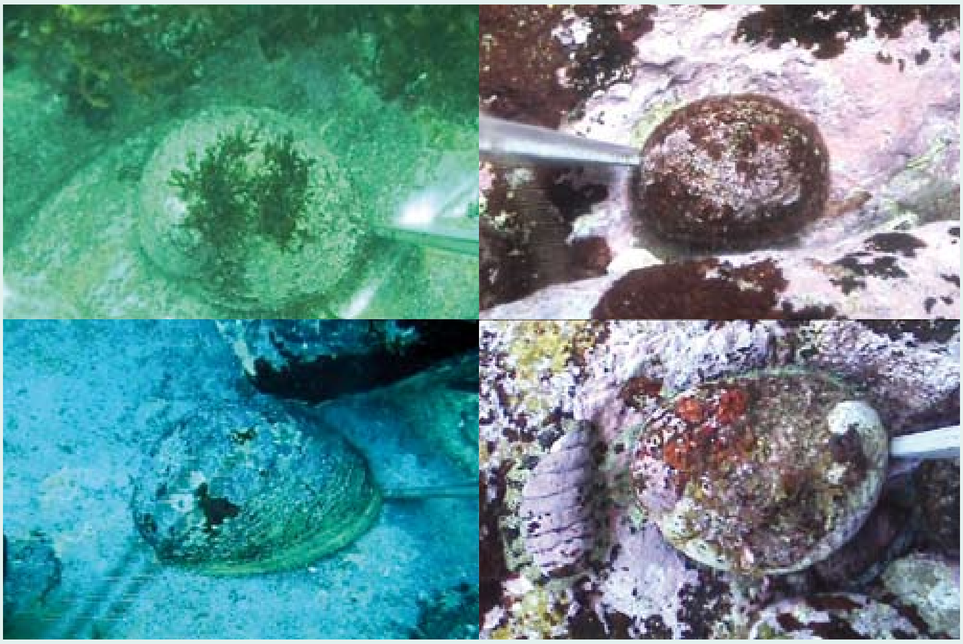
FISHERIES RESEARCH REPORT

No. 167, 2007

Digital video techniques for assessing population size structure and habitat of Greenlip and Roe's abalone

Final FRDC Report – Project 2002/079

A.M. Hart and F.P. Fabris



Department of Fisheries

Australian Government
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Fish for the future

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Fisheries Research Division
Western Australian Fisheries and Marine Research Laboratories
PO Box 20 NORTH BEACH
Western Australia 6920

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Enquiries:

WA Fisheries and Marine Research Laboratories, PO Box 20, North Beach, WA 6920
Tel: +61 8 9203 0111
Email: library@fish.wa.gov.au
Website: http://www.fish.wa.gov.au

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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

Contents

Non Technical Summary

2002/079 Digital video techniques for assessing population size structure and habitat of Greenlip and Roe's abalone

Principal investigator: Dr Anthony M. Hart

Address:
Department of Fisheries
Western Australian Fisheries and Marine Research Laboratories
P.O. Box 20
North Beach
Western Australia, 6920
Telephone: 08 9203 0111 Facsimile: 08 9203 0199

E-mail: Anthony.Hart@fish.wa.gov.au

Objectives

1. Determine the reliability and usefulness of in-water digital video in getting cost-effective, fishery independent counts and measures of abalone (as an alternative to traditional manual techniques).
2. To provide a comparison of abundance and stock structure information (between and within years) for main fishing areas videoed.
3. Develop a time (cost) efficient computer program to extract (frame grab) and measure (within frame) abalone on videotape, and a database where images and data from video can be stored, accessed and interrogated.

Outcomes achieved

A digital video image (DVI) stock monitoring programme was developed for the *Haliotis laevigata* and *H. roei* abalone fisheries in Western Australia. The program used industry divers to collect stock density and length-frequency data using digital video from 51 survey sites across the fishery, while image extraction, data processing and storage is carried out by research staff. Training videos, DVDs, and a comprehensive suite of experimental tests on both abalone species were utilised to achieve this outcome. Comparisons between DVI data collected by industry divers, and fishery independent survey (FIS) data showed mean legal-sized (140 mm+) density of *H. laevigata* to be 0.33 m^{-2} for the DVI method, and 0.35 m^{-2} for the FIS method. This difference was not statistically significant. The DVI method can also measure abundance of pre-recruits, however only samples a small proportion of juveniles. Industry and managers have recognised the potential of the DVI method, and the programme is being scaled up to provide sufficient data for on-going application to stock assessment and management.

Information on the undersized component of abalone stocks, changes in stock density, growth and habitat are not directly detectable through monitoring commercial abalone catches. To make more reliable projections on future catches of abalone, catch data needs to be supplemented with an appreciation of the strength of sub-legal year classes yet to enter the fishery. Traditionally such data is only available though fishery independent surveys (FIS), usually carried out by research personnel, and with substantial costs. However, commercial abalone divers have unequalled access to in-water stocks, and thus have the potential to provide a cost effective means of monitoring stocks within and between years over a large spatial area. To date this has been difficult to achieve because the traditional process for collecting data is considered non-independent (compromised) in the hands of commercial divers, and commercial divers perceive calliper and slate technology as slow, an undue interference and insufficient in coverage to supply representative datasets. However, advances in digital video technology have resulted in a re-appraisal of these limitations. In this project, the potential of underwater digital video imagery (DVI) obtained by commercial divers to supply useful and cost-effective data was investigated for two commercially fished abalone species in Western Australia (*Haliotis laevigata* and *H. roei*).

Extensive experimental validation of the DVI methodology was undertaken for both species. Topics researched included: accuracy of the DVI length measurement technique; effect of observer on length estimation from digital images; effect of method (DVI vs Traditional) on abundance and length estimation of *Haliotis roei* from *in-situ* survey sites; a simulated fishing mortality experiment for *Haliotis laevigata*; effect of swell on quality of DVI images; and comparisons with traditional FIS (Fishery Independent Survey) data. Two training videos / DVDs (one for each species) were produced and disseminated to all industry divers in Western Australia, and presented to industry at meetings. The videos explained the DVI survey methodology and covered such topics as project overview, diver role within the project, equipment and operation, underwater filming techniques, and recording sheet completion. Most divers were individually briefed, and in-water training exercises carried out. Comprehensive feedback was given to all divers that participated. However, with respect to the habitat surveys, as the DVI methodology is predicated on a clearly defined target image, it was not possible to simultaneously collect habitat composition, and abalone length information with the same filming technique, and extra resources and training would have been required. Consequently, attempts to collect habitat data were discontinued.

Accuracy tests yielded negligible bias with both abundance and lengths being reliably estimated with appropriate sampling control and filming technique. In the case of *H. laevigata*, the DVI technique was able to reliably detect a known fishing mortality in an experimental fishing test, with videoing by both commercial industry divers and research personnel detecting the effect. The DVI method produces between 50 and 80% of viable images (images from which a length measurement can be obtained) depending on species and location. Statistical comparisons of a subset of lengths obtained by DVI images, compared with the entire sample (obtained by traditional techniques) generally showed this sub-sample to be unbiased, except for animals in the youngest age classes (< 80 mm length for *H. laevigata*; < 30 mm length for *H. roei*). Comparisons of densities by size-class from fishery independent survey (FIS) data in the Area 2 *Haliotis laevigata* fishery corroborated this result, namely that the DVI method under samples juveniles (< 100mm for *H. laevigata*), although the possibility exist to calibrate this bias using a selectivity curve. Mean legal-sized (≥ 140 mm) density of *H. laevigata* was 0.33 m^{-2} for the DVI sites, and 0.35 m^{-2} for the FIS sites, a difference that was not statistically different.

Participation rate of *Haliotis laevigata* divers increased from 21% in 2003 to 36% in 2004, but declined to 21% in 2006. Number of sites filmed also peaked in 2004, with the total number of sites set-up being 21 in the H. *laevigata* fishery. *Haliotis roei* divers did not begin filming sites until 2005, but ultimately participation rates were higher than for greenlip divers, and 30 survey sites were set-up. The slow initial uptake of the DVI technology by industry divers resulted in the final report being delayed by 12 months to allow for a concerted industry effort, and eventually >80% of the project target of 60 surveys sites was achieved.

A cost-benefit analysis revealed that on the basis of precision and costs, DVI was clearly the optimal methodology for measuring immediate pre-recruits and legal-sized greenlip abalone, but it could not sample juveniles. Our general conclusion is that the DVI method has potential to be a valid assessment tool for the Western Australian abalone industries, and the data would complement existing CPUE and FIS datasets. For this to occur, the programme needs to be scaled up to the appropriate level with quality control of site selection, camera equipment allocation, and clear targets and responsibility for industry personnel undertaking the surveys. Our studies demonstrated that a minimum number of genuinely enthusiastic commercial divers employed to undertake the surveys will provide the best chance of successfully implementing the programme at an appropriate scale to provide valid stock assessment data.

One of the objectives of the project not achieved was to create an automated program for processing the digital footage. The complex nature of the moving images and the camouflaged nature of abalone against their surrounding background meant that an experienced eye was required to detect the shape outline of the shell, a process that could not be effectively programmed into pattern and shape recognition software. Consequently, images were extracted and processed manually, which reduced the overall cost-effectiveness of the DVI technique.

KEYWORDS: Greenlip abalone, Roe’s abalone, *Haliotis* sp, digital video monitoring, stock abundance, length-frequency sampling, industry divers

1.0 Background

Information on the undersized component of abalone stocks, changes in stock density, growth and habitat are not directly detectable through monitoring commercial catches. In addition, abalone are targeted by recreational and illegal fishers from which catch information is limited or absent. Fishery managers and industry stakeholders require information on the size structure of abalone stocks and changes in stock density to assess quota levels. Without this information, the available stock and probable recruitment are unknown, and the ability to sustainably manage stocks is compromised.

Western Australian commercial abalone divers recently trialled a new digital video method for in-water stock assessment. The commercial divers found filming abalone on reefs with digital video straight forward and of high value. The video provided markedly more abalone measures per dive, and covered a greater survey area than is possible with traditional survey techniques. An added value of this process is that video records close up footage of macro flora and fauna assemblages within abalone habitat. Having a time series of such footage will be critical in assessing changes in these assemblages over time. Because the process proved simple in operation and the video clearly highlighted a number of applications for recording and analyzing important stock and habitat information, the Western Australian abalone industry invested in a $6000 digital video unit (camera and housing) to further evaluate the potential for using video technology for abalone surveys. The success of this technology has been outstanding in preliminary assessments of remote greenlip abalone stocks in the Nullarbor region, stunted abalone colonies for "fishdown" assessments and in communicating fishing activities for the purposes of ESD determination.

In other States such as NSW and Victoria, long-term research diving programs established to monitor blacklip abalone stocks utilize caliper and slate technology to obtain information on blacklip abalone size structure; this is a time consuming process. The digital video technology has the potential to provide time and cost efficiencies over traditional research dive survey programs. The methods and preliminary outcomes of using digital video technology were presented at the National Abalone Convention (Adelaide 20-21 August 2001) and were identified along with the Victorian onboard shell measuring instrument as a significant tool that was worthy of further development.

2.0 Need

To make more reliable projections on future catches of abalone, catch data needs to be supplemented with an appreciation of the strength of sub-legal year classes yet to enter the fishery. This requires information on in-water stocks to allow predictions of new recruitment to be confirmed and recruitment failures to be identified. Commercial divers have unequalled access to in-water stocks, particularly in remote regions. Although commercial divers regularly dive areas of interest, and could provide a cost effective means of monitoring stocks, this has been difficult to achieve because: 1) the traditional process for collecting data is considered non-independent (compromised) in the hands of commercial divers, and 2) divers perceive caliper and slate technology as slow, an undue interference and insufficient in coverage to supply representative datasets.

What is needed is an efficient, cost-effective stock monitoring process that utilises commercial abalone divers, around the time of their normal fishing activities, to give fisheries managers and quota holders critical in-water information for the management of stocks. Recent preliminary trials, where researchers utilised digital video surveys filmed by commercial divers, clearly provides the potential for such a process. Whereas researchers need such footage as a data source, the video also provides a mechanism for divers to verify their own perceptions of change on surveyed reefs and convey what they are seeing to licence owners. Such a system also gives divers a further opportunity to contribute to stock management and reduce licence fees under cost recovery regimes.

Presently, video is played back and measurements are taken on two software packages. This process needs streamlining so that access to frames and measuring of abalone is time efficient. Measures and images generated from such a process need to be stored in an appropriate database, where they can be accessed through simple interrogation.

2.1 Objectives

1. Determine the reliability and usefulness of in-water digital video in getting cost-effective, fishery independent counts and measures of abalone (as an alternative to traditional manual techniques).
2. To provide a comparison of abundance and stock structure information (between and within years) for main fishing areas videoed.
3. Develop a time (cost) efficient computer program to extract (frame grab) and measure (within frame) abalone on videotape, and a database where images and data from video can be stored, accessed and interrogated.

3.0 Methods

3.1 Terminology

The process of obtaining estimates of abundance and size-frequency of abalone from underwater digital survey footage involves filming, footage download, image extraction (e.g. frame grab), determination of pixel-calibration ratios, length estimation, and data recording. For the purposes of this report, this process shall be simplified by the acronym DVI ("Digital Video Imagery").

In most cases, DVI is being compared to traditional or standard survey techniques that involve visual observations, *in-situ* length measurements, and recording of information on an underwater slate. Hereafter, this process shall be referred to as "Traditional".

3.2 Video equipment and preparation

The project employed the use of Sony® digital video camera units (Models TRV15, TRV27, and TRV33) housed in specifically constructed waterproof housings. The housings were constructed with a single "pistol grip" handle and a steel extension bar of a specified length. The "pistol grip" handle was the preferred practical design for the high-swell environment of these species, where one free hand was needed to steady the diver and remove impeding obstacles from the camera field of view. The length of the extension bar was species and camera model-specific, with each individual camera assigned its own waterproof housing (*Haliotis laevigata* - Figure 1; *H. roei* - Figure 2). The purpose of the extension bar was to standardise distance of animal from camera lenses so that a digital pixel ratio (# pixels per 1 mm length) could be applied to the captured digital images to enable accurate measurements of abalone shell length (Table 1). See section 3.5 for further details.

Figure 1. Diver holding underwater video camera in housing with pistol grip and extension bar used to film greenlip abalone (*Haliotis laevigata*).

Figure 2. Diver holding underwater video camera in housing with pistol grip and extension bar used to film roe's abalone (*Haliotis roei*).

Table 1. Video camera bar lengths and digital pixel ratios used for length estimation in *Haliotis laevigata* and *H. roei*.

Species	Camera Model	Camera Housing Model/Make	Length of extension bar	Digital pixel ratio (pixels mm^{-1})
H. laevigata	Sony HC26	Ikelite 6038.24	200	2.544
	Sony TRV-15	Fishcam grey grip	200	2.220
H. roei	Sony TRV-27	Ikelite 6035.05	100	5.586
	Sony HC26	Ikelite 6038.24	120	5.290
	Sony TRV-33	Ikelite 6038.07	100	5.012
	Sony HC26	Ikelite 6038.24	120	5.247

3.3 Diver training videos/DVDs

Following preliminary tests of the equipment and underwater filming techniques by research personnel, diver training videos and DVDs were produced for each species. Scripts with dialogue and film footage information such as location, personnel, and descriptions of individual scenes were developed to assist production. The titles of the diver training videos were:

Video Techniques for Assessing Greenlip Abalone

A video for the Western Australian Commercial Greenlip Abalone Fishing Industry
Produced by Frank Fabris and the Mollusc Section, Department of Fisheries,
Duration 21 mins
Copyright 2003 Department of Fisheries, WA and Fisheries Research and
Development Corporation

and

Video Techniques for Assessing Roe's Abalone

A video for the Western Australian Commercial Roe's Abalone Fishing Industry
Produced by Frank Fabris and the Mollusc Section, Department of Fisheries,
Duration 21 mins
Copyright 2004 Department of Fisheries, WA and Fisheries Research and Development
Corporation

All industry divers were sent a copy of the training video relevant to their particular species. A brief summary of the content of the video was also included in the cover sleeve. The summary for the greenlip diver training video was as follows:

> Traditional in-water monitoring methods are often used by Fisheries Researchers to assess population abundance, size and habitat of greenlip abalone. Advances in technology have the potential to reduce costs and increase efficiency of in-water monitoring methods.
>
> This video is produced for the commercial greenlip and brownlip abalone divers in Western Australia. It describes their involvement in the video project and provides a guide to the use of the video equipment.
>
> Topics include:
>
> - An overview of the project
> - Diver role within the project
> - Project equipment & operation
> - Underwater filming techniques
> - Recording sheet completion

3.4 Industry diver filming technique

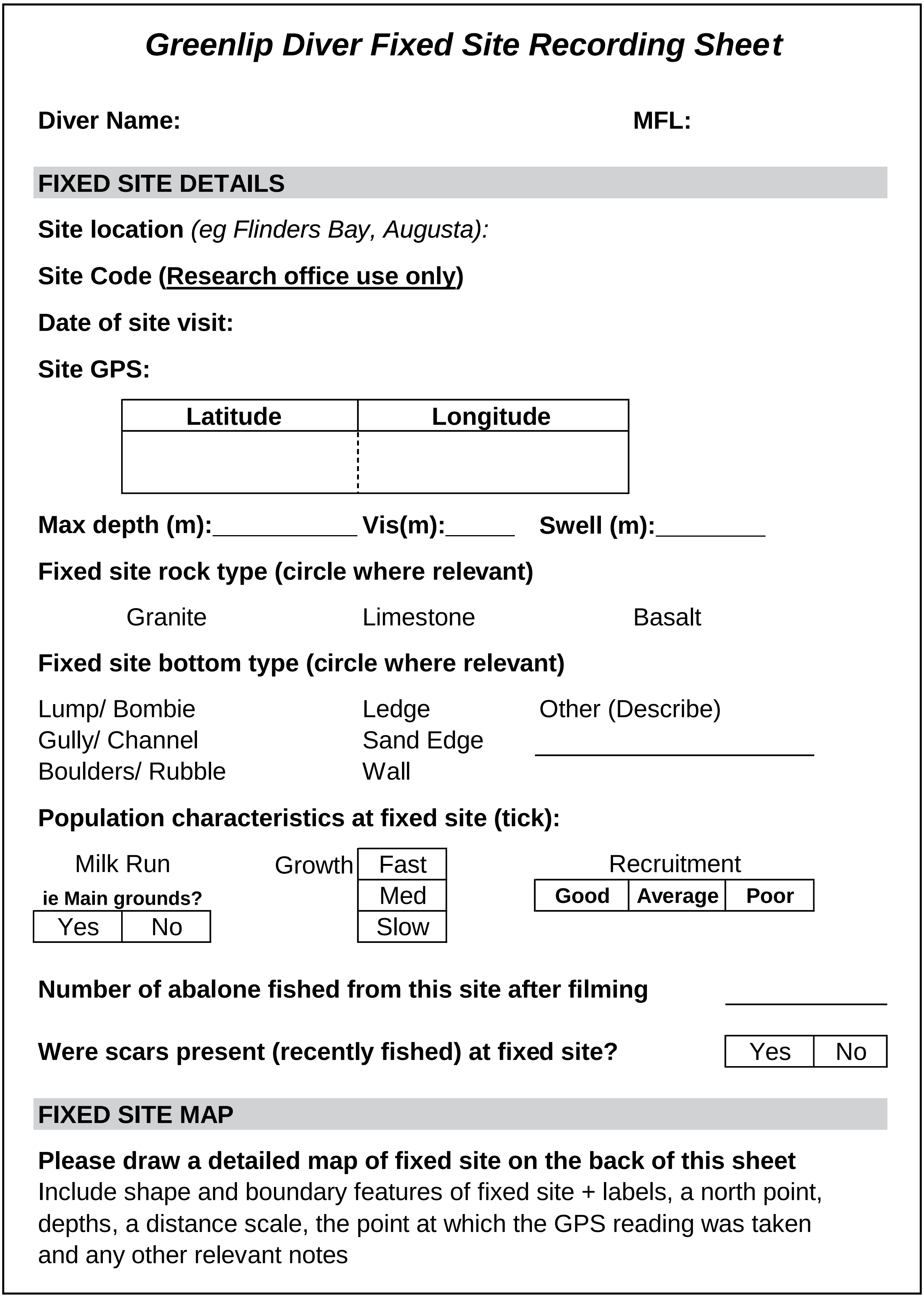
For deployment to industry divers, a survey kit was designed and included the video camera, underwater housing, camera charger, spare battery pack, stainless steel bar, screwdriver, spare screws, and a spanner (Figure 3). Site recording sheets were included with the camera kit, and instructions for filling this in provided as part of the training video. An example of the site-recording sheet for greenlip abalone is provided in Figure 4. Once divers have collected the information, the digital footage and site information was sent back to the Research Division with the survey kit, where the DVI footage was processed for abundance and population size-structure data.

Figure 3. Abalone video survey kit for *Haliotis roei*.

3.4.1 Sampling design: industry diver survey sites

Differences in the habitat of the two species meant that different survey techniques were necessary for each species. The design employed by the greenlip *Haliotis laevigata* divers is *fixed-site* sampling of *non-uniform* area. Divers choose sites, identify the aerial extent of the survey site, mark the boundaries (e.g. with floating ropes, buoys, anchors etc.) and repeatedly film the abalone in this site every year. The average area surveyed was 177 m^2 (± 95 SD), estimated using the equations outlined in section 3.8.2. This design is equivalent with the fixed-site sampling approached adopted as the fishery-independent survey method in the *Haliotis rubra* fishery of NSW (Worthington and Andrew, 1997), except that research divers physically measure abalone in the NSW case.

For *Haliotis roei*, the design employed was *fixed-site* sampling of *non-uniform timed swims*. This species occurs in high densities and shallow water (0-4 m), hence it was not logistically feasible for divers to map out a specific area. Instead, a sampling approach of sub-tidal surveys over a specified timed swim was adopted. Divers were advised that a 10-minute period would be sufficient, but filming time varied between 9 and 30 minutes, and average area surveyed was 40 m^2 (± 27 SD). Exact time periods of filming were obtained from the digital video footage.



Greenlip Diver Fixed Site Recording Sheet

Diver Name: **MFL:**

FIXED SITE DETAILS

Site location *(eg Flinders Bay, Augusta):*

Site Code (Research office use only)

Date of site visit:

Site GPS:

Latitude	Longitude

Max depth (m):___________ Vis(m):_____ Swell (m):________

Fixed site rock type (circle where relevant)

Granite Limestone Basalt

Fixed site bottom type (circle where relevant)

Lump/ Bombie	Ledge	Other (Describe)
Gully/ Channel	Sand Edge	______________________
Boulders/ Rubble	Wall	

Population characteristics at fixed site (tick):

Milk Run

ie Main grounds?

Yes	No

Growth

Fast
Med
Slow

Recruitment

Good	Average	Poor

Number of abalone fished from this site after filming _____________

Were scars present (recently fished) at fixed site? Yes No

FIXED SITE MAP

Please draw a detailed map of fixed site on the back of this sheet
Include shape and boundary features of fixed site + labels, a north point, depths, a distance scale, the point at which the GPS reading was taken and any other relevant notes

Figure 4. Data recording sheet for greenlip divers video survey sites.

3.5 Image capture and extraction

3.5.1 Automated image capture – goals and limitations

One of the objectives of the project was to create an automated program for processing the digital footage. The first part of objective 3 was *Develop a time (cost) efficient computer program to extract (frame grab) and measure (within frame) abalone on videotape.*

The general concept behind this objective was that the basic shape of an abalone filmed during the 2 seconds of “still” shots as the diver held the camera in position, could be detected against the background movement as the diver shifted the camera from abalone to abalone. However, it became obvious from very early footage extraction that such a program was too difficult to construct in practice because of the complex nature of the images. For example, at any given moment within the diver survey footage there was a multitude of moving images and shapes, ranging from the camera itself, to the industry diver clearing benthic flora for a better shot, to many different types of algae swaying in the currents. Moreover, the growth of epiphytes on individual shells, and the camouflaged nature of each shell meant that an experienced eye was required to detect the shape outline of the abalone shell against the surrounding background. Figure 5 shows an example of an obscured greenlip abalone shell from which a shell length could not be obtained.

Consequently, the frame grab program of the image software could not precisely capture the correct number of abalone within a 10 or 20-minute stream of footage because the pattern and shape recognition capacity could not effectively distinguish abalone against the background movement, shapes, and colours.

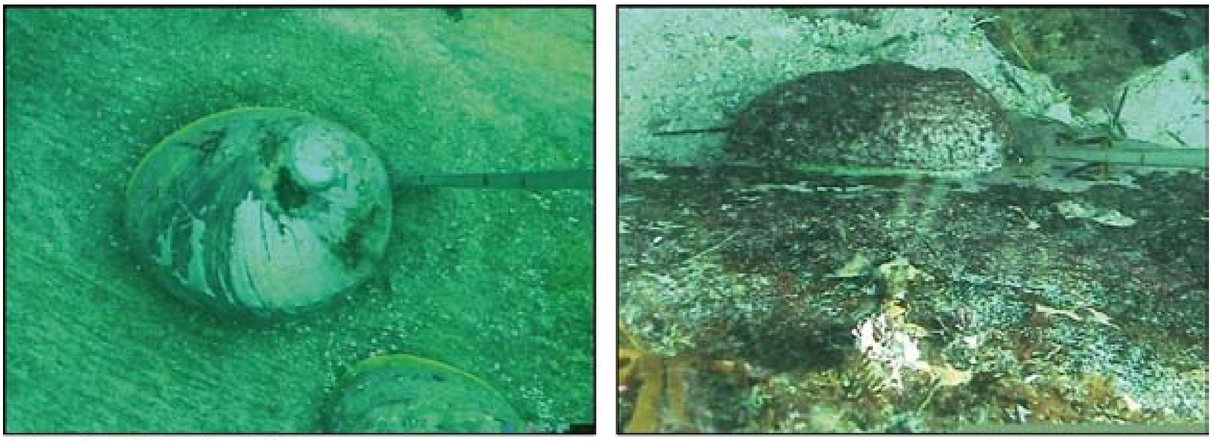
Images were extracted and processed manually, as described in the following sections. The time taken to complete this process was recorded for future cost-effectiveness comparisons with traditional techniques.

Figure 5. Obscured juvenile *Haliotis laevigata* image obtained from industry DVI surveys. The red circle indicates the obscured abalone.

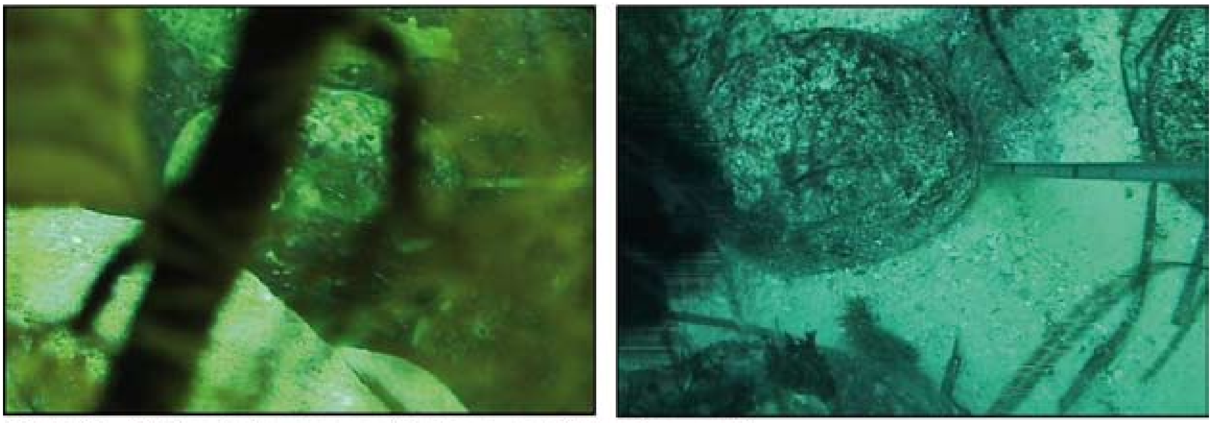
3.5.2 Image analysis and image quality

Once a site has been filmed and a site-recording sheet completed, research staff captured still frames of individual abalone from the digital tape using *BTV Promac* software. *Image J* software was then used to measure the subsequent lengths of abalone calculated from the number of pixels across the long axis of the shell. The pixel calibration values for each underwater housing were pre-determined using images of known length.

The quality of images collected by each diver for each site was critical to the success of the project (and the success of completing accurate stock assessments). For the DVI technique to be successful, a substantial proportion of the abalone filmed in a site need to be able to be measured. The ranges of abalone image qualities that were extracted varied from very poor to clear and sharp (Figure 6). In order to group lengths extracted (and lengths not extracted) from images of varying quality, the effective image code system was developed (Table 2). Only code 1 and code 2 images could be used to extract viable lengths.



Code 1 - Clear length measures



Code 2 - Estimated measure (abalone partially obscured)

Code 3 – Unable to measure (abalone mostly obscured)

Figure 6. Variation in quality of abalone images extracted from abalone diver sites. Each image has been rated (and a length extracted where possible) according to the effective image code system (Table 2).

Table 2. The effective image code system for delineating image quality from DVI footage obtained from abalone industry divers.

Code	Explanation	Quality	Use
1	Clear length	High	Lengths and abundance (counts)
2	Estimated length	Medium	
3	No length taken	Low	Counts only

Factors that affect the ability to extract a length measurement from an abalone image are summarised in Table 3. Most of the factors are under the control of the diver e.g. moving weed away the area beneath the camera lens (left column). Other factors that are out of the control of the diver (right column) include abalone located in deeper cracks and under ledges. Either the diver cannot place the bar correctly next to the animal and/or the image is too dark for a length measure to be extracted.

Table 3. Factors affecting the extraction of length measurements.

Factors controlled by diver	Factors out of diver control
Weed between lens and abalone surface	Abalone obscured by darkness and/or substrate
Diver filming too fast	Abalone not able to be properly accessed by bar
Poor bar angle/position	
Poor filming conditions	

3.5.3 Data storage

Data from the project is stored in 3 formats. The original video footage is kept on the digital video cassettes, as these hold up to 20 Gigabytes of digital information, and at $15 per cassette are a reasonably cheap form of storage. They were labelled and appropriately filed for ease of retrieval. The extracted digital images (using the *BTV Promac* and *Image J* software) are stored according to date, diver, and site into a high-powered network server. The server is an “Xserve G5 Macintosh” network server with dual 2GHz power PC G5 processors, and supports high speed and high band width cabling to enable fast remote processing of abalone images (i.e. from more than 1 external computer simultaneously), and up to 750 Gigabytes of external storage, plus additional capacity if required. Abundance and length data extracted from these images is stored in the Abalone Research Database (ARD), and linked up to date, diver, site, habitat, and other useful information. The ARD is part of the Department of Fisheries FIMS (Fisheries Information Management System) system. The FIMS system incorporates the entire catch and effort, licensing, and Fisheries Research Databases of Western Australia.

3.6 Experimental tests of the methodology

3.6.1 Accuracy of the digital length measurement technique

Once the pixel calibration ratios were completed, the accuracy of the method for estimating lengths of three species (greenlip - *Haliotis laevigata*, brownlip – *H. conicopora*, and roe’s abalone – *H. roei*) was tested. Ten shells of varying size from each species were measured with calipers, and filmed using DVI techniques developed in this project. Size ranges of shells used were: 42 – 190 mm (*H. laevigata*), 53 – 215 mm (*H. conicopora*), and 17 – 107 mm (*H. roei*). Data were analysed separately for each species using a paired *t*- test, and regression coefficients, means, and variances were compared. This experiment tested the accuracy of the method, assuming the filming has been carried out in the correct manner. Diver effects, as briefly summarised in Table 3, will obviously affect the accuracy of the measurements, independent of the DVI technique.

3.6.2 Effect of observer on length estimation from digital images

Four different observers analysed 78 digital images of *Haliotis laevigata* to determine extent of observer bias in the digital measurement of length using the techniques outlined in this report. Each observer independently coded the images according to the criteria in Table 2, and all observers calculated the total time taken to analyse the 78 images. ANOVA was used to analyse the data.

3.6.3 Effect of method (DVI vs Traditional) on abundance and length estimation of *Haliotis roei* from in-situ survey sites

Perth metropolitan *Haliotis roei* stocks are currently surveyed on an annual basis at 9 survey locations. Within each location, fixed quadrats in four habitats (outer, middle, and inner platform, subtidal) are revisited every year to estimate trends in abundance and average size (n ~ 3 to 5 quadrats per habitat). To experimentally compare the DVI technique with the traditional technique, the subtidal habitat at two of the survey locations were chosen. Nine fixed area quadrats (0.5 m^2 each) were examined by each method at each site, for a total of 18 paired samples. Differences in abundance and mean length measured by each survey technique were analysed by a paired *t*-test. Different observers were used for each technique to avoid 'prior-knowledge' bias. Abundance data were log (x + 1) transformed prior to analysis due to heterogeneous variances.

3.6.4 Simulated fishing mortality experiment

The aim of this experiment was to undertake a preliminary evaluation of the efficacy of the DVI technique for measuring changes in the abundance and size of greenlip abalone (*Haliotis laevigata*) under a controlled fishing mortality regime. The experiment also served as an initial training exercise for abalone industry divers, to gain familiarity with the equipment and provide knowledge of site selection and preparation tasks associated with on-going monitoring.

Three experimental sites were set up off Hopetoun on the south coast of Western Australia. Each site contained initially between 70 and 120 abalone (all sizes) and the boundaries were defined using a combination of detailed site maps, star pickets, and underwater florescent tape. Three research divers and five industry divers filmed all sites, before and after fishing. The time span between before and after fishing was 1 to 3 days. The three sites were subjected to an overall fishing mortality of 24% (specifically 20%, 25%, and 26% at each site). Data from different divers was pooled into two experimental "method" treatments, 1) DVI – research personnel, and 2) DVI – industry personnel.

Abundance and length data were extracted from filmed footage using the methods described in Section 3.5, and analysed with a 2-way ANOVA, which compared the effect of time (before, after), and method (DVI - research personnel, DVI - industry personnel) on abundance and shell length of abalone.

A detailed traditional survey was carried out at each site prior to fishing, and all abalone counted and measured. This data served as a reference point.

3.6.5 Effect of swell on film quality of DVI methodology

A qualitative test on the effect of swell on percent of viable length estimates (i.e % of Codes 1 & 2 – see Table 2 for a description of codes) using the DVI methodology was undertaken. A site at Pt Malcolm in the Area 2 greenlip fishery (approximately 200 km east of Esperance) was set-up, and all boundaries marked with fluorescent tape and detailed sites maps. Four different personnel (2 research divers and 2 industry divers) repeatedly surveyed the site over the course of a day, during which there was a substantial decrease in swell. Survey times were 8.30, 9.10, 10.55 and 11.30, and % of viable length estimates were plotted against a qualitative estimate of swell. Quantitative estimates of swell were sought after for statistical analysis, however it was not possible to obtain swell information at this remote location from the Bureau of Meteorology.

3.7 Industry diver training, feedback, and participation

To ensure that industry personnel were adequately trained and encouraged to optimise the skills required to undertake useful DVI filming, a comprehensive feedback process was initiated once they commenced using the DVI technique. The feedback involved assessing the performance of the diver in terms of a % of images that were Code 1, 2, or 3, and supplying technical feedback to this effect. Examples of this process are described for *Haliotis laevigata* and *H. roei* industry divers.

Participation rates in terms of number of divers involved in the project, number of DVI monitoring sites set-up and filmed, and % involvement were calculated for each species and management area.

3.8 Spatio-temporal trends in abundance and size-frequency

3.8.1 Study sites

Industry divers carried out filming in Area 2 and Area 3 of the greenlip commercial fishery (Figure 7), and Area 2, 6, and 7 of the roei commercial fishery (Figure 8). These are the main fishery areas for the two species.

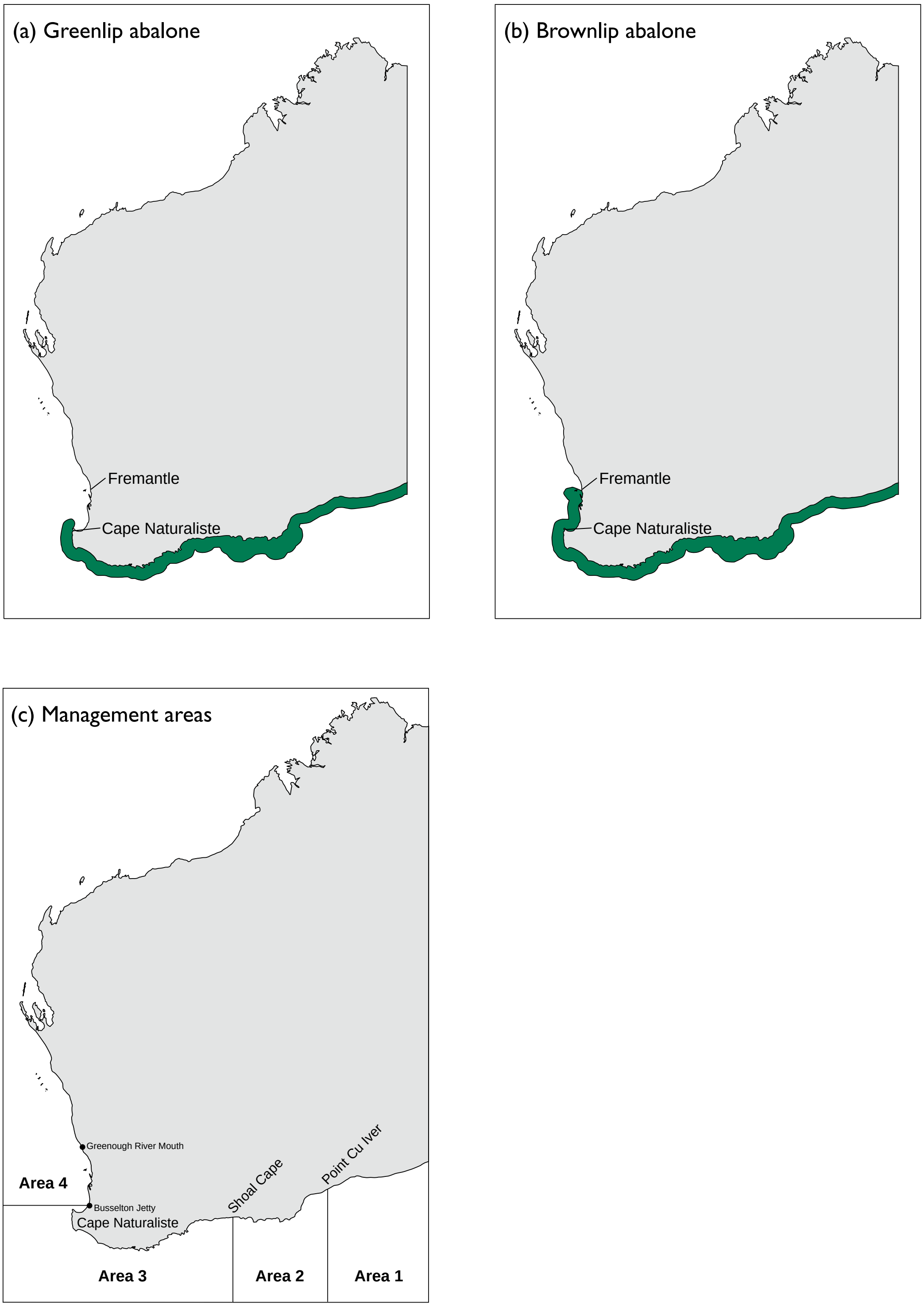


Figure 7. Maps showing the distribution of (a) greenlip and (b) brownlip abalone in Western Australia, and (c) the management areas used to set quotas for the commercial fishery.

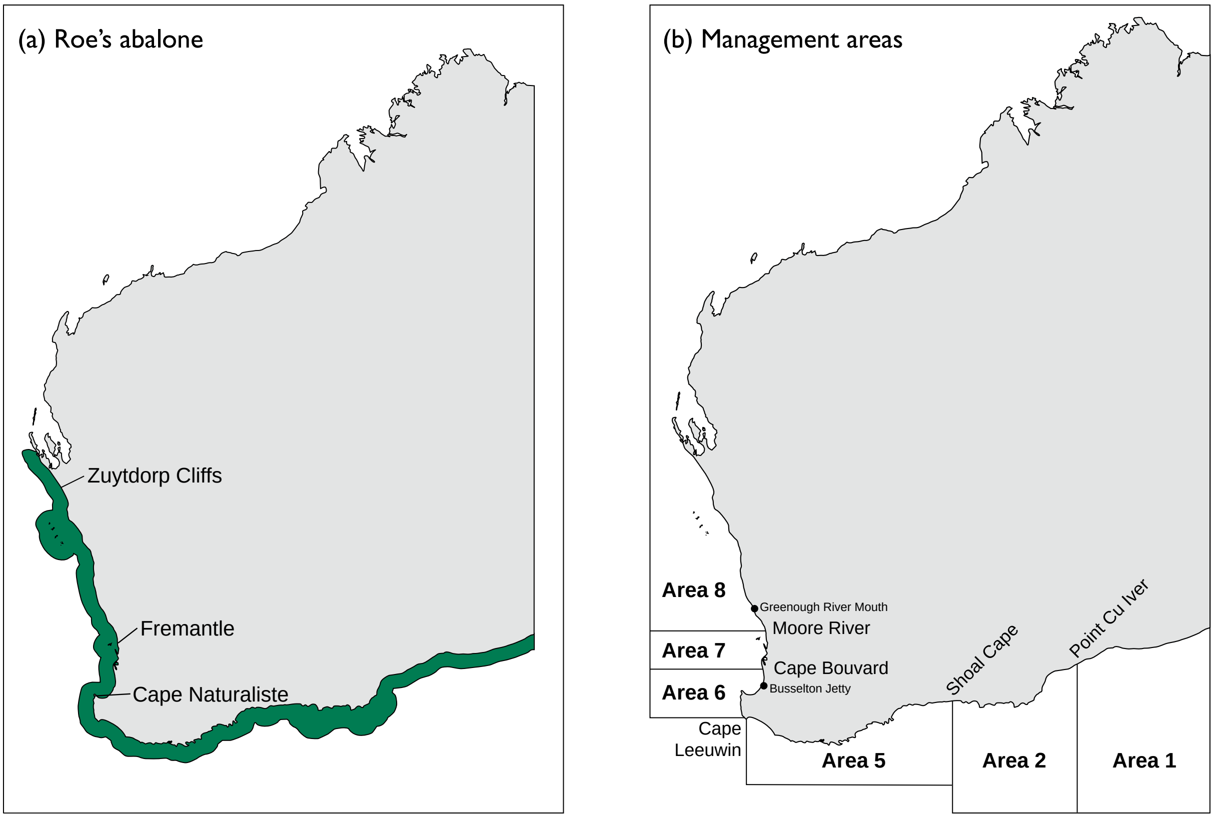


Figure 8. Map of *Haliotis roei* distribution and commercial fishery management areas of Western Australia.

3.8.2 Data analysis

Mean length of abalone from the industry DVI surveys for both species was analysed by a 2-factor ANOVA, with the factors being Year and Site. The DVI abundance count for each species was converted to a density estimate according to the rationale of Beinsenn (1979). Modifications to this rationale for *H. laevigata* proposed by Shepherd (1985) were not applied due to lack of data on swell and algal density.

In an abalone fishery, a timed swim consists of two effort components, searching time (S), and handling time (h). Searching time is the effective measure of effort, as it is time spent searching for abalone, whereas handling time is the time spent handling, or in this case, filming the abalone. As abundance decreases, searching time increases, and handling time decreases, and vice versa. For the DVI methodology, h was estimated from the video footage, and it varied between industry divers (Table 4). Equations are as follows:

$$S_i = T_i - {}^{h}\!/_{60}\, n_i \tag{1}$$

where S_i is the searching time (in mins) for the ith sample, T_i is the total filming time (calculated from the time counter on the digital video) for the ith sample, and n_i is the total number of abalone filmed in the ith sample.

$$A_i = r S_i \tag{2}$$

where A_i is the total area searched (in m^2) in the ith sample, and r is the fishing power / filming efficiency (area searched per minute) of abalone divers. For greenlip divers, r has been calculated at 20 m^2 min^{-1} (Shepherd, 1985; Mayfield et al., 2005a). For roei divers, no assessments of fishing power have been undertaken, however it is expected to be sufficiently lower than for greenlip divers due to the high density of *Haliotis roei* and complex, multidimensional habitat in which it resides. For the purposes of this report, r was assumed to be 5 m^2 min^{-1} for *H. roei* divers.

$$D_i = {}^{n_i}\!/_{A_i} \qquad (3)$$

where D_i is the abalone density for the ith sample.

Considerable variation in divers skill, ability, habitat and environmental conditions exists and these will affect estimates of h and S. It is also likely that estimates of h for each diver will vary until a established filming protocol has been developed.

Table 4. Estimates of handling time (h) for individual abalone divers for each species (n = 30 filmed abalone for each diver).

Species	Diver	Mean h (secs)	Species	Diver	Mean h (secs)
Haliotis laevigata	1	5.1	***Haliotis roei***	1	4.2
	2	5.2		2	3.4
	3	5.7		3	1.0
	4	6.5		4	1.2
	5	2.9		5	2.3
	6	5.3			
	7	3.8			
Average		4.9			2.4

As there was only one count of abundance at each site, spatial variation was measured as the mean overall density per management area. Temporal analysis will be carried out by paired t-test (2 years only) or repeated measures ANOVA (3+ years), however this analysis ideally requires a minimum of 20-30 repeatedly measured sites in order for statistically useful trends to be elucidated.

3.9 Comparison of density and size-frequency data from fishery independent surveys (FIS) and the DVI technique

Experimental tests of the methodology described in section 3.6 dealt with direct comparisons of traditional and DVI techniques under controlled experimental conditions. However, of paramount interest is the ability of the DVI technique, as applied by commercial abalone divers, to accurately describe stock densities and size-frequency for management purposes. An experimental test of this was facilitated by comparison of the 10 × DVI sites filmed by commercial divers with 14 × FIS sites surveyed by research personnel within the Area 2 greenlip abalone fishery (Figure 9). Sites were selected and surveyed independently of each other, and represent a pilot test of the efficacy of the DVI method at a scale appropriate to stock assessment and management.

The FIS method for greenlip consists of laying out 4 × 30 m^2 transects orientated towards the main habitat distribution at a survey site. For example, in a flat granite boulder field, transects are swum along a random compass bearing from a centre; if the habitat is more discreet, such as a gutter or a sand edge, transect direction will be orientated along the prevailing habitat. Such a process enables actual area of habitat to be quantified, although that information will not be utilised in this analysis. All greenlip abalone in the 120 m^2 searched at each site were counted and measured to the nearest mm. Densities of greenlip abalone at the FIS sites were calculated by dividing the count by the area searched (120 m^2). Overall, the data sets were deemed comparable, as the average area surveyed by the industry divers (estimated by equation 2) was 166 m^2.

After examination of the raw data, *H. laevigata* abundance data were divided into juveniles (< 100 mm), pre-recruits (100 to 139 mm), and recruits (≥ 140 mm).

Mean densities were compared with a *t*-test (unequal *n*), and mean lengths compared with a nested ANOVA, with sites being a random factor nested within method. Analyses were carried out using STATISTICA.

3.9.1 Cost–benefit analysis

Examination of precision as a function of number of sites surveyed and total cost of obtaining the data enabled cost-benefit comparisons between the DVI and FIS methodology. Precision (P_i) of method i for different size classes (100-139 mm; ≥140 mm) and number of sites (n) was estimated in the following manner

$$P_i = s^2 / n\bar{x}$$

Estimates of the abundance mean ($\bar{x}$) and variance (s^2) were obtained from n = 19 DVI, and n =14 FIS sites.

Cost (in hours) per survey site (C_s) was estimated as follows:

$$C_s = C_c + C_x$$

where C_c is the cost of collecting the data from each site, and C_x is the cost of extracting the data (from raw data sheets, or video imagery). Cost data were obtained from an analysis of all DVI and FIS sites.

For comparative purposes, the cost in dollars ($C_{\$s}$) was also estimated:

$$C_{\$s} = C_{\$c} + C_{\$x}$$

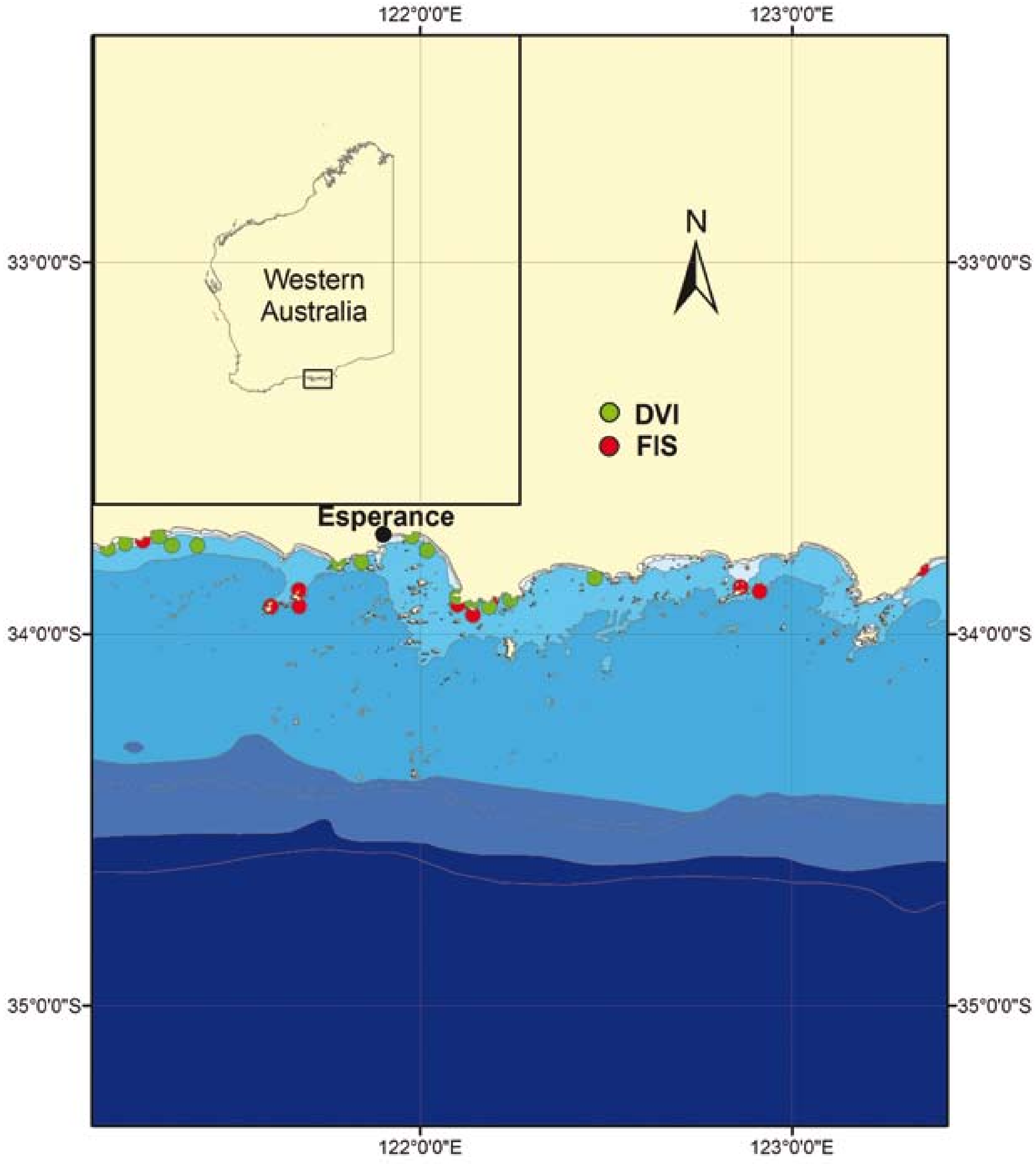


Figure 9. *Haliotis laevigata* survey sites monitored by commercial abalone divers using DVI techniques (green circles) and research personnel with traditional area-based FIS techniques (red circles).

4.0 Results and Discussion

4.1 Experimental tests of the methodology

4.1.1 Accuracy of the digital length measurement technique

For *Haliotis roei*, lengths obtained from digital images were not significantly different from those obtained by measuring directly with calipers (Table 5; Figure 10). For the larger species of abalone, there was a slight positive bias on estimates of length obtained from digitally captured images, to the value of 1-2% in *H. laevigata* (β = 1.016; Table 5) and 3% in *H. conicopora* (β = 1.032; Table 5).

Table 5. Results of a comparison of traditional and DVI methods for measuring shell length of *Haliotis laevigata*, *H. roei*, and *H. conicopora*. β is the slope of the regression through the origin of "digital length" as a function of "caliper length"; P's are the results of a paired *t*-test.

Species	Size-range (mm)	*N*	Mean length (mm)		β	r^2	p
			Traditional	DVI			
H. laevigata	42 – 190	10	122	124	1.016	0.999	0.02
H. roei	17 – 107	10	62	63	1.005	0.999	0.09
H. conicopora	53 – 215	10	155	160	1.032	0.999	<0.01

4.1.2 Effect of observer on length estimation from digital images

Of the 78 images inspected by four independent observers, the majority were code 1 images (clear abalone images), with observer 3 considering that 60% were code 1, compared to observer 4 who considered only 53% to be code 1 (Table 6). Observer 2 considered that 15 images (or 19%) were code 3, and therefore did not attempt to extract a length, whereas observer 1 only considered 3 images (or 4%) to be "unmeasurable" (Table 6).

Overall, the observer error associated with measuring average length was marginal, with observer 2 estimating an overall mean length of 130 mm, compared to 133 mm for observer 3 (Table 6). Observer 3 was the least experienced of all observers, and took the greatest length of time (35 minutes) to process the images.

There was no statistical difference between observers in measuring mean length of *Haliotis laevigata* from this sample (F = 0.61; p = 0.6). Consequently, the measurement of mean length was made from the combined Code 1 and Code 2 images.

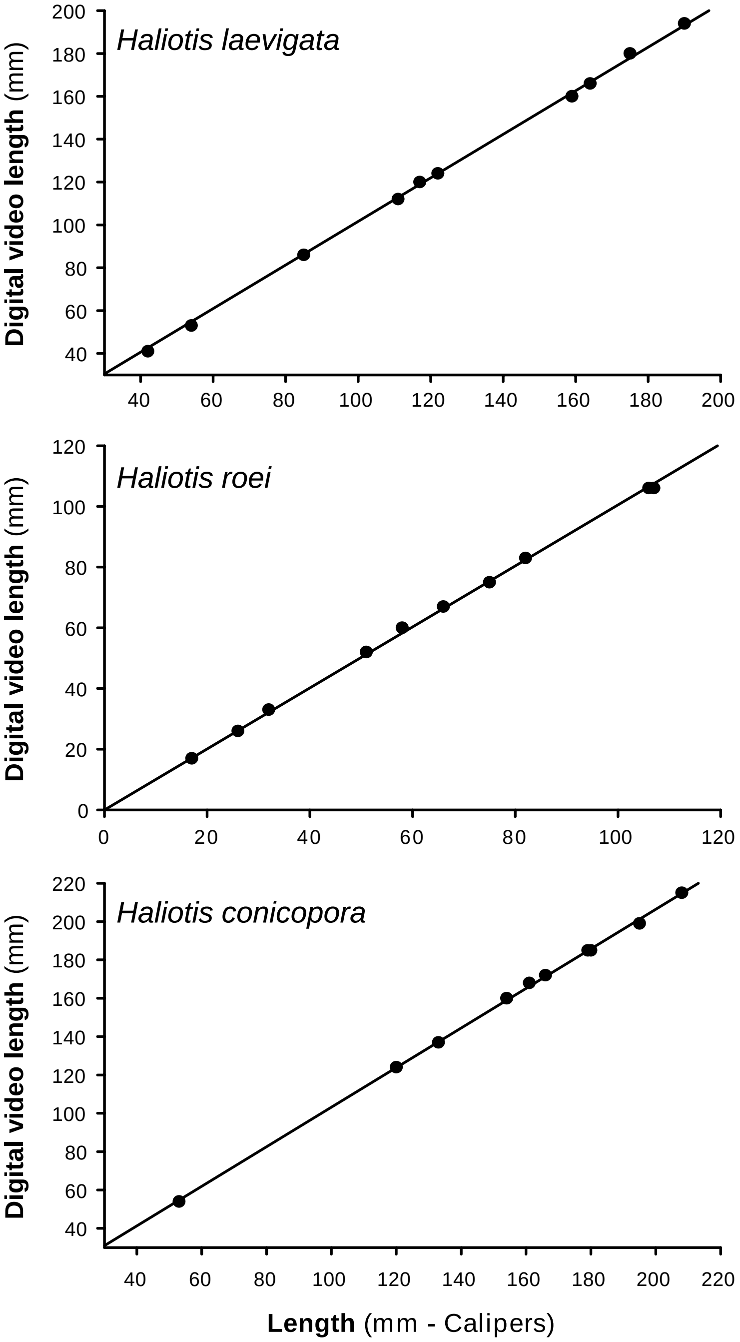


Figure 10. Regressions of digital video (DVI) length as a function of "true length", i.e. length measured using callipers for three species of abalone.

Table 6. Comparisons of observers for estimating the lengths of 78 individual *Haliotis laevigata* from digital video images. Codes 1-3 described in Table 2.

Observer	Code 1	Code 2	Code 3	Mean mm code 1	Mean mm code 2	Overall Mean mm	Measure duration (mins)
1	45	30	3	131.7	131.3	131.5	28
2	42	21	15	130.2	129.4	130.0	23
3	47	27	4	134.8	130.1	133.0	35
4	41	28	9	127.5	136.0	131.0	22

4.1.3 Effect of method (DVI vs Traditional) on abundance and length estimation of *Haliotis roei* from in-situ survey sites

4.1.3.1 Abundance

There was no significant difference in mean abundance (in 18 fixed quadrats of 0.5 m^2) between the two methods, with the overall mean density from the traditional method calculated to be 32 animals per m^2, compared to 30 per m^2 for the DVI (d.f. = 17, $t = 1.40$; $p > 0.05$). Pearson's correlation coefficient (r) was 0.99, indicating a high degree of concordance between the two methods.

4.1.3.2 Length

Of the 98 *Haliotis roei* filmed at Bailey St, 67% were Code 1 or Code 2, i.e. were able to be measured, while at the MAAC club, only 48% of 368 filmed abalone were able to be measured (Figure 11). Hence the number of measured lengths using the DVI techniques was about 50% of the sample from the traditional technique.

There was no significant difference in mean length between the two methods, with the overall mean shell length from the traditional method calculated to be 58 mm, compared to 61 mm for the DVI (d.f. = 16, $t = -1.55$; $p > 0.05$). Pearson's correlation coefficient (r) was 0.58, indicating a statistically significant, but only moderate degree of concordance between the two methods. Figure 12 shows differences in performance of the DVI methodology between two experimental sites, but in general, slightly higher mean lengths are calculated by the DVI method due to the lower number of smaller abalone observed.

Examination of the % length frequency data from the two survey sites showed general overall agreement in population-frequency structure, although it appears that the DVI method is less able to sample the smaller size classes than traditional techniques, which are more adaptable for the complex 3-dimensional habitat in which *Haliotis roei* are found (Figure 13).

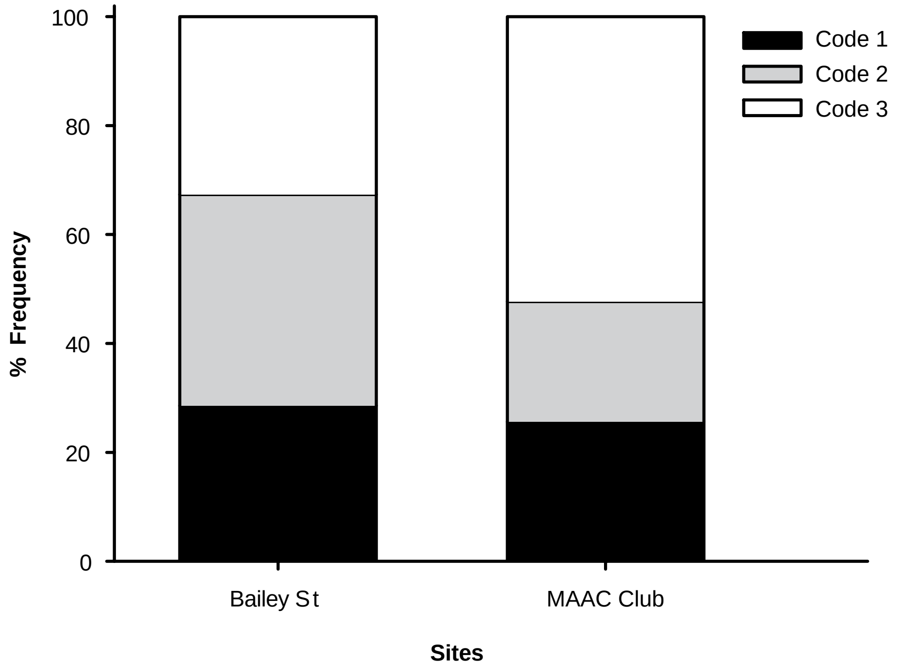


Figure 11. Percent distribution of image codes obtained from DVI applied to *Haliotis roei* at 2 long-term survey sites in the Perth metropolitan fishery. Codes defined in Table 2.

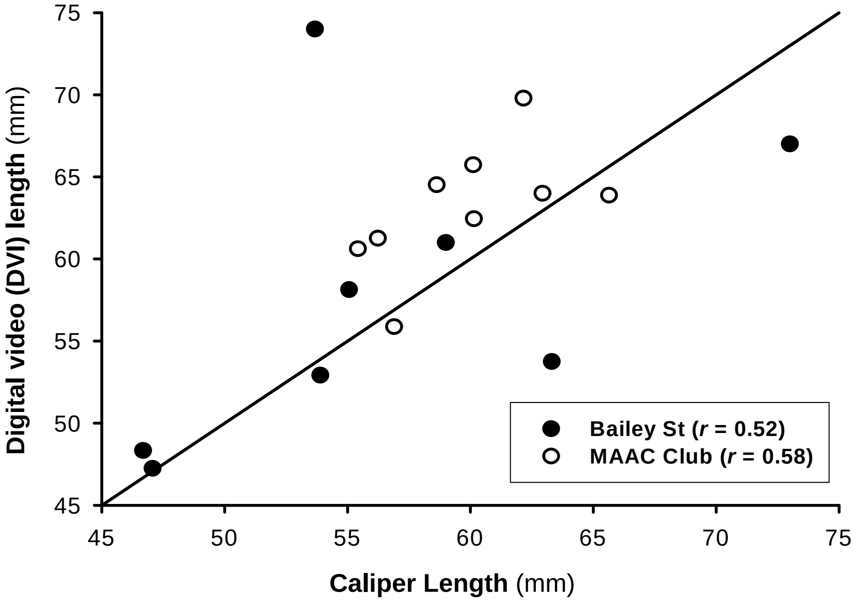


Figure 12. Mean DVI length of *Haliotis roei* as a function of mean calliper length measured within 17 x 0.5 m^2 quadrats at two survey sites in the Perth metropolitan fishery. The diagonal line represents the line of perfect fit, and correlation coefficients (*r*) are given for each site.

4.1.4 Simulated fishing mortality experiment

4.1.4.1 Abundance

There was a significant effect of time (before and after fishing) on abundance of *Haliotis laevigata*, but no effect of method, or any interaction between method and time (Table 7). Mean abundance declined by 29% from 93 to 66 animals (per site), for the DVI – research method (Figure 14), and by 31% from 90 to 62 animals (per site) for the DVI – industry method (Figure 14). Thus, the DVI method detected on average a 30% reduction in density, which compares well with the known fishing mortality of 26%.

4.1.4.2 Length

There was no significant effect of time on mean length of *Haliotis laevigata*, however there was a significant interaction between time and method (Table 7). Figure 15 shows that prior to fishing, there was a significant difference in mean length measured by the two groups of divers, but not after fishing. No method detected a difference in mean length between before and after fishing, and the reference data set (see "Traditional" - Table 8) showed no overall change in mean length following experimental fishing at 2 of the 3 sites.

Examination of mean lengths by individual sites shows that the significant effect prior to fishing occurred mostly at Site 1 (Table 8). At Site 2 and 3, changes in mean length before and after fishing are generally consistent between the Research DVI and Industry DVI methods, and in reasonable agreement with the reference data from traditional surveys (Table 8). Although not significant, the increase in average size following fishing at Sites 2 and 3, as measured by the DVI technique, suggests a slight size-selectivity bias towards larger animals by divers, as was evident in an experimental trial with *Haliotis roei* (Figure 13).

However, it needs to be recognised that the simulated mortality experiment was carried out at the beginning of the industry and research divers training in the use of DVI, and therefore represents a preliminary outcome. Improvements were expected over time as operators became more familiar with the equipment, and benefited from the critical feedback given to them over the course of the project.

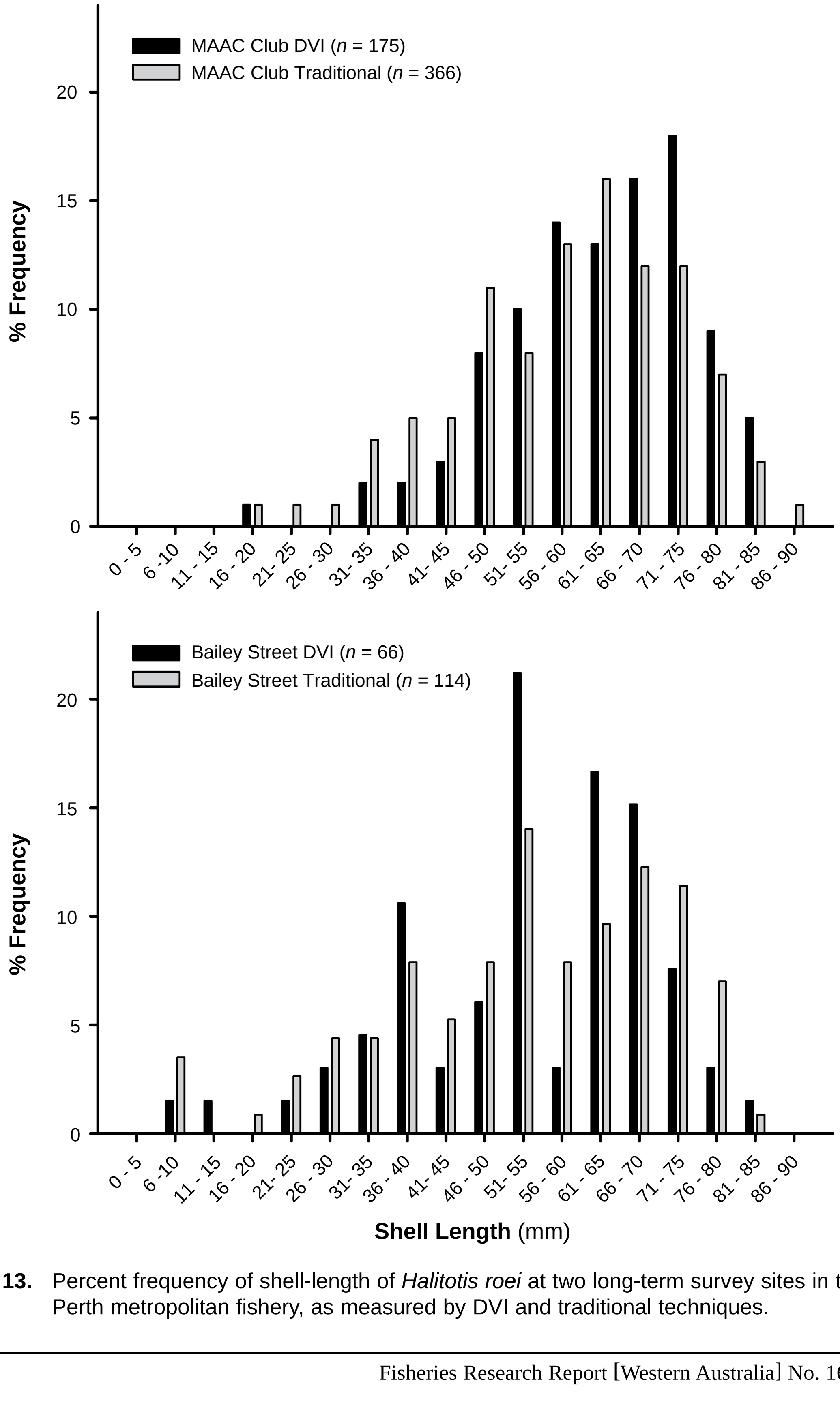


Figure 13. Percent frequency of shell-length of *Halitotis roei* at two long-term survey sites in the Perth metropolitan fishery, as measured by DVI and traditional techniques.

Table 7. ANOVA results comparing the effect of time (before, after fishing), and method (DVI research, DVI industry) on the abundance and mean shell length of greenlip abalone.

Source of variation	d.f.	F	p
Abundance			
Time	1	22.9	< 0.001
Method	1	0.39	0.54
Time X Method	1	0.002	0.96
Error	20		
Length			
Time	1	0.07	0.79
Method	1	9.83	0.002
Time X Method	1	5.00	0.026
Error	921		

Table 8. Mean length of *Haliotis laevigata* at 3 sites subject to experimental fishing mortality, and measured by DVI and traditional techniques. Mean length of animals caught at each site was 132, 133, and 143 mm for Sites 1….3 respectively.

Method	DVI - Research		DVI - Industry		Traditional	
	Before	After	Before	After	Before	After
Site 1						
Mean Length (mm)	120	123	137	125	129	113
Site 2						
Mean Length (mm)	117	120	118	124	122	123
Site 3						
Mean Length (mm)	123	128	117	126	118	118

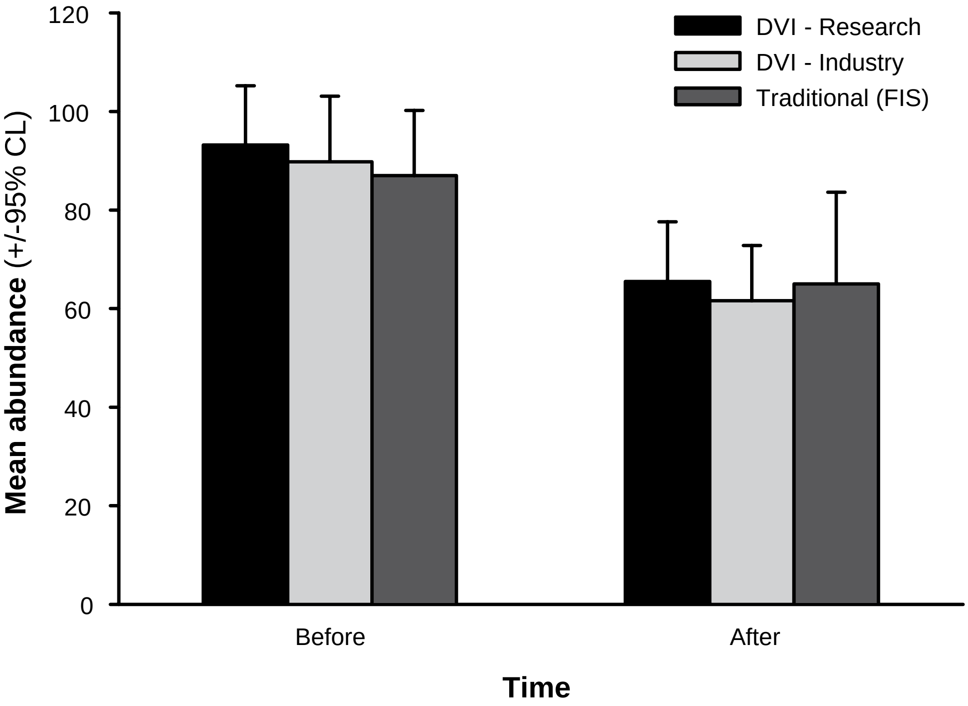


Figure 14. Mean abundance (± 95% C.L) before and after experimental fishing of *Haliotis laevigata* at 3 sites, as measured by DVI methodology.

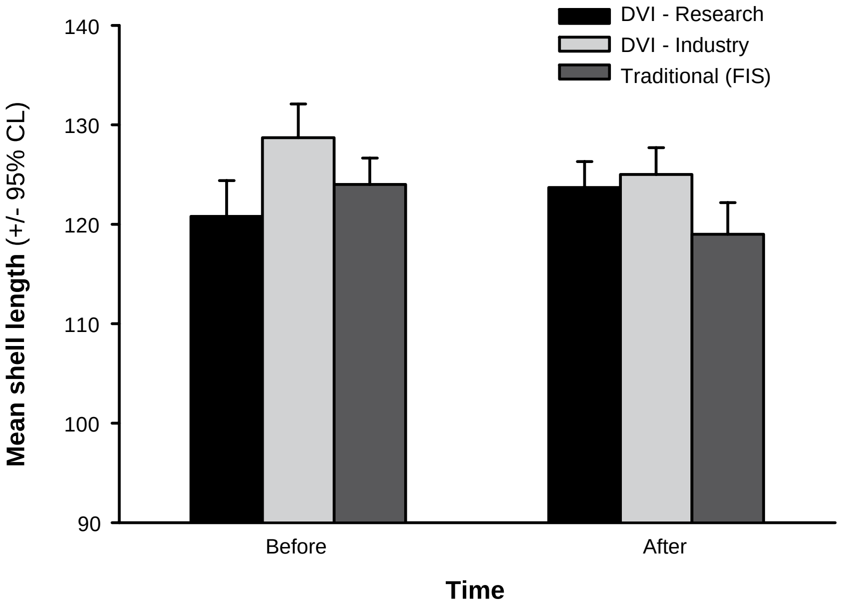


Figure 15. Mean shell length (± 95% C.L) before and after experimental fishing of *Haliotis laevigata* at 3 sites, as measured by DVI methodology.

4.1.5 Effect of swell on DVI footage quality

There was a negative correlation between % of viable length estimates (i.e. Codes 1 & 2) of *Haliotis laevigata* filmed, and size of the swell at a site in Pt Malcom (Figure 16). Although only a qualitative test due to the inability to control swell in an experimental sense, the results agree with the experience of operators familiar with the DVI technique, i.e. that swell has the most influence on the quality of their filming. Consequently, the industry diver recording sheets were amended to include an estimate of swell size.

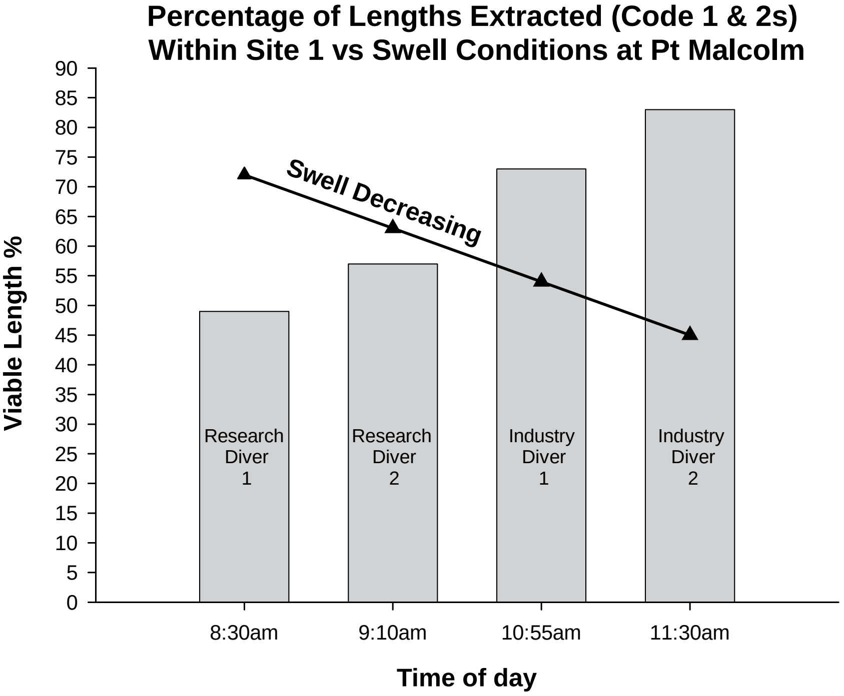


Figure 16. Effect of swell on viable length estimates (Codes 1 and 2) from DVI surveys of *Haliotis laevigata* at a site near Pt Malcolm, surveyed on the 22 October 2005.

4.2 Industry diver training and feedback

Training of divers involved a two-step process. First, all divers were initially sent a video or DVD and individually briefed if possible. Second, two experiments were set up, one in each management area, in which divers were briefed on how to operate a camera, and then given the opportunity in the field to use these under supervision from the research team. They were also shown how to set up a survey site underwater to enable repeated visits over time. Initially, a monthly schedule was made up, assigning times of year in which divers were to be filming their sites, however this proved too onerous on the divers, and more camera's were purchased to give greater flexibility and longer times to complete sites.

A sample of an industry diver feedback sheet is provided in Figure 17. The feedback sheet details the clarity of their DVI images, and general comments on their overall performance. A length frequency chart of their survey site is also provided for future reference (Figure 18). In this particular sample, a problem with site boundaries has been observed in comparison with the previous year's data, with the increase in numbers (144 compared to 76) thought unlikely as a result of natural biological processes. A change of divers monitoring this particular site occurred over this period, and the result highlights a quality control issue with the DVI methodology.

4.3 Participation rates of industry divers

Participation rate of *Haliotis laevigata* divers increased from 21% in 2003 to 36% in 2004, but declined in 2005 to 29% (Table 9). Number of sites filmed also peaked in 2004, with the total number of sites set-up being 19 in the H. *laevigata* fishery.

Haliotis roei divers did not begin filming sites until 2005, however overall participation rates at 42% have been higher than for greenlip divers, and filming already completed for the early part of 2006 (Table 9). A sample length-frequency feedback chart provided to a *Haliotis roei* industry diver is provided in Figure 19.

Slow uptake of the DVI technology by industry divers and the logistical difficulties of sharing only 4 video units between 26 abalone divers were viewed as the main impediments to a larger uptake of the technology by industry divers. Consequently, the success of the second project objective - to provide a comparison of abundance and stock structure information (between and within years) for main fishing areas videoed, has been limited. At the time of writing, only 6 greenlip sites and 3 roei sites have temporal data. The analysis of this data is dealt with in section 4.4.

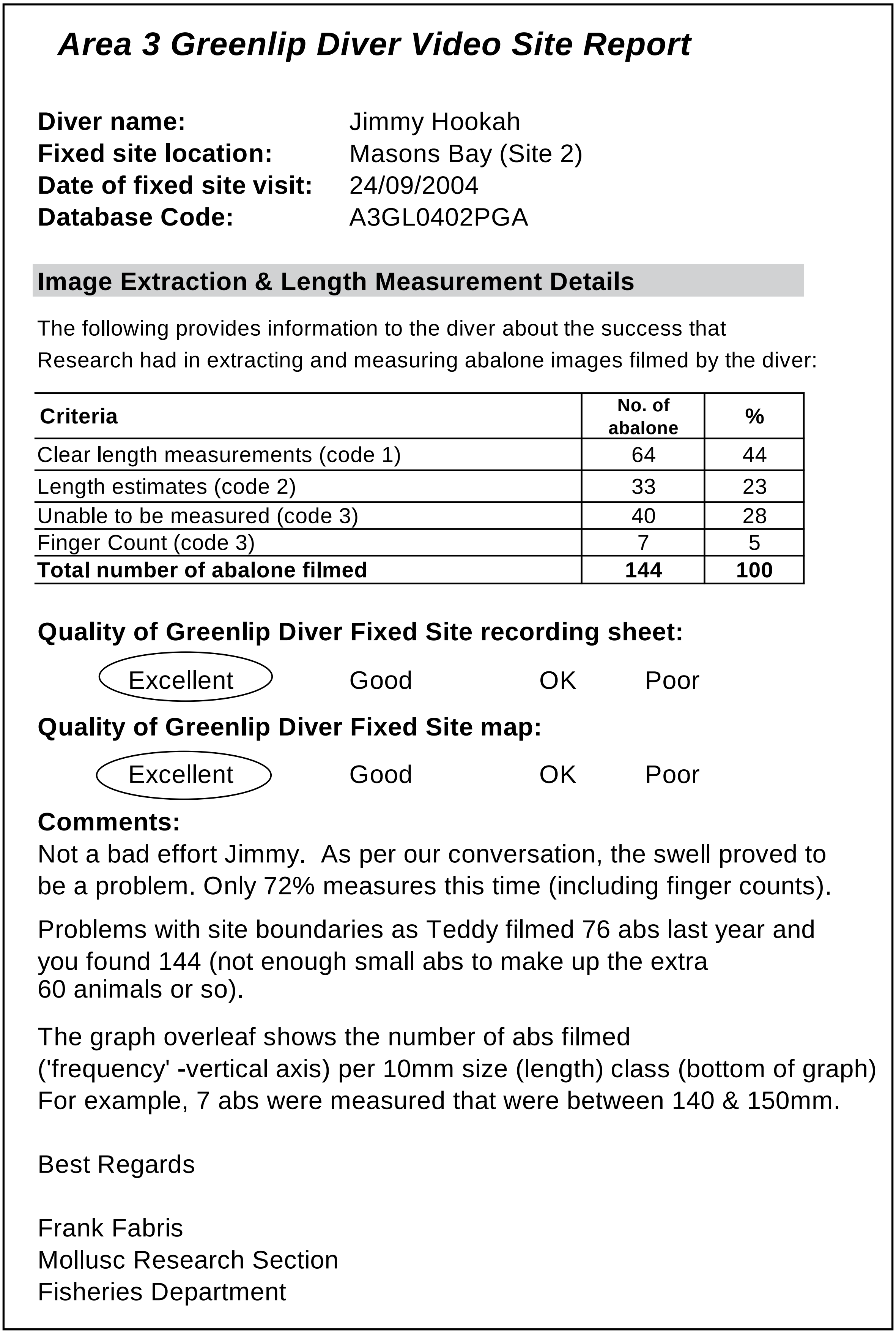
4.3.1 Assessment of participation rates against project targets

The target number of sites given in the project proposal was 60 sites. At the time of report writing, 85% (51 sites) have been achieved (Table 9). Overall, 50% of existing divers participated at least once (Table 9), however this participation was not sustained over the life of the project. Only a minority proportion of divers were genuinely enthusiastic and committed to utilise the DVI surveys. Roe's abalone divers are starting to survey a substantial number of sites (30) on an annual basis, however the greenlip industry divers are not meeting targets (Table 9).

Table 9. Participation rates and number of sites surveyed by abalone industry divers using the DVI technique for stock surveys of *Haliotis laevigata* and *H. roei*.

Species	Year	# divers participating	% participation	# sites filmed	Cumulative site total
Haliotis laevigata	2003	3	21%	3	3
	2004	5	36%	14	14
	2005	4	29%	10	19
	2006	3	21%	10	19
	2007#	2	14%	6	21
Haliotis roei	2003	–	–	–	–
	2004	–	–	–	–
	2005	5	42%	11	11
	2006	4	33%	12	12
	2007	3	25%	25	30
TOTALS@	–	13	50%	–	51

@ Refers to overall totals for the project, not averages of existing data.
# incomplete year – data only to June



Area 3 Greenlip Diver Video Site Report

Diver name: Jimmy Hookah
Fixed site location: Masons Bay (Site 2)
Date of fixed site visit: 24/09/2004
Database Code: A3GL0402PGA

Image Extraction & Length Measurement Details

The following provides information to the diver about the success that Research had in extracting and measuring abalone images filmed by the diver:

Criteria	No. of abalone	%
Clear length measurements (code 1)	64	44
Length estimates (code 2)	33	23
Unable to be measured (code 3)	40	28
Finger Count (code 3)	7	5
Total number of abalone filmed	**144**	**100**

Quality of Greenlip Diver Fixed Site recording sheet:

[✓ Excellent] Good OK Poor

Quality of Greenlip Diver Fixed Site map:

[✓ Excellent] Good OK Poor

Comments:

Not a bad effort Jimmy. As per our conversation, the swell proved to be a problem. Only 72% measures this time (including finger counts).

Problems with site boundaries as Teddy filmed 76 abs last year and you found 144 (not enough small abs to make up the extra 60 animals or so).

The graph overleaf shows the number of abs filmed ('frequency' -vertical axis) per 10mm size (length) class (bottom of graph) For example, 7 abs were measured that were between 140 & 150mm.

Best Regards

Frank Fabris
Mollusc Research Section
Fisheries Department

Figure 17. Sample feedback form to a greenlip abalone industry diver describing their performance, and the results of their surveys. The associated data is in Figure 18.

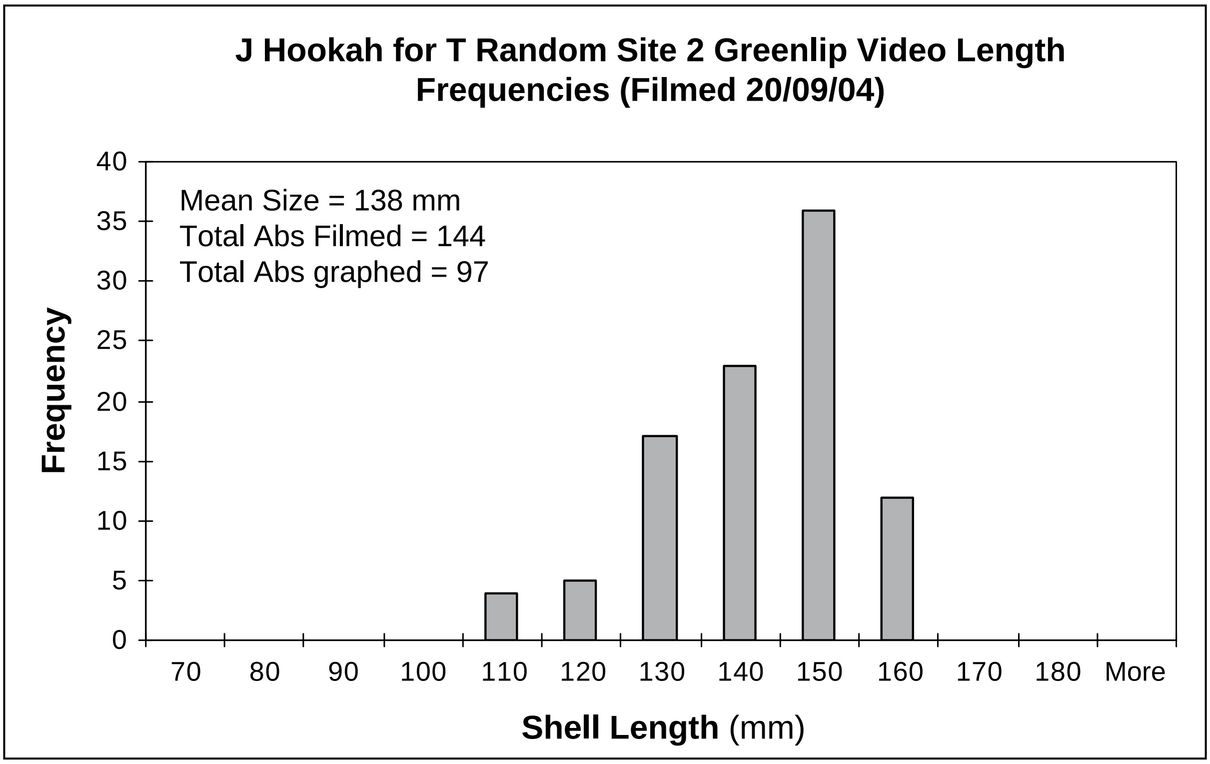


Figure 18. Sample feedback chart for a DVI survey undertaken by a *Haliotis laevigata* industry diver in Western Australia.

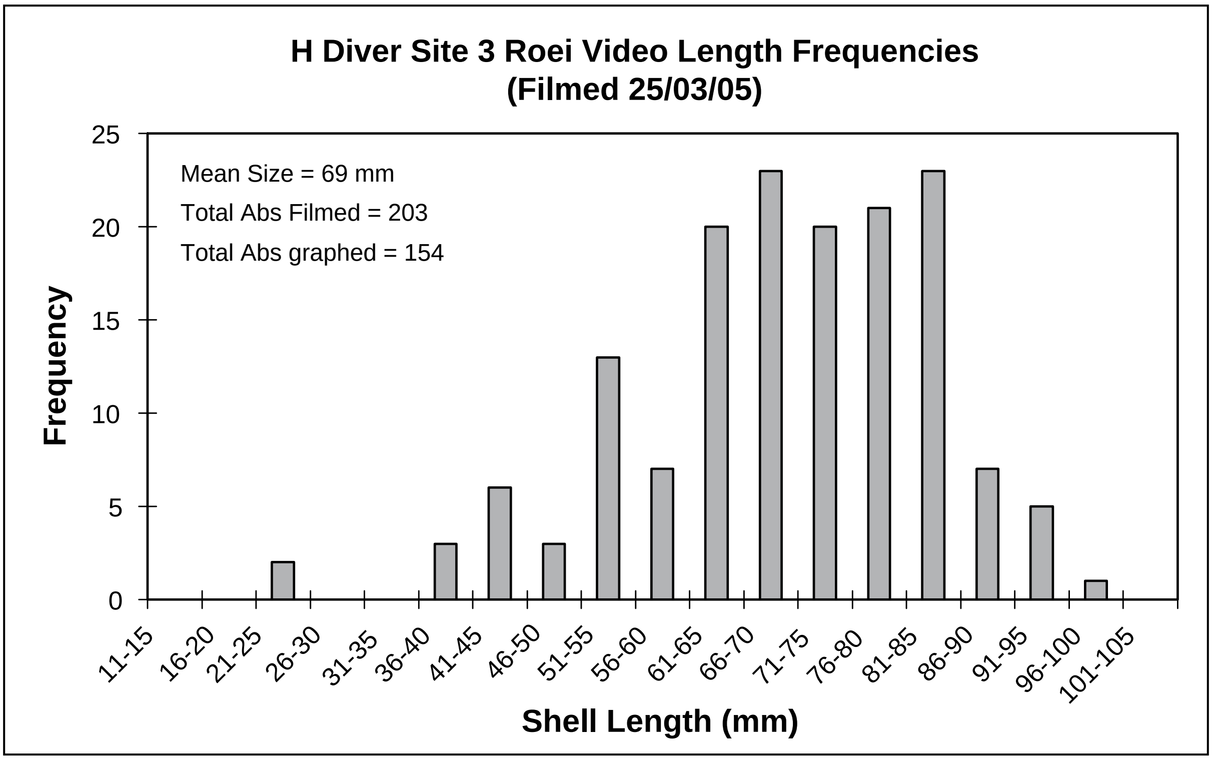


Figure 19. Sample feedback chart for a DVI survey undertaken by a *Haliotis roei* industry diver in Western Australia.

4.4 Spatio-temporal trends in abundance and size

4.4.1 *Haliotis laevigata* DVI sites

The total number of greenlip abalone filmed at 21 industry-monitoring sites during 2003 to 2007 was 3354 abalone from 10 sites in Area 2 and 11 sites in Area 3 (Table 10). Sufficient temporal data was not available to undertake a repeated measure ANOVA of mean abundance over time (n = 3 for 2003/2004, n = 5 for 2004/2005). However at those sites for which a second year of data is available, numbers are presented (Table 10), and some preliminary analyses undertaken.

On average, 26% of all animals filmed could not be measured (Table 10). This figure was similar for each of Area 2 and 3 datasets (Table 10). However, animals not measured were still included in density calculations.

Abundance

Abundance of greenlip abalone varied substantially between the 21 monitoring sites (Table 10). The variation was from 3.60 m^{-2} in Site 15 of the Area 3 fishery in 2006, to 0.17 m^{-2} at Site 9 in the Area 2 fishery in 2005 (Table 10). Overall mean abundance was 0.91 abalone m^{-2}.

In the Area 2 fishery, sites 2, 3, 7, 8 and 9 exhibited a 30-80% density reduction between the 2 survey years 2004 – 2005 (Table 10). Although this was not statistically significant on a 2-tailed paired t-test (d.f. = 4; t = 2.18; p = 0.09), there was a high correlation between the data (r = 0.71), and 3 sites (7, 8, 9) also declined in mean length (Figure 20).

Length

Mean length of greenlip abalone varied significantly between the 21 monitoring sites (d.f. 18, 1115; F=10.1; p <0.001). The variation was from 159 mm in Site 5 of the Area 2 fishery, to 127 mm at Site 1 in the Area 2 fishery (Table 10).

Temporal patterns in 2003/2004 (Sites 1, 11 and 12)

There was a significant effect of time and site on mean length of *Haliotis laevigata*, but no interaction between sites and time (Table 11). Overall mean length increased from 134 mm in 2003, to 137 mm in 2004.

Temporal patterns in 2004/2005 (Sites 2, 3, 7, 8, 9)

There was a significant interaction between time and site on mean length of *Haliotis laevigata* (Table 11). Figure 20 shows that declines in mean length occurred at Sites 7, 8, and 9, but not at site 2 and 3. Patterns at sites 7, 8, and 9 were correlated with a decline in density at these sites (see Table 10).

Table 10. Summary of Area 2 and Area 3 greenlip (*Haliotis laevigata*) diver DVI information. Density and area surveyed calculated with equations 1 - 3 in section 3.8.

Area	Year	Site	Total Number Filmed	Lengths sampled	% Measured	Density (per m2)	Mean Length (mm)	Area surveyed (m2)
2	2003	1	60	37	62	0.61	127	98
	2004	1	83	76	92	0.72	129	115
		2	93	40	43	0.74	135	126
		3	89	61	69	0.4	133	220
		4	93	85	91	1.95	133	48
		5	56	48	86	0.26	159	220
		6	41	40	98	0.48	156	85
		7	102	73	72	1.52	138	67
		8	72	61	85	0.53	140	137
		9	64	40	62	0.51	146	124
	2005	2	91	67	74	0.53	136	173
		3	95	66	69	0.53	138	180
		7	31	18	58	0.36	127	86
		8	31	25	81	0.18	137	168
		9	20	8	40	0.17	124	116
		10	102	87	85	0.58	136	177
	2007	2	149	79	53	0.81	119	305
		3	91	52	57	0.51	130	235
		10	112	73	64	0.45	128	281
3	2003	11	62	55	89	1.03	143	60
		12	75	62	83	1.91	147	40
	2004	11	75	62	83	2.52	147	50
		12	144	97	67	2.6	138	52
		13	65	61	94	0.95	139	68
		14	68	47	69	1.51	132	45
		15	74	49	66	0.83	141	89
	2005	16	128	99	77	0.41	138	314
		17	124	59	48	0.70	137	177
		18	100	54	54	0.53	137	187
		19	79	77	97	1.05	131	75
	2006	11	63	56	89	1.47	149	43
		12	101	80	79	2.77	140	36
		13	65	59	90	0.84	146	77
		14	91	64	70	1.80	129	51
		15	74	32	43	3.60	153	21
		18	136	109	80	0.40	130	272
		19	103	78	76	0.59	125	232
	2007	16	113	99	88	0.37	127	305
		20	81	66	81	0.34	128	235
		21	58	53	91	0.21	137	281
TOTALS/ MEANS			3354	2454	74	0.96	137	142

Table 11. ANOVA results comparing the effect of year and site on the mean shell length of greenlip abalone from industry diver DVI surveys.

Source of variation	d.f.	F	p
2003/2004 (Sites 1, 11, 12)			
Year	1	7.2	0.008
Site	2	41.0	<0.001
Year X Site	2	0.7	0.50
Error	391		
2004/2005 (Sites 2, 3, 7, 8, 9)			
Year	1	19.2	<0.001
Site	4	3.1	0.017
Year X Site	4	3.3	0.011
Error	412		

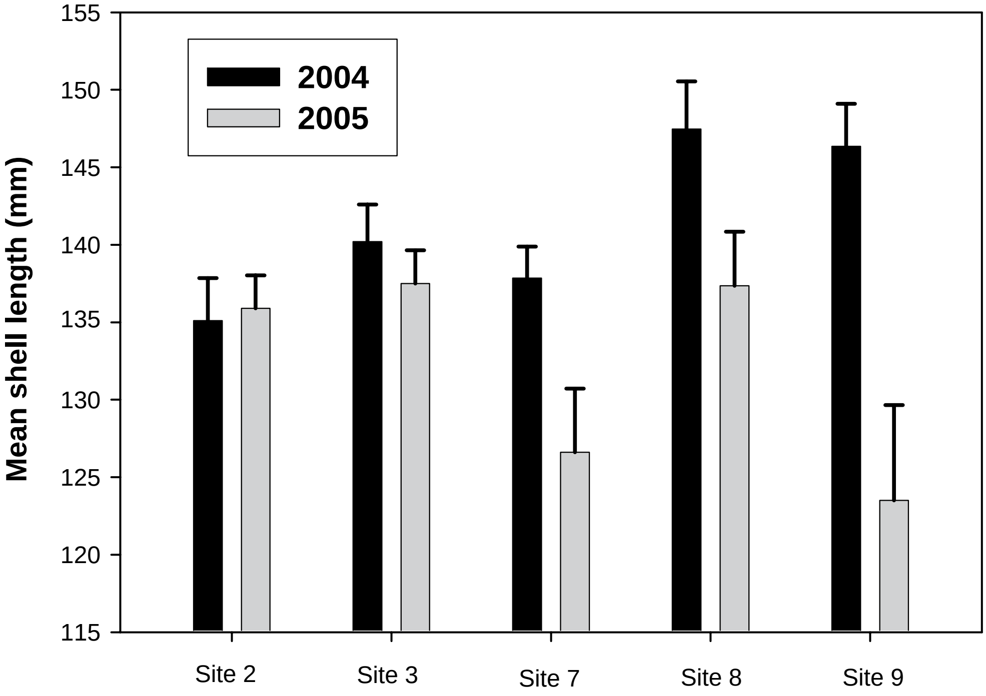


Figure 20. Mean length (± SE) of *Haliotis laevigata* over 2004/2005 at DVI Sites 2, 3, 7, 8, and 9.

4.4.2 *Haliotis roei* DVI sites

The total number of *Haliotis roei* filmed at 30 industry-monitoring sites was 9290 (Table 12).

Abundance

Density of roe's abalone varied substantially between the 30 monitoring sites (Table 12). The variation was from 25 m^{-2} in Site 11 of the Area 7 fishery, to 1.6 m^{-2} at Site 22 in the Area 5 fishery (Table 12). Overall mean density was 7.0 roe's abalone m^{-2}. Mean abundance at Sites 1, 2, and 3 did not differ significantly between 2005 and 2006 (d.f = 2; paired $t = 0.31$; p = 0.78). However time spent filming at these 3 sites increased by 300%, from an average of 10 minutes in 2005, to 30 minutes in 2006, which doubled the overall area surveyed (Table 12).

Length

Mean length of roe's abalone varied significantly between the 30 monitoring sites (d.f. 30, 4391; F = 18.5; p <0.001). The variation was from 57 mm to 75 mm (Table 12). Size-frequency data from the DVI method show considerable difference in size-frequency of *Haliotis roei* between commercially fished management areas 2 and 7, and these were maintained over time (Figure 21).

Table 12. Summary of *Haliotis roei* diver DVI information. Density and area surveyed calculated with equations 1 - 3 in section 3.8.

Area	Year	Site	Total Number Filmed	Lengths sampled	% measured	Density (per m2)	Mean Length (mm)	Area surveyed (m2)
2	2005	1	124	98	79	3.2	66	39
		2	296	143	48	18.4	67	16
		3	203	154	76	7.6	69	27
6		4	170	7	N/A	5.3	N/A	32
7		5	290	135	47	9.5	57	31
		6	183	119	65	8.5	64	21
		7	80	64	80	3.0	63	27
		8	103	61	59	4.4	68	24
2	2006	1*	415	117*	86	4.8	69	77
		2*	440	238*	79	5.8	69	66
		3*	521	181*	83	8.8	70	51
7		7	159	129	81	7.5	63	21.1
		8	147	95	64	5.8	68	25.1
		12	106	83	78	6.84	71	15
		9	151	117	77	8.8	61	17
		10	129	86	66	9.6	69	13
		11	170	118	69	24.9	57	7
		13	109	65	59	2.7	68	40
		5	120	59	49	3.03	69	39
		14	127	89	70	3.25	66	39
7	2007	7	129	76	59	5.4	58	23
		8	173	137	79	7.1	66	24
		12	127	75	59	3.8	69	32
		29	208	153	74	10.7	65	19
		30	182	139	76	8.0	69	23
		9	170	150	88	12.6	63	14
		10	147	86	58	10.6	67	14
		11	161	79	49	10.0	66	16
2		1	266	217	81	6.9	65	38
		2	214	200	93	4.1	67	52
		3	185	153	83	3.6	63	51
		15	203	184	91	4.2	65	49
		16	143	71	50	2.6	73	55
		17	276	179	65	5.7	70	48
		18	304	274	90	6.9	66	44
		19	182	145	80	3.5	62	52
		20	152	132	87	3.6	74	42
		21	315	233	74	4.9	66	64
5		22	96	70	73	1.6	64	59
		23	161	102	63	3.4	70	47
		24	309	177	57	10.8	69	28
2		25	219	178	81	6.1	70	36
		26	304	184	60	9.3	69	33
		27	316	219	69	9.4	71	33
		28	305	255	84	8.8	64	35
TOTALS / MEAN			9290	6026	71	7.0	66	35

* Due to the large number of animals filmed at these sites, the number of lengths sampled is not indicative of the quality of filming, which was very good, but represents only a random sub-sample of total images.

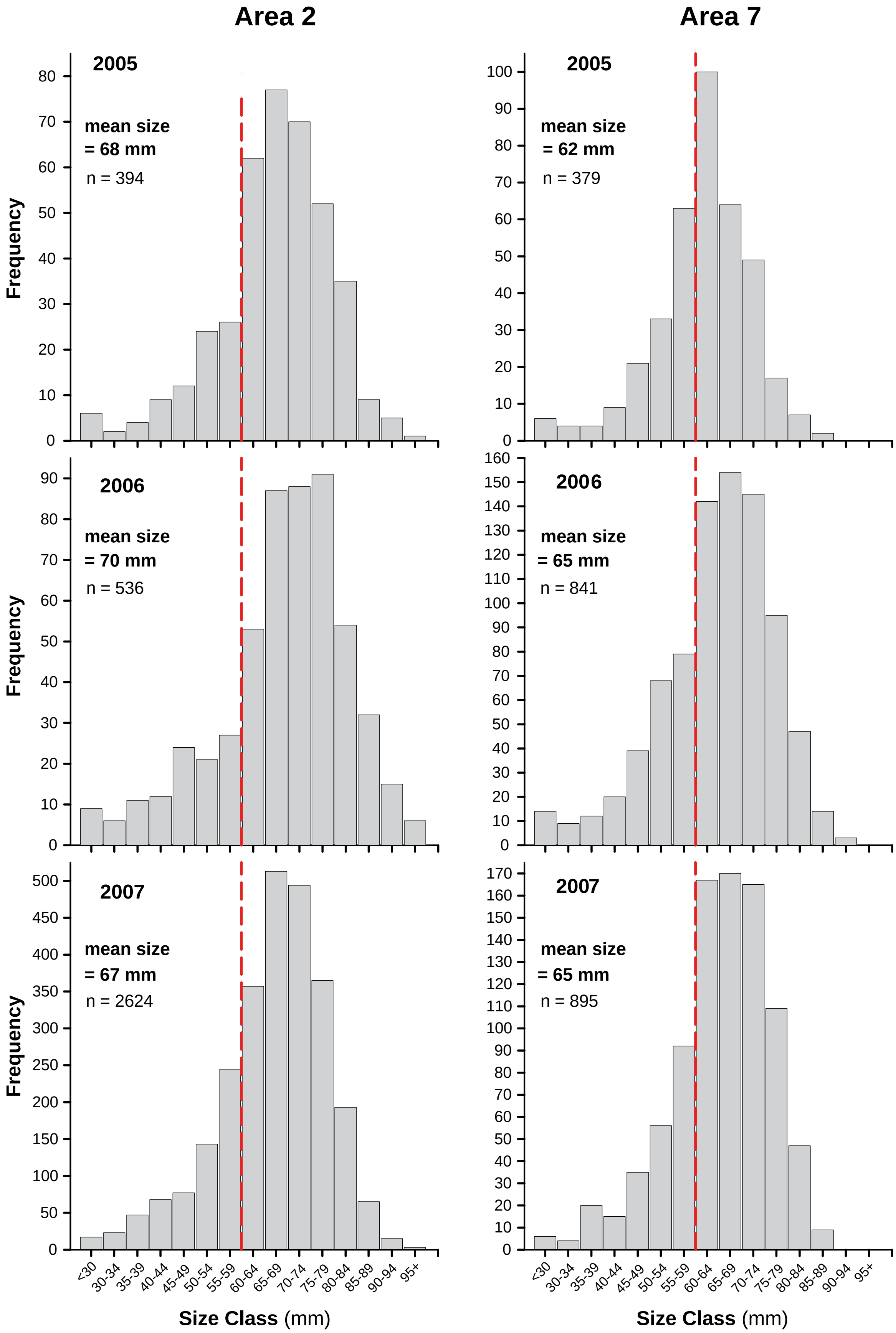


Figure 21. Size-frequency of *Haliotis roei* in fishery management areas 2 and 7 from 2005 to 2007. Data obtained from DVI surveys by industry divers. Figure 8 shows a description of management areas.

4.5 Comparison of density and size-frequency data from fishery independent surveys (FIS) and the DVI technique

4.5.1 *Haliotis laevigata*

There was no significant difference between the FIS or DVI methods in measuring pre-recruit (100 – 139 mm; d.f. = 22, p = 0.21) or legal-sized density (≥ 140 mm; d.f. = 22, p = 0.84) of greenlip abalone in the Area 2 fishery. However, there was a significant difference between the FIS and DVI methods in measuring density of juveniles (d.f. = 22, p = 0.02). Mean density of legal-sized animals was 0.33 m^{-2} and 0.35 m^{-2} according to the DVI and FIS methods respectively (Figure 22).

There was a significant difference between the FIS or DVI methods in measuring length of greenlip abalone in the Area 2 fishery (Table 13). This occurred despite significant variation in length between sites (Table 13). Comparison of the size-frequency of populations measured by both methods show that the DVI method is biased towards the larger animals, in comparison with the FIS method (Figure 23), as was shown by the density analysis.

Table 13. Nested ANOVA results comparing the effect of method (DVI vs FIS) and sites (nested within method) on the mean shell length of *Haliotis laevigata* in the Area 2 fishery.

Source of variation	d.f.	MS	F	p
Method	1	41684	11.02	0.003
Site (Method)	20	5463	10.39	<0.001
Error	1791			

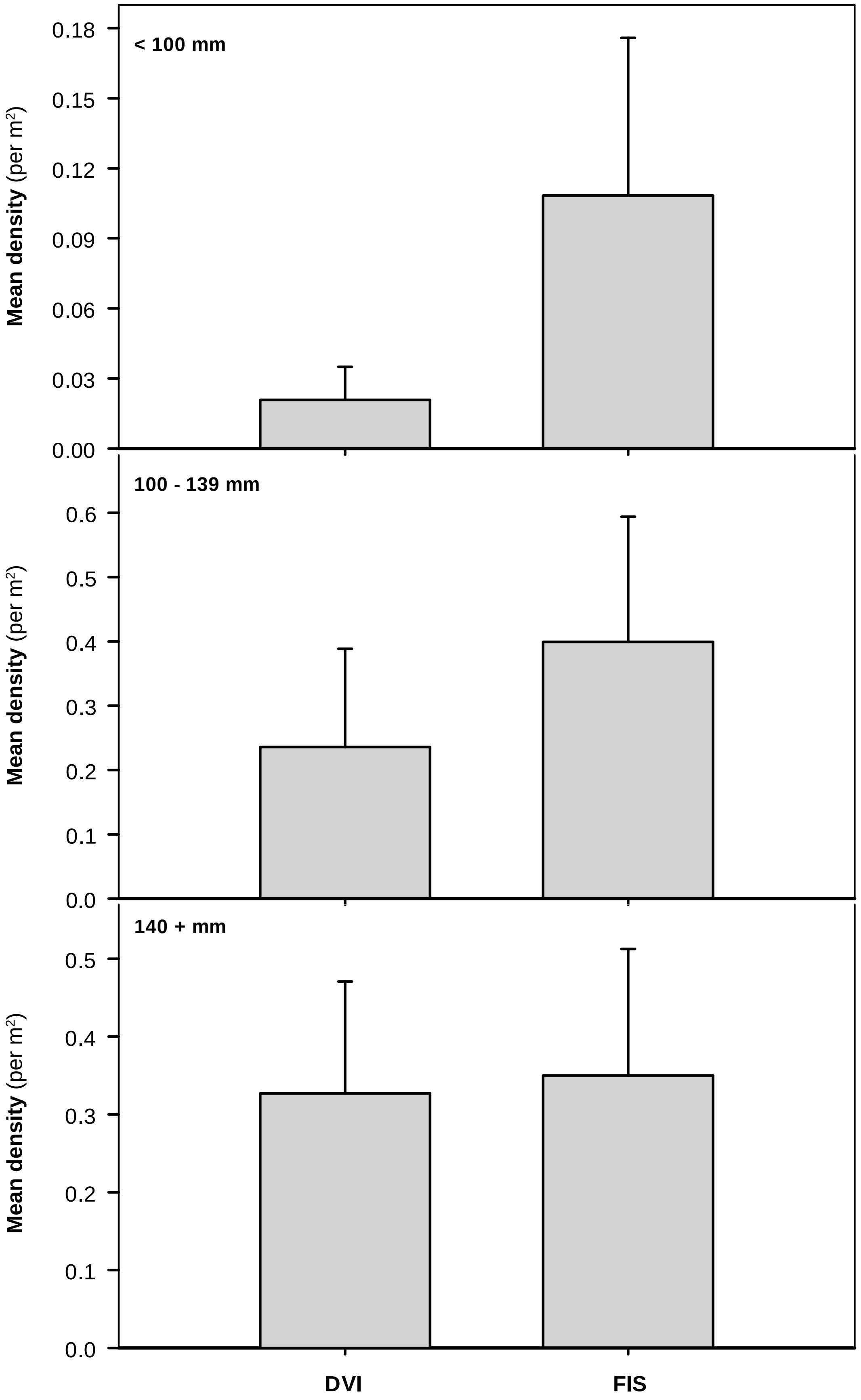


Figure 22. Mean density (± 95% CL) of juveniles (< 100 mm shell length), pre-recruits (100 – 139 mm) and recruits (≥ 140mm) of *Haliotis laevigata* in the Area 2 fishery, as measured at 10 DVI (digital video image) sites and 14 FIS (fishery independent survey) sites.

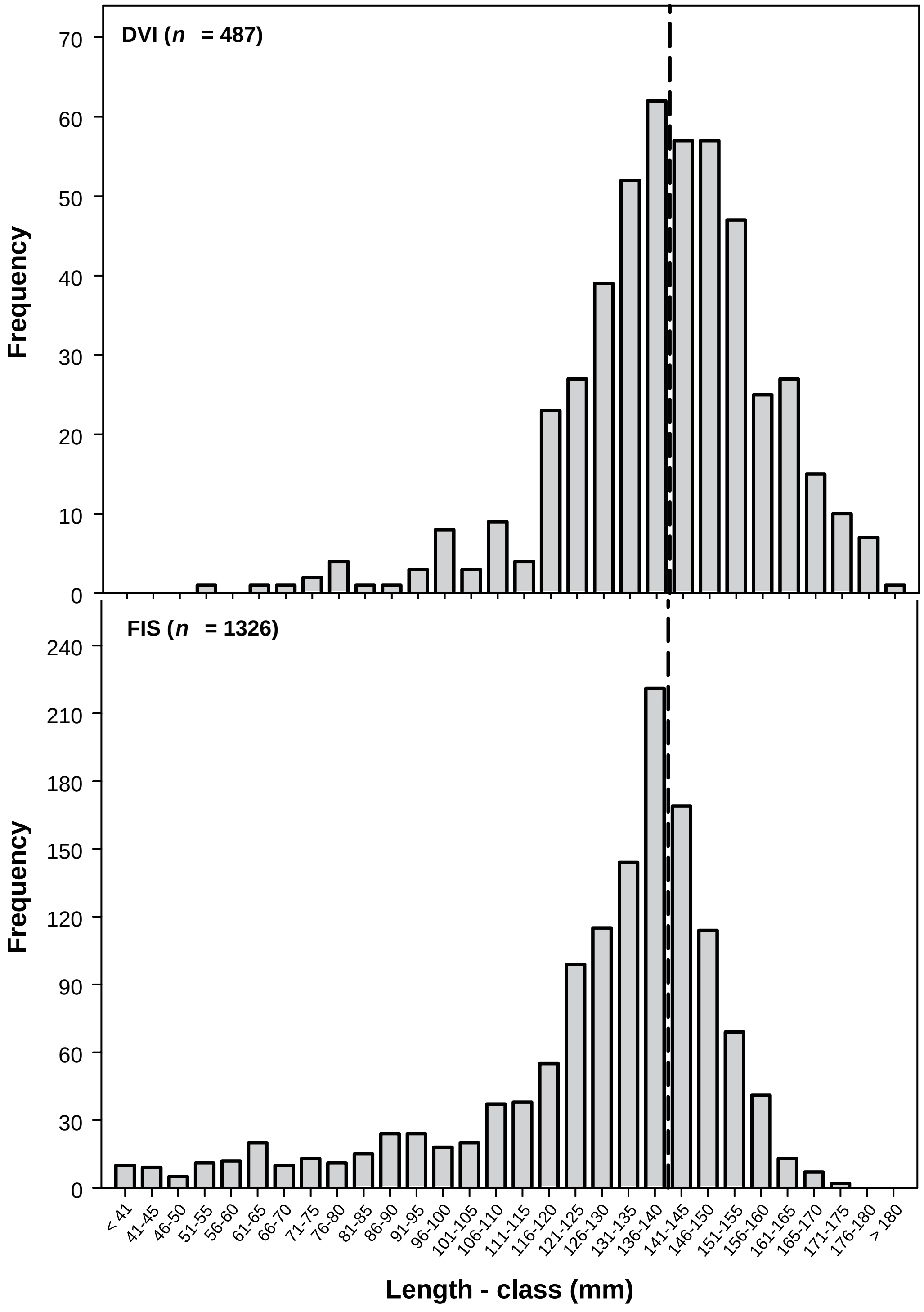


Figure 23. Size-frequency of *Haliotis laevigata* in Area 2, as measured by DVI (industry divers), and FIS (research personnel) survey methods. The dashed line is the legal minimum length (140 mm). Figure 7 shows the management areas.

4.5.2 Cost-benefit analysis

Using estimates derived from Table 14, the cost of obtaining a precision of 0.2 for pre-recruit (100-139 mm shell length) and legal-sized (≥ 140 mm) *Haliotis laevigata* was greater with the FIS method (Figure 24; Figure 25). In particular, the better precision and lower cost per sampling unit for the DVI method, resulted in a cost of sampling legal-sized greenlip abalone that was about 40% of the FIS methodology (Figure 25). The overall cost of surveying a DVI site was $418, which was about 80% of the cost of an FIS site ($510.50 – Table 14).

When sampling greater than 20 sites for both methods, only marginal increases in precision were achieved. For example, to improve precision from 0.2 to 0.15 for pre-recruit sampling, an increase from 20 to 35+ sites is required for both methods (Figure 24). For legal-size abalone, 20 sites will achieve a precision of 0.2 for the FIS method, and 0.15 for the DVI method, however substantial increases beyond this require a doubling or tripling of sampling effort and costs (Figure 25).

Based on precision and costs, DVI is clearly the optimal methodology for measuring legal-sized greenlip abalone. However, the difference between the methods is less evident for pre-recruits (100-139 mm), and the DVI method is not suitable for sampling juveniles (< 100 mm shell length). Also, the accuracy of the data, particularly as commercial divers, rather than trained research personnel are supplying it, is not determined. Further discussion on this is given in section 4.6.3.1.

Table 14. Cost (hours and $) estimates of *Haliotis laevigata* surveys using video (DVI) and transect-based fishery independent methods (FIS). Cs is total cost per site, Cc is cost of data collection, and Cx is the cost of data extraction.

Method	Cost parameter	Cost (hrs)	Cost ($)	Description
DVI	Cc	5.33	$300	**Hours:** 3 sites / day x 2 people (16 hrs/3 sites) **$:** 900 / 3 sites
	Cx	1.97	$118.20	**Hours:** average hours of extraction+ measuring+ data grooming (n = 24 sites) **$:** technical officer @ $50 / hr
	Cs	7.30	$418.20	
FIS	Cc	8.00	$500	**Hours:** 3 sites / day x 3 people (24 hours / 3 sites) **$:** technical officer @ $50 / hr + $100 operating (fuel, equipment)
	Cx	0.42	$10.50	**Hours:** 25 minutes data entry time per site **$:** data entry officer @ $25 / hr
	Cs	8.42	$510.50	

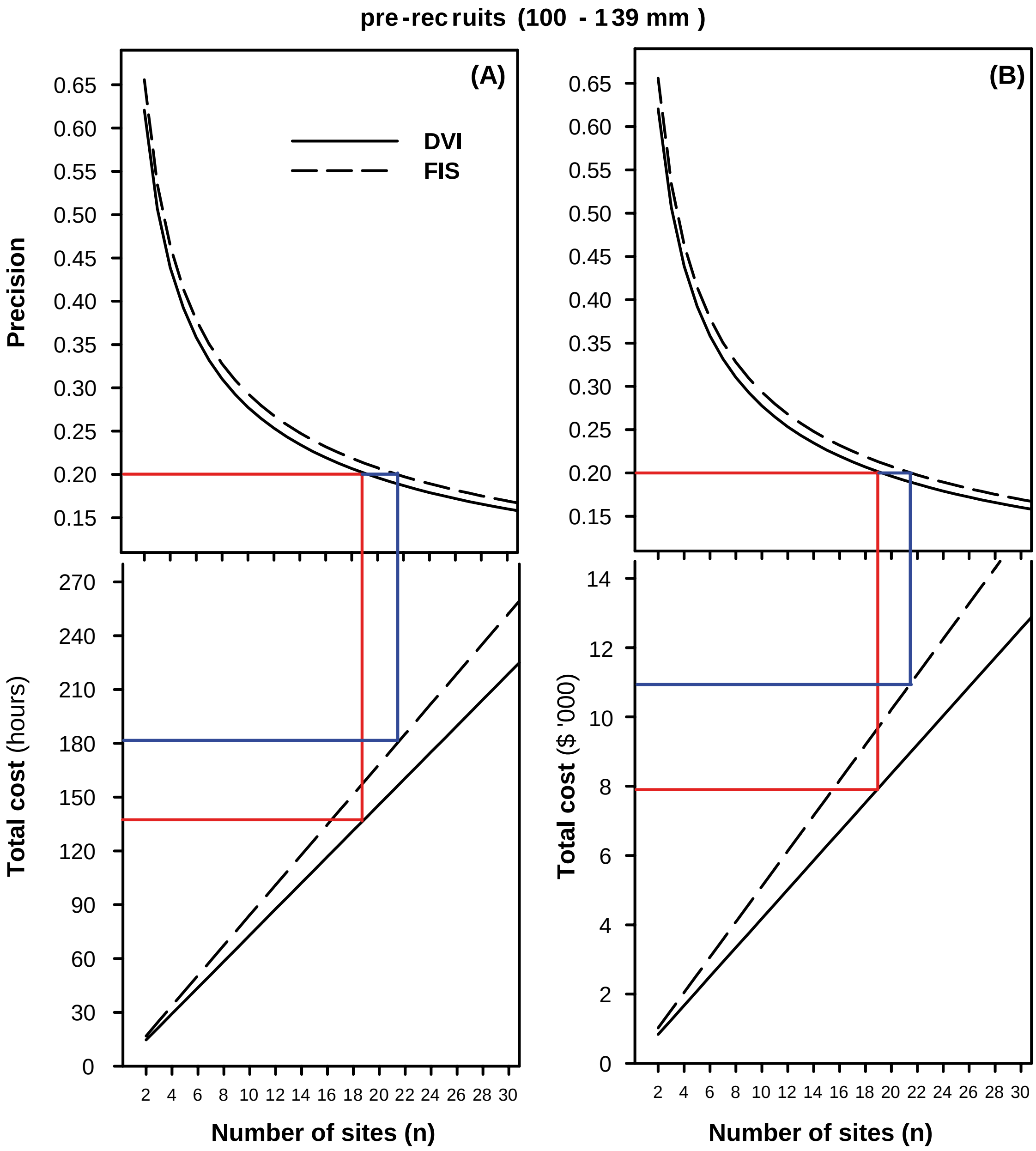


Figure 24. Precision (SE/$\bar{x}$) of the DVI and FIS survey methods as a function of cost (A – hours; B- $) of surveying pre-recruits (100-139 mm shell length) of *Haliotis laevigata*. The cost of obtaining a precision of 0.2 for the DVI (red line) and FIS (blue line) methods is shown.

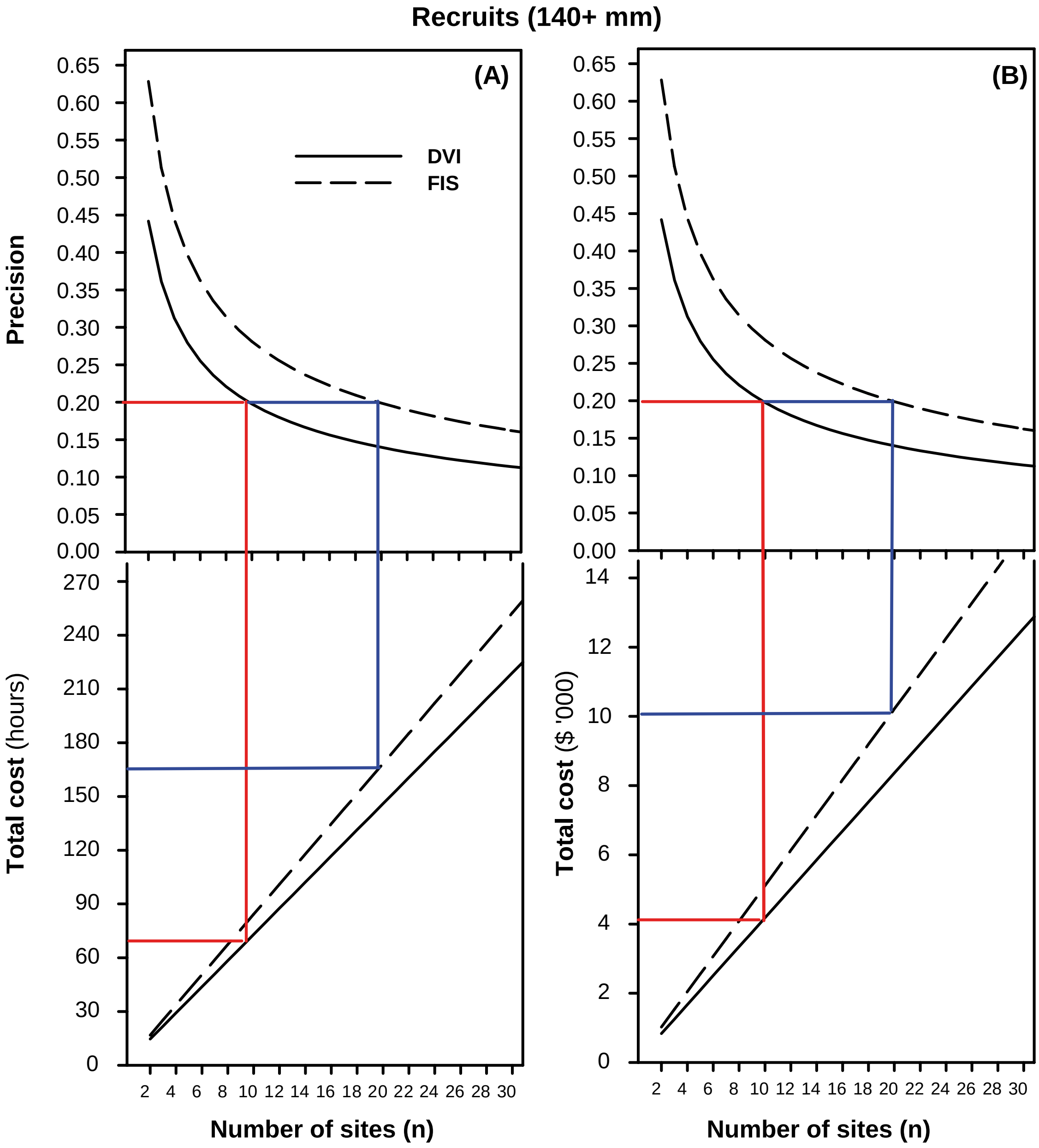


Figure 25. Precision (SE/ $\bar{x}$) of the DVI and FIS survey methods as a function of cost (A – hours; B- $) of surveying recruits (≥ 140 mm shell length) of *Haliotis laevigata*. The cost of obtaining a precision of 0.2 for the DVI (red line) and FIS (blue line) methods is shown.

4.6 General Discussion

Experimental tests of the DVI method proved it to be a satisfactory and potentially reliable method for undertaking abundance and length-frequency surveys of *Haliotis laevigata* and *H. roei* in Western Australia. Accuracy tests yielded negligible bias with both abundance and lengths being reliably estimated when appropriate sampling control and filming technique was applied. The DVI technique will not result in 100% of viable images for individual abalone (Codes 1 & 2), however averages between 50 and 80%, depending on species and location (see Table 6 and Figure 11) can be realised. Statistical comparisons of the mean of a subset of lengths obtained by DVI images, compared with the mean of the entire sample of lengths obtained by traditional techniques (e.g. Table 8; Figure 13) generally showed this sub-section to be unbiased, except for animals in the smallest size classes (< 100 mm length for *H. laevigata*; < 30 mm length for *H. roei*). Furthermore, in the case of *H. laevigata,* the DVI technique was able to reliably detect a known fishing mortality in an experimental test, with both commercial industry divers and research personnel detecting the effect (see Figure 14). However, that experiment also detected an unexplained increase in mean length (see Figure 15), a result considered unlikely as fishing only occurred on the legal-sized portion of the population. This indicates a need to be mindful of site-boundary effects and filming technique. Generally it is possible to detect poor angle of camera position from visual inspection of images, and they are usually given a code 3 rating (unable to be measured; see Table 2).

4.6.1 Industry participation and filming protocols

Substantial effort was given to training industry divers to undertake surveys using the DVI methodology. Two videos/DVDs were produced, one for each species, and in-water training experiments carried out for many of the divers alongside individual briefings. Comprehensive feedback was also given, with the objective being to encourage the divers to stay committed to the project. At the completion of the project, 85% of the target of 60 sites (51 sites) was completed.

It appears that the DVI method may be particularly suited to the *Haliotis roei* industry, as the high density of this species mean a lot more animals can be filmed, although the numbers are negated by image quality to an extent. For example, 1400 Roe's abalone were filmed by 1 industry diver at 3 of his DVI survey sites in a single day. In these situations, only a sub-sample of these animals would be measured, as the frame extraction and measuring process is the most time-consuming. In recognition of the potential of the DVI methodology for the Roe's abalone fishery, the industry has made a major commitment to increasing its survey commitment. At the completion of the project, 30 monitoring sites had been set up.

4.6.2 Spatio-temporal analysis of density and length-frequency

Substantial spatial variation in mean density and length-frequency was measured by industry divers, with 21 greenlip and 30 roei sites surveyed. Density of *H. laevigata* measured by DVI were slightly higher than the published ranges of 0.2 – 0.7 m^{-2} at monitoring sites in South Australia (see Figure 2.12 of Mayfield et al., 2005b), although the discrepancy may be rectified by re-evaluating some of the assumptions of the analysis, such as searching efficiency of the divers while holding a camera. Shepherd & Partington (1995) considered that 0.15 adult (120 mm+) greenlip per m^2 was a minimum viable density below which populations may not be self-sustaining. It is not known whether this figure would apply to Western Australian stocks, however average densities measured by both DVI and FIS methods were above 0.15 m^{-2}.

Overall, the density estimates of greenlip abalone in Western Australia are considered preliminary until further qualifications of searching and fishing efficiency parameters of greenlip divers are made.

Similarly, the statistically significant spatial variation in mean length is suggestive of considerable spatial variation in growth. This is confirmed by unpublished growth data held by the Research Division. Such a result demonstrates that the DVI method, as utilised by commercial divers, is capable of realistically assessing spatial heterogeneity in density and stock structure.

No robust comparisons of temporal trends in density were possible with the limited temporal data, however declines of 60-80% in greenlip density were measured at 3 sites (7, 8, and 9 in Area 2; see Table 10) between 2004 and 2005. This was considered a reliable result as the film footage showed unequivocally that the same area was surveyed, which indicates the method can detect temporal change in realistic, as opposed to experimental, scenarios. Clearly however, until the number of DVI sites reaches a reasonable sample size (minimum of 20 sites per management area), inferences at an assessment and management perspective shall be limited.

4.6.3 Comparisons of industry video surveys with fishery independent research surveys (*Haliotis laevigata*)

Experimental validation aside, the paramount objective of the DVI methodology is to provide quality stock survey information for assessment purposes. Although a robust test was not possible, a preliminary test was undertaken and showed no significant difference in mean density of *Haliotis laevigata* between the two methods for pre-recruits (100 -139 mm) and legal-sized abalone (≥ 140 mm). However, there was a significant difference in density of juveniles between the two methods. Comparisons of mean size showed clearly that the proportion of adult abalone (120 mm+) was substantially higher for the DVI method (87%), compared to the fishery independent surveys (75%). Hence the main difference between the two methods is that industry DVI surveys are not sampling the juvenile portion of the population as effectively as the FIS surveys and will not be able to obtain absolute measures of recruitment (e.g. 2+ or 3 + age classes). However this bias may be corrected in a population model by applying a selectivity curve, the parameters of which can be estimated from comparative studies with absolute density estimates.

4.6.3.1 Cost-benefit analysis

Based on precision and costs, DVI is clearly the optimal methodology for measuring legal-sized greenlip abalone. The difference between the methods is less evident for pre-recruits (100-139 mm), and the DVI method under samples the juveniles (< 100 mm shell length), although this bias could be corrected by a selectivity curve. The real advantage of the DVI method is in providing a broad-scale assessment of a large number of commercially fished abalone reefs, particularly those that are remote or inaccessible, to aid in the assessment of fishing mortality. The disadvantage is that the accuracy of the DVI data, particularly as commercial divers are supplying it, cannot be determined, except indirectly though repeated measures at the same site. This was shown to be a major issue in a comparison of timed-swim research surveys and area-based methods for *Haliotis rubra* (Hart and Gorfine, 1997) and *H. laevigata* (McGarvey, 2004). The DVI is more analogous to a timed swim, which has been shown to be more precise than area-based surveys, but inaccurate, as they rely on estimates of area searched using ancillary parameters such fishing power and handling or filming time per abalone.

It also worth noting that the cost-benefits of the DVI methodology, particularly for sampling legal-sized animals, are likely to be further enhanced by a reduced cost per hour, as well as reduced total hours required.

4.6.4 Optimising and validating the abalone industry diver DVI programme in Western Australia

Our conclusion is that the evidence presented in this report demonstrates that the DVI method has real potential to be a valid assessment tool for the Western Australian abalone fisheries. However for this to occur, the following actions need to be taken.

- Results need to be presented to Industry and a process for future surveys needs to be determined. This could be a combination of research FIS and Industry/Research DVI surveys.
- Responsibility for undertaking the surveys be assigned to 2 or 3 genuinely enthusiastic divers (per area) and appropriate remuneration negotiated.
- Minimum annual site targets need to be set. These are 30 sites for each of the Area 2 and Area 3 greenlip fisheries, and 20 sites for each of the Area 2, 5, 6, and 7 roei fisheries.
- Camera equipment management and allocation needs to realistically account for the relatively small windows of available survey days in relation to weather and fishing commitments.

5.0 Benefits

The most immediate beneficiary of the results of this study is the abalone industry of Western Australia, who now have the potential to be actively involved in monitoring of their own stocks, thus providing useful information beyond their fishery catch rates data. Secondly, the West Australian public benefits because of the enhanced management ability of the abalone stocks, thus reducing risk of stock depletion. The DVI also provides a technique for fishery independent survey data, which is required by the Department of Environment and Heritage for export approval to be maintained. Use of this technique could also be expended beyond commercial abalone divers to the general recreational diving community, sections of which are likely to be enthusiastic about being involved in the DVI research surveys.

6.0 Further Development

One of the real risks to this project is the continual changes and modification of digital video cameras, which render the underwater housing units obsolete relatively quickly. This will make it difficult to keep track of the pixel/bar length ratios necessary to obtain accurate length estimates. There is a need to maintain quality control of this methodological issue.

There may be potential to further develop the method with the use of “trained research volunteers”, such as keen recreational abalone divers that are willing to supply the information to assist with stock management. The Department of Fisheries WA, is currently developing a Research Angler Program aimed at utilising keen fishers, and it would be advantageous to create synergies with this already existing program.

A long-term time series of data to determine trends in pre-recruits and legal-sized abalone is needed before the DVI survey data can be used for management.

7.0 Planned Outcomes

The three project outputs were:

1. A comprehensive report on the reliability of in-water video for abalone reef census to enable cost-effective monitoring of stocks.
2. Provision of a valuable temporal and spatial assessment of abalone abundance, stock structure and growth (between and within years) to provide improved sustainable management of abalone stocks in Western Australia.
3. An industry generated pictorial database of reef health and stock status.

Progress towards completing these planned outcomes is described in the following dot points.

- The above report details the reliability and limitations of the DVI methodology.
- Detailed spatial assessments were made, as reported, however analysis of temporal trends were limited due to the slow uptake of the technology by industry divers. Despite this, a total of 51 sites have been surveyed, and repeated surveys of these locations will provide the temporal data needed for stock assessment purposes.
- Over the course of the project experimentation and industry site surveys, over 13,000 individual images of abalone and the habitats in which they occur have been collected and stored for future reference. A pictorial database of reef health was not achieved due to the necessity for a different sampling and filming regime to be implemented.

8.0 Conclusion

Our general conclusion is that the DVI method has potential to be a valid assessment tool for the Western Australian abalone industries. However, for this to occur, the programme needs to be scaled up to the appropriate level with quality control of site selection, camera equipment allocation, and clear targets and responsibility for industry personnel undertaking the surveys. A minimum number of genuinely enthusiatic commercial divers employed to undertake the surveys is considered to provide the best chance of successfully completing the programme.

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11.0 Appendices

11.1 Intellectual Property

There are no intellectual property issues associated with the materials generated during this project.

11.2 Staff

Dr Anthony Hart (Department of Fisheries, Western Australia)
Frank Fabris (Department of Fisheries, Western Australia)
Dave Murphy (Department of Fisheries, Western Australia)
Jamin Brown (Department of Fisheries, Western Australia)
Jamie Colquhoun (ex-Department of Fisheries, Western Australia)
Boze Hancock (ex- Department of Fisheries, Western Australia)

The Western Australian Fisheries and Marine Research Laboratories at Hillarys Boat Harbour, Perth, are the centre for fisheries research in Western Australia