. laevigata* from Windy Harbour, expressed as a percentage. Collection dates and sample sizes are shown in the top left hand corner. The darker bars represent the number of abalone larger than the voluntary minimum size limit.

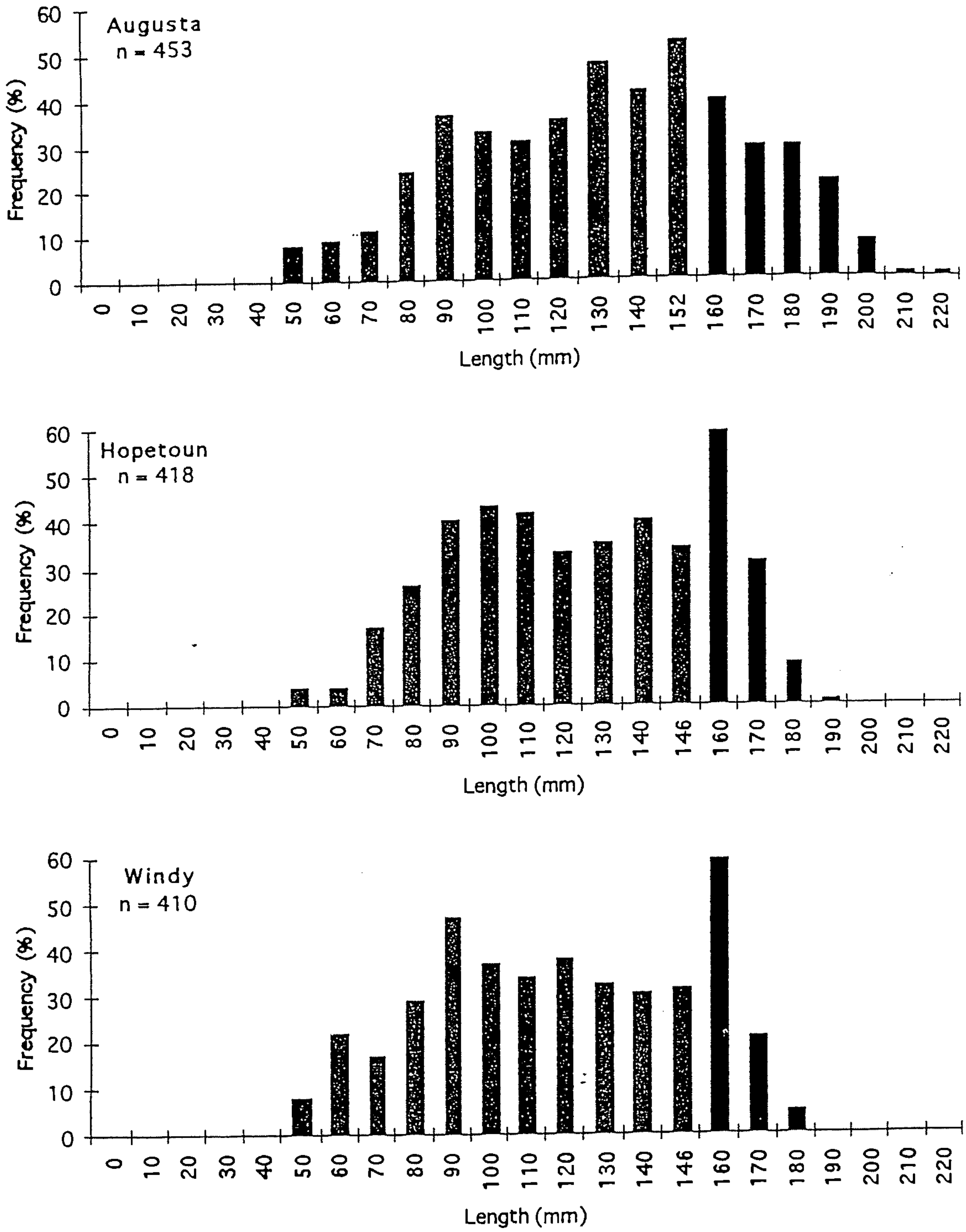


Figure 4d. Total length frequency composition of *H. laevigata* , expressed as a percentage, for all three sites (all samples combined). Sample sizes are shown in the top left hand corner. The darker bars represent the number of abalone larger than the voluntary minimum size limits.

Substantial differences in size composition existed between the three fishing sites. Augusta consisted of 26% legal sized abalone, Hopetoun with 23% and Windy Harbour 20%, (Fig.4a-c). Augusta also contained larger individuals (mean=128 mm, std=37), compared to Hopetoun (mean=119 mm, std=32) and Windy Harbour (mean=113 mm, std=33). A similar phenomenon observed at all three sites was the decline in mean size of abalone, throughout the sampling period. Augusta saw a decline in mean size of 29 mm, Hopetoun 12 mm and Windy Harbour by 21 mm, from the start to the end of their respective sampling periods (Figs. 4a-c).

3.2 Morphometrics

The relationship between shell length, shell width and shell height are graphed to show the distribution of morphological parameters between sites (Fig. 5).

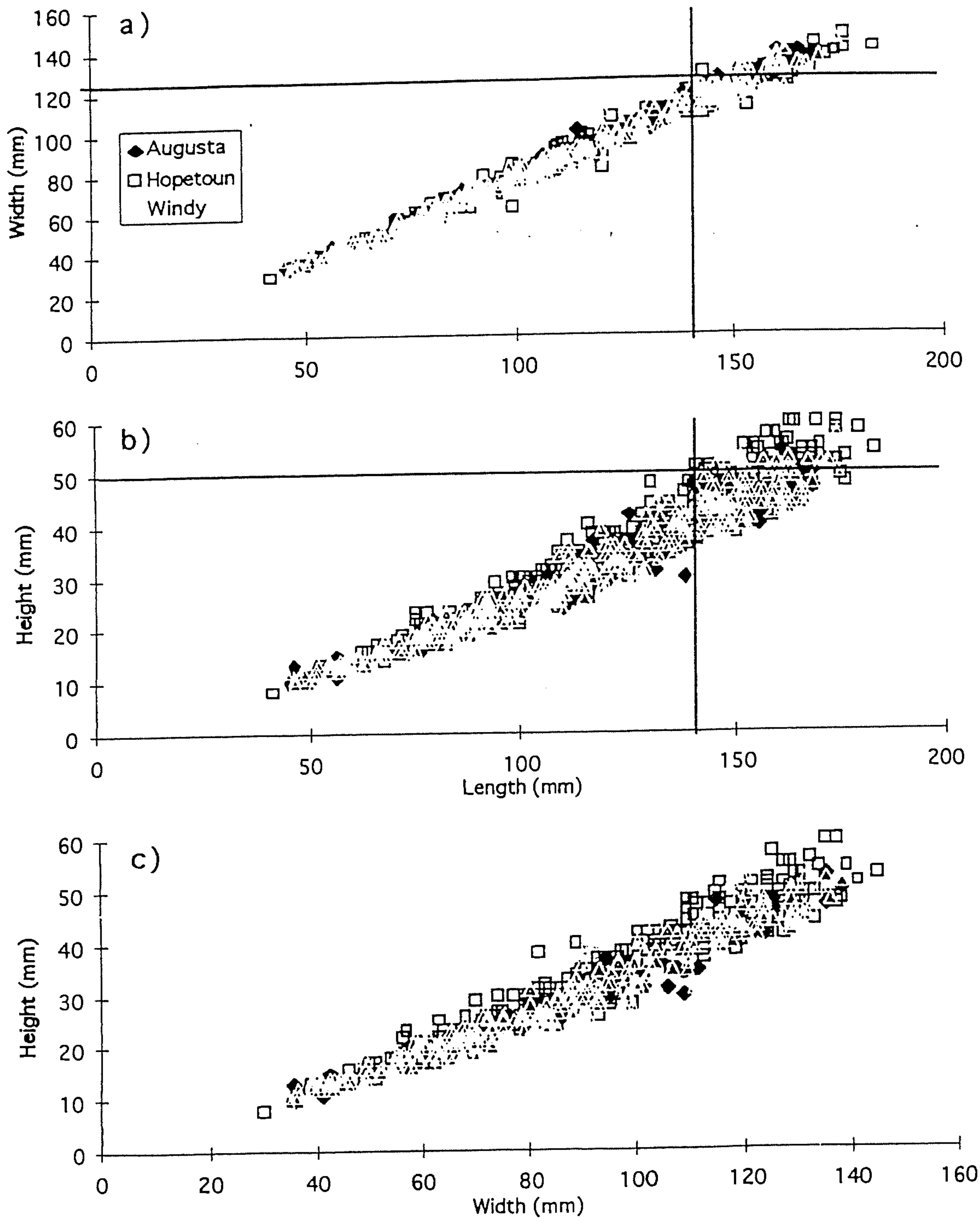


Figure 5. Relationship between a) shell length and shell width, b) shell length and shell height, c) shell width and shell height for *H. laevigata* from the three sites. The vertical line represents the legal minimum size limit and the horizontal line a width or height size limit.

The morphological parameters were estimated, on the log-transformed data (Table 1).

Table 1. Relationship between shell length and shell width, shell length and shell height of *H. laevigata* in south Western Australia. *a* and *b* are constants in the power equation $Y = a.(X)^b$. Other information ⇒ 95% confidence limits for b, r^2 = coefficient of determination n = the sample size, SL = shell length, SW = shell width and SH = shell height.

				95% Confidence Limits (b)			
Site	Parameter	ln (a)	b	lower	upper	r^2	n
Augusta	SL vs SW	-0.599	1.079	1.058	1.098	0.992	94
	SL vs SH	-2.410	1.231	1.178	1.285	0.945	123
	SW vs SH	-1.685	1.132	1.084	1.179	0.961	94
Hopetoun	SL vs SW	-0.555	1.066	1.053	1.078	0.989	315
	SL vs SH	-2.816	1.323	1.293	1.353	0.947	418
	SW vs SH	-2.014	1.216	1.184	1.247	0.949	315
Windy	SL vs SW	-0.594	1.075	1.061	1.089	0.987	309
	SL vs SH	-2.509	1.252	1.223	1.281	0.946	409
	SW vs SH	-1.767	1.151	1.124	1.179	0.956	309

Allometry exists between shell length and width, shell length and height and shell width and height, since at all sites b is significantly greater than 1 (Table 1).

Various shell measurement ratios are shown in Fig. 6. These were not used to test for differences between sites, because there were differences in length between the sites, and if a ratio changes with length then differences in the ratio between sites could be due to differences in length.

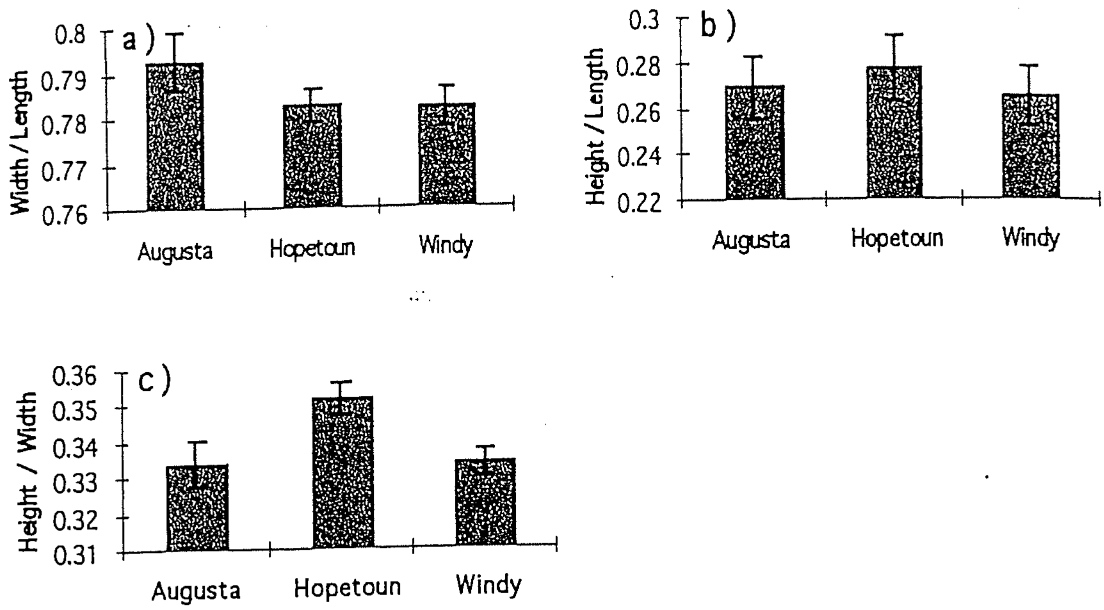


Figure 6. Average ratio with confidence limits for, a) SL vs SW, b) SL vs SH, c) SW vs SH for *Haliotis laevigata*, in south Western Australia.

3.3 Statistical analysis

The assumption of normality and homogeneous variances associated with the analysis of covariance were violated. However, Underwood (1981) suggests that the assumptions of ANCOVA are fairly robust, and that assumptions can be violated in many ways and combinations. Non-noramality encountered in the data, is not likely to seriously disrupt the outcome of the analysis (Underwood 1981). There is a possibility that the heterogeneity of variance within the data may lead to an increase of Type-I errors. Above a certain degree of heterogeneity, the probability of Type-I error is increased.

Table 2A shows that the interaction between ln (length) and ln (width) was not significant (p=0.534). However Table 2B shows that there is significant difference in length-width relationships between sites (p=0.000). Despite the substantial overlap of the length-width plot between sites (Fig. 5a), there is a significant difference between the three sites.

Table 2. Analysis of covariance to examine the morphological parameter width between sites. ln (length) was the covariate. The first analysis (A) tests for the significance of the interaction between ln (width) and ln (length), (i.e, it tests for the equality of slope of the regression lines). The second analysis (B) then tests for equality of the y-intercept between sites.

(A)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SITECODE	0.001	2	0.001	0.450	0.638
LNLEN	60.336	1	60.336	42233.422	0.000
SITECODE*LNLEN	0.002	2	0.001	0.628	0.534
ERROR	1.018	712	0.001		

(B)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SITECODE	0.016	2	0.008	5.487	0.004
LNLEN	83.838	1	83.838	58716.594	0.000
ERROR	1.019	714	0.001		

In the relationship between ln (length) and ln (height) Table 3A shows that there is a significant difference of the slopes between the three sites ($p=0.001$), further statistical analysis is not required. Figure 5b shows that Hopetoun has a slightly higher progression of data points than the other two sites. Table 1 SH vs SL shows that Hopetoun has a higher b constant ($b=1.32$) than Augusta ($b=1.23$) or Windy ($b=1.25$), supporting that there is a difference in height between the three sites.

Table 3. Analysis of covariance to examine the morphological parameter height between sites. ln (length) was the covariate. Analysis (A) examines the significance of the interaction between ln (length) and ln (height) (i.e, tests for the equality of slope of the regression lines).

(A)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SITECODE	0.106	2	0.053	6.047	0.002
LNLEN	101.809	1	101.809	11619.885	0.000
SITECODE*LNLEN	0.123	2	0.061	7.018	0.001
ERROR	8.271	944	0.009		

Table 4 shows that there is a difference in the gradients of height versus width between sites (p=0.002). Figure 5c indicates that Hopetoun has more individuals with larger heights for a given width. Table 1, SH vs SW describes Hopetoun with the largest b constant (b=1.21), implying that at Hopetoun the shells are more domed in shape than at either Augusta or Windy Harbour.

Table 4. Analysis of covariance to examine the morphological parameter height between sites. ln (width) was the covariate. Analysis (A) examines the significance of the interaction between ln (width) and ln (height) (i.e, tests for the equality of slope of the regression lines).

(A)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
SITECODE	0.073	2	0.037	4.576	0.011
LNLEN	83.227	1	83.227	10427.624	0.000
SITECODE*LNLEN	0.097	2	0.049	6.093	0.002
ERROR	5.675	711	0.008		

4 DISCUSSION

The morphometric analysis of length, width and height done here show that these populations exhibit allometric growth; they become more rounded and domed as they grow. The ANCOVA results state that there is a significant difference between all three sites in all three morphometric comparisons, despite the substantial overlap shown in Fig. 5.

Evidence given from the analysis of covariance needs to be interpreted with caution due to the violations of the assumptions. However Table 1 support the results obtained from the analysis of covariance. This suggests that the assumptions are not grossly violated, which would have resulted in higher F values, leading to the possibility of Type I errors (Underwood, 1981).

4.1 Length frequency

Length frequency data indicate that Augusta contains the largest size classes of abalone and Windy Harbour the smallest size classes (Fig. 4d). Information is insufficient to determine whether these larger size classes at Augusta are a reflection of faster growth rates or less fishing pressure, than at the other two sites.

Ekaratne and Crisp (1984) argue that size frequency analysis for marine molluscs is inadequate in determining age because

- the identification of individual age classes for larger abalone is very difficult;
- recruitment rates are variable (Sainsbury, 1982; Shepherd *et al.*, 1987; Tegner *et al.*, 1989); and
- size-dependent predation makes modal progression difficult.

Size frequency analysis has been used successfully to identify age classes (Säinsbury 1982; Fournier & Breen 1983; Clavier & Richard 1986) primarily on younger age classes of gastropods. The authors agreed that with the larger (older) gastropods, the technique of size frequency analysis becomes impractical. As management of abalone is based on the larger size classes, age determination by size frequency was not considered.

4.2 Morphometrics

The results confirmed that allometry exists between morphological parameters (between SL & SW, SL & SH, SW & SH). Figure 5b height versus length and Figure 5c height versus width, both indicate this type of growth, by the exponential shaped curves. These results are consistent with the findings of Poore (1972) and Sloan (1997), suggesting that as the shells grow older, growth in height and width is greater than in length and consequently the shells become more domed.

4.2.1 ANCOVA

Differences in y-intercepts for the length vs width regression (Table 2) suggest that at some earlier age of the abalone, one of the sites grew quicker in width in respect to length.
The y-intercept (parameter a) for Hopetoun is larger than for sites Augusta and Windy Harbour (Table 1), so at a given shell length, Hopetoun abalone will generally be larger in shell width than abalone from either Augusta or Windy Harbour sites.
ANCOVA tests for length vs height and width vs height showed that the regressions had different slopes (Tables 3, 4), which would imply that the growth pattern, or degree of change in shell height, differed between the sites at all sizes of the abalone (Haddon and Willis 1995). This difference in height was between the Hopetoun site and the other two sites (Table 1, Figs. 5b, 5c).

4.3 Alternative size limits

Numerous authors have compared the morphometrics (SL vs SW, SL vs SH), of abalone and shown that they were significantly different between sites (McShane *et al.*, 1988: Worthington *et al.*, 1995). This morphometric heterogeneity is attributed to differences in growth rates between sites (McShane *et al.*, 1988: Worthington *et al.*, 1995).
Commercial divers will tend to avoid fishing areas where there are low number of legal sized abalone, increasing fishing pressure on the populations of faster growing abalone. This may cause serious depletion of the faster growing populations and introduce conflict within the area. Alternative size limits were suggested by Worthington *et al.*, (1995), because slower growing populations reach a smaller maximum size, which leads to the increased fishing pressure towards other faster growing populations. An alternative size limit such as width, would allow the slower growing populations to be fished as well, releasing the pressure on the faster growing populations (Fig. 7).

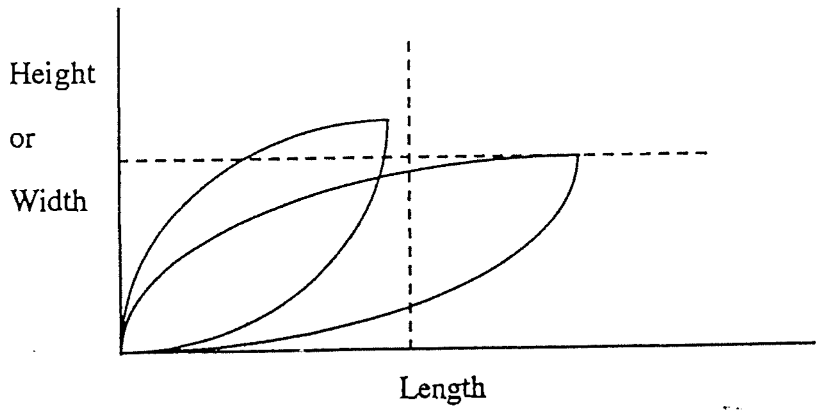


Figure 7. Scatterplot of a fast growing abalone population (blue line) and a slow growing abalone population (red line). The dashed line represents the length limit and the corresponding height or width limit.

The potential benefits of such an alternative size limit are described by Worthington *et al.*, (1995).

For alternative size limits to be effective there need to be distinctive differences in morphology between sites, which implies gross differences in growth rates between sites, such as the situation in Figure 7. The study done here has found the morphological parameters to be statistically different (Tables 2, 3, 4), but they are not large enough to warrant an alternative size limit. The minimum legal length limit of 140 mm when drawn onto Figure 5a & 5b, shows that any individuals above the minimum legal length line can be harvested. If we were to draw a corresponding minimum width or height limit which does not impede onto the legal length limit, we can see that there are no individuals that could be harvested above these lines (Figs. 5a, b).

Since these are the known major producing areas of greenlip abalone in south-west W.A, it is not surprising that there are no significantly 'stunted' populations within the sample. If the study included samples which do not or barely reach the legal size, the above analysis may have yielded different results. If such populations of greenlip abalone exist in Zone 2, then a comparative analysis with these populations used in this study may yield useful information on a minimum width limit that would allow these relatively stunted stocks to be exploited.

ACKNOWLEDGEMENTS

This work was undertaken as part of a requirement in the degree of applied science (Fisheries) at the Australian Maritime College. I would like to thank my supervisor W. J. Nash for his interest, support and help on initial drafts. Dr M. Haddon and T. Braund for their helpful discussion and A. M. Hart at the Western Australian Fisheries Department for providing me with the data base to work with and for his comments along the way.

REFERENCES

Beverton, R.J.H. & S.H. Holt. (1957). On the Dynamics of Exploited Fish Populations. U.K Minist. Agric. Fish. Fish. Invest. (ser. 2) **19**, 533p.

Clavier, J. & Richard, O. (1986). Growth of juvenile *Haliotis tuberculata* (Mollusca, Gastropoda) in their natural environment. Journal of Marine Biological Association of the U.K. **66**, 497-503.

Day, R.W. & Fleming, A.E. (1992). The determinants and measurement of abalone growth. In S.A. Shepherd, M.J. Tegner and S.A. Guzmán del Próo (eds.), Abalone of the world: biology, fisheries and culture. Fishing New Books, Oxford, **12**, 141-168.

Ekaratne, S.U.K. & Crisp, D.J. (1984). Seasonal growth studies of intertidal gastropods from shell micro-growth band measurements, including a comparison with alternative methods. Journal of Marine Biological Association of the UK, **64**, 183-210.

Fisheries Report, 1996-1997. State of the Fisheries Report, Abalone managed fishery. Fisheries Department of Western Australia, 30-33.

Fournier, D.A. & Breen, P.A. (1983). Estimation of abalone mortality rates with growth analysis. Transaction of the American Fisheries Society, **112**, 403-411.

Haddon, M. & Willis, T.J. (1995). Morphometric and meristic comparison of Orange roughy (*Hoplostethus atlanticus* : Trachichthyidae) from the Puysegur Bank and Lord Howe Rise, New Zealand and its implications for stock structure. Marine Biology, **123**, 19-27.

King, M. (1995). Fisheries Biology, Assessment and Management. Fishing News Books, Australia.

McShane, P.E., Smith, M.G. & Beinssen, K.H.H. (1988). Growth and morphometry in abalone *Haliotis rubra* (Mollusca: Gastropoda). Australian Journal of Marine and Freshwater Research, **39**, 161-166.

McShane, P.E. & Smith, M.G. (1992). Shell growth checks are unreliable indicators of the age of the abalone *Haliotis rubra* (Mollusca: Gastropoda). Australian Journal of Marine and Freshwater Research, **43**, 1215-1219.

McShane, P.E., Schiel, D.R., Mercer, S.F. & Talbot, M. (1994). Morphometric variation in *Haliotis iris* (Mollusca: Gastropoda): analysis of 61 populations. New Zealand Journal of Marine and Freshwater Research, **28**, 357-364.

Nash, W.J. (1992). An evaluation of egg-per-recruit analysis as a means of assessing size limits for blacklip abalone (*Haliotis rubra*) in Tasmania. In S.A. Shepherd, M.J. Tegner and S.A. Guzmán del Próo (eds.), Abalone of the world: biology, fisheries and culture, Fishing New Books, Oxford, 318-338.

Poore, G.C.B. (1972). Ecology of New Zealand abalones *Haliotis* species (Mollusca: Gastropoda) 3, Growth. New Zealand Journal of Marine and Freshwater Research, **6**, 534-559.

Tissot, B.N. (1988). Morphological variation along intertidal gradients in a population of black abalone *Haliotis cracherodii* Leach, 1814. Journal of Experimental Marine Biology and Ecology, **117**, 71-90.

Underwood, A.J. (1981). Techniques of analysis of variance in experimental marine biology and ecology. Oceanography and Marine Biology Annual Review, **19**, 513-605.

Ward, T.J. (1986). Abalone biology and fisheries in Australia, A review of research. Australian Fisheries Service, D.P.I., Canberra, Fisheries Paper, **86-12**, 1-25.

Wilkinson, L., Hill, M. & Vang, E. (1992). SYSTAT stastistics, Systat for the Macintosh, Version 5.2. Evanston, Illinois, 298-301.

Worthington, D.G., Andrew, N.L. & Hamer, G. (1995). Covariation between growth and morphology suggests alternative size limits for the blacklip abalone *Haliotis rubra*, in New South Wales, Australia. Fishery Bulletin, **93**, 551-561.

Prince, J.D. & Shepherd, S.A. (1992). Australian abalone fisheries and their management. In S.A. Shepherd, M.J. Tegner, and S.A. Guzmán del Próo (eds.), Abalone of the world: biology, fisheries and culture, Fishing New Books, Oxford, **27**, 407-426.

Sainsbury, K.J. (1982). Population dynamics and fishery management of the Paua, *Haliotis iris* I. Population structure, growth, reproduction and mortality, New Zealand Journal of Marine Freshwater Research, **16**, 147-161.

Shepherd, S.A., Mower, A.G.J. & Hill, K. (1987). Studies on Southern Australian Abalone (genus *Haliotis*). VIII Growth of *H. scalaris*. Transaction of the Royal Society of South Australia, **112**, 93-95.

Shepherd, S.A. (1988). Studies on Southern Australian Abalone (genus *Haliotis*), VIII, Growth of juvenile *H. laevigata*. Australian Journal of Marine and Freshwater Research, **39**, 177-183.

Sloan, S.R. (1997). Aspects of the biology of the southern Australian Abalone *Haliotis cyclobates*, Peron 1816 (Mollusca: Gastropoda) at Taylor Island, South Australia. Bachelor of Applied Science (Fisheries), Unpublished report, Australian Maritime College, Beauty Point, Tasmania.

Tegner, M.J., Breen, P.A. & Lennert, C.E. (1989). Population biology of red abalones (*Haliotis rufescens*), in Southern California and management of the red and Pink, *H. corrugata* abalone fisheries. Fishery Bulletin, US, **87**, 313-39.