Abalone Industry Development: local assessment and management by industry.

Final report for FRDC project number: 2005/024

Robert Day
Jeremy Prince
Harry Gorfine
Luke McAvaney
Patrick Gilmour

THE UNIVERSITY OF MELBOURNE

Australian Government

Fisheries Research and Development Corporation

Project No. 2005/024

Abalone Industry Development: Local assessment and management by industry.

Final report for FRDC project number: 2005/024

By

Rob Day
Zoology Department, University of Melbourne, Parkville, 3010, Australia.

Jeremy Prince
Biospherics Pty Ltd. 24 Hickory Street, South Freemantle, 6162, Australia.

Harry Gorfine
Department of Primary Industries Victoria, PO Box 114, Queenscliff, 3225, Australia

Luke McAvaney
Zoology Department, University of Melbourne, Parkville, 3010, Australia.

Patrick Gilmour
Zoology Department, University of Melbourne, Parkville, 3010, Australia.

February 2010
Published by The University of Melbourne
ISBN 978-0-646-53174-8

Disclaimer
The authors do not warrant that the information in this document is free from errors or omissions. The authors do not accept any form of liability, be it contractual, tortious, or otherwise, for the contents of this document or for any consequences arising from its use or any reliance placed upon it. The information, opinions and advice contained in this document may not relate, or be relevant, to a reader's particular circumstances. Opinions expressed by the authors are the individual opinions expressed by those persons and are not necessarily those of the publisher, research provider or the FRDC.

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

2005/024	**Abalone Industry Development: local assessment and management by industry.**

PRINCIPAL INVESTIGATOR: Dr Rob Day

ADDRESS: Zoology Department, University of Melbourne
Parkville, Vic. 3010
Telephone: 03 8344 6262 Fax: 03 8344 7909

OBJECTIVES:

1 Develop, evaluate and document the Reef Assessment approach in Victoria, South Australia and NSW.
2 Test and validate biological assumptions underlying Reef Assessments.
3 Establish base-line (Year 0) measurements that provide a basis for predictions, and will provide the basis for a powerful long term (10-20 year) study of the level of parental breeding stock required to optimize long term production
4 Specify an Internet site template that provides industry with a facility for timely access to information and an avenue for feedback that reduces the delay between observations of reef-scale events and required adjustments in management strategy.
5 Build a simulation framework based on selected reef stocks, which will facilitate consistency in the synthesis and analysis of the performance of individual reefs
6 Facilitate, develop and document local scale co-management by industry organizations through collaborative workshop processes.
7 Develop and test a training syllabus for abalone divers, covering biology and stock dynamics, the use of indicators, and how they relate to stock assessment.

NON TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

1. Five abalone associations in Victoria, South Australia and New South Wales have held workshops and discussed the reef assessment approach. The 3 Victorian associations have implemented and developed the approach, and it became invaluable to them when reef-stocks were depleted by a viral disease. The approach is now incorporated into the Victorian abalone management plan. Some aspects have been used in South Australia, and are under consideration in NSW.

2. The biological assumption that doming reflects relative gonad size has been validated, allowing a confident use of this approach by industry and Fisheries Victoria in management arrangements.

3. Size at maturity data have been measured on a large number of reef areas to establish a basis for size limit decisions.

4. An internet site is now operational in Victoria, providing divers with timely information, making management to reef-stock targets possible.

5. Two different models were developed to simulate the performance of individual reef stocks. These have been used at industry meetings to simulate the way recovery times after disease are affected by management options.

6. Collaborative workshop processes have been documented, and developed to the point where a risk based process for TAC advice has been implemented, and software developed under the project to support this.

7. Four training modules have been produced, covering abalone biology, fishery management, reef-scale stock dynamics, indicators and assessment, and how stocks recover after disease; to allow training of all stakeholders in the fishery.

8. A prototype industry database of reef-stock information has been designed; and implemented in the Victorian central zone. Software for risk based fine scale management has been developed.

Because abalone larvae do not move far from their parents and abalone on different reefs start to reproduce at very different sizes, it is important to manage the stocks in each area with different size limits and catch limits. Otherwise, although the overall quota limit for a fishery zone at a given size limit may be correct, those places where abalone grow fastest are likely to become depleted, while areas with slow-growing abalone would be under-utilised. Such fine scale assessment and management of reef-stocks cannot be achieved by state regulations alone, so that collaborative management by industry stakeholders, assisted by state management agencies and researchers, is essential. This project was developed as a collaboration between researchers, industry stakeholders and managers, to empower industry to assess reef-stocks using diver observations of the shape and fouling of abalone shells.

Abalone emerge from crevices when they first mature, then slow their growth as they increase egg production. Jeremy Prince developed a theory that fully mature abalone should be recognisable by the type of fouling that colonises a shell after emergence, and by the domed shape of the shell, which houses the larger volume of a mature gonad. Our results showed that this theory is correct, and we have assisted industry to use diver observations of abalone shells to classify reefs and set appropriate minimum size limits. We also measured growth and sizes at maturity on key reefs. It became clear that size limit constraints will shift where divers fish most, so catch caps are needed as well as size limits, to ensure stocks are harvested according to their production.

Collaborative workshops have now become firmly established in the three Victorian abalone associations, to decide on voluntary changed size limits and catch caps for each area along the coast. The decision process became easier and faster as the approach became better understood and stakeholders gained confidence in it. Such collaboration is well-understood to be more difficult in large groups, where participants are less aware of each other's activities, and where individual participants have less to gain from restraint and less resources to survive hard times. Thus collaborative fine scale management (FSM) was understood to be more difficult in New South Wales, and has not been achieved as yet. Instead they have developed other ways to improve the management process. The central zone of South Australia has developed close collaboration with the state management agency to develop a fine scale assessment of Kangaroo Island blacklip stocks.

To observe catch limits for individual reef areas, divers need a rapid feedback system to show how much has been caught on each reef is needed. Fisheries Victoria developed an internet system called 'Divers Web' to do this. Further, a large amount of information accumulates about each reef-stock over time. A database design and software to organise and store this information has been developed. The reef-stock management process has now been used as the basis for TAC advice to the minister in the newly developed Victorian Abalone Management Plan.

To make informed management decisions, all stakeholders need an understanding of what is known of abalone biology, why fine scale management is needed, how management affects stocks and how depleted stocks recover. During this project, the authors provided explanations at industry workshops in each zone, but to ensure training is available to new entrants in future, training modules were developed.

Collaborative decisions require an agreed decision process and documentation. Initially a decision tree and hand recording were used. A risk-based FSM decision process has now been developed, together with software to record decisions and calculate risk-based limits. Voluntary increases in size-limits incur costs on stakeholders; and experience has shown that if voluntary limits exceeded the legal limits enforced by state agencies by too much, the risk of a diver undercutting the agreed sizes became too great. This is 'the problem of the free-rider' who gains from the restraint of others. Fisheries Victoria has assisted the associations by changing legal limits along blocks of coastline to bring these closer to agreed voluntary limits.

The workshop-based FSM process became invaluable to industry in the Victorian Western, and later Central zones, when the Abalone Viral Ganglioneuritis (AVG) disease began to spread from Port Fairy. Through the FSM process the associations had reliable estimates of production from affected areas and were able to negotiate with Fisheries Victoria progressive reductions in the TAC within the season, based on agreed catches that would have come from these areas. Workshops facilitated group planning of the harvest of remaining TAC allocations in unaffected areas, to prevent a 'race for the last fish' that would have occurred if operators risked losing the income of their reduced quota. Workshops also discussed strategies to deal with disease depletion and develop applications for small 'rapid response' grants. As the virus spread slowly once the danger of human assisted spread was understood, the central zone used workshops to plan preventative measures, and then attempted to create a 'firebreak' (by removing abalone from an area) to stop AVG spread. Other researchers have noted that once the collaborative process is established, outside stresses may act to strengthen it.

Project resources were combined with rapid response funds to develop two models to help stakeholders compare the effects of management actions, especially when stocks are recovering from disease depletion. The first produces the best prediction possible, but relies on fitting to prior annual survey data and is thus limited to reefs where these are done. The second is based on assumed ages of abalone, but provides very good comparisons of the results of management options.

KEYWORDS: abalone, industry empowerment, fine scale management, stock dynamics, reef-stock assessment, co-management.

ACKNOWLEDGEMENTS

This project was designed, proposed, and implemented with the help of application co-investigators other than the authors: the Executive Officers of the Western Abalone Divers Association, Harry Peeters, and of the Victorian Abalone Divers Association, Vin Gannon; and Dallas D'Silva, Senior Marine Fisheries Manager in Fisheries Victoria. Further co-investigators who joined us and contributed substantially were Duncan Worthington, Executive Officer of the Abalone Council of NSW; Michael Tokley, Executive Officer, Abalone Council of Australia; and Alan Taylor, Executive Officer of the Eastern Zone Abalone Industry Association. Besides the substantial funding from the FRDC, the in kind contributions of these industry organisations contributed substantially to the success of this project. Fisheries Victoria contributed substantial time of managers and researchers at workshops, the development of an internet information feedback system, and fieldwork facilities. The University of Melbourne contributed the chief investigators time, facilities, and the financial accounting for the project.

A steering committee directed the project and we are thankful for their guidance, especially our chair, Ian Cartwright, director of Thalassa Consulting, and Crispian Ashby, Program Manager, FRDC. Other members were Bob Pennington, chair of the Abalone Industry Association of South Australia; John Smythe, Director of the former Abalone Development Corporation and NSW abalone diver; Stewart McGlashan and later Sasha Ruff, Abalone Managers in Fisheries Victoria; Sean Sloan, Martin Smallridge and Craig Noel, South Australian Abalone Managers in PIRSA; Doug Ferrell, Daryl Sullings and Nathan Macnamara, Abalone Managers, NSW Department of Primary Industries; Jonas Woolford, representative of the South Australian Western Zone Abalone Association, and Geoff Ellis, Executive Officer of the Eastern Zone Abalone Industry Association.

Jeremy Cooper, CEO Paua Industry Council of New Zealand; Malcom Hadden, senior scientist, TAFI; Patrick Hone, Director FRDC; John Hoult (Tasmanian Abalone Council); Tony Johnstone (Tasmanian Abalone Producers); Stephen Mayfield, Subprogram Leader, Molluscan Fisheries, SARDI; Craig Mundy, Abalone Research Group Leader, TAFI; and Grant Pullen, Tasmanian Abalone Fisheries Manager, were invited observers to steering committee meetings who contributed their expertise and ideas.

A number of students contributed unpaid time to investigate issues related to this project. We are grateful to Luke McAvaney (supported by an Australian postgraduate scholarship), Patrick Gilmour (part supported by project funds and part by University of Melbourne funds), who each have carried out PhD research crucial to this project, and Athol Whitten and Alastair Jones contributed in smaller projects.

Above all the project could not have achieved success without the support and commitment of a great many abalone licence owners and divers in all five fishery zones. We are grateful to all.

BACKGROUND

Worldwide, abalone resources have proved difficult to sustain. Global production peaked in 1969 around 29,000t per annum and is now falling below 10,000t per annum (FAO figures). During the 1980s the realization that abalone stocks can collapse suddenly prompted FIRTA to fund a series of parallel projects in NSW, Victoria, Tasmania and South Australia. As a result, we are fortunate that more is known about abalone, especially in Australia, than almost any other fish (Day & Shepherd 1995).

What we know about abalone biology

Tasmanian research (FIRTA 85/53) was the first to begin effectively sampling post-larvae on corallines (Prince & Ford 1985) and used this technique in experiments that suggested abalone populations are localized, as their larvae have limited dispersal (10 – 100s m) (Prince *et al*. 1987, 1988b). That project also verified a shell ageing technique for Tasmania, later used by Nash (1992b) to map the variability of size of maturity around Tasmania. Nash’s comparative study of blacklip around Tasmania demonstrated that abalone maturity is largely age related, and size at maturity (together with maximum size) is highly variable between populations (Prince 2004, 2005). These finding have been confirmed by parallel studies in South Australia (Shepherd & Laws 1974, Shepherd *et al*. 1992) and Victoria (McShane *et al*. 1988; McShane 1991).

Thus an important result of previous work is that we know that local abalone stocks are separate and vary greatly in size of maturity. In contrast abalone fishery management zones span several hundreds of kilometres. Legal Minimum Lengths (LML) applied regionally have extremely variable effects across the component stocks; totally protecting all breeding stock in locations with a small size of maturity, while allowing the total removal of breeding stock in the most productive areas with the largest sizes of maturity (Prince 2003c, 2004, 2005). Thus stocks exhibit relatively independent and highly variable population dynamics across reef complexes (McShane & Naylor 1995; Prince *et al*. 1998).

Populations close to access points or in preferred diving areas attract focused fishing effort and if the regional LML preserves insufficient breeding stock they are prone to depletion and even local extinction. Other reefs with fast growth then become vulnerable to serial depletion. In each fishery the area of lost productivity is steadily increasing (Prince 2001).

The first study of growth encompassing post-larvae, juveniles and adults was in Victoria (FIRTA 82/37), and showed that recruitment of post-larvae to reefs may be sporadic, but recruitment to the fishery is ‘smoothed’ by very variable juvenile growth (Day & Leorke 1986). Thus growth is crucial to recruitment rate. This study was the basis for new stochastic models of growth (Troynikov *et al*. 1988, Bardos 2005) that are now used to fit size distributions in the national abalone model. We now know (Day & Fleming 1992) that growth varies enormously between reefs, so again, zonal models will misrepresent local stocks as they must use average growth. Even more important, recent work in culture (Huchette *et al*. 2003a,b; Day *et al*. 2004, Daume *et al*. 2004) and in the field (Huchette 2003, Dixon & Day 2004, Dixon *et al*. 2006) shows that growth is density-dependent, so that heavily fished stocks will grow faster, and the appropriate LML is likely to increase. Thus as fishing pressure comes onto stocks, they may change their population characteristics so as to become more vulnerable to depletion. The simulation by Bardos *et al*. 2006 suggests that under density dependent growth, stocks may not appear to suffer any reductions initially, but depletion may occur over years without obvious signs.

Fisheries agencies lack the spatially explicit data (abundance, size structure, size and age at maturity, growth rate) required to assess and manage these resources at the small scale (10-100s m) appropriate to abalone. In the age of “user pays” and “cost recovery” it seems unlikely that they will ever have the resources and capacity to collect data of sufficient resolution, conduct the multiple small scale assessments required, or to enact and enforce management at the required scale. Thus the primary sustainability challenge facing this industry is down-scaling processes of management, assessment and monitoring this fishery to the scale of 10 – 100s of meters appropriate to the ecology of abalone (Prince *et al*. 1998). Both Industry stakeholders and managers in all states have been well aware of these issues at various levels for some time.

A key aspect of management is to maintain egg production. LMLs are an attempt to ensure abalone produce sufficient eggs before they are harvested. Many studies have related fecundity to length (e.g. Shepherd *et al*. 1992) and more rarely weight (Shepherd, PhD thesis p59). These relations also vary greatly between reefs. Many size at maturity studies underpin legal LMLs, but the size at which the gonad appears may not be very relevant, because larger abalone produce thousands of times more eggs than smaller ones. What is needed is an indicator of substantial gonad production. Worthington & Andrew (1998 - FRDC 93/102) noted the rounder shape of smaller maturing (stunted abalone) and as a means of increasing access to these stocks suggested reforming LMLs as a measure of width as it would correspond better with gonad size.

The Western Australian Zone 2 divers (T. Adams, WAFIC) instituted their own program of reef-scale management in the early 1990s with the aim of rebuilding productivity in the abalone grounds around Cape Leeuwin. During that initiative they introduced Prince to the idea that shell shape (doming) and the extent of fouling could be used as an indicator of substantial egg production potential, and achieved the only documented recovery of an abalone stock (Prince 2003c, Prince *et al*. 2008). While measures growth rate, size at maturity and fecundity require research, abalone divers can assess % of domed fish.

In stunted areas, abalone grow to a small maximum size and become round and domed (high). But these are the reefs that have been lightly fished due to an overall LML, so that these stocks are also at high density. We propose that for all stocks once abalone approach asymptotic length they become round and domed, and increase fecundity, but this is not seen today on faster growth reefs, where larger domed abalone have been removed, and densities lowered. Litaay & DeSilva (2000) suggested that rounder shells produce less eggs when given spawning cues, but Dan Morse (pers. comm.) suggests larger abalone spawn only part of their available eggs on each cue; and retain others to ensure eggs are released at many times during the season to increase settlement success. This would in fact increase the importance of older, more domed reproducers to future recruitment. On the other hand we know that older abalone in stunted stocks tend to be more infested with polychaete borers, and these reduce their condition (McDiarmid *et al*. 2004). Thus very bored abalone would likely produce less eggs and this may have influenced Litaay and DeSilva's results.

The SA Central Zone partly funded an ARC SPIRT project under Rob Day to investigate (a) whether seeding could be used to restore reef stocks (see Dixon *et al*. 2006) and (b) how local greenlip stocks respond as density is reduced by fishing, to improve management. Lower density led mainly to faster growth of post-larvae, juveniles and adults (Day *et al*. 2004, Huchette 2003, Dixon & Day 2004) and this led to earlier emergence and maturity (McAvaney *et al*. 2004). In short-term experiments with adults at reduced density, fecundity increased rapidly only for abalone near their final size. Note that these would be removed first by divers. Shell volume increased when size-specific fecundity increased (McAvaney 2004); supporting the use of doming as an indicator of increased fecundity. The simulation model of the density dependent growth effect (Bardos *et al*. 2006) suggests that increased growth as fishing reduces density may require continued adjustment of reef LMLs, as abalone get less and less time to reproduce before capture at a constant LML.

Thus the gaps in ecological understanding we needed to fill were (1) to clarify how doming, fouling and boring relate to fecundity so that they can be used as field indicators of stock fecundity, (2) how growth rate affects maximum size and the pattern of doming, as density is reduced by fishing, and (3) what stock fecundity is required to sustain reef stocks. Question 1 was addressed fully in this study. Questions 2 and 3 require measurements of density, growth, size distribution, etc on a range of reefs over time. In this project we have gained the required initial information on a small set of reefs, so that later work can help industry answer them.

We planned also to use the available information in simulation models of the measured reefs so as to "guess" their response to fishing history based on our current understanding of local dynamics. FIRDTF in the early 1990s funded Dr Philip Sluczanowski of the S.A. Fisheries Department to develop Abasim (Prince *et al*. 1991), a coloured computer simulation model of a single abalone reef, with the aim of developing tools that would be useful to empowering divers and managers to engage in the fine scale management of the fishery. We wanted to build on that foundation.

Industry co-management

Successful sustainable management of a common property resource requires a trio of crucial elements: a fixed set of resource harvesters with substantial long-term interests; an effective allocation and management regime; and sufficient biological knowledge of the resource dynamics (Grima & Berkes 1989). This project aimed to provide tools to achieve the last two essentials. We acted on the basis of four beliefs: (1) reef-scale management is essential; (2) anything other than industry based management at this scale would be prohibitively costly; (3) co-management by resource users is effective in sustaining stocks (as demonstrated by many international studies, e.g. Pinkerton 1989, Meppem 2000); and (4) that if some crucial gaps could be filled, we could provide to industry sufficient biological knowledge for effective local-scale management.

It is now recognized internationally that the best management of common property resources involves co-management between government and industry stakeholders (Pinkerton 1989, Meppem 2000). Australia supports this process by various institutional co-management arrangements in most states, but the effectiveness of this process is limited by a lack of industry empowerment and ownership of the process of stock assessment, and thus the basis for collaborative management decisions.

This project arose from industry initiatives in Victoria, and industry support and involvement then spread to other states. Industry drove the development of the project, and both industry and management representatives were co-investigators on the application. A steering committee to direct the project was then set up by the FRDC, and this included both industry and management representatives from all three states involved.

In 2001 FRDC invited Jeremy Prince to address the 1st National Abalone Conference in Adelaide (Prince 2001). Prince outlined the challenges confronting sustaining abalone fisheries, and was subsequently invited to address the Victorian Central divers (VADA) and later a meeting of the Western Zone Associations (WADA) on the same issues. In April 2002 WADA commissioned him to conduct a rapid appraisal of the existing statewide LML for stocks in their zone.

Prince (2002) proposed shape and fouling of abalone shells be used to infer the size of full adult fecundity in relation to the existing LML. He recommended that WADA introduce a range of voluntary LML increases (particularly at the Portland end of the fishery) and develop their capacity to manage at the scale of the existing reef codes (1-2 km). On at least one key reef (The Crags) the decisions made at that time are already credited with reversing a perceived decline. In 2003, after discussions about the flow of effort around the fishery following their LML manipulations (Prince 2003a), WADA also began to control catch levels at the scale of reef codes. In October 2003 Prince (2003b) conducted an initial Reef Assessment Workshop for WADA. At that workshop WADA members agreed to assess reef stocks on the basis of existing catch statistics and industry knowledge (the appearance of the shell at the LML and long term catch trends for each reef code). Each reef was assessed against 8 stock status categories, each with an agreed management strategy. With this agreed process WADA assessed 45+ reef-code stocks, developed a strategy to address the immediate needs of WADAs core reefs, and agreed LMLs and catch reference limits for each reef code. WADA also agreed on fish-down proposals for several reefs, so as to further reduce harvests from core reefs (Prince 2003b).

In October 2004 WADA undertook a second Reef-Code Assessment Workshop; and the license owners began discussing the development of an agreed longer term harvest strategy aimed at unambiguously stabilizing their resource and in the medium moving themselves into a position capable of capitalizing on the marketing opportunities offered by assured supply of known size categories and controlled timing. More radically, at that meeting the owners present agreed to consolidate their TACC reduction for the two years at 25% of the 2003 level (i.e. 2005 TACC is 75% of 2003). In March 2005 Prince ran another workshop for WADA at which it was agreed that the TACC reductions should be focused on the Portland end of the fishery and closed a number of the Portland reefs with the aim of re-opening them at significantly higher LMLs in several years.

In the context of predictions from the Victorian abalone model of a slow decline, these decisions were formalized in a Memorandum of Understanding with Fisheries Victoria (FV) each year, and led to recommendations from the Victorian Fisheries

Co-management Committee and FV that resulted in restricting reductions in the TACC for 2004 and 2005.

Parallel to the WADA process the association of Victorian Central Zone Abalone Divers (VADA) has pioneered the use of catch caps to redistribute effort within the zone, daily catch limits and reef-code size limits above the state set LMLs. They have also developed the use of catch measuring machines to provide size distributions of catches as useful indicators of reef-stock status. In May 2004 the Victorian Abalone Divers Association (VADA) of the Victorian Central zone commissioned Prince and the CEO, Vin Gannon, to begin conducting Reef Assessment Workshops in the Central Zone. At their first workshop VADA members were briefed in the principles of Rapid Assessment, some core reef-codes were assessed, and preliminary proposals for some reef-code LMLs were developed. A second reef-code assessment workshop was held in October 2004 and a preliminary assessment made of all Central Zone reef-codes.

Fisheries Victoria, the Victorian Abalone Fishery Committee (AFC) and PIRVic supported this pro-active industry management. The AFC took these reef–scale management arrangements into account in recommending TACs for 2004. FV incorporated the reporting of reef scale location into its real time Integrated Voice Response (IVR) facility used by divers to report their catches post-landing, and instituted regular updates of catch statistics to enable divers to adjust their distribution of fishing effort to avoid exceeding the mutually agreed local catch caps. During the development of the proposal, discussions were held with abalone industry associations in all states. The Western Australian abalone industry supported our project and anticipated useful results for them. While some license holders in Tasmania have experimented with similar reef-scale LMLs, the Tasmanian Abalone Council considered that the current management arrangements in Tasmania render this project too complex to attempt there, but they suggested benefits would flow to Tasmania from this project. The industry associations from the Eastern Zone of Victoria, NSW, and the central and Western zones of South Australia opted to join the project. The southern Zone of South Australia was already involved in a related project headed by Stephen Mayfield of SARDI. The two projects arranged joint meetings in the SA southern zone, and industry stakeholders were provided funds to attend workshops in other zones by the project.

NEED

There is abundant scientific evidence that micro-management of abalone fisheries is needed, as explained in the Background section above, and state management plans, research and development priorities reviews by various groups (e.g. NSW FMP, Newman & Smith 2001, Victoria's ENRIC 2002, MacArthur Agribusiness FRDC Needs Review 1999) have recognized this. State financial resources are - and under cost recovery in each state will remain - insufficient to support assessment and management of individual reef-stocks.

This project proposed the alternative: to empower industry stakeholders with assessment tools and processes for collaboration between industry stakeholders to achieve management outcomes. Collaboration with management agencies, and tools to monitor and evaluate the industry management process are also needed. We also hoped to create an innovative industry culture and stimulate "collective industry strategic thinking and cohesion" (Quoted from the FRDC Needs Review).

Empowerment of industry also addresses the strategic priority for more participatory co-management of the resource (e.g. SA 2002-7 R&D plan) and inclusive ownership of management decisions. Industry participation is a priority in most states (e.g. Newman & Smith 2001). Some industry associations had committed to addressing reef-stock management, as we have explained in the Background section, and we set out to underpin industry initiatives with the required biological information, modelling and collaboration tools, so that reef-scale assessment and management processes could be adopted by other industry associations.

We hoped also to facilitate co-management, whereby the fine scale management process could become accepted by management agencies as a secure basis for sustainable management, in accordance with the provisions of the EPBC Act 1999. FRDC's Needs Review identified the "lack of spatial methodologies and modelling tools" as a substantial risk to the industry. We planned to build on extensive previous biological research on abalone (as reviewed above) to allow industry associations to progressively understand and model the relationship between fishing and reef-stock production. We expected that such modelling would encourage future integration of state zonal management processes with the industry reef-scale process.

During the project, a new urgent need for the fine scale management approach arose in Victoria, due to the slowly spreading devastation of reef-stocks by the new Abalone Viral Ganglioneuritis disease (AVG), which began to spread out from Port Fairy in the Victorian Western Zone. Fine scale management then became urgent because reef-stocks were devastated to different extents and at different times by the disease, while some remained unaffected. We needed also the simulation models, to examine how disease would affect stock dynamics, and how fast recovery would occur and fishing could resume under different management options, so as to sustain the stakeholders in the fishery. The increase in urchin invasion of some reefs in the Victorian Eastern Zone during this project is another process that forces management to focus on individual reef-stocks.

OBJECTIVES

1. Develop, evaluate and document the Reef Assessment approach in Victoria, South Australia and NSW.

The approach was developed by holding initial workshops for quota owners and divers in each zone, at which we presented the need for reef-stock management, the suggested approach and the evidence for it, and discussed diver's observations of reef areas. The workshops were arranged by the industry association and funded by the project. We recorded these workshops and fishing decisions were documented by the industry association. This report represents an evaluation and documentation of the approach.

2. Test and validate the biological assumptions underlying the Reef Assessment Workshops.

This objective was met by carefully directed sampling at sites in each zone chosen to represent slow, medium and fast growth sites. The gonad sizes, number of eggs in females, and the shell size, doming shape and fouling were recorded. The sampling was carried out by Fisheries Victoria contract divers, and the analysis of gonads and shells by Luke MacAvaney, a PhD student supported by a scholarship from the University of Melbourne. These studies confirmed the biological assumptions underlying the assessment approach.

3. Establish base-line (Year 0) measurements that provide a basis for predictions, and will provide the basis for a powerful long term (10-20 year) study of the level of parental breeding stock required to optimize long term production.

This objective was only partially met. We retained it in the revised proposal despite the substantial budget cut required for that revision, but we found it impossible with reduced funds, to determine stock abundances on reef areas beyond those already surveyed by Fisheries Victoria. Instead, we were able to establish size at maturity and growth rates on a good sample of these reef areas, which provide the data needed to model the reef-stock dynamics. Future work should examine cost-effective alternatives to collect the important baseline data on stock abundance, so that optimal levels of harvest can be calculated.

4. Specify an Internet site template that provides industry with a facility for timely access to information and an avenue for feedback that reduces the delay between observations of reef-scale events and required adjustments in management strategy.

This objective was met by the development of the 'Divers Web' system by Fisheries Victoria, to provide internet access by divers to the current total catches on each reefcode, with updates within days. Diver's web has been an invaluable tool in workshops, allowing real-time verification of catches on reefs, and aiding management of the distribution of effort. . In addition a database system and other web-based tools have been developed that can provide internet access by divers to industry data.

5. Build a simulation framework based on selected reef stocks, which will facilitate consistency in the analysis of the performance of individual reefs.

This objective became urgent when disease devastated stocks in the Victorian Western and Central zones. Funds from a TRF application were combined with this project, and two different simulation tools were developed. One is a revision of the “Abasim” program, an age-based model, using the estimated ages of abalone. This provides excellent ways to compare the effects of management scenarios. The second is a size-based model adapted from the National abalone model, using the best available growth, maturity and survey data for reefs (Bardos 2004). Two management scenarios can be compared to evaluate the better option. These models were invaluable in assessing management options during the recovery of stocks from the viral disease, and will also be used in self-driven education of industry stakeholders about stock dynamics.

6. Facilitate, develop and document local scale co-management by industry organizations through collaborative workshop processes.

This objective was met in two ways: first by the attendance by researchers in industry workshops to facilitate the reef assessment process, and second, by the recording of industry workshops by Patrick Gilmour, a PhD student on a scholarship partly supported by the project, who investigated the development of collaborative management and its relation to various kinds of stakeholder incentives. An illustration of the success of this process is the fact that there has been 100% compliance with the many voluntary closures of reefcodes in Victoria when the maximum allocated catch was reached.

7. Develop and test a training syllabus for abalone divers, covering abalone biology and stock dynamics, the use of indicators, and how they relate to stock assessment.

Various presentations were made by researchers at industry association workshops as requested by industry. These have been extended and arranged into a series of training modules for new entrants to associations, covering abalone biology, fisheries management, the need for and process of fine scale management, stock dynamics and the process of recovery after depletion. These 5 training modules have been sent to the industry associations to use. At the last steering committee meeting, it was decided to convert these to an audio-visual package, as extension was seen to be central to the project, and these training packages will allow ongoing extension of the project approach to industry.

METHODS

1. Validation of shell shape versus fecundity.

Sites were chosen by divers in 4 zones to determine the relation between fecundity and shell size and shape. Large, medium and stunted maximum size sites were selected in each zone. Permits were obtained from the management authority (Fisheries Victoria or PIRSA). Abalone samples were collected with the help of commercial abalone divers during peak gonad season (Sep-Nov 2006) for gonad and shell shape analysis. Additional sites were sampled in the Eastern Zone around Marlo, where tagged abalone were collected for shell shape and growth analysis. The sites are characterised in Table 1 below. For blacklip, at each site, 100 abalone were collected from the entire size range present. Further collections of 20 abalone at each site in the Eastern and Central Zones (Victoria), were targeted towards newly emergent individuals to obtain information about the size and age at which abalone emerge from crevices. These shells were aged using the ring count method (Prince et al. 1988a, Shepherd et al. 1995). In total some 2600 abalone were sampled. Pursuant to the conditions of the permits, gonad tissue was preserved and the meats disposed of by fisheries staff.

For greenlip, Sites were selected at Tiparra reef, South Australia in careful consultation with local divers and industry representatives, as this produces most of the greenlip catch for the zone. Sampling focused on areas where previous work by Dixon and Day (2004) had measured growth (Table 2). Slow growth areas were very lightly fished, whereas fast growth areas are heavily fished. At each site, about 100 abalone were collected by Luke Royans (an abalone diver) from the entire size range present. Abalone were transported to Melbourne University live, and processed immediately.

The analysis of these 2600 abalone was carried out by Luke McAvaney, with assistance from Alistair Jones and other volunteers. Each sampled abalone was weighed (total wet weight), shucked and dissected with the viscera (including gonad tissue) labelled and preserved in 70% ethanol. Meats were weighed separately (meat weight) and then disposed of. Levels of epiphytic growth were recorded and shells were then labelled, cleaned of epiphytic growth and dried. Measurements of shell shape were then taken using digital callipers connected to a computer. Measurements were taken of length, width, height at spire, shell thickness and doming index (along both short and long axes of the shell). Fecundity was measured by dissecting preserved gonad tissue from viscera, desiccating the gonad tissue in an oven, and weighing to the nearest 0.001g. For males, only dry gonad weight was measured, but for females egg counts were made in addition to the dry gonad weight data.

In addition, Luke McAvaney investigated the relationship between doming and repeat spawning, to investigate whether older, more domed abalone would be likely to have greater spawning success, beyond simply the numbers of eggs produced. This was done by a paid contract to SARDI, for the use of their spawning facilities. Domes and flatter greenlip were collected by Luke Royans, under a permit from PIRSA, and taken to SARDI, where each female was spawned several times, the eggs sampled and measured, and the fertility of the eggs investigated by mixing them with sperm and examining development.

Table 1: Description of the sites sampled.

Western Zone – David Forbes	
Mills reef	– stunted
Levys reef	- fast
Thunder point	- fast
Murrels	- stunted
Seal caves	- medium
Jones bay	- medium
Central Zone – Johno Rudge	
Kirk's Point	- Slow
Back Beach	- Fast
Cape Schanck West	- Medium
Portsea Back Beach	- Fast
Cape Schanck	- Slow
Eastern Zone – Johno Rudge	
Quarry Beach	- Slow
Shipwreck to Seal Creek	- Slow
Little Rame Lee	- Medium
Iron Prince	- Medium
Sand Patch Lee	- Fast
Big Rame	- Fast
Eastern Zone (Marlo Tags): - Johno Rudge	
West Cape	
East Cape	
Pearl Point Outside	
Pearl Point Inside	
Frenchs Narrows	
South Australia Central Zone (Greenlip)– Luke Royans	
Tiparra Site 1	- Stunted.
South Reef (1 mile west of light)	
Tiparra Site 2	- Fast.
Main Reef (bit outside)	
Tiparra Site 3	– Fast.
'500'	
Tiparra Site 4	– Stunted.
Inside Light	

Table 2: Sites sampled at Tiparra for shell shape and fecundity

	Apparent Growth Rate	Reference Site (Dixon & Day 2004)	K	L∞
Site 1: South Aggregation	Slow	Aggregation	0.185	149.63
Site 4: South Light	Slow	Sandgutters	0.234	135.28
Site 2: Main Reef	Fast	Fast 1	0.317	145.72
Site 3: '500'	Fast	Fast 2	0.449	147.48

2. Baseline sampling

Field sampling in Victoria focused on relating growth and habitat features to maximum size and fecundity, and thus reefs where previous tagging or growth data is available were sampled in most cases. The sampling was done in conjunction, as far as possible, with the regular summer monitoring by PIRVic. Specifically, tagged abalone released 12 months ago at 5 sites near Cape Conran in east Gippsland were recaptured and analysed to make an exhaustive array of morphometric and reproductive measurements. Other sites have been selected on the basis of differing growth characteristics, backed up by good sets of growth increment measurements from previous tag-release -recapture studies. During the course of the project industry associations in all three zones in Victoria were consulted about locations of importance where these types of data were lacking, then sampling was initiated in each instance. There were varying degrees of success depending on tag recapture rates and constraints arising from combination of seasonal weather and reproductive conditioning on the timing of collections. We aimed to provide data on two fast, two medium and two slow growth sites in each zone.

Growth was estimated by fitting von Bertalanffy parameters to tag recapture data, or in a few cases by using data from very similar sites where such data was already available. Fecundity has been estimated on the basis of the dry weight of the gonad, when dissected from the digestive gland. This was preferred to wet gonad weight or numbers based on egg counts from a known subsample of wet gonad tissue, because there were significant differences between individual wet gonad weights based on the level of fixation achieved in ethanol. Estimates of gonad volume used by other authors (Tutschulte & Connell 1981; Lleonart 1992; McAvaney 2003) were tried, but found to underestimate that total gonad content for smaller animals in which gonad tissue does not adequately cover the conical appendage for measurement. Significant amounts of gonad tissue (determined microscopically to hold ripe eggs) were found along the gut in these animals, and this gonad tissue could only by measured by full dissection.

3. Workshops

The Introductory workshops for zonal associations followed a planned format. Divers and Licence holders were presented with the background abalone biology and the decision tree process for assessing the status of reef-stocks by Jeremy Prince, with additional input on the objectives of the project and how the project would work by Rob Day. Harry Gorfine in Victoria, and SARDI in South Australia provided historical data for each reef-code, and some examples were discussed. Industry then discussed whether to develop and implement these ideas in their zones. Subsequent workshops involved a repetition of the biology and management issues, to allow everyone to become familiar with them, and then reef-stocks were discussed and assessed. Patrick Gilmour recorded workshops, produced minutes, and studied the collaboration process. Victorian workshops were also almost always attended by Fisheries Victoria management staff – usually Dallas D'Silva and the abalone manager. Those zones that took up the approach fully then began implementation of the process, and developed it further. From this point the workshops were industry driven, with the researchers present only to assist with information and comments.

During the project, the Eastern Zone Industry Association has revised its objectives to use the workshop approach facilitated by the project (and the project has facilitated this), while the South Australian associations have become less interested in Industry controlled fine scale management. The New South Wales association struggled to agree on fine scale voluntary process, preferring a state regulated fine scale process. They are now supporting a higher size limit in one area.

4. Development of simulation models and other software for industry.

There was a perceived need to develop a simulation tool and a graphical interface suitable for use by abalone divers and owners, so that stakeholders could use it to evaluate the potential results of management options at the reefcode level. As a result of the outbreak of the AVG disease in the Victorian Western Zone, this need became particularly evident. The priority then was for an interface to be developed to allow a rapid first exploration of possible implications of the viral mortality on future management decisions at the WADA workshop on responses to the depletion of stocks, and to calculate projections of reef recovery to WADA in January 2008.

We attempted to develop a simulation tool that would use what was known about the stocks on a reef, with minimal assumptions. Thus the National abalone model was taken as a basis, as it can be fitted where there is sufficient data to estimate the current status of stocks, and is based on stochastic growth models and size distributions rather than an age-length relationship. The interface features were based on the earlier Abasim simulation tool, which had proved successful in conveying concepts of stock dynamics to industry. We have called this 'Abmodeller'.

In addition, Jeremy Prince and John Tonkin have produced Abasim II, which can be used to explore management scenarios, and was used in the Western Zone workshops. Like the first Abasim, this is based on assumed ages of abalone, and we do not have reliable age estimates for stocks in most states, but Abasim II can be tuned to apply to stocks on a reef, provided key features of the dynamics of those stocks are known.

The preliminary design of Abmodeller was developed by computer science students at the University of Melbourne, with the help of David Bardos, and the final design of the graphical tool was by Francis Byrne, one of the students, acting as a software consultant. First, the data for several sites in the western Zone were fitted with a modified version of the National Abalone Model, based on abundance and size-frequency data from the annual surveys of those reefs, the catch history estimated for those reefs, and the estimates of growth and mortality that appear to apply. These results are then used in a simulation engine programmed by David Bardos to produce estimates of the numbers and weight in each size class in the future, given the catches and LMLs that will apply each year.

The students designed a shell that would allow users to input the reef of interest, the start year of the simulation, any depletion level by disease, and future LMLs and catches, and would then produce colour graphs of the numbers of projected stocks, with each size class in a different colour, and also the weight of the catch. Users can then change the future management and see how the outcome changes.

During the project it became evident that industry needed a database to store the past catch history for reefcodes, industry- based records, such as the size distributions of abalone in the catch, recorded by measuring machines they have adopted, and also the decisions each year made in the workshops. There was no budget for these in the proposal, but a start was made using University computer science students, who designed a pilot database. Later, savings made during the project were used, with the approval of the steering committee, to set up a database both at the Victorian Partnership for Advanced Computing (VPAC), and on a server bought by VADA. Similarly, using contributions from VADA and project savings, software to support the workshop decision making and a risk-based process to formulate a suggested TAC was developed and demonstrated at the last steering meeting.

5. Development of a training syllabus.

Various proposals as to the form of the syllabus were developed, using experts in developing training and specifying competencies. These were brought to the steering committee for approval. But it appeared that what industry representatives considered useful was not a specification of the syllabus and competencies required, but the actual training content – information on the biology of abalone, stock dynamics, and the way in which management, and in particular the fine scale management approach promulgated in this project, works. Rob Day therefore developed training modules as ‘Powerpoint’ presentations, with accompanying handout notes, which could stand alone, and be delivered by industry to new entrants in training sessions. At the last steering meeting it was decided we would use remaining savings in the project budget to develop these presentations into audiovisual packages that could be used in a stand-alone way.

RESULTS AND DISCUSSION

1A. Validation of shell shape versus fecundity for blacklip

This work set out to validate the relation of shell shape and fecundity described in Prince et al. (2008). Shell shape differs between sites with different apparent growth rates. Shells at stunted (slow growth) sites tend to be both taller (at the spire) for a given length, and have higher doming indexes on both shell axes than shells from fast growth areas (Figures 1-3, Table 3). These sites also tend to have relatively wider (ANOVA: $F_{1,248} = 9.498$ $P = 0.002$) and taller shells than fast growth sites, whether measured at the spire ($F_{1,346} = 220.74$; $P<0.001$; Figure 4), or in front of the spire ($F_{1,346}=89,223$; $P<0.001$; Figure 5). Shells at sites with medium growth have intermediate shapes (Figures 1, 2). This is consistent across all zones and suggests shell shape could be used to distinguish reefs of unknown growth rate.

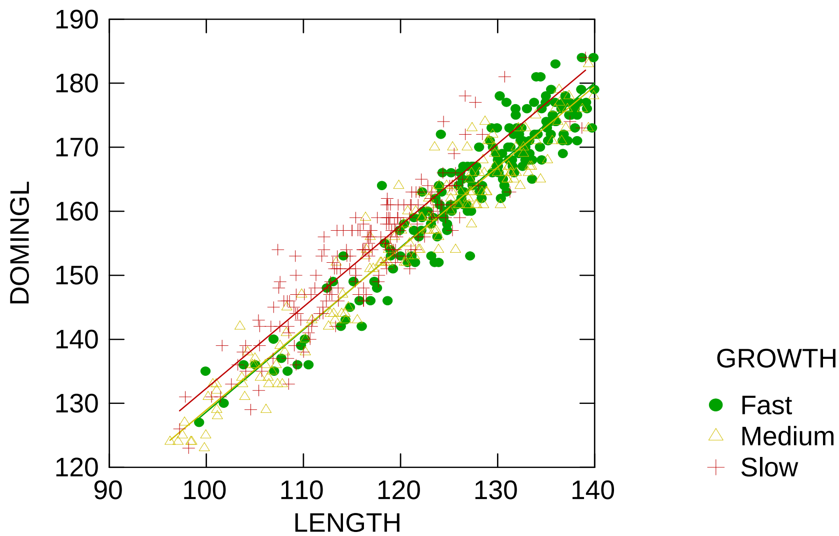

Figure 1: Doming (along long axis) against Length for all Western Zone sites

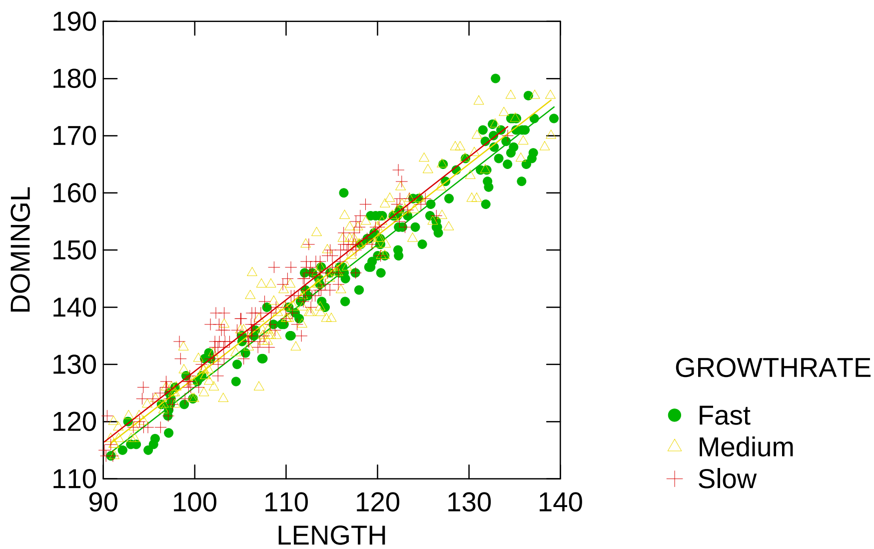

Figure 2: Doming (along long axis) against Length for all Eastern Zone sites

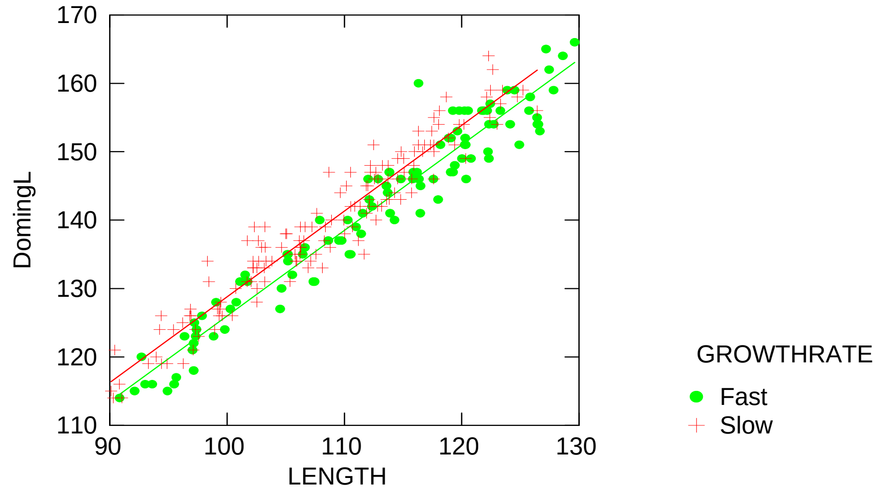

Figure 3: Doming (along long axis) against Length for Fast and Slow growth sites in the Eastern Zone

Table 3: ANOVAs comparing Doming index against growth rate for two zones

Source	SS	df	MS	F-ratio	P value
Western Zone					
GROWTH RATE	1045.702	2	522.851	32.490	<0.001
LENGTH	36249.483	1	36249.483	2252.516	<0.001
ERROR	6195.762	385	16.093		
Eastern Zone					
GROWTH RATE	592.029	2	296.014	25.202	<0.001
LENGTH	337488.541	1	337488.541	28733.421	<0.001
ERROR	6530.501	556	11.746		

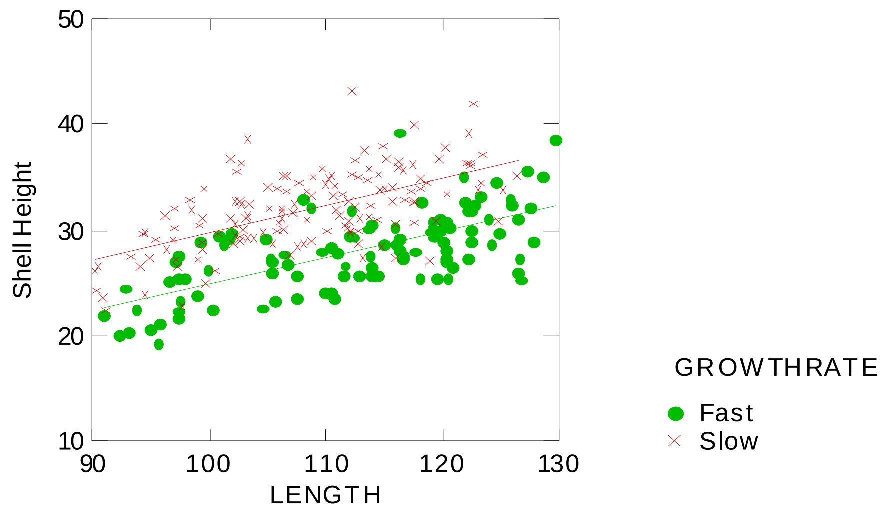

Figure 4: Plot of Shell height against Length for Eastern Zone sites

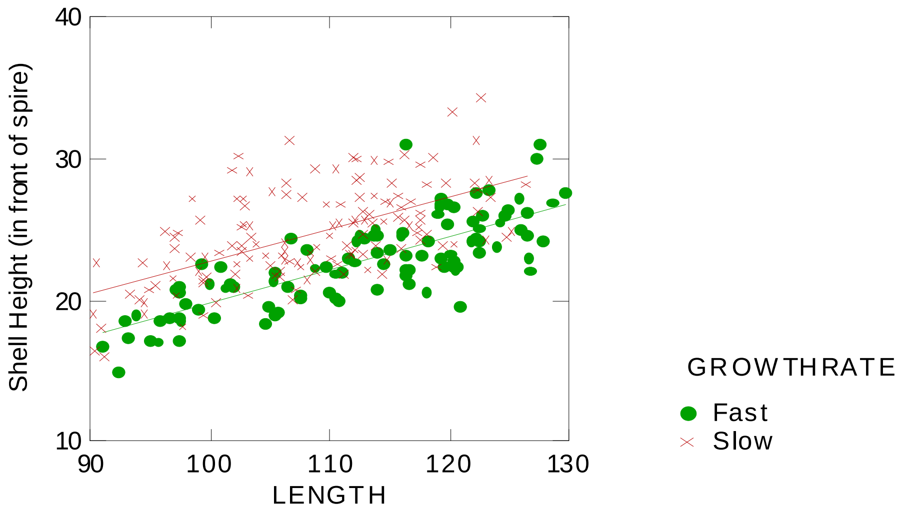

Figure 5: Shell height (in front of spire) against Length (Eastern Zone)

Meat Weight:

Meat weight and gonad size are often positively correlated in abalone samples, so that meat weight might be useful as a proxy for fecundity. There was a negative relationship (Meat weight as Prop of total weight = -0.418 x Doming Index + 0.520) between meat weight (expressed as a proportion of total weight) and doming, measured as a proportion of total length ($F_{1,440}$ = 37.323; P<0.001; r^2=0.08, Figure 6). More domed abalone have lower meat weights than those with flatter shells.

We suggest that more domed abalone have different proportions of their weight in meat and gonad. The positive relation noted elsewhere may simply be a reflection of the size and condition of abalone. Larger abalone and abalone in better condition would have both greater meat weight and larger gonads. Unfortunately, more domed abalone may also often be in poorer condition due to shell borers, and thus we need to examine effects of borers closely. It should be noted that, whilst the results are statistically significant, the r2 value is low and the effect is only strong at 3 sites in the Eastern Zone (Figure 5). The effect is likely due to the prevalence of boring organisms on the surface of older, domed shells. What this result indicates is that the relationship between shell shape and fecundity may be affected by other factors.

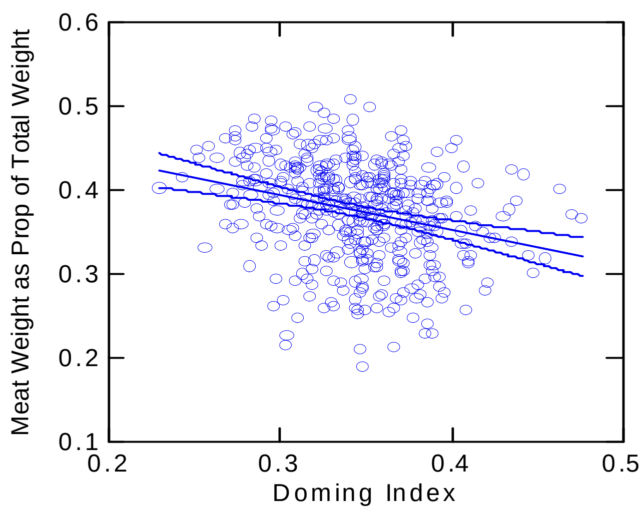

Figure 6: Meat weight (as proportion of total weight) against Doming Index (EZ data combined)

Potential Fecundity:
Egg numbers in abalone appear to be significantly and positively related to shell shape (Table 4, Figure 7). This relationship however, appears to be a complex one involving the interaction of shell shape, fecundity, infestation load, natural variability and growth rate. Of the 5 doming index measures developed, 3 showed a statistically significant positive relationship between shell shape and fecundity (Table 4), with correlations tending to be stronger for fast growth sites (Figure 8).

Table 4: Pearson Correlation Matrix for blacklip abalone doming indices and fecundity (* indicates statistically significant positive relationship)

	Height / Length	Width / Length	Nose Height / Length	Doming Length / Length	Doming Width / Length
Gonad Weight	0.241*	0.199	0.247*	0.176*	0.109

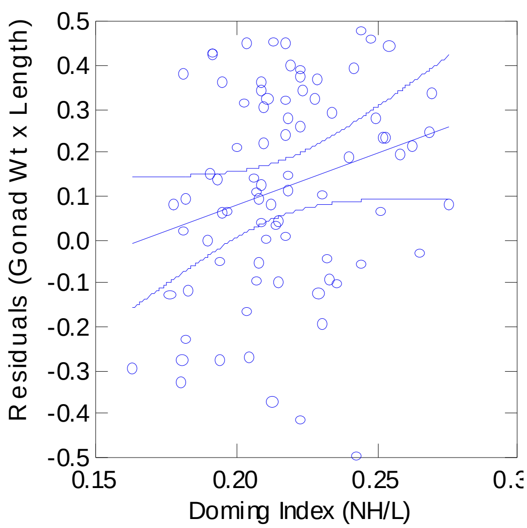

Figure 7: Residuals from a gonad weight x length regression against Doming Index (Eastern Zone data).

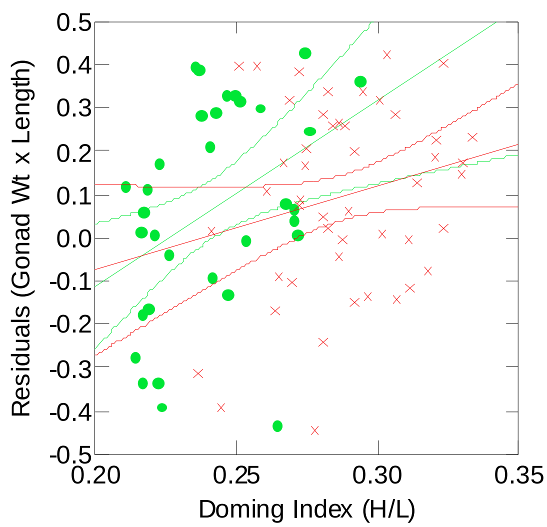

Figure 8: Residuals from a gonad weight x length regression against Doming Index (2 EZ sites). Circles=fast, Crosses=slow growth.

Comparisons between sites with different growth rates suggested that abalone in the small size classes (<105mm) at slow growth sites, had higher fecundity compared with small animals at fast growth sites. This is due to the smaller size at which abalone at slow growth areas attain sexual maturity and may relate also to doming. However, the prevalence of larger abalone (130-170mm) with relatively large gonads present at fast growth sites suggests that overall egg production will be higher at fast growth sites, regardless of any effect of doming on fecundity (Figure 9).

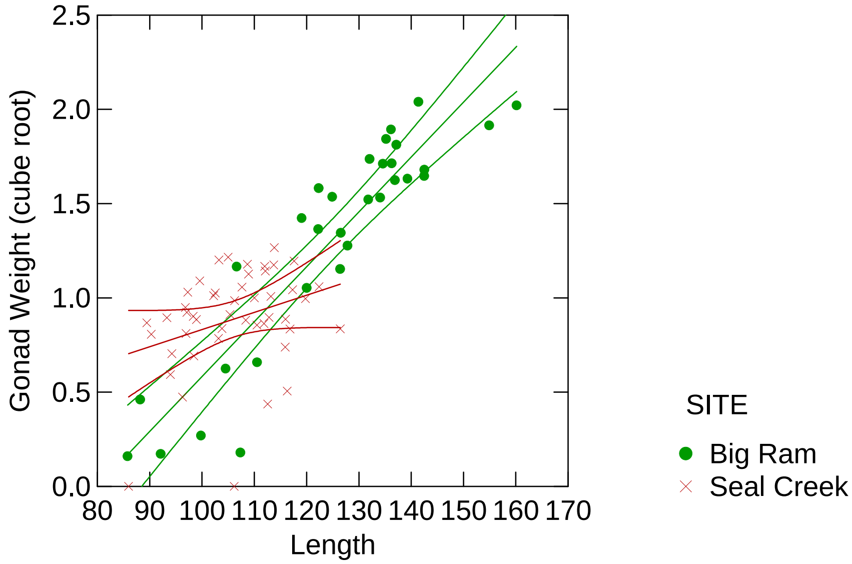

Figure 9: Cube root of Gonad Weight against Length for 2 sites in the Eastern Zone, Victoria. Circles=fast growth; Crosses=slow growth.

Influence of borers:
The level of scatter present in the data relating to fecundity (Figures 7, 8) also suggests that another variable is confounding the fecundity results, obscuring the analysis. As boring organisms are known to significantly reduce growth and fecundity in abalone, it seems likely that they would affect this analysis. In an attempt to quantify the level of borer infestation present in samples, shell weight was used as a proxy. Shell weight was found to differ between fast and slow growth sites, with slow growth sites tending to have heavier shells (Figure 10A). Further, animals with heavier than expected shells for their length (i.e. more heavily bored) tended to have lower gonad weight (i.e. lower fecundity; Figure 10B). Thus shell infestation by borers is an important variable in the shell shape/fecundity analysis and will need to be carefully measured.

The prevalence and assemblage of organisms (including sponges and polychaete worms in the family Spionidae) on shells may also relate to shell shape as many of these taxa bore into the outer layers of the shell. Shells can either be very brittle and weak or heavily reinforced with nacre under heavy infestation. It is likely that the prevalence of these boring organisms will have an impact on the energetics, reproductive potential and shape of infested abalone (McDiarmid *et al*. 2004).

Unfortunately, shell thicknesses were too variable to be of use in investigating the effect of borers. Further, the extent of infestation is not always apparent on visual inspection of the shell, as sponges and corallines can hide extensive shell damage.

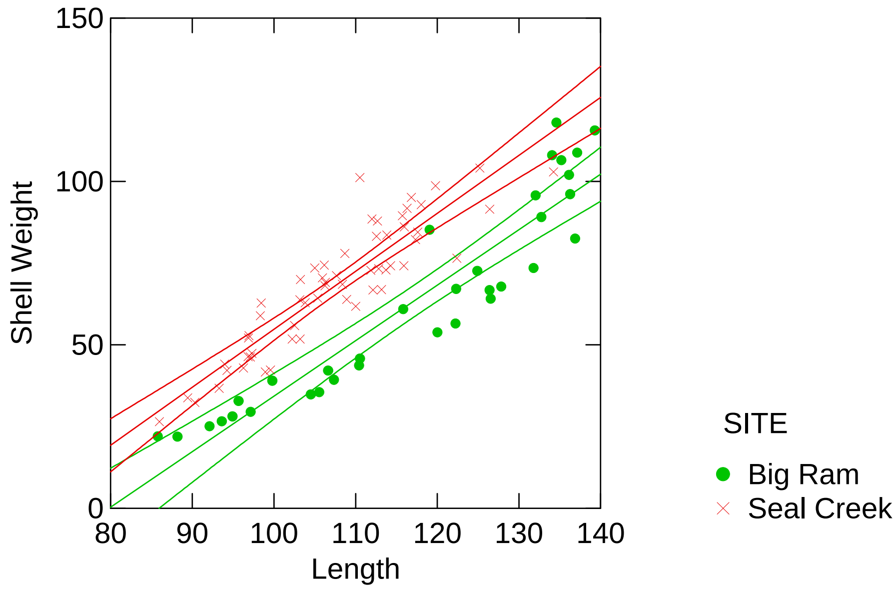

Figure 10A: Plot of Shell Weight against Length for 2 sites in the Eastern Zone, Victoria. Circles=fast growth; Crosses=slow growth.

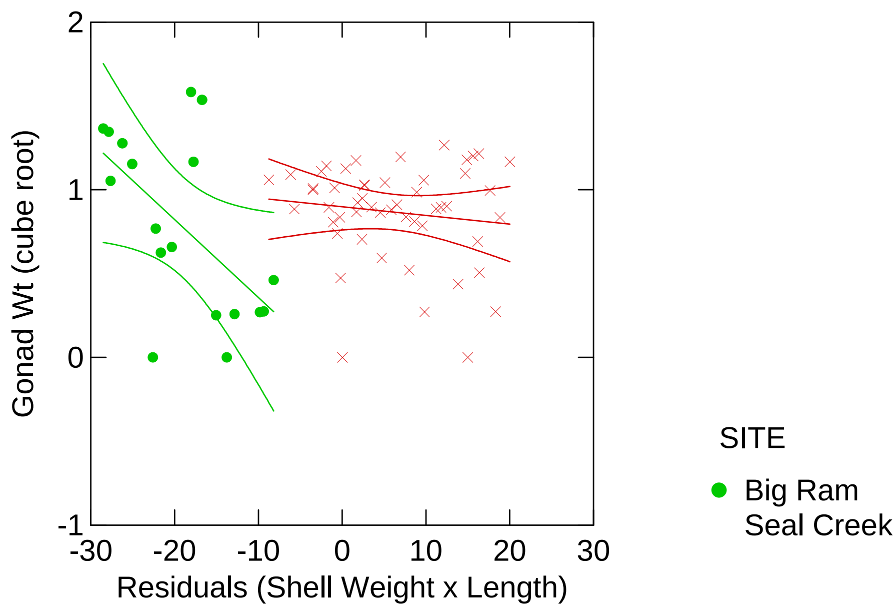

Figure 10B: Plot of Cube root of Gonad Weight against residuals of a shell weight x length regression for 2 sites in the Eastern Zone, Victoria. Circles=fast growth; Crosses=slow growth.

1B. Validation of shell shape versus fecundity for greenlip

This work on greenlip from South Australia aimed to validate the relation of shell shape and fecundity described in Prince et al. (2008), in a parallel way to that reported above for blacklip. Greenlip abalone differ from blacklip in their appearance, habitat preference (Shepherd 1973) and spawning behaviour (Shepherd & Laws 1974). Greenlip abalone shells have a different morphometry: they have a smoother shell, without the shell ridging and raised respiratory pores seen in blacklip. They occupy rocks among sand and seagrass, aggregate to spawn annually, and their larvae may well disperse over longer distances than blacklip. Thus the relation of shell shape to fecundity might well differ in this species.

First, principal component analysis was used to reduce the number of variables used to describe shell shape (Table 5). Three different measures of shell shape are very informative (have high Eigenvalues). A discriminant function analysis showed that the height/length ratio was best to classify shells to sites, although sites within each growth rate category were not significantly different. As growth rate and shape varies within sites, and probably with age, this is not surprising. It remains to be seen which measures are most informative for predicting individual characteristics.

Table 5: Principle Components Analysis of shell shape measurements

Factor	PC1	PC2	Eigenvalue
Doming Length / Length	0.919	0.018	3.333
Nose height / Length	0.899	0.019	1.203
Height / Length	0.887	0.115	0.743
Doming Width / Length	0.867	-0.162	0.405
Width / Length	0.256	0.797	0.193
Meat Weight / Total Weight	-0.274	0.727	0.124

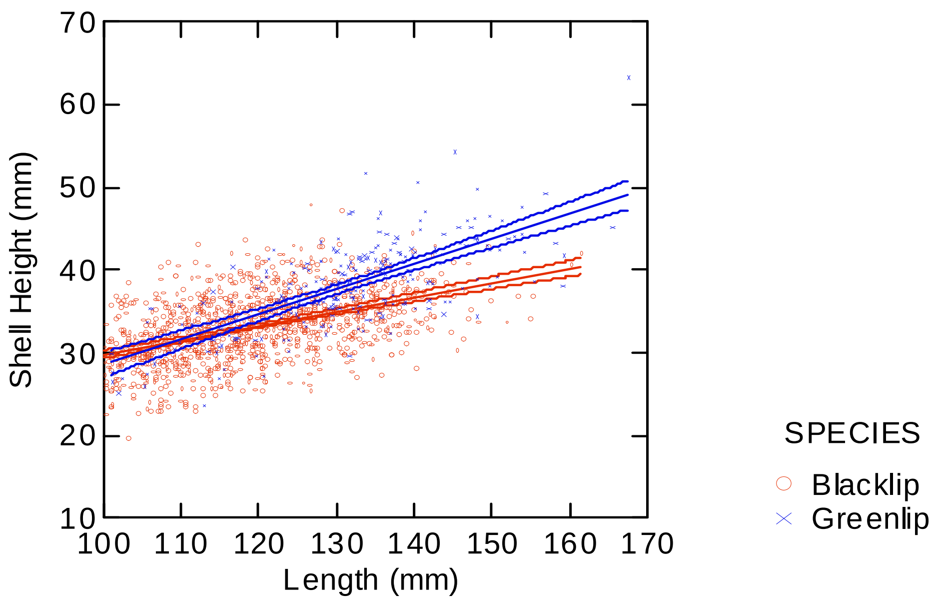

Figure 11: Regressions of shell height versus length for blacklip and greenlip abalone.

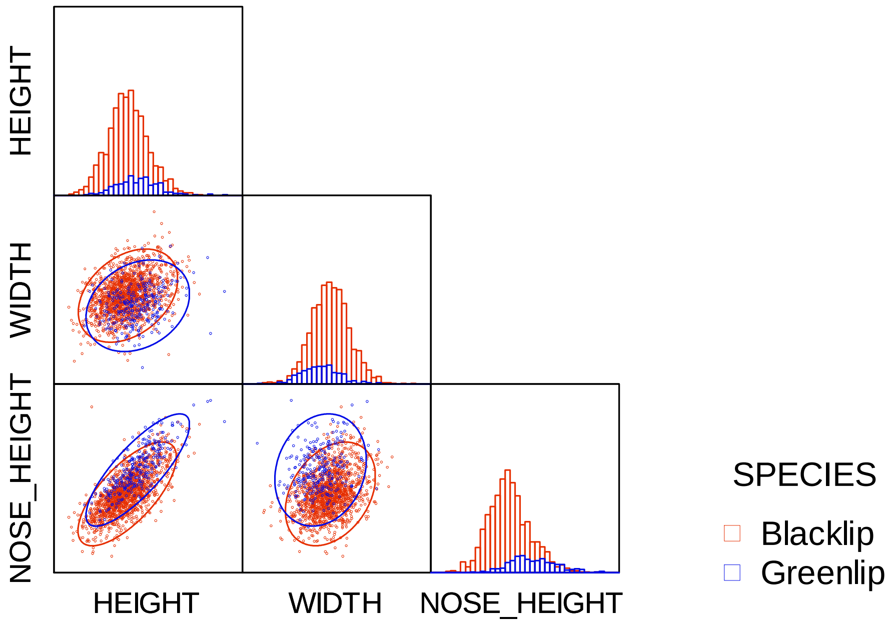

Figure 12 Scatterplot matrix of the residuals from regressions relating shell height, nose height and width against length, for both greenlip and blacklip

When greenlip are compared to blacklip shells (see above), it is clear that shell shape and doming differs between these species. Shell height increases faster with length in greenlip (Figure 11), and when adjusted for length, greenlip shells tend to be higher but narrower at, and in front of the spire than in blacklip abalone (Figure 12).

Dry gonad weight was regressed against the residuals of a height x length regression, as plotted in Figure 13, and this indicates a significant positive relationship between fecundity and doming at 3 of the sampled sites. The remaining site showed no significant relationship. This site has the largest asymptotic length and the most rapid juvenile growth (high ‘k’) so that the lack of a doming effect on fecundity may be because at this site the abalone are harvested before they become both large and domed. In addition, at this site there might be a mixture of large and smaller abalone, such that smaller abalone grow rapidly initially (producing a higher k at this site), but become domed at small sizes while their gonads are relatively small, whereas larger abalone develop larger gonads but are harvested before they begin slowing their growth and doming.

Overall, we conclude that doming is an indicator of greater fecundity in greenlip. With regard to the indication from these results that harvesting at Site 500 may prevent doming of larger abalone, we suggest that the SA central zone should monitor this site for possible declines in productivity.

The investigation of spawning of domed versus less domed greenlip supported the validation of the value of doming as a useful assessment measure. Briefly, abalone were not more likely to repeat spawn whether their shells were highly domed or not, but total egg diameter and nucleus diameter (and thus egg quality) was positively related to doming index, and domed abalone released larger eggs in their second spawning in terms of total diameter and cytoplasm diameter, compared with flat abalone.

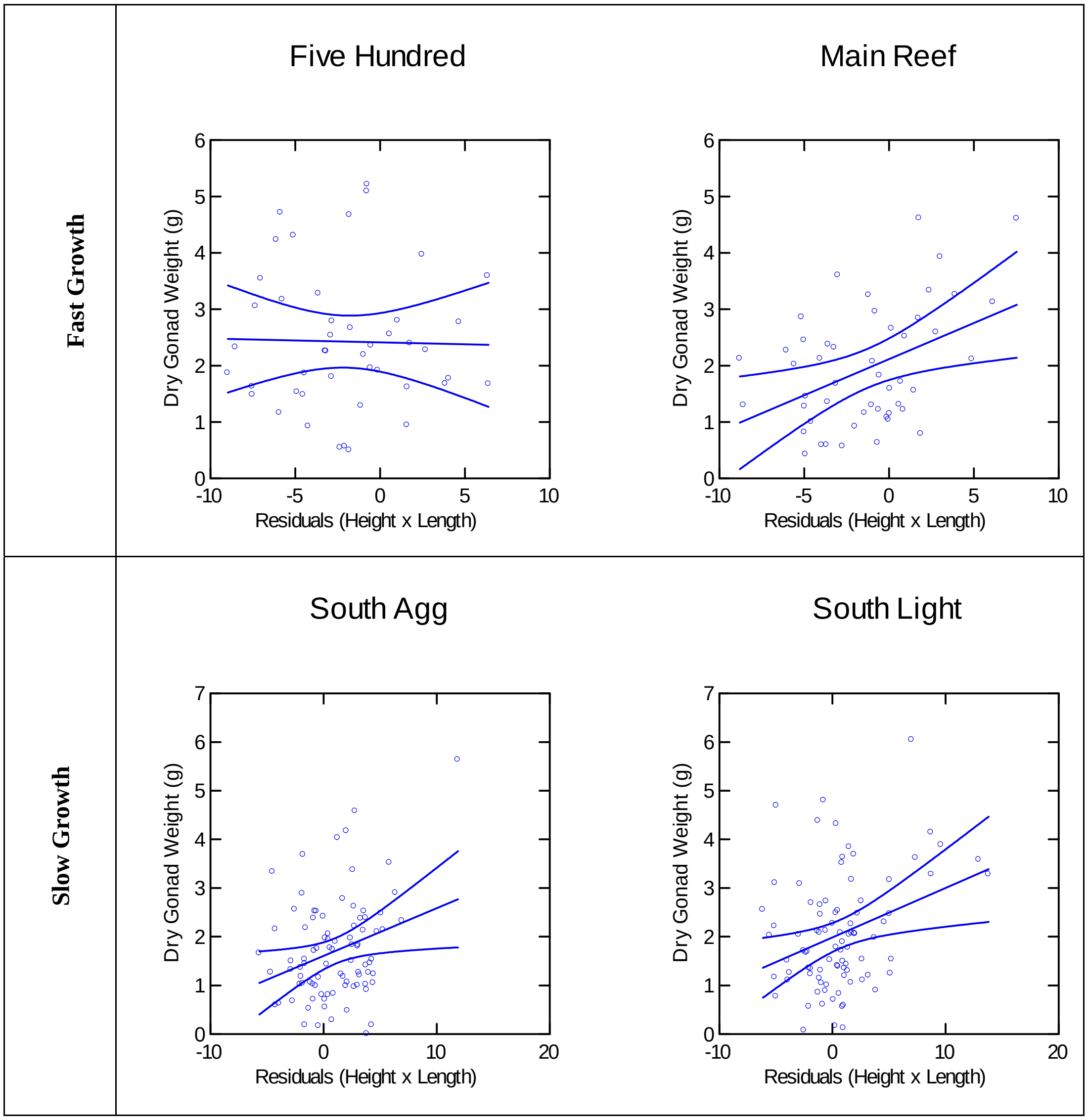

Figure 13: plots of gonad weight against residuals of regressions of shell height versus length (indicating the relation of fecundity to doming, adjusted for size)

2. Baseline sampling

The major biological parameters of importance to industry and to management are the growth and fecundity schedules. Extensive sampling by Gorfine's team at Fisheries Victoria has been done at 14 reefcodes in the Eastern Zone, and 20 reefcodes in the Central zone, to estimate the growth rates and relative size at maturity of abalone at these reefcodes. The advent of the abalone ganglioneuritis in the Western Zone prevented such work. This disease may well have changed the growth rate and onset of gonad development on reefs, as a result of reduced densities of juveniles and adults. Previous experimental work on greenlip juveniles and adults in South Australia (McAvaney *et al*. 2004, Dixon and Day 2004) showed that the growth of both juveniles and adults increased and the onset of gonad development occurred earlier at reduced densities. Thus gonad sampling work will be required on these reefs as they recover, and will be commenced shortly by DPI Victoria. The estimated parameters for the chosen sites are shown in Table 6.

Table 6: Growth and Fecundity parameters for 17 sites in Victoria. $F=a+bL^3$ where F is dry gonad weight in mg, L is length in mm. * estimated from a nearby similar site

Zone	Growth Rate	Site Name	Growth K (se)	Growth L_∞	Fecundity A	Fecundity B($*10^{-6}$)	Fecundity R^2 (corr)
Western	Fast	Thunder Pt	0.422* (0.019)	140.6*	-1.656	2.520	0.713
		Levys Pt	0.422 (0.109)	140.6	-1.055	2.397	0.596
	Medium	Bully Cove		117	-1.185	2.580	0.875
		Jones' Bay	0.224*(0.037)	125*	-1.174	2.540	0.804
	Slow	Murrels	0.218 (0.065)	115.8	-1.058	2.318	0.680
		Mills Beach	0.369 (0.060)	129.1	-1.212	2.488	0.504
Eastern	Fast	Sandpatch	0.317 (0.039)	151	-1.331	2.411	0.686
		Big Ram	0.423 (0.032)	153.9	-1.472	2.208	0.807
	Medium	Little Ram	0.227 (0.035)	125.7	-0.042	2.097	0.768
		Iron Prince	0.270 (0.095)	148.9	-1.151	2.005	0.876
	Slow	Quarry Beach	0.17*	131.6*	0.413	0.872	0.333
		Seal Creek	0.17*	131.6*	0.156	1.211	0.408
Central	Fast	Portsea Back Beach	0.384 (0.185)	? 138	-0.111	2.163	0.780
		Back Beach	0.298* (0.067)	? 135	-1.006	2.027	0.711
	Med	C. Schanck West	0.20*	139.7*	-0.669	2.365	0.959
	Slow	Kirks Point	0.241* (0.014)	119.0*	0.163	2.374	0.875
		C. Schanck	0.190 (0.053)	123.9	-0.628	2.397	0.904

3. Workshops

During the workshops, participants became more and more familiar with various issues involved in industry-based fishery management of abalone stocks, and various lessons were also learned about how collaboration between participants will operate. These results from workshop processes were extracted by Patrick Gilmour, from his records of the industry workshops.

Fishery Dynamics and Fine-scale Management

The biological principles underlying fine-scale management are relatively well-established: abalone are relatively locally-recruiting; and their rates of growth and maturity vary between areas. The way abalone are fished is also important. Abalone are not randomly fished across all populations, but areas are selectively fished based on factors such as:

- How close they are to port (closer populations attract more effort)
- Catch rates (higher-catch areas are fished preferentially)
- Shelter (sheltered areas in the lee of wind or swell may attract more effort)

- Shell characteristics and market demand (areas with ‘clean shell’, good recovery or of a particular size may be targeted according to market/processor demand)
- Depth (shallower populations may attract more effort because divers’ no-decompression time is longer)

The biological characteristics of abalone therefore combine with the spatial nature of fishing to make them vulnerable to serial depletion. This occurs where an area is preferentially fished (because it is close to port, shelter etc.). If the broad size limit in that area is not high enough to protect that population (i.e. they mature at a higher size), it will be fished-down to a point that inhibits recovery. This transfers effort to other preferred areas, where it may not be sustainable, and so the process repeats.

This dynamic of small populations, broad-scale size limits and free-flowing effort is the underlying rationale for managing abalone stocks at finer spatial scales than done under government-based management. It is also important in understanding the lessons from fine-scale management and how it can be best implemented. The following sections outline general but repeated observations about the dynamics of abalone fisheries being managed at a fine-scale and the key lesson to be drawn.

Effort will shift according to catch rate

Divers respond to catch rates as a natural part of abalone diving. High catch rates areas are (almost) always preferred to low catch rate areas:

- Higher catch rates reduce the time on the water, running expenses and thus improve profitability
- Higher catch rates are also more desirable (generally) because divers have to swim less and spend less time in the water.

Effort will concentrate on more accessible areas

Areas closer to port will typically attract more effort than those further away. This dynamic is particularly pronounced when divers’ profitability margins are strained by low wages or high fuel costs.

Increasing the size limit will (generally) decrease catch rates in the short-term

Size-limit increases clearly mean in a given area, less abalone will be available for divers to catch. This means catch rates will decrease.

The extent to which catch rates will decrease, however, will depend on the level of fishing pressure, the magnitude of the change and the growth rate of the abalone. Small size limit increases in high-growth areas may not be noticeable. Large size-limit increases are likely to have much more of an impact.

Increasing the size limit can improve catch-rates in the medium-term

Abalone grow at different rates during their lifetime, i.e. their growth is not linear. There is a period when their growth rate is very high—they will add much more mass during a set period than they will at any other time. For example, during this peak period of growth, they may double in mass in two to three years. This offers a lot of potential for improving the ‘yield-per-recruit’— fewer, bigger abalone can be taken for the same weight.

If abalone are being fished before or during this peak growth period, this potential is not being realised. Adjusting size limits so that abalone are taken at the tail-end of this growth spurt means catch rates can actually increase in the medium term (years)—less abalone may be taken at the higher size limit, but these abalone will be much heavier.

Size limits will 'lock-out' certain abalone
Increasing the size-limit in any area will mean less abalone are available to harvest. Some of these abalone will eventually grow through the size limit and be 'recruited' to the fishable population. Other, 'stunted' abalone will never get big enough to fish (because of their particular position, access to food, age etc.). In an area of any scale, the key is to find the size-limits that maximises the potential from that area. This will always mean that some abalone are left uncatchable.

Finding the size-limit that maximises the potential from an area is difficult. Important points to be wary of are:

- A size-limit increase, across a broad area may lock-out areas of smaller-maturing abalone.
- But, it is important to see the potential of an area—what abalone would have been there if there was no fishing? In areas heavily fished, the remaining populations are often the small fraction of the original stocks that are protected by the size limit. All of the others (that grew bigger and matured at a higher size limit) have already been fished out. What could abalone grow to in those bigger-growing areas?

If areas are 'locked-out', effort will spread elsewhere
The TAC means a certain amount of abalone will be caught. If areas (small or large) are 'closed-off' because of size-limit increases, the abalone that would have been caught there will be caught somewhere else.

When all of the stocks are all in good condition and are not fully exploited, there is 'room to move'. Effort can be shifted from reef A to reef B, and, provided reef B is able to accommodate this effort, no detrimental effects will result. However, if B is already fully exploited, or, the size limit is insufficient at B to protect sufficient numbers of breeding abalone, then:

- Reef B will be fished down, leading to effort shifting elsewhere again;
- Or, if Reef B is already being fully exploited, then effort will move to reef C, where the same dynamic occurs.
- Fast-growth areas, where abalone consistently grow above the size limit are particularly at risk in these instances because they offer good catch rates, but the size limit may be insufficient to preserve enough breeders.

The critical point is that the level of catch in the fishery is set. If catch is not taken from one area (because catch-rates are low, or because there are no fish to take), it will be taken from another area. In a fishery where the size limits are not set to properly protect all the stocks, overfishing will occur. Size-limits and the total-catch are inter-dependent, they need to be considered together. The more heavily exploited a fishery is, the more they have to be considered together.

Catch-caps can help spread effort, but only when the TAC is appropriate
Capping the catch from each reef/area is a way of ensuring effort is spread around the fishery.

Capping is particularly useful when there are healthy stocks that are not being fished because of preference for areas that are more:

- Accessible/economic to access;
- Easily fished/sheltered;
- Desirable from a processing/marketing perspective.

Although capping is a way of forcing effort into less-desirable places to fish, some areas will cost more to fish. There is little point in catching abalone from an area when it is not profitable. This is an important consideration when the costs of fishing are separated from the quota entitlement—i.e. when divers are contracted at a fixed rate per kilogram, it matters little to the owner how much it costs to catch the quota, but operational costs are critical to the diver.

Capping is also less useful when the fishery is fully exploited. There is little point in capping an area so that effort is forced somewhere else, if those other areas cannot sustain that effort. Thus, the total catch is of prime concern.

General lessons about industry cooperation

Fine-scale management and voluntary compliance
It has largely been too complicated and costly for government authorities to collect data and devise, monitor and enforce rules at 'fine-scales'. Movements towards finer-scale management have, therefore, been based almost entirely on voluntary, industry-driven initiatives. Throughout this evolution towards industry-based co-management, one of the main issues has been in garnering compliance with industry-devised rules; rules that have no legal authority. This is a classic issue around the world where groups self-manage resource-systems—avoiding the problem of free-riders. Free-riders are resource-users who benefit from the actions of others (such as those divers who chose to catch abalone at higher size limits), but do not bear any of the costs themselves (as they still fish at the lower size limit). Key lessons, therefore, revolve around issues of trust, cooperation, monitoring and the rule-making process.

Free-riders threaten motivation as well as management
In any situation that requires cooperative sacrifice, an individual will do better for themselves if they free-ride or cheat on cooperative agreements. This often comes at the expense of the collective good. In all of the abalone fisheries where fine-scale management was evolving free-riders (non-compliers), or the threat of free-riders, was an issue.

Size limits illustrate the vulnerability of voluntary limits to free-riders. Compliant divers could harvest an area at a set voluntary size, leaving behind abalone that are above the legal size limit, but below the voluntary limit. There is then nothing to stop a free-riding, non-compliant diver from then fishing that area and harvesting all the abalone left behind.

The risk of this free-riding behaviour happening, however, varies from place to place. In areas that are visited infrequently, or have an abundance of abalone above the size limit, the risk of free-riders 'spoiling' the work of others is reduced. Alternatively, the risk is greater in in high-effort areas that are visited frequently. Abalone stocks are more likely to be fished down to the size limit so any voluntarily left by a diver are particularly vulnerable.

Free-riding behaviour clearly has the potential to impact on management efforts by negating the voluntary restraint of cooperators. The extent of this impact relates back to fishing pressure and rates of non-compliance. But, free-riding also has an impact on people's motivation. People do not like being taken advantage of. Most people also have a strong norm of fairness. Thus when somebody is perceived to be taking advantage of others' hard work, it often leads to a vicious cycle of people questioning 'what's the point?'. Divers often describe cheating behaviour as something that sets in like a 'virus' or 'rot' that grows and spreads throughout a group. Thus, even the perception of free-riding behaviour can have deleterious consequences for cooperation.

Seeing the results of cooperation is important

Natural systems are complex and dynamic. Thus, there is an inherent level of uncertainty in any management activity. For example, increasing size limits should theoretically increase the number and weight of abalone on a reef, but the relationship is not clear—abalone may die, growth may slowed because of competition, poachers may steal them—there are numerous conceivable outcomes. For this reason, some people may be hesitant to incur costs now (such as the extra effort of increasing size limits) when the future benefit (better-condition stocks) is less-than-sure.

Several cases suggest, however, that when the benefits of actions start to be visible—when people could see the fruits of their labour—they were assured that their efforts had been worthwhile and were more motivated to act further. This partly stems from greater certainty that the biological theory underlying fine-scale management is sound. I.e. that increasing the size limit does improve the resource.

Seeing the benefits of fine-scale management was also an assurance that people could cooperate, that free-riding behaviour was not going to negate any of the benefits. Thus, in a reversal of the 'rot' of non-cooperation noted in the previous section, seeing the benefits of cooperation can help to bolster people's confidence in the process. It can also induce 'conditional cooperators' (people who are particularly wary of being cheated) to participate. The belief that cooperation can work with less-than 100% compliance is therefore important in starting the process moving.

Although physically seeing the benefits of management actions was most convincing, relating examples success from other groups was also a persuasive way of allaying concerns.

Seeing the need to do something is important in the first place

One of the main factors that appears to be important in generating cooperative agreements and initiating fine-scale management is the perception that something actually needs to be done. This can be seen both at the fishery-scale, and at the scale of individuals. Those who perceive the fishery is in reasonable condition and that the status quo management is okay, typically see no need to change—a case of 'if it ain't broke, don't fix it'. This fits well with observations from other natural resource systems that suggest moves towards co-management are often only done when there is a crisis—then it is clear something needs to change.

This also points to the importance of having a shared understanding of the problem or issue. Cooperation and agreement between industry members was much easier in cases where people had similar appreciations of the situation. Finding areas/cases of shared understanding is therefore a useful way of initiating collaboration between parties that may otherwise disagree.

Trust and cooperation take time to build

The more-successful cases of industry-based fine-scale management did not emerge overnight. The trust, cooperation and belief that management can work, takes time to build. It should also be noted that it can be damaged very quickly when people do not act in good faith. To build trust, small steps were often necessary in the beginning when stakeholders were working with each other for the first time. As noted above, one of the ways to start generating agreement and cooperation is where people have a shared understanding.

Cooperation is easier in smaller groups

It is widely appreciated that, in line with several of the points above, cooperation is easier to initiate in smaller groups. Smaller groups facilitate better cooperation between people and allow trust to build quicker. They also enable people to monitor each others' actions more closely.

Although larger fisheries are obviously disadvantaged in terms of group size, there is still potential that informal territorialities will promote 'sub-group' discussions and agreements. This possibility is enhanced if the intrusion of 'outsiders' into territories can be minimised.

Monitoring compliance is important for maintaining cooperation

As noted previously, perceptions about other people's compliance are important. They contribute to trust (or a lack of it), cooperation and broader perceptions of the efficacy of fine-scale management. If compliance-rates are perceived to be low, the value of fine-scale management is also diminished.

The ability to monitor people's compliance enhances the capacity of groups to self-manage. This is one of the reasons why small groups are more conducive to effective cooperation. Monitoring:

- Checks if people are adhering to rules, therefore enables violators (free-riders) to be punished or sanctioned in some way.
- In checking for free-riders, monitoring also provides reassurance to the group that they are not being cheated.
- Aside from monitoring to deter free-riding, monitoring is also important as a logistical tool—it helps managers (fishers or otherwise) to track progress against a management goal or target. 'Divers' Web', setup by Fisheries Victoria, is a good example of this, allowing all industry-members to track the catches from different reef areas and plan their fishing around what catch-caps have or have not been met.

There are both formal and informal systems of monitoring. Two formal systems have been used in fine-scale management of abalone. First, government-employed fisheries officers have monitored FSM issues as part of regular enforcement duties. Where voluntary rules are broken, the industry association executive is informed. Second, there has been random monitoring of catch (shell size) at the time of processing. A random sample of a diver's catch is taken and checked for compliance with voluntary limits. This also provides a valuable source of length-frequency data.

Informal monitoring also occurs. Divers check up on each other by looking at where others are fishing (on-water observations), what their catch rates have been (inferred from time on the water and how much they land) and what the abalone look like when they bring them to shore (size distribution, shell shape, etc). An example divers frequently cite is when someone else re-fishes an area they have recently fished themselves at a voluntary size limit—if the second diver still gets a good catch the first diver often infers the second has taken all the ones that were voluntarily left.

Developing effective monitoring and sanctioning systems is a key challenge
Although the above systems of monitoring do occur, they are often ineffective:

- Government-based monitoring by fisheries officers is costly. The complexity of fine-scale rules has also meant that traditional approaches, such as inspections of catch at-sea, can be circumvented. Divers, for example, may report their catch was from an area with a lower size limit to where it was actually caught. It is possible to develop regulations to avoid these loopholes, such as at-sea reporting, bin-sealing etc., but this can reduce the flexibility of divers and imposes additional burdens in what is already a heavily regulated process.
- Processor-based sampling has become increasingly ineffective. It is only done in one processing plant and the proportion of catch going to this plant is decreasing. This is not to say compliance is decreasing, but it offers more opportunity to avoid having one's catch checked, and contributes to the perception that people may not be complying
- Informal monitoring by industry members can give broad ideas about compliance, particularly where the rules are clear-cut such as with closed areas. It is less useful in terms of monitoring compliance with size-limits etc. In these cases it would be unreliable as a source of evidence for imposing formal sanctions.

Sanctions and punishments are also an important part of discouraging free-riding. Under voluntary agreements, even if monitoring is effective, industry groups have few options for sanctioning rule-violators. One of these options has been to threaten a divers' employment through the quota owner. However, if the quota owner condones (and sometimes encourages) free-riding behaviour, the industry association has little recourse. In some instances, individuals have resorted to verbal and physical abuse.

In an effort to prevent this, industry groups have been moving towards legally-enforceable fine-scale rules. That is, they have sought to regulate size-limits etc., meaning fisheries officers could monitor compliance and punish non-compliers.

Regulating fine-scale management through government is not straightforward, however. As noted above:

- Government-based monitoring and enforcement is costly. Using current procedures (at-sea inspections etc.), enforcing fine-scale management rules is only likely to be more costly.
- Fine-scale rules will need new monitoring procedures to be developed to close off loop-holes that could be exploited – such as reporting catch from the wrong area
- Such new procedures are an additional burden and may reduce flexibility. Also, more-complex procedures increases the risk of divers making unintentional mistakes. Under a government-based system, such mistakes would carry a heavy penalty.

Thus, two of the key challenges for industry-based management are first, developing simple, objective, flexible and cost-effective monitoring systems. Technology such as GPS loggers, vessel monitoring systems (VMS) and shell-measuring machines may have potential in this area. Second, a fair system of sanctioning that can be applied to all industry-members needs to be developed. Experience from other self-managed resource-systems suggests it is important to have a system of graduated sanctions.

The support of state managers and compliance officers is critical

One of the simple ways voluntary, fine-scale size limits have been supported without changing monitoring or enforcement systems has been through broad-scale increases in the legal size-limit. This reduced the difference between voluntary and legal size limits. For example, if the voluntary size limit was 125 mm, and the legal was 110 mm, there would be significant stocks of abalone between 110 and 125 with no legal protection, and which a free-rider could harvest without fear of punishment. If however, the legal size limit was raised to 120 mm, the difference is much smaller. Raising the legal size limit at a broad scale also maintains the simplicity and rigour of the government monitoring and enforcement system.

It is, of course, a balancing act to set the optimal legal size limit across a broad area without closing off too many stocks. The process industry has adopted in Victoria, therefore, has been to experiment with voluntarily-raised size-limits for several years to develop a better understanding of what the impact of a broad-scale size-limit increase would be. I.e., it has been a process of learning what the growth potential of the different abalone stocks is, the levels of harvest that come from different areas and the amount of stock that would be ‘cut-out’ through size limit increases.

In cases where substantial areas of smaller, ‘stunted’ abalone are cut-out by broad-scale size-limit increases, it is possible to still fish these areas through special ‘fish-down’ permits. Such permits make it easier for the government monitoring and enforcement system to control the catch from such areas and ensure they are not used as loopholes for undersize fishing in other areas.

How the costs are distributed amongst members is important

Fine-scale management rules have different impacts on different stakeholders in the abalone industry. Just in terms of nominated divers and quota owners, changes to the total quota influence both divers and owners, but size-limit increases and closed-areas typically only impact on divers. They are the ones who will have to spend more time fishing or fish in less-preferred locations.

In garnering the support of all industry members, therefore, it is important to consider:

- Pay rates and compensation
- Job security
- Who participates in the decision-making process

All industry-members need to participate in the fine-scale management process

Rules cannot simply be devised by quota owners and dictated to nominated divers under threat of punishment or termination. This sort of process reflects the outdated command-and-control approach of centralised government managers. It should be well-recognised that if the people who actually fish do not believe in the rules (i.e. they do not see any value to themselves, others or the environment), then they will always find a way to circumvent them.

Developing rules that are understood to be fair and beneficial is critical.
Importantly, this will also reduce (but not eliminate) the need for costly monitoring and sanctioning systems—people are less likely to go out of their way to ‘beat the system’ if they see the system as fair and in their own interests.

Therefore, it is critical to ensure all industry members can freely participate in the industry-management process. This opens everyone up to the same learning process—e.g. it exposes people to the same information about the state of the stocks or the value of size-limit increases. Participation also helps instil a sense of ownership over the management process—the rules become ‘our rules’, as opposed to rules imposed by a state bureaucracy, instilling them with more of a moral and social impetus for compliance. Finally, involving all industry members helps create rules that are flexible, workable and sensitive to the actual job of fishing. Such rules are much more likely to cooperated with than complicated, burdensome and inflexible ones that people do not see the point of.

Externalities, such as poaching, also need to be addressed
In building and maintaining cooperation within industry it is also important to consider the influence of external disincentives. Poaching is one example. The benefits of fine-scale management are typically accrued as healthier stocks—larger, more-abundant abalone. If these stocks are vulnerable to poaching, there is a risk that the short-term costs incurred through FSM will be wasted.

In areas vulnerable to such externalities there is a need to assess the real risks. Often, the perceived magnitude of the problem may be different to its actual magnitude (as is the case with low levels of non-compliance). In cases where externalities are a real threat, they should be addressed in collaboration with the relevant authorities.

Summary

Distilling the discussion above, it appears to us that important lessons and ways forward for industry-based fine-scale management are:

- Size-limits should be increased gradually through a process of adaptive management;
- There may be substantial yield-per-recruit gains if current size limits are lower than the peak in abalone growth rates;
- Size-limits, catch-caps and total catch should be all considered together. Size-limit changes will move effort around in the fishery and this needs to be accounted for;
- Areas that have been depressed for some time may benefit substantially from total closure, as even a small amount of infrequent fishing can keep them in a depressed state;
- Perceptions of people’s compliance are important—there needs to be at least some form of monitoring to assure people that cheaters will be caught out;
- Benefits can be realised without 100% compliance;
- Seeing the benefits of cooperation/management is a powerful motivator;
- Cooperation and trust take time to build and can be fostered through small steps;
- Monitoring and sanctioning systems need to be simple, workable and fair;

- Broad-scale increases to the legal size-limit can complement voluntary rules;
- The distribution of who bears the costs and benefits of FSM need to be considered;
- Inclusive and open co-management processes are important for developing support for industry-devised rules.

4. Development of simulation models and software for industry.

Abmodeller was demonstrated by Rob Day to the Western Zone at a recent meeting in Port Fairy, using the previously obtained fits to the crags and other sites initially depleted by the AVG disease, in order to show the expected recovery under various management options. Abasim II provided similar but less definitive estimates. Francis Byrne has also installed Abmodeller on the server that has recently been bought by VADA. Francis has also developed a pilot database for the management of industry abalone data, and installed it on that server. Arrangements have been made to install both the database and the simulation tool onto a server operated by VPAC (Victorian Partnership for Advanced Computing), so that they are available to all abalone stakeholders.

Unfortunately there are many limitations as yet to the use of both the database and the simulation tools. First, the database, which was not funded through this project as a result of earlier steering committee decisions, is only at a pilot stage, and many aspects, such as security of access to only those who are stakeholders, verification of data after input, etc still need to be developed.

The Abmodeller simulation tool relies on the fitting of data to a reef by the revised reef-scale version of the National Abalone model. This can only be done for reefs where there is sufficient data, and the fitting process requires a skilled modeller to oversee it, to ensure spurious or impossible parameters are not produced. Thus there is a need to produce a set of fits to all the reefs for which we have survey data, and extrapolations to reefs with similar catch histories, where we can estimate growth and fecundity. This set of fits would then reside on the database, available for use by the simulation tool. The graphics used in the simulation tool is a freeware program provided by Google, so that the simulation model must be used while online, to draw down the graphics tools.

Abasim II also requires parameters for the reefs to be modelled, and it may be that these parameters are easier to determine for future reefs. There is considerable value in using two models with different approaches to scenario problems, as one of the problems of models is that they can easily provide a false sense of security in the predictions, and if two alternative models produce very similar results, one can be more confident this reflects reality. Abmodeller makes use of the tried and tested National model, and the best data available for reefs, while Abasim II makes use of assumptions about size-at-age and fecundity schedules, which appear to be valid across a wide range of reef-stocks.

In spite of the limitations of each tool, the simulations produced for the Western Zone reefs demonstrate the potential of this approach. They were well received in the Western Zone, where the graphics of both models could be easily understood by all. It is hard to estimate how realistic models based on less data would be. Exploration of the National model sensitivity has shown that it relies mostly on good estimates of growth rates and the size frequency of emergent abalone on reefs, and much less so on the quality of the abundance estimates from surveys. Thus it may be possible to modify this tool to accept data that is easily collected by industry. Abasim II probably relies critically on the estimates of size-at-age, which arise from the analysis of growth that is used to tune it. It remains to be seen which tool will prove most useful in future, but we are very well placed with two such tools, based on different assumptions and data. Certainly the Abasim II provides a very good tool for self-driven education of industry stakeholders about the dynamics of stocks. We still need to incorporate into both models the probable effects of density-dependent growth and the possible role of adults in maintaining habitat areas for successful settlement and survival of abalone larvae.

The function of the database to provide maps of reefcodes, past catches and other data, has been tested at various VADA workshops, and was demonstrated at the last steering meeting. Software to support and record the workshop decision process, and a risk-based process to generate a suggested TAC was also demonstrated.

5. Development of a training syllabus.

The project proposal included the development of a training syllabus, to allow industry to train stakeholders in the biology and fine scale management of abalone. It became clear however, at the Steering Committee meeting early in 2009 that the Industry wanted training content, rather than simply a set of competencies defining a syllabus. Thus a set of 4 lecture modules were produced and distributed to industry associations. These together provide a training course. Thus the project has provided more than a syllabus, but not training trials, due to the changes in direction by industry. Assistance in implementing the training has been offered, if industry associations wish to conduct their own trials. In addition, an extra module has been delivered to VADA to explain the issue surrounding the recovery of reef stocks after depletion by disease.

The training modules were delivered to the Industry associations as ‘powerpoint’ presentations, with accompanying pdf notes for printing to give to course attendees.

The four training modules are entitled:

1. ‘How do abalone live?’ – an explanation of abalone biology, focused on the blacklip and greenlip species.
2. ‘Management of Abalone Fisheries’ – information on the objectives and principles of management of fisheries as applied to abalone, including assessment and modelling.
3. ‘Fine-Scale Management’ – explaining the need for management at the scale of local stocks, and the means whereby industry can assess and manage stocks.
4. ‘What makes a fishery sustainable?’ – an advanced course in the principles of abalone fishery dynamics, including density dependent responses of stocks, effects of environmental change, variation between reefs, risks and risk management, and ways to reduce risks.
5. The extra module explains the dynamics of stocks depleted by disease, and how these will be affected by fishing.

BENEFITS AND ADOPTION

The adoption of the benefits of this project was an automatic process, as this project was conceived and developed with industry and managers, and built around an extension program of industry workshops. The most easily demonstrable benefits of this project in Victoria are that the Victorian fishery is now essentially managed on a fine scale basis, with the reef-stock assessment and management method, and the workshop process, incorporated into the Victorian abalone management plan. Other tangible benefits include new tools that the industry has to facilitate management, such as the two management scenario models designed for industry use, the Diver's Web internet system, the abalone industry database design and risk management software and the training modules for new entrants.

Other benefits involve industry empowerment and collaboration, and co-management with Fisheries Victoria. In April 2007 the minister for Water, Environment and Climate Change, John Thwaites, presented Len McCall, president of WADA with a Victorian Coastal award for excellence in the innovation category, for the fine scale management process they had pioneered.

As this project was designed to provide benefits for industry stakeholders in 5 zones, and also for management, and was directed by a steering committee that included industry representatives and managers plus an independent chair, we asked the chair, industry representatives and managers to write statements of the benefits as they see them. These are inserted below.

The results of this project also provide benefits for abalone fisheries in other states. Beyond that, while the peculiar biology of abalone renders such management essential for sustainability, we believe that collaborative action by industry to control how fishing is done at a fine scale would be of great benefit in a wide range of fisheries. Thus we have added a section to discuss how the results of this project could be adopted in other fisheries; and the benefits of such adoption.

Independent chair, Ian Cartwright.

An important aspect of the project outcomes has been building of trust and relationships between government and industry stakeholders in Victoria through the work of the project team and Steering Committee. At the outset of the project, there was strong support for increased implementation of the co-management approach. The AVG virus, and the realisation that a combination of regulatory and voluntary approaches to implementing FSM would be required for success in Victoria, led to increasing tensions between government and some sectors of industry. These tensions became evident in the meetings of the Steering Committee. By adaptation and cooperation across jurisdictions the Project Team were able to provide research outcomes directly in support of both industry and government, with advice as the virus progressed. These inputs assisted in rebuilding confidence in the co-management approach and improving government/industry communications. They have also been instrumental in rebuilding strategies.

From the lessons learned, the project team also had critical input into the harvest strategy for the new Victorian Abalone Management Plan, which has gained the acceptance of all zones, including the Eastern zone, which was not involved initially. In this way, the project has resulted in direct tangible benefits for abalone management in Victoria and for government/industry relationships. At the final meeting of the Steering Committee it was evident that co-management and FSM, using the methods refined and developed by the project, had gained renewed and formal support from Fisheries Victoria.

Western Abalone Divers Association (WADA), by Harry Peeters.

The fine scale management practices adopted by WADA in the years leading up to the virus outbreak in June 2006, enabled WADA to collect reef code catch and size data at a scale small enough to be applied to the rehabilitation of individual reefs post virus. Had these fine scale practices not been adopted pre virus, it is doubtful if the resource would ever have recovered without a total closure for decades. WADA had a workshop process in place prior to the FSM project but this was able to be refined and enhanced by the project. The project has provided an ongoing learning experience for the divers and quota owners in the Western Zone. These fishermen now have as good a working knowledge of abalone resource management as most abalone fisheries managers in Australia and better than most abalone fishermen. The project has enthused WADA members to the point where they are actively pursuing further research for the zone. The continued interaction of researchers and fishermen at a very practical level has broken down many previously held suspicions and doubts about the value of scientific research.

Victorian Abalone Divers Association (Central Zone, Victoria), by Vin Gannon.

The Victorian Abalone Divers Association Inc. (VADA) has fully embraced the concept of managing the abalone resources in the Central Zone of Victoria. Since the beginning of the project, VADA has conducted approximately 13 workshops, the initial ones providing background information and training to participants. The topics covered in the workshops included shell shape, biology, density dependence, abundance, fishing pressures, food handling, quality control, risk management, and decision making.

This education which is now reflected in the training packages provided a firm base for industry to becoming empowered in the decision making and management of its industry. During the term of the project the industry was faced with the very real prospect of collapse because of the spread of abalone viral Ganglioneuritis (AVG) along the coast and into the Central Zone. Through the education processes and the empowerment of industry in making management decisions, they were able to separate the issues of virus spread, from the issues of having to manage the remaining unaffected abalone stocks in a sustainable way.

This saw industry remove itself from operating near virus AVG fronts, raising community awareness about sustainability issues and review the overall impacts of the implementation of marine parks and the displacement of fishing effort. In this highly charged environment, and after conducting a reef code by reef code assessment of the stocks, the Central Zone abalone industry stakeholders in 2007, as a result of a fine scale assessment elected to take a 140,000 kilogram drop in TACC, contrary to the formal government model outputs. In addition 11 different legal minimum length areas were developed throughout the zone and they were made enforceable through the use of Fishery Notices.

Since this time, the Central zone has managed the effects of AVG virus with minimal assistance from government and at the same time looked forward to the future in terms of how to best rebuild the industry. This has involved VADA in being actively involved in the drafting of a formal harvest strategy based on fine scale management of reef codes in the fishery, with allowances for a structured risk based approach to decision making and the ability to recognise and respond to problems and opportunities proactively.

This has also seen VADA actively involved in development of a software program that records the outcomes of the Central Zone TACC Forum workshops, and the strategies developed at them to further enhance the sustainability of abalone stocks.

The last Central Zone TACC Forums held in 2010 saw the initial use of the software package (still under development), which involved linking reef code information to research, use of Google maps, etc. This assisted industry enormously, and the application of the principles of fine spatial management saw the industry accept control of obvious problems that now could be recognised. This resulted in the workshop outcome providing for a further reduction of TACC in the Central zone of 132,000 kilograms. This workshop process and outcome was repeated twice with different facilitators, with similar results. Additionally the workshop process has identified 13 different LML areas as well as leading to the development of Focused Fishing Guidelines that will allow access to abalone stocks in particular areas, or stocks with a particular characteristic.

The industry in the Central Zone of Victoria has been, and is currently faced with a number of issues affecting the sustainability of the abalone resource. If it had not been for Project 2005/024 the issues facing the stakeholders would have been substantially worse. The project can be credited with contributing to the industry's ability to respond proactively when faced with the most complex and dire circumstances.

Looking into the future, while the industry is not happy with the circumstances they find themselves in, they are looking towards developing a future for themselves by applying the learning's and resources that the project has allowed them to develop.

VADA would like to thank all the investigators and participants in the project for their time and commitment. I feel that it has been a very successful project, which has built a strong foundation for the future growth of the Central Zone abalone fishery. This future growth can only be completed through the application of the principles of fine scale management of the Victorian Central Zones abalone resources.

Eastern Zone Abalone Industry Association, Victoria, by Geoff Ellis.

The Eastern Zone Abalone Industry Association was slow to embrace or understand the concept of fine scale management and the benefits that can flow from them. With two and a half years of the project remaining, the Eastern Zone recognised the importance of fine scale management (FSM) and took steps to catch up on the implementation of workshops already undertaken by the other participants in the project.

At projects end, the Eastern Zone had fully embraced and understood the concept of FSM. The investigators had implemented workshops in Mallacoota and had conducted coal face interviews with our stakeholders. The outcome of the workshops and interviews meant that the licence holders and divers recognised that fine scale management was essential to resource management and sustainability. The skills and knowledge imparted at the project meetings has resulted in a continuation of the principles of FSM enduring after the project has formally concluded.

As a result of applying the lessons learned the Eastern Zone participants, through the workshops, recognised the necessity to reduce the TACC and adjust LML on a finer scale that is applicable to various reefs within the zone. Scepticism that permeated through the zone with respect to fine scale management has been replaced by a better understanding of the principles of fine scale management. This has facilitated an accepted reduction of the TACC and the lifting of the size limits as practical solutions to problems that would otherwise been swept under the carpet.

In the future I see the lessons learned as a solid foundation upon which to build a more mature and sustainable industry. I compliment the investigators on the successfully conducted and completed project and look forward to working with them into the future.

Fisheries Victoria, DPI, by Sasha Ruff, abalone fishery manager.

Victoria is home to one of the last sustainable abalone fisheries in the world. The commercial abalone fishery in Victoria has faced a number of challenges over recent years. These include the abalone disease currently affecting stocks in the south-west, reduced abalone beach prices, sea urchin spread associated with climate change in the east and in Port Phillip Bay, increased running costs and reduced quotas.

The adoption of the FSM approach has increased collaboration between industry, fishery managers and researchers. This has enabled a more coordinated and cooperative approach to managing the fishery and its challenges. Following the impact of the abalone disease; reef closures, conservative quotas and size limits were able to be implemented with the support of the Western Zone Abalone Divers Association, to maximise stock rebuilding. These initiatives have also been implemented in the central and eastern zones with support of the Victorian Abalone Divers Association and the Eastern Zone Abalone Industry Association respectively. Of note, whilst the principles of FSM apply across the fisheries, the implementation process includes the necessary flexibility and adaptability to deal with different management scenarios. A partnership approach with the industry is vital and has helped ensure improved knowledge of abalone biology, reef dynamics and fisheries management practices.

To ensure the Victorian fishery remains a sustainable wild harvest fishery, a FSM approach is being incorporated into the draft Victorian Abalone Fishery Management Plan. The use of zonal reef assessment and TACC /LML setting forums will not only ensure industry/stakeholder consultation, but also underpin the implementation of harvest strategies.

Abalone Council of NSW (Shareholders perspective) by Duncan Worthington.

Progress on the project in NSW has taken a similar path, albeit at a slower pace, than other zones/states. Early workshops were facilitated by the Abalone Council of NSW and involved Jeremy Prince presenting his broad-scale ideas and consideration of how they fitted with local NSW observations by shareholders and divers on the stock and its dynamics. These early workshops resulted in proposals for catch planning and local size limit changes to better manage stocks at a finer scale. While there was considerable discussion and consultation on the proposals for finer scale management and the need for some form of regulation rather than voluntary adherence, progress on implementation was slow and Industry became frustrated. A Ministerial Review by a Special Abalone Recovery Group (SARG) made strong recommendations about the need to progress Finer Scale Management and particularly size limits, but in response to the review, the Minister recommended the implementation of a broad-scale, state-wide size limit increase to 117 mm, while a Finer Scale Management Implementation Plan was developed.

A further recommendation of SARG related to the development of a Structured Fishing Program to reopen to fishing the previously closed Region 1 and 2. The Structured Fishing Program involved a form of finer scale management that involved catch planning and the collection of greater fine scale stock information through the use of GPS and depth loggers. Further, the Abalone Council of NSW successfully applied for funding to the FRDC Tactical Research Fund, to enable funding support to develop the use of the GPS loggers in NSW, as part of the Structured Fishing Program. This form of finer scale management is currently being extended throughout the fishery in NSW. Also, in one of the most positive fishery management moves in NSW, IINSW have recently confirmed their intention to move to the first finer scale size limit in NSW, by implementing an industry-supported, 120 mm length limit on reefs that contribute about 25% of the state catch, south of Wonboyn. This first regulated finer scale size limit, which is likely to be extended to more areas and sizes, and extension of catch planning and the Structured Fishing Program, provides a very positive development and likely future for Finer Scale Management in NSW, although planning and resources to support these developments will need to continue to be improved.

NSW Abalone Divers perspective, by John Smythe.

Progress in NSW must be reviewed against a background of a fishery under "stress" caused by loss of quota over the past five years and a more recent low beach price for NSW abalone. Low prices and low quotas have seen rationalisation as some divers got out and others accumulated more quota to remain viable. There have also been internal disputes within industry about how the resource should be managed or enhanced and the value of finer scale management. At an earlier project workshop those present agreed to a 2mm increase in the south of the state, but the industry subsequently did not implement this. Now there is support to increase the limit in the southern sector to 120mm. A proposal to increase size limits to 120 mm in the South will benefit 25% of the NSW fishery, yet ignores the other 75%.

Through the workshop process I feel that some industry stakeholders are getting the idea of FSM but I felt the workshops were dominated by a few quota owners and the divers who are actually on the bottom each fishing day were ignored, or did not speak or even turn up. There has been rhetoric from managers and Ministers re FSM but very little willingness on their part to assist industry to move from an expensive fishery independent survey/assessment system. On the other hand all attempts to increase the size limits in NSW have been opposed severely by industry representatives.

In 2008 the Minister increased the minimum size to 117mm against severe opposition from industry representatives and processors. This was partly to comply with IINSW requirements that measures be taken to enhance abalone stocks by increasing biomass. The biomass is increasing, with reduced TAC and the increased size limit giving rise to lower visitation rates on reefs, higher average catch per effort values, and a substantial increase in the size of abalone in NSW catches. In many areas there may be further benefits by increasing the size limit to 119mm, as recommended by the TAC committee and based on the outcomes from the 2mm increase to 117mm.

However, a number of things are facilitating monitoring catches and stocks on a finer scale. The IINSW have changed reporting requirements, and now require GPS co-ordinates rather than broader zones/sub-zone reporting. Data loggers have been provided from the fishery budget. The Abalone Council of NSW is managing the roll out of data loggers to divers and has also arranged for an undersized button where we use a scale of 1 to 5 to record sightings on the bottom of undersize abalone. Over time this will indicate changes in biomass. With all divers now using data loggers, the scale of the fishery information has vastly improved.

Abalone Industry of South Australia, by Michael Tokley.

The South Australian central zone abalone fishery's participation in the Fine Scale Management project has been fruitful. Of the few occasions that the industry members (licence holders, divers and deckhands) met, the result has been the consideration and investigation of areas which would benefit from a finer scale focus for management of the stocks.

In particular, the blacklip abalone stocks around Kangaroo Island have been the subject of several iterations of proposals to fine tune the harvest strategies available to the divers. The divers are aware that a decision made in 2001 to voluntarily increase the harvestable length of both blacklip and greenlip from 130mm shell length to 135mm shell length in the whole area, although for very good reasons, resulted in marginalising some areas so that divers do not harvest them anymore.

All licence holders, divers and deckhands are keen to pursue finer scale management measures throughout the zone in an attempt to have an optimal harvest strategy and maximise their economic return from their diving operations. There is still a lot of work to be done, but industry is ready and willing to undertake the next phase of this challenge.

PIRSA Fisheries, South Australia, by Craig Noell, abalone fishery manager.

The South Australian government is in the process of developing a new management plan and harvest strategy for the abalone fishery. The harvest strategy aims to increase the level of industry input into the decision making process and move towards finer-scale management. It draws on lessons from the current project, extensive interaction with industry and other work on fine-scale management in South Australia. However, PIRSA fisheries acknowledges that the three zones in South Australia are at different stages with regards to adopting finer scale management. The harvest strategy therefore needs to be flexible enough to accommodate these different stages and levels of capability.

Benefits to other states and to other fisheries.

While this project involved the abalone fisheries in 3 states, we have kept in touch with the industry in Western Australia, Tasmania and New Zealand, particularly with

Tasmania, the largest abalone fishery in the world. Industry members, managers and researchers were invited to our steering committee meetings as observers. It is clear that management on finer scales than previously is now practiced in Tasmania. Nevertheless, the clear advantages of the form of industry co-management at fine scales achieved by this project have yet to be achieved elsewhere. We hope to engage with industry and management in all these fisheries, as they are best placed to work out how to achieve this, and history shows they quickly adapt successful approaches.

FURTHER DEVELOPMENT

Historically abalone stocks have been assessed and managed regionally using CPUE trends. This is now accepted as a flawed approach, as abalone stock dynamics vary between reefs, and broad-scale catch per unit time data do not index abundance. Further, it is now accepted that both assessment and management must be at a finer scale to avoid serial depletion of stocks.

Around Australia various approaches to reef-scale surveying and assessment are being trialled (e.g. 2004/019; 2005/024; 2007/066; 2008/077). During this project, the Victoria industry associations in particular, have adopted and adapted a new management approach using qualitative reef-scale assessment. They now use qualitative indicators to develop Harvest Strategies and plan catch levels and size limits for each reef. The new Victorian Abalone Fisheries Management Plan implements a new approach to setting zonal TAC's based on fine scale catch levels. Rather than using quantitative models applied to zone-wide trends as before, under the FMP, zonal TAC levels will be based on summing the catch targets for each reef as determined by assessment workshops of the reefs in each zone.

The consensual workshop approach to reef scale assessment and management, using qualitative indicators, principally shell shape and size and catch trends, is proving remarkably effective. Through this process WADA, VADA and EZAIA have all chosen to drive zonal catch levels down, when the zonal model could have been used to maintain the TAC. They have used the reductions to target management at reefs identified as being under pressure and needing rebuilding. In the case of WADA and VADA, and excluding the impact of AVG, zonal catch levels have been driven down by >25%. This is faster than even an aggressive Department could have hoped to reduce TACs, if that had been their intention.

The success of both the fine scale assessment approach using shell shape and other data, and the management approach using information and collaboration between industry stakeholders and co-management between industry and state managers, suggests these are both areas that will repay further investment by the FRDC and all stakeholders. While we suggest that assessment improvement will only be effective in the context of effective fine scale management, and more effective management will require and take advantage of better assessment, we have considered the needs for and value of investment in each of these areas separately below.

Investing in a secure collaborative management regime

There is an urgent need to find more effective ways to harness skills, talents and contemporary technologies to create positive behavioural changes among abalone stakeholders to adapt and sustain their fisheries. Managing aquatic resource sustainability is becoming increasingly complex. Our tendency to view and explain the dynamics of a fishery in a linear, static way is insufficient to deal with today's challenges. Focusing on biological processes and largely excluding the dynamics of the fishers is manifestly inadequate in addressing sustainability objectives. A "whole-system", inter-disciplinary approach is needed to deal with the sustainability challenge of optimising abalone production into the future. This is especially pertinent today as market forces and climate change are already having substantial effects on the current and future prosperity of Australian abalone fisheries when compared with the direct impacts of fishing mortality.

This fine-scale management (FSM) project has provided a foundation of workshop-based structured decision making, in which industry resource knowledge is a major input, and has established a substantial baseline of social demographic information. In Victoria a major outcome has been the recent implementation of a formally structured harvest strategy framework. This is designed to ensure a planned distribution of fishing effort, so as to optimise outcomes for stakeholders in each of Victoria's three fishery management zones. This harvest strategy framework has been incorporated into a new revised Victorian Abalone Fishery Management Plan (VAFMP) and will be a cornerstone for reporting under the EPBC Act (1991). The Victorian abalone industry is now keen to capitalise on FRDC's investment in the FSM project, by implementing the technology and knowledge that arose from it, under the new VAFMP. This VAFMP represents a considerable departure from the previous one, and its success will rely heavily on the way in which industry stakeholders of each abalone fishery participate as a committed collective in the process. Patrick Gilmour's work in this project has provided an initial view of the issues (see Results – Workshops). Internal cohesion, conciliation and consensus will be the predictor variables for effective functioning of this proposed system.

Developing a structured approach is one thing; being able to test and maintain its effectiveness is an even greater challenge. A new fishery system perspective of evaluating and managing the process is required to ensure that this harvest strategy framework delivers the intended sustainable outcomes. To sustain and build on the achievements to date, and thus invest in the investment that the FRDC and stakeholders have made, it is essential to utilise the skills of social scientists and allied specialists, able to objectively evaluate qualitative and semi-quantitative observations about social interactions among potentially competing interests.

Future research should focus as much on "working on the business" as it does on "working in the business". There is a need to:

1) Understand those processes and techniques that will effectively engage industry participants in critical analysis of the harvest strategy; provide industry participant input to effective implementation; and create industry learning from the process;

2) Evaluate the effectiveness of participatory action research and decision-making processes in building industry social capital and resilience;

3) Increase industry sustainability by improving industry engagement with responsible resource stewardship, thereby also validating these processes to satisfy community expectations of industry ESD responsibility;

4) Identify potential lessons for other industries in regard to harvest strategy implementation and partnership management approaches.

Investing in a new integrated reef scale assessment approach

The reef assessment workshops have made clear there is an urgent need for enhanced reef scale data collection. This need focuses particularly on the relationship between size and Spawning Potential Ratio (SPR), abundance, size structure of the catch and stock, and the magnitude and distribution of catches within reef codes.

Where consensus has been difficult to develop - for particularly contentious reefs or in some jurisdictions – these cases have shown that a more quantitative approach to reef scale assessment will sometimes be required. Quantitative data can settle particular conflicts and move forward the management process for a particular reef to the more consensual, cost effective approach based on qualitative indicators that was developed through this project. To obtain quantitative data for individual reefs, indices of reef scale abundance, SPR, etc. need to be developed that can be easily and cost-effectively obtained at the reef scale.

To date, data on abundance has been available for only a limited number of Victorian reefs, monitored annually by contract survey divers. These data have been crucial in setting up reef-scale modelling to support management decisions about opening reefs as they recover from AVG, and in other reef areas that proved contentious. But the process incurs a high cost, recovered from the industry. While there are no alternatives, it is essential to maintain these surveys, which establish "standard" reefs with a quantitative assessment, to which other reefs can be compared, but it is not feasible to expand these surveys to new reefs. Growth and maturity data are also important, and this project has expanded the reefs for which growth data and size at maturity data are available, but again the work required incurs significant costs.

In Western and Central Victoria the need for quantitative data for reefs is urgent, as the context for developing and implementing an integrated approach to reef scale abalone assessment will be increasingly to deal with re-opening reefs as they recover from the viral impact. In this new context historical catch and effort data are of limited immediate use, because the level of depletion caused by AVG on each reef is not known.

Some reefs have already been considered for re-opening after several years of closure in the Western Zone, and a return to more quantitative methods has been necessary. The recently completed TRF 2008/077 entitled '*Developing cost-effective and reliable industry-based surveys to advise re-opening and conservative management of abalone populations on AVG-impacted reefs*' involved using commercial and research divers to estimate standing biomass, using relatively standard scientific transect survey techniques. These estimates, along with estimates of abalone productivity, were used to estimate risk averse catch levels that might be used to gather more qualitative data with which to slowly restart the Reef Assessment process. Experience gained with that project suggests this approach will cost about $30,000 and take 2-3 months per reef code.

The Western Zone has 27 more AVG reef codes requiring surveying and re-opening. In time the Central Zone potentially will have another 30-40 reef codes requiring a similar process to re-open them.

Further development is needed is to integrate various research approaches to reef scale assessment into a single scientifically validated model. This should support all facets of the burgeoning new reef scale abalone harvesting strategies. The assessment tools must be cost-effective and acceptable for industry adoption. Further, the data and assessment techniques need to be applicable for both:

- once-off biomass surveys for restarting fishing after disease events,
- long term setting of reef-scale catches and size limits in both consensual and conflict situations.

The results of this project, along with those of a recent group of FRDC projects (e.g. 2004/019; 2005/024; 2007/066; 2008/077) now make it possible to see how a range of new technologies and analytic approaches can be combined to achieve the end required: cost-effective scientific assessment at reef scales, and reef scale catch caps that can be reliably summed to support Government set zonal TACs. In the context of reef-scale management, investment in such cost-effective assessment would result in very large benefits to the industry.

Further development is crucially needed to integrate, adapt and implement the new ideas and techniques to create a working model of reef-scale assessment that is flexible enough for several purposes. The methods should be suitable to be applied across all jurisdictions, be useful to re-open reefs after closure, utilize simple qualitative indicators so that reef-code catch levels can be set cheaply, and also be capable of being worked up to a rigorous quantitative analysis, where needed to address conflict. The history of the Australian abalone industry repeatedly demonstrates that the network of divers and quota owners rapidly transfers successful new approaches across jurisdictions. Further development should support implementing new working models of reef assessment with the expectation that successful techniques will be transferred virally through Australian jurisdictions.

Below we outline what we think the future of reef scale abalone assessment looks like. By describing what we think the future logically looks like, we can see more clearly the details of what future developments are most required, and the value of investment in developing this approach.

A new integrated approach would support managing each reef to conserve a target level of spawning biomass on each reef. This target may be determined through the literature and refined by future research; and we assume would be set at internationally acceptable levels by government management plans. Within that broader policy framework we anticipate the new reef assessment techniques would be flexibly adapted to the specific needs of each association and zone, and designed to be implemented along a ‘cost-effectiveness versus quantitative precision’ continuum.

At the most cost effective end of the continuum, spawning biomass targets for reefs would be defined in terms of Spawning Potential Ratio (SPR) (also called % Spawning Per Recruit or % Eggs Per Recruit). This is the level of spawning allowed by a level of fishing relative to the SPR expected in the unfished state - i.e. there would be 100% SPR before fishing began. Targets would be set for each reef in terms of shell size and shape determined through once off SPR studies for each reef. The status of reefs relative to targets could be tracked simply and cheaply on each reef simply by measuring shells in the catch collected from each reef, and comparing the catch profile to target shell shapes for each reef. These data might be collected either through shell measuring in processing sheds, or through the GPS loggers by divers. The key is to develop convenient and inexpensive methods that industry will adopt. Incremental changes in catch and size limit would then be determined with a decision tree or similar decision support framework, until the SPR targets are achieved in terms of shell size and shape.

At the other, more expensive end of the continuum, for some reefs and regions fully quantitative model based estimates of current biomass relative to some benchmark period, will be needed into the future. To make this possible in future at reduced cost, we envisage the near routine collection and archiving of electronic data that records diver tracks, abalone sizes and shapes. Again, methods must be suitable for industry adoption. In time this would develop into a powerful time series of data on catch, the area searched, sizes and shape by location, and through time. As discussed below, these data would become a powerful cost effective engine for developing new reef scale indices of abalone abundance, growth and SPR, and to model and forecast reef stock dynamics. We believe that within 5 years, further development of abundance indices based on 'catch per area swept' rather than 'catch per unit time', together with size trend data and rapid and repeated estimates of reef stock growth and reproductive parameters, is going to make accurate and reliable quantitative stock assessment feasible at reef scales. This will obviously take quite some further development in techniques, and the assessment techniques developed will need to be mechanized within the database to be feasible, accessible to industry and cost effective across many reefs. While it is essential to maintain surveys of the sample reefs for the present, recourse to quantitative assessment for any reef may well become possible for auditing purposes or to reduce conflict, in the future.

We foresee three recent developments will be central to reef scale assessment and suggest continued priority for further coordinated development in these fields.

1. GPS Dive Track and Abalone Size Data: Biomass estimation

Central to the new approach would be the routine or widespread use of GPS logger data to collect dive tracks and sizes of abalone. For the approach to work as proposed, a significant part of the fishery, but not all divers, would need to collect size and dive track information. Spatially intricate size structure data could be used to manage reefs towards size based targets. We believe that abundance indicators based on 'catch per area swept' rather than 'catch per time', could become central in cost effective quantitative assessment at reef scales; and that in the long term (5-10 years) catch per area of reef, and size trends will prove highly definitive for quantitative modelling of stocks.

Currently commercial catch rates are calculated from diver data on the basis of catch per time and this is known to be a poor index of biomass. Research divers generally conduct counts within a known area and compute trends per unit area. Prior to GPS dive logger data becoming available, no-one could consider applying an area-swept approach to commercial catch data in order to estimate abalone abundance trends. However, this approach can feasibly be applied to dive tracker data; and with further development the approach has much to offer. As large amounts of dive tracker data are now potentially available, the obvious next step for further development is to explore using catch per unit area as an index of abundance, rather than the much used but discredited 'catch per unit of time'.

With further development, we see that this approach could be applied both to provide cost effective snapshot surveys of standing biomass so that reefs can be re-opened, and also, along with size trends, to provide a reliable long term indicator of abundance at reef scales. As time series are accumulated over time, this could make quantitative reef scale assessment reliable, feasible and even cost effective.

A.) Snapshot Estimates of Standing Biomass.

When reefs recover from depletion, harvesting too early or too intensely can prevent recovery, and management must be especially precise. If the effectiveness of divers at finding abalone in an area is known and dive tracker data can be used to estimate the area divers search to make a catch, then an estimate of density per unit area can be derived. Catchability 'q' the proportion of abalone that a diver finds when searching an area of reef, has already been estimated several times by Australian scientists and would be relatively routine to re-estimate under different conditions and for different divers using GPS loggers. Potentially, snapshot biomass estimates could be as easy as pre-defining the reef area and plotting the fishing of several divers starting their swims at differing randomly placed points through the area.

B) Quantitative Analysis of Time Series.

We believe dive track data will be useful in creating new indices of abundance based on trends in catch per area swept, and size structure. Time series of these data might provide the basis for reliable, cost effective and auditable reef scale stock assessment. If data are archived to accumulate time series from which trends could be estimated, there would always be the potential at some time in the future to conduct a quantitative assessment for a reef code, for auditing purposes or because conflict made it necessary to undertake the expense.

We see fertile ground for further development in the use of these data, starting with the immediate need to develop databases for archiving and providing access to the data already collected and now being collected at greater rates. There also needs to be further development of the algorithms and analytical procedures, to make the envisaged assessment techniques possible. The immediate further development would be to develop data handling and analytical techniques to test our assertions and ideas for the use of these data.

2. Cost Effective Estimation of Growth, Reproduction & SPR targets.

Until this project the studies required to develop the SPR model for a reef, needed to estimate the size of shells at the SPR target, would take several years and a cost of $40-$50,000. Samples would be collected to study reproduction, and a large tag and recapture study would be necessary to estimate growth. There are 30-50 reef codes in each zone, and some contain multiple abalone reefs. In practice not many tagging studies are conducted and a few growth curves are assumed to apply over large parts of each zone.

The principles established through this project and those related to it (2004/019; 2005/024; 2007/066; 2008/077) demonstrate the relationship between shell shape and reproductive stage. This means that the size and shape of abalone on a reef at the mandated SPR target can be estimated on the basis of a single size-based sample from that reef. From that sample the change in shell shape with length can be measured and the size of abalone on the reef with shell shape characteristic of the SPR target determined. This is a powerful insight in itself. Rather than an extended expensive research process, data from a single sample can be used to inform the SPR model required to support reef assessment.

However, this finding can be extended significantly with further development. We also understand that over broad regions in Australia abalone mature and reproduce at about the same age, it is just size that is highly variable. Putting these two propositions together, it can be inferred that from the way shell shape changes with size on a reef the underlying growth at age relationship can also be 'back-calculated'. We believe the measures of shell shape used can be refined to achieve sufficient precision in such estimates. Fully developed, this idea means that the SPR models needed to inform size based SPR targets, and also to parameterize quantitative reef scale assessments, might be derived from analysing a single size based sample from each reef at a cost of something like $5-10,000 each.

It is also possible that the principles being developed here, by which abalone shell shape can be measured by inexpensive sampling programs and used to determine SPR and to back calculate underlying growth curves, are more widely applicable to other species. The shell shape characteristic being used in the approach is related to volume versus size, as abalone grow mostly in length initially, before increasing mostly in volume, and then increasingly diverting resources into reproduction. It seems likely that other species also follow this same pattern, in which case volume versus size trends might also be informative with them.

3. Linking biomass to growth and SPR: density dependent growth

The advent of the disease and the crucial need to forecast (model) stock recovery has highlighted the importance of understanding how growth rates are linked to biomass in reef stocks. Earlier work on greenlip in SA showed that growth, time to initial and full maturity (thus SPR) and perhaps also maximum size and reproductive potential all change with biomass density, and the experience of industry with blacklip stocks has led to a firm belief among industry and researchers that this is true also of blacklip. As yet however, there has been no way to estimate the parameters of this process, which may crucially alter the recovery dynamics of stocks, and also their response to exploitation over time. The development of methods using shell shape to recover information on SPR and growth now provides the opportunity to estimate and model the process on reefs, so as to provide more secure management. What is required is time series for reef-stocks of both biomass estimates and growth and SPR estimates. Without the development of the industry based and cost-effective methods, this would be impractical. Once the methods are developed, and data has accumulated as biomass builds on recovering reefs, the density-dependent parameters can be estimated and incorporated into models that inform reef-scale assessment by industry.

4. Database Development to facilitate industry access to and use of data

There is an increasing amount of dive tracker information being collected and we predict it will become increasingly valued both for reef-scale management and the R&D processes to improve management. In the Victorian Central Zone VADA already has >1 million data records from voluntary data collectors. In the Western Zone all divers will now collect dive tracker data. But continued industry adoption and support for data collection will depend on both access to the data and seeing how it is used to inform management. This project has already developed a pilot database for industry data, so that it is accessible over the web to stakeholders. A fully developed database capable of rapid access to much larger quantities of data, able to host the software needed to model reef stock dynamics, and with good user security is needed, to ensure that good time series begin to be accumulated and information can be effectively used. There is also an immediate need to develop protocols around providing access to the data for R&D purposes. In the short term some work should be undertaken to make sure data is being collected and archived compatibly so that in the future large scale meta-analyses are facilitated.

PLANNED OUTCOMES

The outcomes expected as a result of this project, as originally written in the application, are reproduced below with an explanation of what eventuated.

1. Development of effective industry-based assessment and reef-stock management.

This outcome has been achieved fully by the three industry organisations in Victoria, and to a lesser extent in other states. In Victoria, the reef-stock catch setting workshops are attended by the abalone fishery manager from Fisheries Victoria, and the outcomes are used as advice towards the TAC set by the Minister for the Zone. This meets the need for reef scale management, and the public benefit is improved management and sustainability of resource. Thus this project has changed the management process in these fisheries.

In South Australia all the zones (and management) are now aware of the need for finer scale assessment and management. There have been arrangements made for defined catches to be taken from particular areas. Moreover, there is a growing involvement of industry in management, with the peak industry body (Abalone Management South Australia) giving direct advice to the Director of Fisheries on matters such as the TAC. In New South Wales there is now industry support for a raised size limit in the southern part of the fishery, and a new system that should aid industry-based assessment is being implemented, but management of catches at a fine scale appears unlikely in the near future.

2. Divers will use a set of scientifically established indicators of reef-stock status to assess the effects of fishing.

This has been achieved by the validation of the link between shell shape and egg production. There is an important benefit to the industry in terms of increased confidence in their assessments, a benefit to the divers whose observations have become important to the abalone associations, and public benefit of improved management. There is also a growth dividend to the divers – higher size limits mean more weight per abalone chipped. Nevertheless there is still a qualitative nature to the observations, so that cost effective means of electronic data collection would be a great improvement, to allow better estimation of optimal harvests and maximum economic output. The chair of the steering committee noted that one of the key strengths of this project was the direct translation of research into management.

3. Industry associations will use an assessment training syllabus to train new divers.

This has recently been achieved by the development of training modules, which have been distributed to the associations. As the numbers of new entrants are small it will take some time to see the benefits of this output, but the modules should allow future industry development to improve diver input into the management process, and thus improve management.

4. The industry-based stock assessment process developed in this project will be used in 3 states, and provide a basis for the development of industry-based fine-scale management (FSM) processes in all abalone producing states.

This outcome has been partially achieved. It is already a reality in Victoria, South Australia should achieve it soon, and NSW now has a strong commitment by industry and a growing commitment by government. Victoria has integrated FSM into the new state management plan. The example of Victoria shows that full FSM is possible, through revisions of the state management process to support an industry process, and provides one possible model for all other states with abalone fisheries. The public benefit would be improved management and sustainability of the abalone fishery as a whole, and this should have benefits for industry stakeholders in terms of markets too.

5. It is envisaged that these steps will avert or minimise the need for further reductions in zonal catch quotas among abalone fisheries.

Further reductions in quotas have been minimised but not averted. Various reasons are responsible in different zones, most being outside the control of this project. The viral disease impacted the Victorian Western and Central zones, and would have been disastrous if not for this project. The Central and Eastern zones consider that the advent of Marine Park exclusions has also affected them. The Eastern Zone has been affected by alteration of habitats by black sea urchins. NSW has been impacted by disease, urchins and poaching. Nevertheless, it is generally agreed that such reductions have been minimised by the FSM process set up by this project. This process allowed an orderly fishing regime, with progressive reductions after the viral disease began depleting reef-stocks, and has also allowed similar adaptive responses to urchins. It also facilitated the use of underutilised greenlip stocks in the Western and Central zones.

It is important to note that increases in LMLs as a result of this project have improved the sustainability of stocks, and led to greater yields per recruit. They also allowed mature stocks to build up prior to the virus depletion, which almost certainly has hastened the stock recovery process post-virus.

All these changes have produced both a private benefit to the abalone industry and a public benefit to the state.

6. Empowerment of divers and licence holders to have constructive and effective input into the assessment and management of their respective fisheries will imbue them with a stronger sense of resource stewardship and greater ownership of management strategies.

We have seen this benefit eventuate. Education by (and of) fishery scientists has provided a common appreciation of the biology and fishery-dynamics and thus a framework for discussions. The workshops have provided an open forum to develop a common understanding of the state of the stocks, critically examine different perspectives and address conflicting understandings. Such open participation of both divers and quota owners in workshops appears to be critical to develop agreed rules that industry members will "buy-in" to. The key issue is that the industry management process can be seen to be open, transparent, defendable and responsible. Thus we have seen industry members benefit by empowerment, and both the industry and the public will benefit from improved management.

7. Management costs should reduce as industry progresses towards greater self-regulation.

At this stage management costs have not decreased as a result of the implementation of FSM in the Victorian commercial abalone fishery. This is largely due to the additional management and assessment resources that have been required to deal with unforseen challenges such as the abalone virus. Nonetheless, there is a mix of regulatory and non-regulatory FSM tools to manage the fishery at present and this partnership approach has ensured the benefits of FSM outweigh the costs. Given the increasing role of industry in future FSM approaches, it is reasonable to expect that management costs will be maintained at current levels for the short to medium term. Members of the steering committee agreed that in the long term costs should decrease.

Thus there is a likely benefit to the states. The alternative of state micro-management would appear to be very costly.

8. If states respond by relating zonal to reef scale management, or by developing state auditing processes, Australian abalone fisheries will be able to more readily demonstrate that they are sustainably managed in accordance with the wildlife trade provisions of Part 13A of the EPBC Act 1999 (Commonwealth).

The first condition has been implemented in Victoria, but the second may well be needed too. Certainly the industry process now is able to control catch and size limits at a finer scale, and this markedly reduces the serial depletion problem. The approach also offers industry the opportunity to set harvest strategies that relate to both sustainability and markets, and thus improve the economic yield from the fishery. But better data collection and auditing may be needed when production is affected by environmental factors, or financial stresses impact on industry. Demonstrating sustainable management takes time, but we expect this outcome to eventuate, and provide both a benefit to the industry, and a national benefit in maintaining the value of exports.

9. Once the objectives of this project are met, industry, in collaboration with state agencies, can secure and demonstrate sustainable management at the local scale using processes accepted as valid. We expect this can be shown to be successful in a 4-year project, after which the management process can be extended by obtaining better information on local stock dynamics across many stocks.

This outcome has eventuated in Victoria, although we were optimistic – it required 5 years for the completion of this process. We believe we now have a more sustainable and efficient industry. Perhaps more importantly, industry now clearly sees the value of extending the management process by obtaining better information on stocks by trialling various cost effective means to collect the key data required.

CONCLUSIONS

This project has transformed the role of industry associations in management of the abalone fishery in Victoria, so that they are now an integral part of the management process, although elsewhere the project has had less effect. The relationships between industry stakeholders and researchers and managers have also dramatically changed during this project, and this applies not only in Victoria but also elsewhere. Researchers have become assistants and facilitators for industry and managers, while the management process has become more of a partnership between industry and state management agencies: co-management. While it is clear this change was in train in some areas before, the project has greatly accelerated it.

This outcome owes much to the reef-stock assessment workshop approach adopted by this project. Extension has been at the heart of this project, and this was integral to its success. In the Victorian associations that took most advantage of the project resources, the presentations by and discussions with researchers on abalone biology and management topics; and also learning by researchers of the industry knowledge; led to a common understanding of issues, especially the state of the stocks. The industry-run workshops provided an open forum to address conflicts and critically examine diverse perspectives. In this context, the use of diver observations in a structured way, based on validated performance measures, empowered industry stakeholders to develop rules owned and adopted by all. This process in turn led the industry associations to negotiate and collaborate with Fisheries Victoria for regulatory change to produce a more cost-effective co-management process that is expected to enhance the sustainability and security of the resource.

The discussion above shows these outcomes were based on the development of the workshop process, and the biological validation of its assumptions. But various other outputs of the project have facilitated and enhanced the outcomes:

1. The development by Fisheries Victoria of the Divers Web internet access system, which shows divers how much has been caught on each reef-code, played an essential part in establishing fine scale management, as opposed to simply fine scale assessment. Fine scale assessment alone would not have empowered the industry, nor could it have enhanced sustainability by preventing serial depletion.

2. The provision at workshops of tables and graphics for each reef-code, showing both Fisheries Victoria data and industry data, anchored discussions and provided a context for diver's observations, facilitating decisions. These data are now incorporated into a database industry can access. Further, software has been developed to call up the data for each reef-code, and to facilitate and record a risk based version of the reef-stock assessment process. This forms the basis for the TAC advice process designed by Fisheries Victoria, in collaboration with industry.

3. The determination of growth rates and size at (full) maturity for many reefs with a survey history provided a framework for modelling the dynamics of these key reefs. The development of the two simulation models, designed for industry stakeholders to use, allows better exploration of the consequences of management options. The more rigorous model is restricted to those reefs for which survey data is available, but the other Abasim type model can be more easily tuned to represent other reefs.

4. The training modules provide a means for industry associations to introduce future entrants to the industry to the information that underpins the reef-scale management process, and is relevant also to the management processes in all states.

While the Victorian outcome is a model to show how fine scale co-management can be achieved, the outcome in other zones was different, presumably because this model is not appropriate to them without modification. The paths taken by NSW and South Australia can be understood in terms of their different circumstances.

Compliance with collaborative initiatives was an issue in all the fisheries, and more-so in areas with lower levels of trust. Levels of trust within industry were measurably higher in small industry associations, likely linked to the ease with which individuals can monitor others actions. Issues of trust, both within industry and between industry and government, hindered the adoption of FSM in NSW where economic stresses in the NSW fishery further exacerbate social tensions. We conclude that the high number of shareholders there makes developing collaborative action more difficult.

It appears that developing a collaborative system requires an initial impetus: industry members need to be in some way dissatisfied with the status quo. The SA Central Zone, which has a relatively stable fishery in good condition, has progressed at a slower pace because 'the need for change' is less apparent. Similar trends can be seen across stakeholders within fisheries - those with less concern are less likely to be interested in change.

We were very fortunate that the Victorian Western zone had initiated collaborative action before the project began, in response to an earlier stress, as the advent of the disease would have been too sudden and urgent to allow a collaborative response to develop. The levels of trust and collaborative experience already built up by the WADA workshops, and the capacity as a result of the project to associate specific catch areas with catch levels, allowed them to share the reduction of TAC within the fishing year by amounts proportional to the impact of the disease. In addition through the workshops there was group planning of the remaining harvest allocations across areas left unaffected, in order to prevent the ‘chase for the last fish’ that would otherwise have occurred as each unit holder became worried they might lose even the income from the remaining quota.

The Victorian Central Zone association were also able to respond to the threat as a result of a well established workshop process, and arrange to forego quota in areas ahead of the virus front, to ensure no risk that divers would spread the disease further into their zone. They were able to obtain expert advice and arrange permits for a firebreak operation, complete with full bio-security measures, in which every quota owner in the zone participated. In both these cases, it appears that once collaboration had been established, a crisis strengthened it, as opposed to the ‘every man for himself’ response to crises commonly noted in unstructured groups.

Thus we conclude that the project has produced more informed, resilient and empowered industry groups operating in the fishery.

REFERENCES

Bardos D.C. (2004). "Estimatrix" growth modelling and matrix estimation software for abalone populations. Distributed with the national abalone model under FRDC project 1999-116: Development of a spatially-structured model for stock assessment and TAC decision analysis for Australian abalone fisheries.

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

Bardos DC, Day RW, Lawson NT & Linacre NA (2006) Dynamical response to fishing varies with compensatory mechanism: an abalone population model. Ecological Modelling **192**: 523-542.

Day, R.W, Fleming, A.E. (1992) The determinants and measurement of abalone growth. In: Abalone of the World: Biology, Fisheries and Culture. (Eds: Shepherd, SA; Tegner, MJ; Guzman del Proo, SA) Fishing News Books, Oxford, pp 141-168.

Day, R., Gilmour, P. and Huchette, S. (2004) Effects of density and food supply on postlarval abalone: behaviour, growth and mortality. Journal of Shellfish Research. **23**: 1009-1018.

Day,R.W. & Leorke, A. (1986) Abalone catches - what factors affect them? Australian Fisheries. **45**: 32-36.

Day,R.W. & Shepherd,S.A. (1995) Fisheries biology and ecology of abalone: Introduction. Marine and Freshwater Research. **46**: iii-v.

Daume, S., S.M.H. Huchette, S. Ryan and R.W. Day (2004) Nursery culture of *Haliotis rubra*: The effect of cultured algae and larval density on settlement and juvenile production. Aquaculture. **236**: 221-239.

Dixon, C.D. and Day, R.W. (2004) Growth responses in emergent greenlip abalone to density reductions and translocations. Journal of Shellfish Research. **23**: 1223-1228.

Dixon CD, Day RW, Huchette SMH & Shepherd SA (2006) Successful seeding of hatchery-produced juvenile greenlip abalone to restore wild stocks. Fisheries Research. **78**:179-185.

Dundas-Smith, P. (2004) Re: Results of the 2004-05 R&D application round and advice for 2005-06. Letter to FRAB chairs and others, 28 May 2004.

Grima, A. and F. Berkes (1989) Natural resources: access, rights-to-use and management. In: F. Birkes (ed.) Common Property Resources: ecology and community-based sustainable development. London, Bellhaven press. pp 33-54.

Gorfine, H, Day, R, Bardos, D, Taylor, B, Prince, J, Sainsbury, K, & Dichmont, C. (2008) Rapid response to abalone virus depletion in western Victoria: information acquisition and reef code assessment. Final Report to Fisheries Research and Development Corporation Project No. 2007-066. The University of Melbourne. ISBN: 978-0-9806389-0-5

Huchette, S.M.H (2003) Density-dependence in the early life stages of abalone. PhD thesis, The University of Melbourne.

Huchette S, Dixon C, Day R & Shepherd S (2005) Density-dependent growth of juvenile greenlip abalone (*H. laevigata* Donovan) in their natural habitat in Australia. In: Richard, G. (ed) Proceedings, 3rd international congress of European malacological societies. p 91.

Huchette, S.M.H., Koh, C. S. and Day, R. W. (2003a). Growth of juvenile abalone (*Haliotis rubra*) in aquaculture tanks: effects of density and ammonia. Aquaculture **219**: 457-470.

Huchette, S., Koh, C. S. and Day, R. W., (2003b). The effects of density on the behaviour and growth of juvenile blacklip abalone (*Haliotis rubra*). Aquaculture International **11**: 411-428.

Lleonart, M. (1992) A gonad conditioning study of the greenlip abalone *(Haliotis laevigata)*. BSc Hons thesis, University of Tasmania, Hobart. pp. 162.

Litaay, L. M. and S. S. De Silva (2000). Reproductive performance indices based on physical characteristics of the female blacklip abalone *Haliotis rubra*. Journal of Shellfish Research **19**: 522.

Macarthur Agribusiness (1999). Final Report, FRDC1998/170. Wild abalone fisheries R&D needs review.

McAvaney, L. A. (2003). Factors influencing gonad development in the greenliip abalone *Haliotis laevigata*. BSc Honours Thesis, The University of Melbourne.

McAvaney, L.A. Day, R.W., Dixon C.D. and Huchette, S.M. (2004) Gonad development in seeded *Haliotis laevigata*: growth environment determines initial reproductive investment. Journal of Shellfish Research. **23**: 1213-1218.

McDiarmid H., Day, R., and Wilson, R. (2004) The ecology of polychaetes that infest abalone shells in Victoria, Australia. Journal of Shellfish Research. **23**: 1179-1188.

McShane, P.E. (1991) Exploitation models and catch statistics of the Victorian fishery for abalone *Haliotis rubra*. Fisheries Bulletin. **90**: 139-146.

McShane, P.E. (1998). Assessing stocks of abalone (*Haliotis* spp.): methods and constraints. In: Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management, Nanaimo, 6 March – 10 March, 1995. Jamieson, G.S. and Campbell, A. eds. Canadian Special Publication of Fisheries and Aquatic Sciences **125**: 41-48.

McShane, P.E., Black, K.P. and Smith, M.G. (1988). Recruitment processes in *Haliotis rubra* Leach (Mollusca: Gastropoda) and regional hydrodynamics in southeastern Australia imply localized dispersal of larvae. Journal of Experimental Marine Biology and Ecology **124**: 175-203.

McShane, P. E. and Smith, M.G. (1991) Recruitment variation in sympatric populations of *Haliotis rubra* (Mollusca: Gastropoda) in southeast Australian waters. Marine Ecology Progress Series. **73**: 2-3.

McShane, P.E. and Naylor J.R. (1995). Small-scale spatial variation in growth, size at maturity, and yield- and egg-per-recruit relations in the New Zealand abalone *Haliotis iris*. New Zealand Journal of Marine and Freshwater Research **29**: 603-612.

Meppem, T. (2000). The discursive community: evolving institutional structures for planning sustainability. Ecological Economics **34**: 47-61

Nash, W.J. (1992a). Age determination of blacklip abalone (*Haliotis rubra*) in Tasmania. In: D.A.Hancock (ed.) The measurement of age and growth in fish and shellfish. Bureau of Rural Resources, Canberra. pp. 88-92.

Nash, W.J. (1992b) An evaluation of egg-per-recruit analysis as a means of assessing size limits for blacklip abalone (*Haliotis rubra*) in Tasmania. In: Shepherd, S.A., Tegner, M.J. and. Guzmán del Próo, S.A. (eds). Abalone of the World: Biology, Fisheries and Culture (Proceedings of the 1st International Symposium on Abalone. La Paz, 21 November - 25 November, 1989). Fishing News Books. Cambridge. pp. 318-338.

Newman, G. and Smith, D.C. (eds) (2001). Research needs and priorities for fisheries in Victoria 2001/02 – 2005/06. Prepared by the Research Committee, Fisheries Co-Management Council. FCC. Melbourne.

Prince, J.D. (1989).The Fisheries Biology of the Tasmanian Stocks of *Haliotis rubra*. PhD. thesis, University of Tasmania, 174pp.

Prince, J.D. (2001). Wild stock abalone production; where are we going? In: Charting Our Future: National Abalone Conference, Adelaide Australia, August 2001.

Prince, J.D. (2002). A rapid appraisal of the minimum size limit for the Victorian Western Zone abalone fishery. Document prepared for the Western Abalone Divers Association, Victoria. March 2002.

Prince J.D. (2003a). A discussion paper about Western Zone Management. Document prepared for the Western Abalone Divers Association, Victoria. March 2002.

Prince, J.D. (2003b). Developing Environmental Assessment & Management Decision Making Skills. A Course Developed for the Western Abalone Divers Association, Victoria. October 2003.

Prince, J.D. (2003c). The barefoot ecologist goes fishing. Fish and Fisheries **4**: 359-371.

Prince J.D. (2004) The decline of global Haliotid (abalone) production in the late twentieth century; is there a future? Invited address to the Second International Symposium on Stock Enhancement and Sea Ranching. Kobe, Japan 28 Jan. – 1 Feb. 2002. Chapter 31 pp 427-443 in “Stock Enhancement and Sea Ranching: Developments, Pitfalls & Opportunities” Blackwells Publishing Ltd.

Prince, J.D. (2005) Combating the tyranny of scale: Micro-management for micro-stocks. The Scientific Technical Bases for the Sustainability of Fisheries Miami, USA November 2001. Bulletin of Marine Science **72**: 557-577.

Prince, J.D. & Ford W.B. (1985). Use of anaesthetic to standardize efficiency in sampling abalone populations (genus *Haliotis*; Mollusca; Gastropoda). Australian Journal of Marine and Freshwater Research. **36**: 701-706.

Prince, J and Hilborn, R. (1998). Concentration profiles and invertebrate fisheries management. In Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Edited by G.S. Jamieson and A. Campbell. Canadian Special Publications in Fisheries and Aquatic Science. **125**: 187-196.

Prince, JD, Peeters H, Gorfine H, Day RW (2008) The novel use of harvest policies and rapid visual assessment to manage spatially complex abalone resources (Genus *Haliotis*). Fisheries Research. **94**: 330–338.

Prince, J.D., Sellers, T.L., Ford, W.B., Talbot, S.R. (1987). Experimental evidence for limited dispersal of haliotid larvae (genus *Haliotis*: Mollusca: Gastropoda). Journal of Experimental Marine Biology and Ecology **106**: 243-263.

Prince, J.D., Sellers, T.L., Ford, W.B. & Talbot, S.R., (1988a). A method for ageing the abalone Haliotis rubra (Mollusca: Gastropoda). Australian Marine and Freshwater Research, **39**: 167-174.

Prince, J.D., Sellers, T.L., Ford, W.B., Talbot, S.R. (1988b) Confirmation of a relationship between the localized abundance of breeding stock and recruitment for *Haliotis rubra* Leach (Mollusca: Gastropoda). Journal of Experimental Marine Biology and Ecology **122**: 91-104.

Prince, J.D., Sluczanowski, P.R., Tonkin, J.R. (1991) AbaSim: A graphic fishery. South Australian Department of Fisheries, Adelaide. ISBN 0 7038 1899 3 Software and Manual pp. 34.

Prince, J.D., Walters, C. Ruiz-Avila, R. and Sluczanowski, P. (1998). Territorial user's rights in the Australian abalone fishery. In Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Edited by G.S. Jamieson and A. Campbell. Canadian Special Publications in Fisheries and Aquatic Science. **125**: 367-375.

Shepherd, S.A. (1973) Competition between sea urchins and abalone. *Australian Fisheries*, **32:** 4.

Shepherd, S.A., Avalos Borja, M. and Quintanilla, M.O. (1995) Toward a chronology of Haliotis fulgens, with a review of abalone shell microstructure. Marine and Freshwater Research, **46**: 607-615.

Shepherd, S.A. and Laws, H.M. (1974) Studies on southern Australian abalone (Genus *Haliotis*), II. Reproduction of five species. Australian Journal of Marine and Freshwater Research. **25**: 49-62.

Shepherd, S.A, Godoy, C. and Clarke, S.M (1992) Studies on southern Australian abalone (genus *Haliotis*) XV. Fecundity of *H. laevigata*. Journal of the Malacalogical Society of Australia. **13**: 115-121.

Troynikov, V.S, Day, R.W. and Leorke, A.M. (1998): Estimation of seasonal growth parameters using a stochastic gompertz model for tagging data. Journal of Shellfish Research **17**: 833-838.

Tutschulte, T. and Connell, J.H. (1981) Reproductive biology of three species of abalones (*Haliotis*) in Southern California. *Veliger*, **23**: 195-206.

Worthington, D.G., Andrew, N.L. (1998) Small-scale variation in demography and its implications for an alternative size limit in the fishery for blacklip abalone (*Haliotis rubra*) in New South Wales, Australia. In Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Edited by G.S. Jamieson and A. Campbell. Canadian Special Publications in Fisheries and Aquatic Science. **125**: 341-348.

APPENDICES

APPENDIX 1: INTELLECTUAL PROPERTY

There was no commercial IP requiring patents or protection involved in this project, but the software developed is of value to the industry, as are the training modules. If the software is developed further and considered salable, the interests of the contributors to this project will need to be implemented, as defined in the FRDC contract for the project, but this is not likely at this stage. Similarly, the project contract would be used if the training modules are developed into a DVD or training course for use elsewhere. In this case the rights of the photographers whose images appear in the modules will need to be protected too.

The project developed an agreement with the Steering Committee to ensure the rights of the PhD students to publish their theses were not restrained by the fact that project material was used, which might include commercially sensitive information. This was that drafts of the chapters would be circulated to the steering committee, who undertook to approve these within a reasonable period, the lack of any objection over 2 months being taken as approval. While a number of chapters have been presented to the steering committee by the end of the project, others still need to be circulatedfor approval.

APPENDIX 2: STAFF

Project coordinators: Julia Smith, Rona Spicer, Louisa Billeter, Patrick Gilmour.

Modellers and programmers: David Bardos, Francis Byrne, John Tonkin

MAFFRI staff involved in fieldwork, analysis of samples: Justin Bell, David Forbes, Johnno Rudge.

PhD students involved in the project: Luke McAvaney, Patrick Gilmour

APPENDIX 3: PAPER DESCRIBING THE FSM APPROACH OF THIS PROJECT.

The Novel Use of Harvest Policies and Rapid Assessment to Manage Spatially Complex Abalone Resources (Genus *Haliotis*)

Jeremy D. Prince*, Harry Peeters**, Harry Gorfine***, Robert W. Day***

* Biospherics P/L, PO Box 168, South Fremantle, WA 6162, Australia

**Western Zone Abalone Divers Association PO Box 5330, Geelong North, VIC 3215, Australia

*** The University of Melbourne, Zoology Department, Parkville, 3010. Australia.

Keywords

Harvest policy, decision tree, rapid assessment, spatial complexity, Haliotids

Abstract

To date the development of harvest policies has focused on the use of indices estimated from quantitative stock assessment models. Where does this leave the small scale and spatially complex resources for which costs and logistics prevent adequate data collection and so the construction of quantitative assessment models at scales appropriate for the scale of component populations being fished? This paper presents a novel harvest policy framework developed in Australia, by the Victorian Western Zone Abalone Diver's Association (WADA) to assess and manage their resource at the scale of component abalone reefs (100s to 1,000s m). This novel harvest strategy policy uses a rapid visual evaluation of population fecundity based on shell shape and appearance. Codified and applied using a decision tree it is being used in Australia by a growing number of zonal abalone industry associations. Abalone populations on reef complexes are being assessed and managed with voluntary catch caps and voluntary minimum lengths larger (than legal minimum lengths). It will probably be decades before a satisfactory quantitative analysis on the efficacy of the approach will be possible but positive anecdotal accounts and the relatively rapid spread of the approach in Australia suggest industry members believe they are seeing benefits.

Introduction

Decision rules and harvest policies provide a means for integrating and codifying systems of monitoring, assessing and managing fisheries. Much of the current work and discussion about harvest policies, decision rules and their evaluation focuses on the use of indices quantitatively estimated using stock assessment models to assess the status of relatively large scale geographically extensive fisheries (e.g., Sainsbury et al. 2000; Punt et al. 2001).

There is, however, a growing realisation that many marine resources are not extensive uniform resources amenable to a 'big-science' approach through the application of quantitative assessment and management strategies (Hilborn et al. 2005). Instead many resources are comprised of a mosaic of relatively independent and variable smaller sub-stocks or meta-populations effectively comprising multiple micro-fisheries within the larger scale resource that may be managed under a regional framework of assessment and management (Prince 2005). In spatially complex fisheries managed at regional scales fishing pressure is applied differentially across the component populations. Fishing pressure focuses on the most attractive populations according to a sliding scale of preferences. The most attractive during any period are vulnerable to sequential over-fishing, which may result in localized recruitment collapses and even localized extinctions, eroding the productivity of the resource.

Gulland (1969) stressed that at the basis of all fishery assessment models was the assumption that the unit of stock being fished had a level of homogeneity and mixing such that it responded uniformly to fishing. The challenge in small scale and spatially complex fisheries is to reduce the scale at which management and assessment is performed down to the scale of the component stocks or populations. With some species the difficulty is that the biological scale is far smaller than the scale at which government agencies feasibly collect data, perform quantitative assessments, or enforce management regulations. The situation is further complicated by the cost of assessing and managing a large number of component sub-populations within a fishery. Larkin (1997) proposed that as a rule of thumb a fishery only sustain management and assessment costs up to around 10% of the value of the fishery. In spatially complex fisheries comprised of multiple small scale populations the challenge is not only down-scaling the processes of assessment and management as a whole but also down-sizing the cost of the scientific and management processes for each component sub-stock or micro-fishery.

This paper describes the genesis of an approach to the assessment and management of spatially complex fisheries using principals of rapid assessment, decision rules and harvest policies. The approach is novel because of its use of qualitative morphometric markers (shell shape and appearance) to gauge fishing pressure at the scale of individual abalone (Haliotid) reefs. It is also novel because the local industry associations assesses, decide and implement the harvest policy for each reef. Reef code harvest policies are being implemented with voluntary reef scale size limits and reef catch caps to distribute the Total Allowable Commercial Catch (TACC) set for the zone by government regulation. In a reversal of the normal ‘top-down’ approach to management, in some cases the industry process of reef assessment is being used to inform the agency’s TACC setting process.

Abalone Fisheries

Abalone (Haliotids) are large herbivorous molluscs, highly prized by the eastern Asian markets, that inhabit shallow coastal reefs and are the basis for valuable dive fisheries in many countries around the world. Despite large investments in assessment, management, and sea ranching, global annual production from the wild has declined from around 29,000t in 1969 to below 10,000t in 2003 (Prince 2004). Australia has the largest remaining commercial abalone fisheries landing >5,000t per annum, and while catches have remained relatively stable in recent years, serial losses of productive area across all spatial scales (100 m – 100 km) are being observed and reported by commercial divers, and TACCs have begun trending down.

The Australian abalone fisheries are managed across 5 separate state jurisdictions (New South Wales, Victoria, Tasmania, South Australia, Western Australia) each of which is broken into several regional fisheries comprising several hundred kilometers of coastline. In reality the management of these fisheries have evolved along parallel paths over four decades, as described by Prince and Shepherd (1992). Our focus here is the Victorian fishery which primarily catches blacklip abalone (*Haliotis rubra*). In 1968 the Victorian fishery was divided into three management zones each spanning several hundred kilometres of coastline. The number of commercial divers in each zone was also limited in 1968 to those active at the time (a total of 164). Through diver attrition and a policy of ‘two for one’ license transferability, this number has been reduced to the current 71 licences; 23 in the Eastern Zone, 34 in the Central Zone and 14 in the Western Zone (Fisheries Victoria 2002). During the early 1970s minimum legal shell size limits (LMLs) were implemented; two for *H. rubra* across the three Victorian regions. Catch levels were controlled in 1988 with total allowable commercial catch quotas (TACCs) introduced for each zone. Within each zone TACCs were equitably divided among the respective access licence holders in each zone, effectively creating Individual Transferable Quotas (ITQs) that could be temporarily traded among licence holders (Fisheries Victoria 2005). Through this evolution in management there has also been separation of the licence to dive for abalone, and the right to own quota. When licence limitation was first introduced the law stipulated that the owner of the diving licence must be the person diving for the abalone. More recently under the quota system the restrictions on quota ownership have been removed although the restriction on number of divers of quota has been retained. In the context of the discussion below this, means industry participants includes:

- quota owners who dive (a minority of the industry these days)
- divers who own no quota, but lease quota to dive, and
- quota owners who no longer dive, or who have never dived.

Under the existing Victorian Abalone Fishery Management Plan annual fisheries assessments are conducted through the Abalone Fishery Assessment Group (AbaloneFAG) convened by Primary Industries Research Victoria (PIRVic), the research division of the Department of Primary Industries (DPI). The AbaloneFAG includes participants from all major stakeholder entities. A keystone of the regional assessment process is the prescribed use of a quantitative fisheries model of each zone that estimates the risk for current and alternative levels of catch that current and future abalone biomass is or will be less than specific zonal reference values. The Abalone Fisheries Committee (AFC), a sub-committee of the Fisheries Co-management Council (FCC), is charged with using these results from formal AbaloneFAG workshops to formulate independent advice about future zonal TACs that is communicated via FCC to the Minister for Primary Industries.

Abalone Ecology

The ecology of abalone has important implications for their management which have been discussed by Prince (2003, 2004, 2005). Only a brief summary is found here to provide context for this study.

Growth, Maturity, and Emergence

Juvenile abalone live cryptically in the interstitial spaces within reefs. As sub-adults they emerge from the cryptic habitat to join adult feeding and breeding aggregations on the surface of the reef (Prince et al. 1988). Characteristically, growth rates, the average maximum size attained, and the size of maturity are highly variable. This variability is seen over local (100s – 1 000s m) and regional scales (100s km) (Leighton and Boolootian 1963; Sloan and Breen 1988; Day and Fleming 1992; Prince 1989; Nash 1992; Naylor and Andrew 2001). However, contrary to expectations, maturity and emergence from the cryptic juvenile habitat is principally determined by age, rather than size (Shepherd and Laws 1974; Prince 1989; McShane 1991; Nash 1992)

Spatial Complexity

Throughout their life cycle the scale of abalone dispersal (larval, juvenile and adult) is generally limited to scales of 10s – 100s of meters so that abalone reefs are effectively self-recruiting populations. The small scale of the self-recruiting populations and the variability of size of maturity between populations makes assessment and management extremely complex. Abalone fisheries are nothing like the single freely mixing “units” of stock assumed by Gulland (1969). Instead they are spatially complex comprised of many (1,000s - 10,000s) relatively independent and highly variable populations (Prince 2005). Thus, zonal legal minimum lengths (LML) and total allowable catches (TACCs) fail to protect reefs with relatively larger sizes of maturity which may experience localized recruitment overfishing. While nearby abalone populations with a relatively small size of maturity might remain virtually unfished.

The need for more spatially explicit assessment and management of abalone fisheries was identified more than a decade ago (Prince and Shepherd 1992; McShane 1995; Prince et al. 1998); however, attempts to model the fishery at reef scales have been impeded by data insufficiencies (Gorfine and Dixon 2000). Model parameters are basically biased averages across many different populations and acquiring reliable spatially explicit indices of abundance is problematic. This is because catch rates tend to hyper-stability (Prince 1992; Prince and Hilborn 1998) and structured surveying too expensive to be applied to a large proportion of the reefs (Gorfine and Dixon 2000). So while the Victorian Abalone Fishery Management Plan includes a provision for the adoption of finer scales of management nothing is prescribed beyond reef code catch performance indicators based on historical variation in catch. Modelling at the reef scale remains an unrealistic proposition because of the logistical impediments and prohibitive costs of acquiring sufficient data. Recognition of these assessment limitations have provided official impetus to support the development of the alternative ‘bottom – up’ methods for defining reef scale productivity.

The initiative described here had its inception in 2002 when the Western Zone Abalone Diver’s Association (WADA), the industry association for the western most of three Victorian management zones, requested one of us (JP) to initially appraise the utility of their zonal LML. This request prompted the formalization of a technique for the rapid assessment of abalone reefs and eventually the decision by WADA to begin voluntarily implementing harvest policies at the scale of reefs.

Rapid Assessment

Central to the rapid assessment technique is the notion that the relative maturity of abalone can be visually determined by the shape and appearance of their shell. An idea first suggested for *H. laevigata* in the early 1990s by a commercial abalone diver in the Western Australian Zone 2 fishery, Mr Terry Adams. This notion can be supported qualitatively using our general understanding of the structure of *H. rubra* populations developed through a body of largely descriptive research (Prince et al. 1988; Prince 1989; Nash 1992; Worthington et al. 1995; Worthington & Andrew 1998; Prince 2003; Saunders et al. 2008). The studies of most direct relevance in this context are that of Worthington et al. (1995) and Worthington & Andrew (1998) who noted that at the current New South Wales LML abalone with a smaller size of maturity were rounder than larger maturing abalone. More recently Saunders et al. (2008) have shown in South Australia that the height to length ratio of the shell of *H. rubra* in south-eastern South Australia can be used as a 'morphometric marker' for distinguishing between populations with large and small size of maturity.

The use of this principle to rapidly assess reefs H. iris reefs in New Zealand was qualitatively tested by JP during 15 years participation in New Zealand's commercial free-diving fishery. Visual observation of reefs around southern New Zealand were used to predict long term trends that had been experienced, were compared with the trends documented in the private logbooks of commercial diving colleagues, thus proving to himself the basis of the appearance abalone shells can be used to assess reef status. All this being said it must be acknowledged that, while the idea now has considerable currency amongst Australian abalone researchers, managers, divers and quota owners, its basis still remains semi-quantitative. In Australia considerable research funds are now being directed at scientifically scrutinizing this idea and Saunders et al. (2008) is likely to be the first of numerous studies on this topic.

Here we illustrate the principles underlying the Rapid Assessment of abalone reefs using data collected by Prince (1989) for populations of *H. rubra* in SE Tasmania, Australia. Other regions and species would be expected vary in their age and size of maturity to the populations discussed here, however, it is our belief that the broader life history and morphological patterns described here for *H. rubra* are displayed by most if not all abalone species.

Shell Appearance

The fast rate of juvenile growth produces a thin flat oval shell shape. Remaining wedged tightly into dark interstitial reef spaces little if any epibiota colonises their shells. This means that newly emerged maturing abalone can be recognised by their flat clean shells (Fig. 1). As sub-adults, the linear flat growth slows while growth in shell thickness and meat weight continues (Fig. 2). During the maturation period the whirl of the shell deepens its spiral. Shell shape changes from flat and oval, rounding (Worthington et al. 1995; Worthington & Andrew 1998) and deepening (Saunders et al. 2008). Thus, through maturation they change from a flat oval shape to being more bowl-like, substantially increasing the volume of their shell and their total weight. Having emerged from dark cryptic habitat within the reef into the light on top of the reef, a succession of fouling organisms invades the clean surface of their shell as they mature. Over the several years it takes to approach their maximum length, weight and fecundity the shells will take on the appearance of the surrounding reef surfaces (Figs. 1&2).

Stock-recruitment relationship

As with many invertebrate species there has been a long and spirited debate in the scientific literature as to whether there is a relationship between stock and recruitment in abalone (Harrison 1986; Sluczanowski 1986; McShane 1995; Shepherd and Partington 1995). This has apparently now been settled in the affirmative (Shepherd and Baker 1998) although there are still virtually no studies that have quantified the form of that relationship. Shepherd and Baker (1998) provide possibly the only published study of the relationship and their conclusion was that while the natural productivity of abalone populations varies greatly preserving 50% of potential reproductive production is an appropriate biological reference point for sustaining productive abalone populations.

Figure 1: Photograph of a selection of emergent legal sized Haliotis iris taken from the same aggregation showing the gradation with increasing size, from flat oval shells free of epiphytic growth to heavily fouled rounded bowl-like shells, typically seen in abalone species and related to their maturing and emergence from cryptic juvenile habitat. Photograph by J. Prince.

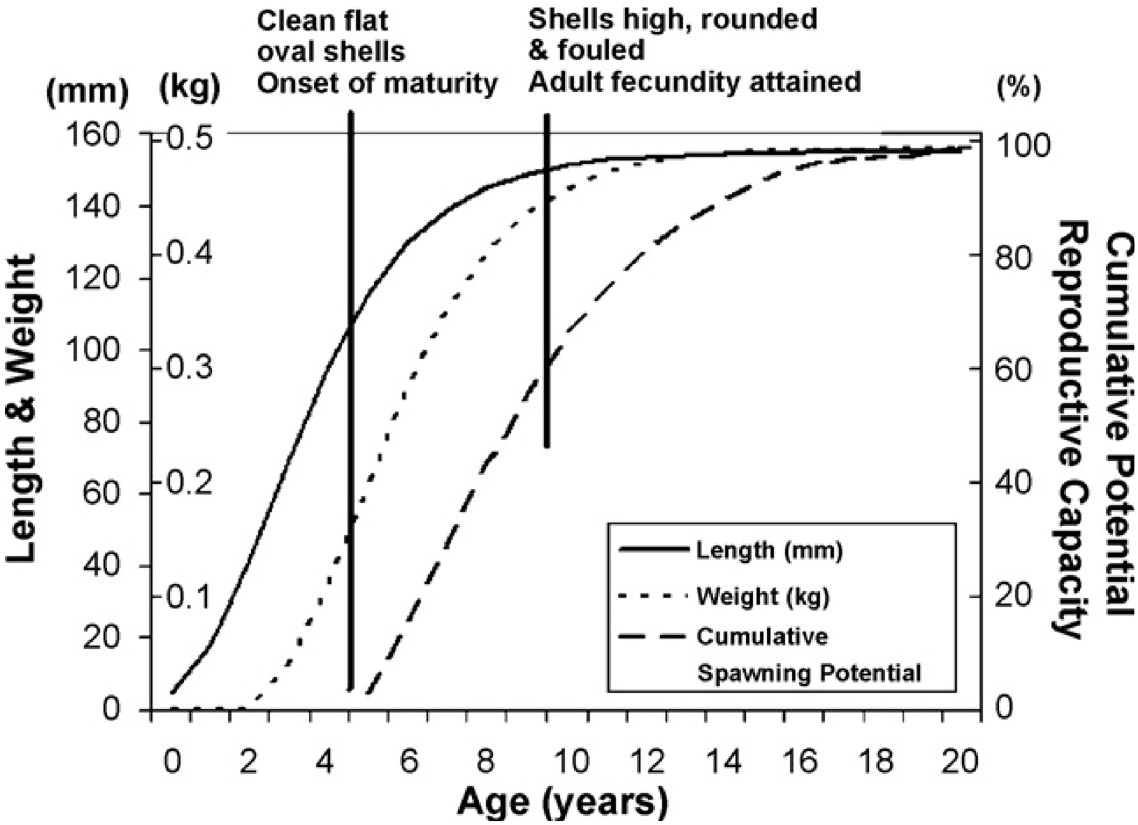

Figure 2: Age – length relationship for George III Rock Haliotis rubra population together with the weight at age curve, and the estimated Potential Reproductive Capacity Ogive (right axis) for the same population. Data from Prince (1989).

Figure 2 shows the length at age curve an *H. rubra* population on George III Rock, Tasmania. The length age curve is plotted along with the corresponding weight at age curve, and the estimated cumulative reproductive capacity (right axis), or spawning per recruit (SPR) estimated using data from Prince (1989). These data are used illustratively here, but are consistent with the patterns seen more generally around Tasmania (Nash 1992). It shows that sub-adults take about 5 years after they emerge (10 y.o.) to develop approximately 50-60% of their potential life long egg production and that by 18-20 years of age a cohort will have contributed >95% of its potential reproductive capacity. Assuming natural survival rates of around 80-90% per annum, the weight gain during the 5 year maturation process doubles the biomass of the cohort and increases potential reproductive capacity increases from <5% to 50-60% of its unfished potential.

Even acknowledging the paucity of our knowledge about the precise nature of stock and recruitment in abalone, when stated in these terms the value to the fishery of preventing the fishing of newly emerged sub-adults and leaving them on the reef to attain full adult fecundity (10 y.o. in this population) is self evident. At this stage of the technique's development shell shape and appearance has not been precisely calibrated with potential egg production. It is not yet possible to overly prescriptive about how appearance and shape correlates with precise levels SPR. Similarly we do not know the form of the stock recruitment relationship, so how would we determine optimal egg production levels. Despite this, it is possible to recommend leaving newly emerged sub-adult abalone on reefs until they have matured and attained adult levels of fecundity, and using this knowledge rapidly assess abalone populations.

The Visual Assessment of Reefs

Recognizing the coincidence in abalone populations between emergence and sexual maturity, and understanding the way shell shape and appearance changes with maturity and emergent living provides powerful visual keys for rapidly assessing the status of abalone populations. Shells sampled from a catch or inspected in situ are examined with regard to:

1. The size of first maturity and emergence ascertained by the size of clean flat shelled individuals,
2. The size of full maturity and approximately 50% potential reproductive capacity gauged from size of individuals with rounded bowl-like shells and fouling like the top of the reef, and
3. The overall size distribution of the sample relative to the size of first maturity, 50% potential reproductive capacity and the LML.

Additionally, the following supplemental observations can be made by abalone divers and solicited during the reef assessment workshops conducted with industry:

1. The proportion of emergent abalone being left behind because they are smaller than the LML, and
2. The appearance of abalone shell at the size of the LML (flat, oval and clean; or high, rounded and fouled).

The underlying logic behind the visual assessment process can be illustrated using two examples; first, a depleted population, and second, a lightly exploited stock. Populations at risk of severe depletion and recruitment overfishing due to high exploitation rates and low levels of preserved reproductive capacity are comprised principally of recently emerged maturing sub-adults. These individuals all tend to have clean flat oval shaped shells because they have only recently emerged from the cryptic juvenile habitat and there has been is insufficient time for their shells to be colonised by fouling epibiota. Divers will observe relatively few abalone below the LML in these populations and will report being able to take most of the abalone they find (>75%). This is because the size of maturity and emergence in these populations is either close to, or larger than, the LML and protects insignificant levels of breeding biomass. In contrast, lightly exploited populations are comprised of multiple fully mature and emergent adult year classes, recognised by the bowl-like shape of the shells and the mature fouling epibiotic assemblages on their shells. Clean, flat-shelled individuals comprise a small proportion of these populations (<10%).

Involvement of Commercial Divers

Using the rapid assessment technique the capacity of stock assessors can be enhanced by interviewing experienced divers or holding reef assessment workshops. The features used to appraise LMLs; size of emergent abalone, shell shape and extent of epibiotic growth, and how they vary spatially within the fishing grounds are learned by divers who depend on these observations to fish efficiently. With the supportive input of divers 100’s of km of abalone carrying shoreline can be rapidly assessed over 5–10 days of interviews by a researcher or several days of reef assessment workshops facilitated using the decision tree described below. As well as using these techniques to assess reefs, we have found that converted into succinct language these principles provide a highly effective means of educating abalone divers and motivating their involvement the process of assessment and reef scale management.

Reef Assessment Decision Tree

The logic underpinning the process of rapid assessment has been codified into a decision tree (Fig. 3) designed to facilitate discussion and decision making by reef assessment workshops comprised of quota owners and divers of a management zone. The use of the decision tree has been found to structure and discipline the discussions and by making the decision making process transparent helps build the communal support required for industry associations to initiate voluntary action at reef scales. The Decision Tree is used to place each reef area into one of eight exploitation categories and each exploitation category has an associated pre-agreed Harvest Policy (Fig. 3). The primary indicators used for the categorization are simple fine scale catch and effort trends over the previous 5-15 years, and the appearance of the abalone shell on each reef.

Catch rate trends are not used because they tend to be strongly correlated and thus, hyperstable (Prince 1992; Prince and Hilborn 1998). Effort and catch trends match each other because because divers have a lot of knowledge divers have about comparative stock abundance on each reef. Taking advantage of this knowledge, we use simple trends in catch or effort as crude indicators of stock abundance. In Australian most jurisdictions have collected catch and effort statistics for at least a decade at the scale of ‘reef codes’ which typically encompass 1-10 km of coastline. In practice, where fine scale catch and effort data has not always been available we have found that groups of divers can reliably provide qualitatively reports on whether effort and catch trends on a reef have been rising, falling or stable.

In the first level of the decision tree (Fig. 3) the question asked is; has effort and catch been (1) unstable (rising or falling), or (2) stable? Where effort and catch has been unstable (1) the question asked at the second level is; has effort and catch been (1a) declining, or (1b) rising? The former answer (1a) ‘declining’ results in the assessment that the reef is in the second severest category of overexploitation (category 2) with at least growth overfishing occurring, and possibly also recruitment overfishing. The population will be comprised almost entirely of newly emerged abalone with clean flat shells. The latter answer to this initial second level question (rising - 1b) indicates either that fishing pressure is increasing on the population (category 4), or that the population is recovering in response to previous management interventions (category 5). In both cases the population will be primarily comprised of newly emerged abalone with clean flat shells mixed with a smaller percentage of fouled and rounded shells. On the category 4 reefs the proportion of fouled and rounded shells will be falling over time, while it will be increasing on the category 5 reefs.

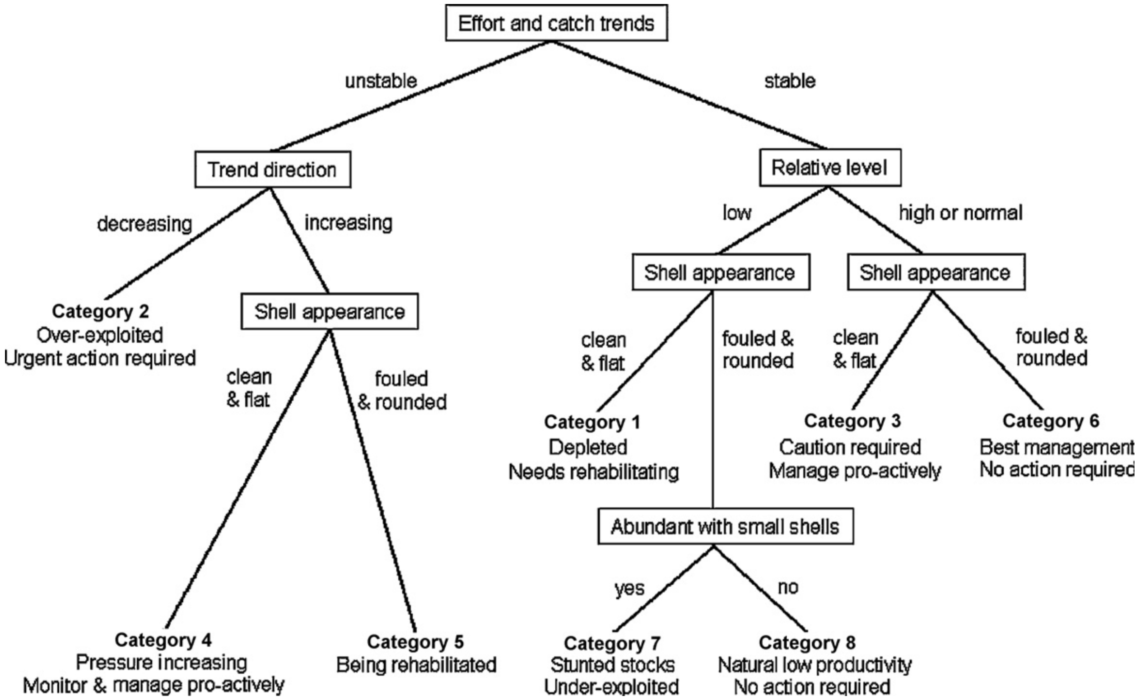

Figure 3: The Decision Tree developed to encapsulate the Harvest Policy developed to structure Reef Assessment Workshops in the Western Zone abalone fishery of Victoria, Australia. The first level of assessment is made on the basis of medium-long term (5-15 year) trends in the catch or effort for each reef code, and the second level of assessment is based on the shape and appearance of the shell around the size of Minimum Length.

If the answer at the first level of the decision tree is, effort and catch is stable (2), the second level question is whether the effort and catch are stable at comparatively low (2a) or high levels (2b). In the case of the former (2a) historic effort and catch data, anecdotal accounts from industry members, and the appearance of the shell, can be used to distinguish between areas that declined in the past due to recruitment overfishing (category 1), under utilized (category 7), or naturally unproductive (category 8). In the case of category 1 reefs there will usually be some evidence (quantitative or qualitative) that a significant decline in catches and the population occurred in the past, but even without that evidence category 1 reefs can be identified because what remains of the population will be almost entirely newly emerged sub-adults with clean flat shells considerably larger than the LML. Category 1 reefs are the most severely overexploited and the most depleted; a recruitment decline has occurred and a continuing low level of effort is holding breeding biomass down at low levels. Categories 7 and 8 can be distinguished from category 1 by evidence that no decline in catch and effort has occurred and the high proportion of fouled and rounded shells in the population. Category 8 reefs are, for unknown reasons, naturally unproductive and are distinguished from the underexploited Category 7 reefs by the low abundance of abalone. The lightly exploited nature of Category 7 reefs is indicated by the abundance of fully mature abalone with rounded and fouled shells. In the modern fishery the low level of exploitation in these areas is normally due to the fact that the size of maturity, and often also the maximum length in these areas, is small compared to the LML.

If the catch and effort is stable (2) at high levels (2b) the appearance of the shells will indicate the category of the reef. The abalone on category 3 reefs will be comprised almost entirely of newly emerged sub-adults with clean flat shells. This is the third most overfished category and the appearance of the shell indicates the population is being growth overfished and is probably threatened by recruitment overfishing. In contrast, the populations on category 6 reefs are distinguished by the fact that almost all the abalone are fully mature, having fouled and rounded shells.

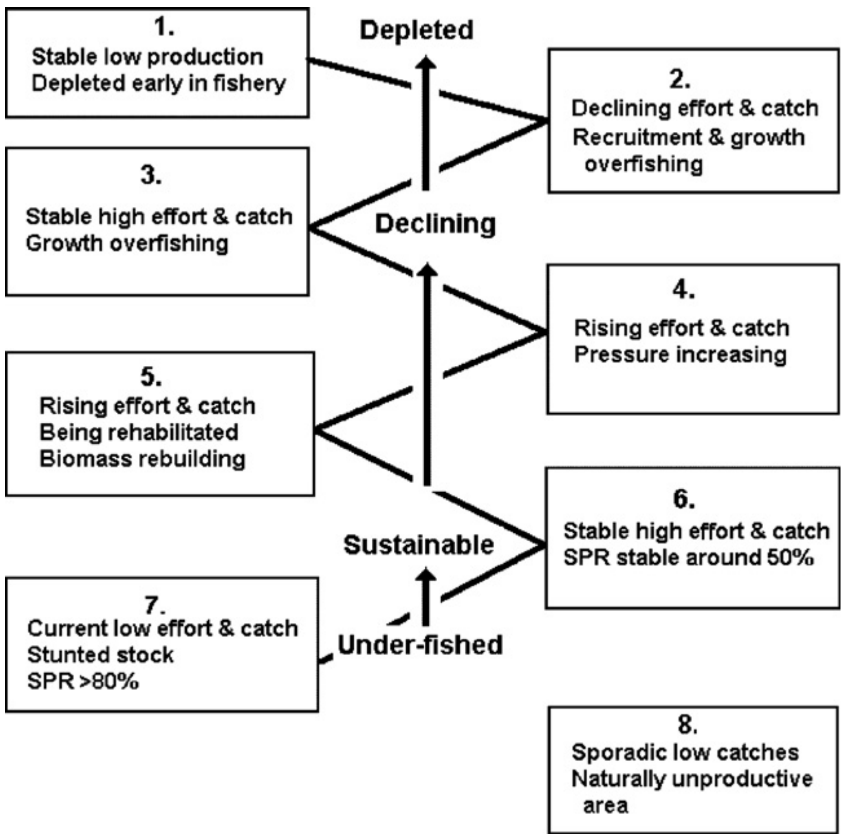

Figure 4: Schematic showing how the Reef Categories defined by the Decision Tree (figure 4) form an exploitation / rehabilitation continuum between depleted (Category 1) and under-fished (Category 7).

The Process of Depletion and Rehabilitation
These different reef categories can be considered as forming a gradient of exploited or managed states (Fig. 4). From under-fished (category 7) through well managed (category 6) and recovering (category 5) to declining (categories 4–2) and depleted (category 1) states. Clearly the purpose of reef management is to progress all reefs towards the sustainable productivity typical of category 6.

Case Studies in the Victorian Abalone Fishery

Western Zone
In March 2002 the Western Abalone Divers Association (WADA) from the Victorian Western Zone requested a rapid appraisal of the current 120 mm legal minimum length applied across their reefs. Their divers were interviewed and ground-truthing dives were conducted with several of them. Shells in catches from across the zone

were examined and lengths measured. Two consultative, and one reporting meeting were held with the membership of WADA. The appraisal was that the western end of the Zone generally has a size of maturity > 120 mm and has experienced some degree of recruitment overfishing. In the eastern end, around Port Fairy the abalone in many areas mature at lengths < 120 mm. Relatively higher levels of breeding biomass are maintained beneath the LML and production has been more stable. In response several voluntary reef code minimum lengths (VML) larger than the legislated LML were suggested. Agreement on this action was, in this first instance, difficult due to the mistrust divers felt towards each other, and their frequently stated belief that others would not comply with voluntary measures. A useful first step towards developing the consensus needed for action was when members embraced the concept that if the majority of divers complied, improved management outcomes would result even if a minority did not comply.

A reef that was important in brokering initial agreements was The Crags; comprising >7% of annual catches it is located midway between the two principal ports. It was important in initial discussions because it was one of the few reefs for which divers from each end had a shared common experience. The divers tend to operate close to their home ports at either end of the zone and have relatively little experience of the differing trends occurring at the other end of the zone. Initially this caused divers from each main port to have differing perspectives. Situated in the middle, The Crags was used by a broad cross section of divers from both eastern and western ends. It provided a rare basis of broadly shared experience. This made it easier to develop consensus for action on The Crags. Initially a 125 mm VML was agreed for The Crags, 5 mm above the LML. By the following October, 2003, divers were unanimously agreed that The Crags had improved. Catch rates in terms of abalone per diving hour were felt to be similar, but divers reported the weight of the abalone felt greater and they were noticing their daily weight of catch improving. This is a short term response which must be due to reducing growth overfishing. This rapid and widely perceived success at The Crags convinced the divers that the reef scale management approach was worth pursuing (the VML for The Crags is now 135 mm) and extending more generally through the Zone. Since that time conviction about the efficacy of the process has continued to grow with experience, leading to increasing participation in reef assessment workshops and improving compliance with the voluntary agreements. By 2006 local enforcement officers were estimating 95% compliance with WADA's voluntary agreements about reef scale VMLs and catch caps (D. D'silva, Department Primary Industry, Victoria personal communication).

At first only willing to experiment with VMLs, in February 2003 WADA recognised unplanned flows of effort and catch were occurring around the zone due to the VMLs implemented the year before. Consequently they agreed to assess all their 36 reef code and set catch caps and VMLs for each. During the second half of 2003 WADA appointed a part-time executive officer (EO) to implement and drive the association's processes. The decision tree was developed at his request to codify the principles of rapid assessment. In October 2003 WADA membership agreed to the use of the decision tree and assessed each of their reefs. The initial assessments were reviewed at following meetings, but changed so little that the practice was stopped in order to focus on the implementation of the reef scale harvest policies that flowed from their assessment.

In October 2003 WADA used the reef assessment process to develop a proposal for a 7.5% reduction in the 275t TACC for 2003/04. This proposal conflicted with the

9% reduction recommended by AFC on the basis of the zonal assessment model. WADA argued its newly established process should be allowed time to develop and the Fisheries Victoria supported their request. Over the 2004/05 season, the new system of reef code quotas operated with considerable success. Fisheries Victoria adapted their quota reporting system to real time accounting. Progressive catch reports for each reef code were made available on a Fisheries Victoria website in real time so that each evening divers could use progressive catches to the end of that day, to plan their diving on the following day. With this data WADA's EO tracks catches and as catch caps approach makes contact with divers using email and phone to ensure are aware the catch caps is approaching, and again notifying them that the catch cap is filled and the reef code is now voluntarily closed. Conformation with agreed reef code catches has always been reasonably high and is now virtually complete.

In October 2004 WADA began generating proposals for multiple minimum lengths within some reef codes based on codes of conduct developed around fine scale maps. At that workshop they also decided to close several of the reef codes they had assessed as being in Category 1 & 2 to make this possible they recommended a further 18% reduction of their zonal TACC for the 2005/06 quota year, to 210t. This would have represented a 24% reduction over two years. On this occasion WADA was forced to argue against the AFC and some dissident members of the Western Zone who recommended catches remain at the 2004/2005 level. Subsequently, the TACC for 2005/06 was set at 221 tonnes, representing a 20% reduction over two years from the previous long term level. A noteworthy and significant event for the development of processes for reef scale management occurred at this time. Several members of the Western Zone who had chosen to not join WADA lobbied the Minister responsible for fisheries to reject WADA's TACC submission in favour of the AFC proposal based on the regional assessment model The Minister on advice from his Department advised them that they should have participated in the reef assessment workshops if they wanted their views taken into account.

Each year WADA now holds two reef assessment workshops of 1-2 day duration. These are attended by a large majority (but not all) divers and quota owners. Representatives of the management (Fisheries Victoria) and research agencies (PIRVic.) also attend. The first meeting of the quota year is in October, two thirds of the way through the quota year which begins 1 April. The first meeting discusses reef scale catch, effort and size trends through to the end of the previous calendar year. At this meeting catch caps for each reef code are discussed and consensually decided. The sum of the reef code catch caps becomes the basis of WADA's submission for the following year's zonal TAC. On the basis of the October workshops, and the AFC's zonal model based advice on TACC's WADA negotiates a Memorandum of Understanding (MOU) with DPI Victoria specifying the level of zonal TAC, WADA's spatial allocation of the TACC and reef codes VMLs. The second meeting of the annual cycle is in February or March prior to the start of new quota year on April 1. It is used to review the status of each reef code nearing the completion of the quota year, finesse and finalize the catch caps, and review the VML, for each reef code.

There are now three tiers of minimum lengths. There are several regulated sub-zonal legal minimum lengths which provide enforceable basal levels. In a few pockets lower legal length limits are negotiated and temporally implemented under strictly controlled permit conditions including; previous scientific studies to demonstrate a particularly low size of maturity, restricted fishing, and heightened enforcement and surveillance. The upper tier of the length limits are the VMLs set above legally binding LMLs. In some reef codes there are multiple VMLs. Commonly VMLs differ above and below 15m of depth, or inside and outside various lagoonal structures.

The Victorian Central Zone

In May 2004 the industry association for the Central Zone, the Victorian Abalone Divers Association (VADA), held its inaugural reef assessment workshop and used the decision tree developed for WADA, to begin assessing their reefs. Since that time VADA, has basically followed the model of the adjoining Western Zone, holding two reef assessment workshops annually, and have observed support for their process grow and take root. In contrast with WADA's approach, but consistent with the more homogenous nature of the Central Zone reefs, VADA uses fewer VMLs and reef catch caps, with each covering a broader area of reef and several similar reef codes. Another interesting difference is that in contrast to WADA, which uses an independent facilitator (JP) to run workshops, VADA's executive officer has facilitated all but the first two assessment workshops. While VADA had implemented VMLs and reef catch caps, until recently they accepted the status quo TACC recommended by the AFC on the basis of their zone's stock assessment. However, in late 2007, in response to concern over several historically important reefs assessed as being in categories 2 and 3, they requested a 100t reduction in their approximately 760t per annum zonal TACC. As with WADA the requested TACC reduction was then targeted at reducing catch caps for the areas of concern.

Extension of the Approach

Abalone

In July 2005 Australia's federal government principal fisheries R&D fund granted four years funding for reef code assessment workshop to be extended to 5 zonal abalone associations; the final zone of Victoria, the New South Wales industry association, and the South Australian Central Zone association. The project also has funding for quantitatively testing the principals underlying the rapid assessment technique, and for setting up reference sites for future evaluation studies. Across the Tasman Sea the New Zealand abalone fisheries industry body, the Paua Management Company has invited an address on this approach for their annual national industry conference in 2008.

Other Species

At the broadest level the novel approach described here is based primarily upon a 'common sense' or 'rule of thumb' approach to assessment and management, rather than a rigorously quantitative approach. The 'rule of thumb' being applied is to maintain conservative levels of breeding biomass on each reef. The rounding and fouling of the shells is used as an indicator of a conservative SPR. Where a quantitative approach is logistically challenging we believe specifically adapted versions of this visual rapid assessment may be broadly applicable. Our observation is that trochus (Trochus niloticus) and a wide variety of gastropod also display noticeable changes in their shape and at a certain stage of their growth which based on our experience could well be associated with maturity. Quite possibly a practiced eye, such as a fisherman's, could notice a change of girth or perhaps colouration, associated with maturation in a range of finfish and sharks. Similarly sex ratios in species with sex specific growth patterns, or that change sex with age and size, might potentially be used similarly, as rapid visual qualitative gauges of exploitation pressure.

Evaluation of the Approach

These initiatives in the Victorian abalone fishery have not been in place for long enough to quantitatively test their efficacy. With the age of emergence being 6-10 years, 10-15 years will be needed to quantitatively evaluate the approach in terms of recruitment trends. In time we hope this will be made possible using the baseline surveys now taking place across the 5 zones, and three Australian states conducting reef assessment workshops. In the mean time we expect commercial catch effort data to soon be showing the shorter term yield per recruit gains that have been reported. Unfortunately an unexpected factor will increase the challenge of quantitative evaluation. Since May 2006 an, as yet, undescribed herpes-like virus (Hooper et al. 2007) has inflicted 30-95% mortalities, across all year classes, on most western zone Victorian reefs, and the infection has now crossed into the central zone. In this situation, in order to evaluate this approach here, we are reliant on qualitative evidence. The growing engagement of the broader Australian abalone and now New Zealand abalone industry associations, and associated government agencies demonstrates, if not the efficacy of the approach, that a broad group of people believe it is effective.

Conclusions

This paper has described a novel approach which uses a qualitative rapid assessment in the form of a decision tree to decide harvest policies for component abalone reefs within a zonally regulated system. While we cannot quantitatively prove the efficacy of the approach at this time we are confident growing interest in, and use of this approach by the Australian abalone industry indicates the intrinsic merit of the approach. On this flimsy basis we are so bold as to think this approach offers several important widely applicable lessons which are:

A Decision Tree can be a powerful way of logically structuring and presenting the logic of fisheries assessment to decide and form consensus for small scale management policies. In our situation the transparent logic codified in the decision tree facilitated discussion, decision making, and generated support for implementing harvest policies.

A second lesson was how working examples engender support for broader change. Quickly perceived improvement at The Crags fostered support for reef scale assessment among WADA divers, and compliance with reef code VMLs and catch caps. Beginning at a pilot scale with several individual reefs, rather than the entire zone, made it easier for a community of stakeholders to agree on initiating change. In this respect the immediacy and apparent magnitude of the yield per recruit effect divers are now reporting from a wide range of reefs exceeded our previous expectations. This greatly assisted the adoption and implementation process for reef scale assessments. It is also a reminder that working mainly with declining ‘one-way trip’ fisheries provides little experience with ‘re-bound’ dynamics.

The final lesson we think can be drawn from this study is that, in spatially complex fisheries where stakeholders have a long-term interest in the sustainability, a well founded common sense and transparent approach to assessment and management can be extremely effective in developing fine scale harvest policies, even when the approach is quantitatively crude.

Acknowledgements

We acknowledge the Western Zone Abalone Divers Association (WADA) and in particular the chairman Mr Len McCall for funding this work since 2001, and for contributing so much to its development. Acknowledgement and thanks again to Mr Terry Adams of Western Australia who first drew our attention to the importance of the appearance and shape of abalone shells. Also acknowledgement to Mr Vincent Gannon; who as WADA's diving secretary initiated this project in 2001, now as non-diving EO of VADA he facilitates it reef assessment process. Thanks to the various staff of Fisheries Victoria and PIRVic for their support and belief. Finally we acknowledge the long-term of the Australian Government Fisheries Research and Development Corporation (and its predecessors) leading up to this current program (FRDC 2005/024).

References

Day, R.W., and Fleming, A.E., 1992. The determinants and measurement of abalone growth. In: Shepherd, S.A., Tegner, M.J., Guzmán del Próo, S.A., (Eds.).Abalone of the World: Biology, Fisheries and Culture. Fishing News Books: Blackwell Scientific Publications. Cambridge, pp.141-68.

Fisheries Victoria, 2002. Abalone Management Plan. Fisheries Victoria, East Melbourne. 66 pp.

Fisheries Victoria, 2005. Fisheries (Abalone) Bill 2005. Fisheries Victoria, Melbourne. 241 pp.

Gorfine, H.K., Dixon, C.D., 2000. Abalone stock assessment - 1999. Fisheries Victoria Assessment Report No. 27. Marine and Freshwater Resources Institute, Queenscliff, Victoria, Australia. 74 pp.

Gulland, J.A., 1969. Manual of methods for fish stock assessment. Part 1. Fish population analysis. FAO Manual of Fisheries Science 4, 1–54.

Harrison, A.J., 1986. Gastropod fisheries of the Pacific with particular reference to Australian abalone. In: Jamieson, G.S., Bourne, N. (Eds.), North Pacific Workshop on Stock Assessment and Management of Invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92, 14-22.

Hilborn, R., Orensanz, (Lobo), J.M., Parma, A.M., 2005. Institutions, incentives and the future of fisheries. Phil. Trans. Roy. Soc. B. 360, 47–57.

Hooper, C., Hardy-Smith, P., Handlinger, J., 2007. Ganglioneuritis causing high mortalities in farmed Australian abalone (*Haliotis laevigata* and *Haliotis rubra*). Aust. Vet. J. 85, (5) 36-42.

Larkin, P.A., 1997. The costs of fisheries management information and fisheries research. In: Hancock, D.A., Smith, D.C., Grant, A., Beumer, J.P., (Eds.), Developing and Sustaining World Fisheries Resources: the State of Science and Management. CSIRO Publishing, Melbourne, pp. 713-718.

Leighton, D.L. and Boolootian, R.A., 1963. Diet and growth in the black abalone, *Haliotis cracherodii.* Ecology, 44, 227-38.

McShane, P.E., 1991. Exploitation models and catch statistics of the Victorian fishery for abalone *Haliotis rubra*. Fish. Bull. 90, 139-146.

McShane, P. E., 1995. Recruitment variation in abalone: its importance to fisheries management. Mar. Freshwater Res. 46, 555–570.

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: Shepherd, S.A., Tegner, M.J., Guzmán del Próo, S.A., (Eds.).Abalone of the World: Biology, Fisheries and Culture. Fishing News Books: Blackwell Scientific Publications. Cambridge, pp. 318–338.

Naylor, R. and Andrew, N. (2001) Paua – is the current size limit always appropriate? A case study at Taranaki and Banks Peninsula suggests not. Seafood New Zealand. July 2001, pp33

Prince, J.D., 1989. The Fisheries Biology of the Tasmanian Stocks of *Haliotis rubra*. PhD. thesis, University of Tasmania, pp. 174 .

Prince, J.D., 1992. Using a spatial model to explore the dynamics of an exploited stock of the abalone *Haliotis rubra*. In: Shepherd, S.A., Tegner, M.J., Guzmán del Próo, S.A., (Eds.).Abalone of the World: Biology, Fisheries and Culture. Fishing News Books: Blackwell Scientific Publications. Cambridge, pp. 305-317.

Prince, J.D., 2003. The barefoot ecologist goes fishing. Fish & Fish. 4, 359–371.

Prince J.D., 2004. The decline of global abalone (Genus Haliotid) production in the late twentieth century: is there a future? In: Leber, K.M., Kitada, S., Blankenship, H.L., Svasand, T., (Eds.) Stock Enhancement and Sea Ranching: Developments, Pitfalls & Opportunities. Blackwells Publishing Ltd. Pp. 427-443.

Prince, J.D., 2005. Combating the tyranny of scale for haliotids: Micro-management for micro-stocks. Bull. Mar. Sci. 72, 557–577.

Prince, J.D., Hilborn, R., 1998. Concentration profiles and invertebrate fisheries management. In: Jamieson, G.S., Campbell, A., (Eds.), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci. 125, 187–196.

Prince, J.D., Sellers, T.L., Ford, W.B., Talbot, S.R., 1988. Recruitment, growth, mortality and population structure in a southern Australian population of *Haliotis rubra* (genus Haliotis; Mollusca : Gastropoda). Mar. Biol. 100, 75–82.

Prince, J.D., Shepherd S.A., 1992. Australian fisheries for abalone and their management. In: In: Shepherd, S.A., Tegner, M.J., Guzmán del Próo, S.A., (Eds.).Abalone of the World: Biology, Fisheries and Culture. Fishing News Books: Blackwell Scientific Publications. Cambridge, pp. 407-426.

Prince, J.D., Walters, C., Ruiz-Avila, R.J., Sluczanowski, P., 1998. Territorial user's rights in the Australian abalone fishery. In: Jamieson, G.S., Campbell, A., (Eds.), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci. 125, 367–375.

Punt, A.E., Smith, A.D.M., Cui, G., 2001. Review of progress in the introduction of management strategy evaluation (MSE) approaches in Australia's South East Fishery. Mar. Freshwater Res. 52, 719-26.

Sainsbury, K.J., Punt, A.E., Smith, A.D.M., 2000. Design of operational management strategies for achieving for achieving operational fishery ecosystem objectives. ICES J. mar. Sci. 57, 731-741.

Saunders, T.M., Mayfield, S.S., Hogg, A.A., 2008. A simple, cost-effective, morphometric marker for characterising abalone populations at multiple scales. Mar. Freshwater Res. 59, 32-40.

Shepherd, S.A., Baker, J.L., 1998. Biological reference points in an abalone (*Haliotis laevigata*) fishery. In: Jamieson, G.S., Campbell, A., (Eds.), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci. 125, 235-245.

Shepherd, S.A. and Laws, H.M., 1974. Studies on southern Australian abalone (Genus *Haliotis*), II. Reproduction of five species. Aust. J. Mar. Freshw. Res. 25, 49-62

Shepherd, S.A., Partington, D., 1995. Studies on southern Australian abalone (genus *Haliotis*) XVI. Recruitment, habitat and stock relations. Mar. Fresh. Res. 46, 669-680.

Sloan, N.A. and Breen, P.A., 1988. Northern abalone, *Haliotis kamtschatkana*: fisheries and synopsis of life history information. Can. Spec. Publ. Fish. Aquat. Sci. 103, pp. 46.

Sluczanowski, P.R. 1986. A disaggregate model for sedentary stocks: the case of the South Australian abalone. In: Jamieson, G.S., Bourne, N. (Eds.), North Pacific Workshop on Stock Assessment and Management of Invertebrates. Can. Spec. Publ. Fish. Aquat. Sci. 92, 393-401.

Worthington, D.G., Andrew, N.L., Hamer, G., 1995. Covariation between growth and morphology suggests alternative size limits for the abalone, *Haliotis rubra*, in NSW, Australia. Fish. Bull. 93, 551–561.

Worthington, D.G., Andrew, N.L., 1998. Small-scale variation in demography and its implication for an alternative size limits in the fishery for blacklip abalone (*Haliotis rubra*) in New South Wales, Australia. In: Jamieson, G.S., Campbell, A., (Eds.), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Can. Spec. Publ. Fish. Aquat. Sci. 125, 341-348.