Towards an industry-based abalone fishery monitoring program

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Seafood Industry Victoria

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Fisheries Research and Development Corporation

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NON-TECHNICAL SUMMARY

2002/083	Towards an industry-based abalone monitoring program

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Objectives

1. Facilitate acquisition of data via industry including tagging for growth, size at maturity and length frequency of the catch
2. Promote industry self-sufficiency in data collection including the training of deckhands and divers in sampling, measuring and recording techniques.
3. Develop appropriate management protocols to support on-going voluntary data collection by divers.

Non Technical Summary

Commencement of this project coincided with the Victorian abalone industry shifting towards increased self governance at sub-zonal scales. This shift entailed adoption of spatially explicit mechanisms, beyond those prescribed by existing regulations, for managing the operation of the catching sector. Although supported in-principle by government, these changes were industry-driven, and facilitated by the three catching sector associations. Eventually these voluntary arrangements were formalised with memoranda of understanding between two of the industry associations and Fisheries Victoria. The over-arching aim of this project to initiate a program of industry-based resource monitoring was consistent with this evolving micro-management regime. Consequently, the emerging micro-management needs influenced the direction of the project and the nature the monitoring strategies that were explored.

The initial focus on data collection centred primarily on the needs of PIRVic in delivering in assessing the performance of the management of the fishery on behalf of Fisheries Victoria. This government centric view was reflected in the initial emphasis of using divers and their deckhands in lieu of field technicians to obtain growth and size at maturity data and in using questionnaires to acquire divers' observations of resource status. Although data collection objectives were pursued, these endeavours acquired less importance as the project progressed and became increasingly aligned with satisfying emerging information and management needs for industry self-governance.

Although micromanagement initiatives were creating increased demand for resource information, contemporary contractual arrangements between fishery access licence owners and the diving contractors they engage to harvest their individual quota allocations tempered expectations about divers' collecting research data in addition to their fishing activities. The focus of the project tended to split between practical tasks in which industry could engage to improve prospects for sustainability, for example stock

rehabilitation and exploration of seldom fished reefs, and providing mechanisms for meaningful engagement of industry in the synthesis and analysis of information for resource assessment on a reef by reef basis.

In keeping with the overall aim of empowering industry to engage in scientific assessments of their fishery and collect information to support industry-driven management initiatives, several workshops were held during the course of the project, each building on its predecessor. Both Western and Central Zones played pivotal roles in supporting workshops. However, it should also be acknowledged that Eastern Zone industry members had independently developed their own process several years earlier and did not express the need for similar assistance from this project. Doubtless, this was partly a reflection of the relatively healthy state of Eastern Zone stocks that, in contrast to the other zones, had led to recent TAC increases.

Data acquired during the project were either analysed by PIRVic scientists who used the resultant information to make management recommendations or were summarised and collated for use by industry during reef scale assessment workshops. The Eastern Zone industry was the first to avail itself of outputs from the size at maturity analyses to set reef-specific voluntary minimum lengths that were larger than the prevailing legal minimum length. The Western and Central Zone workshops were a driving force that took the project beyond the originally specified objectives for industry data acquisition to develop mechanisms to engage divers in reef by reef assessment and micromanagement processes. Reef report cards and graphic user interfaces were developed to inform divers and licence owners and capture their contributions and decisions during workshops. Competency based training packages were developed to build capacity among industry members to make meaningful contributions towards fisheries assessment.

Although divers were enthusiastic about participating in the project, it soon became apparent that expectations they would undertake extensive research work without remuneration were unreasonable. Indeed two of the research divers engaged by PIRVic were also contracted abalone divers who were not in a financial situation that allowed them to donate their time to undertake work for which they would normally be paid. This did not reflect an absence of goodwill on the part of divers (the industry in-kind contribution to this project was substantial) but rather that someone has to pay those who collect research data and that the best people to collect specific data will inevitably be a subset of the diving community who choose to specialise in this field. In a cost-recovery environment, as applies to almost all of Australia's abalone fisheries, industry ends up paying one way or another. This also does not mean that there aren't areas where industry can supply useful information in conjunction with their fishing without unacceptable imposts on divers. This project explored those boundaries and provides some clear guidance for the most appropriate approaches for efficiently collecting the different kinds of data necessary for quantitative fisheries assessments.

Significantly, outputs from the project have already translated into tangible management outcomes for the Victorian abalone fishery. These outcomes represent a sub-ordinate layer of management that should enhance the effectiveness of legislated management arrangements applied at management zone and regional scales. Reef scale management avoids the problems of averaging across reefs and focuses management at a scale commensurate with the recruitment dynamics and productivity of abalone populations.

Outcomes Achieved

- **TAC setting from fishery modelling incorporating a broader range of industry acquired data**
- **Establishment of voluntary micro-management strategies including larger minimum size limits, catch caps and daily boat limits for individual reefs**
- **Intervention by industry to rehabilitate depleted reefs**
- **Improved access to seldom fished stocks via new management arrangements**
- **Better informed catching sector with respect to abalone biology and assessment**
- **A nucleus for future self-governance by Australia's abalone industry**

Keywords
Abalone Industry, Resource Assessment, Micro-management

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This project would not have been possible without considerable cooperation and support from the following organisations:

EZAIA – Eastern Zone Abalone Industry Association

VADA – Victorian Abalone Divers Association

WADA – Western Abalone Divers Association

Many individuals gave freely of their time and, in addition to those who are members of the aforementioned associations, we would like to thank those pioneering divers who we interviewed, especially those no longer directly connected with the fishery.

FINAL REPORT

2002/083 Towards an industry-based abalone monitoring program

Background

The Victorian abalone fishery yields around 14% of the global supply of wild abalone and in 2002/03 when this project was initiated was worth approximately $AUD62M to licence holders. Among Victorian-managed fisheries it is the State's most economically valuable. The Victorian abalone industry has a history of supporting research of their fishery and has directly participated in several research projects over the years (e.g. Gorfine et al. 1996). During 2001 Victorian abalone industry associations expressed a strong desire to substantially increase their involvement in the collection of fishery assessment data. Impetus for this desire stemmed from an emerging realisation that more comprehensive input data were required to ensure that outputs from the application of a length-based fishery assessment model developed by the Marine and Freshwater Systems platform of Primary Industries Research Victoria (PIRVic) reliably reflected the status of the resource. This model is an important component among a suite of tools used to provide scientific advice to fishery managers, but the quality of model outputs is inevitably limited by its inputs. Industry did not have the expertise to collect additional information without assistance and PIRVic did not have the human and financial resources to support this initiative without external assistance. PIRVic and FRDC have invested heavily in the development of models suited to the unique characteristics of abalone population dynamics. To realise the potential management benefits from the resultant technology, substantial investment in the acquisition of supporting data is required.

Industry and PIRVic had already embarked on a range of fishery dependent data collection strategies in addition to traditional catch and effort reporting. An on-board observer program had been introduced (Gorfine and Dixon 2001) and commercial catch sampling in abalone processing factories was underway. Industry had also developed an onboard shellfish measuring instrument with great potential to improve the quality and quantity of catch and effort data. This instrument measures the maximum shell diameter of each abalone caught as it is packed into a fish bin aboard the vessel. At the same time date, time of day and GPS co-ordinates are logged. Provision has also been made to record effort as time spent underwater. Limited sea trials conducted by industry indicated that the instrument was reliable and efficient. The concept and its potential was well received following presentation at the inaugural National Abalone Convention and at the 2001 annual general meetings of the Victorian Abalone Divers Association and the Western Abalone Divers Association. Divers from Victoria's Eastern Zone had expressed more cautious interest in the device. However, the different fishery dependent sampling strategies were in their infancy, the data collected was relatively sparse and despite the potential for these data, their usefulness for quantitative fishery assessments was largely untested.

Discussion at an Abalone Fishery Assessment Group (AbaloneFAG) workshop during 2001 highlighted the need to engage additional staff that can operate jointly between PIRVic and Seafood Industry Victoria (SIV) to realise industry's desire to participate in resource sampling and data acquisition. Growth, in particular was identified as one life history parameter for which more data and improved analytical tools were required urgently. Abalone exhibit extreme spatial heterogeneity among growth rates, even over relatively small spatial scales to the extent that abalone growth data are not amenable to analysis based on conventional modelling techniques. At PIRVic, Troynikov (1998) developed stochastic methods for analysing growth for animals displaying highly heterogeneous patterns of growth and Troynikov and Gorfine (1998) demonstrated the importance adopting a stochastic approach to analysing distributions of growth data for several Victorian abalone populations. This work has since been extended to improve the statistical robustness of growth analyses (Bardos 2004).

These PIRVic results and those of preceding research (see Day and Fleming 1992) clearly indicated the necessity to obtain good growth datasets from as many abalone populations as possible. Averaging among populations, or extrapolating from populations of known growth to those with unknown growth, was mostly inadequate with potential to produce misleading results. Indeed, modelling some regions of the Victorian fishery had amply demonstrated problems arising from inadequate or unrepresentative information about growth. In such instances it was difficult, if not impossible, to fit fishery models to temporal patterns in length-frequency distributions. The only long-term solution to this dilemma is to release tagged abalone en masse at as many locations as possible.

Size at maturity was another variable of interest because onset of reproductive maturity occurs with age rather than size (McShane et al. 1986, Nash et al 1994). This means that size at maturity is as highly variable as growth and that this variability must also be accommodated via appropriate ogives in fishery models. The other main category of data with high priority for increased sampling was the size structure or length-frequency of the commercial catch. One important requirement for these data stems from industry observations that the modelling assumption of knife-edge selectivity only applied in the Western and Central Zones of the fishery and was invalid for abalone stocks on many reefs in the Eastern Zone. Divers informed the AbaloneFAG that they often left at least a 5mm margin above the legal minimum length for capture and that for some reefs they had introduced voluntary size limits that were substantially larger than the LMLs. This meant that pooling of length frequency data could inadequately portrays the size structure of the catch and that, as with growth and size at maturity, reef by reef sampling is required. This would enable spatially representative selectivity curves to be included in fishery models.

Another area of information gathering about which the Victorian industry was passionate was the capture of industry perceptions about the contemporary status of the resource and its supporting habitat and the incorporation of this information in assessments of the fishery. Better utilisation of diver information was identified as a high priority for R&D in the 'Wild Abalone Fisheries Research and Development Needs Review' commissioned by FRDC (Project No. 98/170) during 1998. Exhibit C of the Review report indicated that this area of research activity was emphasised during consultations with all abalone producing States other than NSW. PIRVic had previously trialed a voluntary questionnaire, however it was poorly subscribed despite widespread distribution. At best a written questionnaire is only able to acquire information on several occasions during the year and consequently many of the respondents will be relying on memory. Feedback from industry is that better and more information would be forthcoming if relevant questions were asked of divers during their day's fishing. This can be best accomplished by periodically posting scientific observers aboard abalone fishing boats.

Stakeholder participants at the 2001 AbaloneFAG urged PIRVic to assist SIV in pursuit of funding from FRDC to support their proposal. It was the view of the meeting that the acquisition of growth, size at maturity and catch length-frequency should be realised with the utmost urgency. It was also recognised that there was a need to train divers and their deckhands in techniques for collecting data and samples. It was intended that, where possible, this training should fully utilise and complement the investment already made by FRDC in the Australian Seafood Industry Education Network (ASIEN) and in association with the Natural Heritage Trust funded SeaNet extension project hosted in Victoria by SIV. After some discussion about whether the proposal should be submitted by PIRVic or SIV, it was agreed that SIV should take the leading role as Principal Investigator to manage the project. However, in recognition that PIRVic had the necessary scientific infrastructure and experience to engage the required staff and design the project in detail, PIRVic was allocated a substantial role as Co-investigator.

As the project progressed industry became increasingly pro-active in the pursuit of finer scale management processes. Although quantitative model-based assessments were being delivered at sub-zonal scales, the demands of managing at the scale of reef complexes were beyond such analyses. Under these circumstances reliance on industry-derived data was acquiring greater importance than it had previously. In a sense, this project and the shift towards finer scale management were co-evolving events. Industry, now more than ever, had a strong reason to embrace a more self-determined approach. However, this came at a time when the abalone industry was generally under more financial stress in terms of market value and reduced catch-quotas than it had experienced for many years.

Need

Although Victoria had a well-established fishery independent monitoring program, in recent years the research focus was towards improving the quality and quantity of available fishery dependent data. To properly realise this goal there was a strong and urgent need to make better use of industry (particularly the catching sector) as a vehicle for sampling and data acquisition. Fishery independent monitoring is costly and limited by PIRVic resources, however it is well recognised that industry can potentially provide sampling opportunities that are at least an order of magnitude more numerous than those provided by fisheries agencies and research institutions. For instance, Victorian abalone divers each spend an average of about 50–55 days at sea each year to obtain the TAC. This equates to a total of at least 3,500 potential sampling opportunities. On many occasions divers visit more than one reef per day so that the number of opportunities is probably closer to about 5,000. The central issue was how to effectively utilise this industry potential for fishery assessment, recognising those limitations arsing from the commercial abalone divers' primary objective of maximising daily catches.

Scale fisheries have for many years had the benefit of scientific observers and fisheries extension officers, whereas such support for abalone fisheries is rare. Clearly this type of support was needed for the Victorian abalone industry to effectively engage in sampling and data collection to support improved assessment of their fishery. In the absence of this support, industry based sampling would at best be ad hoc and at worst ineffective and unsustained.

One of the areas that had already demonstrated potential for industry participation was tagging abalone for growth studies. Growth in abalone characteristically exhibits high spatial heterogeneity to the extent that growth for one location has little meaning for other locations. Despite the release of about 35,000 tagged abalone across commercially important reefs, recapture rates had demonstrated that in most instances this quantity was inadequate for obtaining sufficient growth data for fishery models to accommodate spatial heterogeneity in growth representatively. This presented particular challenges for modelling an abalone fishery at a geographical scale commensurate with the known population biology of this genus. The abalone industry offers one of the best opportunities for obtaining good growth data for a large number of locations, but experience had shown that effective participation of industry members is difficult to achieve without persistent motivation.

Objectives

1. Facilitate acquisition of data via industry including tagging for growth, size at maturity and length frequency of the catch
2. Promote industry self-sufficiency in data collection including the training of deckhands and divers in sampling, measuring and recording techniques.
3. Develop appropriate management protocols to support on-going voluntary data collection by divers.

As the project progressed it went beyond these original three objectives to explore processes for engagement of divers in the synthesis and analysis of the data that they were able to acquire and the application of these data to support voluntary micro-management initiatives as well as input to regulated management decisions.

Methods

A field extension scientist was engaged to conduct the field components of the project. This included liaison with industry and accompanying abalone divers at sea to undertake tagging, sampling for size at maturity, commercial catch sampling and recording fine-scale catch and effort and diver observations.

The extension officer also co-ordinated and oversaw the release of hatchery-reared juveniles as a trial to rehabilitate two depleted reefs in the Western Zone, and surveys of seldom fished blacklip and greenlip stocks in the Central and Western Zones.

Although involving commercial abalone divers to tag abalone had proved useful in the past, it soon became apparent that this was an unrealistic expectation given the large number of abalone to be tagged during the course of their fishing activities. It was decided to use diving contractors instead incurring additional costs that limited the quantities of tags that could be released. Nonetheless, several thousand abalone were released at five sites in the western region of the Eastern Zone around Cape Conran, which has experienced increased fishing effort since the introduction of a substantial marine park at Point Hicks. This region is not currently assessed due to paucity of biological data and it was hoped growth increments from tag recaptures and size at maturity estimates from macroscopic gonad indices would help redress this deficiency.

Shellfish measuring machines coupled to GPS and data loggers to enable electronic acquisition of shell length and vessel position data were used through out the field components of the project to record the catch. In addition, industry used these machines to acquire substantial length-frequency data during the course of their normal fishing operations.

In keeping with the overall aim of empowering industry to engage in scientific assessments of their fishery and collect information to support industry-driven management initiatives, several workshops were held during the course of the project, each building on its predecessor. Both Western and Central Zones played pivotal roles in supporting workshops. However, it should also acknowledged that Eastern had independently developed its own process several years earlier and did not express the need for similar assistance from this project. This was also partly a reflection of the relatively healthy state of Eastern Zone stocks that in contrast to the other zones had led to recent TAC increases.

Data acquired during the project were either analysed by PIRVic scientists who used the resultant information to make management recommendations or were summarised and collated for use by industry during reef scale assessment workshops. The Western and Central Zone workshops were a driving force that took the project beyond the originally specified objectives for industry data acquisition to develop mechanisms to engage divers in reef by reef assessment and micromanagement processes. Reef report cards and graphic user interfaces were developed to inform divers and licence owners and capture their contributions and decisions during workshops. Competency based training packages were developed to build capacity among industry members to make meaningful contributions towards fisheries assessment.

More explicit details of the methods employed are described under each of the ensuing subsections that report on the various project topics investigated.

Results/Discussion

Overview

During the course of this project several events helped shape the way the objectives were pursued. To some extent the methods were modified accordingly and the focus shifted from the data needs for government agency led assessments applied across the three relatively large management zones of the fishery, to satisfying the needs of industry-driven assessments and micro-management initiatives at the scale of reef codes used for reporting catches. The reef code scale reflects the scale over which divers operate whereas the zonal scale is one that government fisheries managers have traditionally applied their policies. It is also a scale consistent with what is known about abalone population dynamics. Limited dispersal beyond localised scales creates dislocation among populations that coupled with strong influences from highly variable environmental determinants of growth and productivity results in varied capacity to sustain fishing among reefs. Management regimes that attempt to average parameters along large tracts of coastline run a high risk of exposing many reefs to overfishing through serial depletion among essentially segregated abalone populations.

Among the topics listed in the preceding Methods section, most emphasis was placed on extension and training aimed at engaging industry stakeholders in the reef-scale assessment process and less emphasis was given to using divers as a vehicle for generating data necessary for quantitative model-based assessments.

Project outputs included the development and trialing of a prototype reef-scale assessment package and an industry questionnaire, exploration and assessment of the potential of regions that have been subjected to negligible fishing effort in recent decades and stock restoration via industry releasing hatchery-reared juveniles and translocating reproductively mature adults from adjacent reefs that support healthy stocks. The application of electronic shellfish measuring calipers linked to data loggers and GPS was supported to acquire commercial catch length-frequency data at the reef scale. A limited amount of tagging was undertaken by industry, however research divers completed more substantial tagging and acquisition of size at maturity data for areas previously excluded from formal assessments because of paucity of data. On-board observations were completed as part of the sea-based activities during the project.

Engaging industry in fishery assessments

Questionnaire

An industry questionnaire was drafted in conjunction with representatives from divers' associations and trialed with different groups from the catching sector (Appendix 3A). Expertise was sought from Swinburne University to ensure that the structure of the questionnaire was valid and amenable to analysis.

Method

The questionnaire was delivered as a personal interview to ensure that respondents had ample opportunity to carefully consider their response to each question, request clarification where necessary and not consort with other respondents. Nonetheless, for various personal reasons some of the people interviewed chose not to respond to particular questions or occasionally offered responses that were inconsistent with the question format or its content. Sixteen members of the Western Zone fishery and 17 from the Central Zone were interviewed. Eastern Zone industry members declined to be interviewed because of concerns about how the information would be used, however they did request copies of the interview questions and have since developed their own questionnaire the results from which remain confidential and are not disclosed out side their industry association.

The researchers working on the project cannot claim any specific expertise in the construction and delivery of questionnaires. Although expert advice was sought this did not necessarily ensure that all questions were appropriate nor did it ensure that responses were free from bias and speculation beyond the respondents' direct experiences and observations. One example is the concern expressed about the prevalence of illegal activity within marine parks into which it is reasonable to expect that licensed divers no longer venture. The questions covered several overlapping areas associated with diver demographics, fishing practices and preferences, and resource and habitat observations. Although the questions were grouped the order was somewhat haphazard so the responses were re-grouped during collation.

Summary and discussion

Many of the responses between the two zones were similar. This was particularly true for diver demographics, age composition, vessel characteristics, and proximity of residence to home port in each instance. Nonetheless there were also differences that mostly related to differences in physical geography and resource status. The results are summarised and discussed below

Diver demographics

Age ranges were similarly broad across both zones with averages in the forties bracket. The majority of respondent either were or have worked as commercial abalone divers, however many also played other roles reflecting a relatively high level of vertical integration among catch sector, post-harvest and investment roles. Unlike the Western Zone, many of the contract divers interviewed in the Central Zone had also worked as deckhands. Overall, about half to two thirds of the divers had worked as deckhands prior to taking up abalone diving. The range of experience in the fishery (1 to 40 years) and average number of years experience in the low to mid teens was almost the same between the two zones.

Most divers resided close to their home ports with several exceptions for those who travel relatively long distances to access ports. About 40% of divers had experience working interstate as abalone divers. This was mostly in NSW and TAS for periods of five years or less. About one fifth of respondents stated that they were involved in fisheries other than abalone including long-lining, pearl diving and aquaculture.

Fishing practices
The majority of divers in both zones would accept minimum daily catches of between 350–500 kg, with greater tolerance of lower catches in the Western Zone compared with the Central Zone. Catch rates of 75-100 kg/hour seemed to be the preferred range for most of the divers interviewed, however almost half of the Western Zone divers specified a threshold of 50 kg/hour. Most divers reported that they fished most of the reefs within their respective zones. Under ideal weather conditions most divers stated that they would visit reefs that were difficult to fish under adverse sea conditions. These reefs were mostly located in the western region of each zone where local launching facilities were unavailable but good catches were anticipated. The maximum depths to which they were prepared to dive ranged from 10 to 30 metres with averages in the low to mid 20m range.

Processors seem to have had more influence over Central Zone than Western Zone divers, with the former nominating abalone size and meat recovery as the main criteria specified influencing their fishing to meet processor demands.

Although not a direct response to the question posed, those from Western Zone responding ‘other’ cited holiday closures or too much stock as reasons for processor influence. Central Zone divers noted that market preferences for qualities such as foot colour or smaller abalone from Port Phillip Bay influenced targeting.

The majority of divers interviewed defined fishing effort as time spent underwater. The non-response by some might be a reflection of not wanting to admit that they are at odds with the majority of divers. Two divers, one in each zone, recorded their effort as time spent at sea.

Equipment
Consistent with a previous study (Gorfine and Dixon 2001) a larger proportion of Central Zone divers (71% compared to 44%) used monohulls rather than twin-hull boats. Despite the differences in hull type the vessels were of similar length. Most divers powered their boats with twin motors and Central Zone divers’ vessels were more powerful on average than those used in the Western Zone. Most boats were equipped with a depth sounder and most Central Zone divers’ boats also had a GPS. Only about half the Western Zone boats had a GPS.

Surface supplied breathing apparatus was used exclusively as the main source of compressed air for diving. Oxygen was used by many divers as a topside decompression gas, and for additional safety a couple of Western Zone divers used enriched air mixtures (nitrox) delivered from a cylinder bank instead of a hookah compressor. Several divers used an independent back-up air supply and about one third of Western Zone divers reported using an electromagnetic protection device to ward off sharks.

Resource status
Western Zone divers nominated some of the reefs around Cape Bridgewater and The Crags west of Port Fairy as having the best stocks, whereas those on the leeward sides of the headlands in the region west of Portland had the most depleted stocks. In the Central Zone Cape Otway and Phillip Island were identified as possessing the best stocks and various reefcodes on the Mornington Peninsula Back Beaches and within Port Phillip Bay as having the worst. To some extent the Central zone nominations are consistent with industry’s anecdotal information about patterns of illegal fishing.

Despite declining stocks 40% of Western Zone divers thought that the resource status was the same as when they first started fishing, the remainder believed that it had worsened. Three of the six respondents who indicated it was the same were experienced divers with many years of abalone diving, whereas the other three had only recently commenced in the fishery. In the Central Zone 35% thought that stocks were worse and 24% thought that they were better. There was no clear pattern to suggest that these responses were related to years of experience in the fishery.

Substantial proportions of divers from both zones were fishing more reefs within their respective zones than when they first commenced in the fishery. Quota introduction did not change the number of reefs fished among those who were fishing at the time (1988). Respondents also commented that reefs within their zone that have been historically under-utilised were generally characterised by low catch rates. Five out of 16 Western Zone divers and 6 out of 17 Central Zone divers responded that they fish under more adverse weather conditions than they used to during the past. Western Zone divers responded unanimously that they were not working closer to port than when they started, whereas one out of 17 Central Zone divers ventured that he now fished closer to port.

Eight Western Zone divers (50% of respondents) believed the size composition had changed since they started diving for abalone as did a similar proportion of Central Zone divers (10 respondents or 50%). Among Western Zone respondents 5 believed that the abundance of smaller abalone had increased whereas 2 thought that the abundance of larger abalone had increased. Among Central Zone respondents 7 suggested the abundance of smaller abalone had increased and 3 thought that the abundance of larger abalone had increased. Divers were fairly evenly split on whether or not they thought post-fishing stock recovery rates had become longer or were the same, however none suggested that stock recovery rates had improved.

Only 2 out of 11 Western Zone divers said that they now fished deeper than during the past, whereas 6 out 11 Central Zone divers now fished deeper. Half of the divers in each zone (7 out of 14 Western Zone & 6 out of 16) thought that the habitat had become degraded since they had commenced commercial abalone diving.

Threats to resource sustainability
Threats to the future of the fishery were identified to include marine parks, illegal fishing and direct and indirect effects from changes in abundances of other organisms.

A general comment from Western Zone respondents was that marine marks had caused a re-direction of fishing effort thereby increasing pressure on the remaining fishing grounds. One diver suggested that whilst the impact across the Western Zone might not be great numerically, the personal impact on his abalone diving was high. Another suggested that it would not be until the impact of displaced effort on populations became apparent in the future that the significance of the marine park introductions would be known. A third diver criticised the choice of locations where marine parks were sited and suggested that a more protected section of coast such as within Bridgewater Bay would have been a better option for locating a marine park.

Among Central Zone respondents' comments on marine parks, several divers claimed that they had lost access to about two-thirds of the reefs from which they used to harvest abalone. For some it was the loss of access to reefs accessible for fishing during adverse weather that was the biggest impact. Central Zone respondents believed that not enough research had been done prior to introducing marine parks and there were concerns expressed about lost productivity due to quota reductions. Concerns were also expressed about the prevalence of illegal fishing within marine park boundaries and commercial divers' inability to now rotate fishing effort among reefs as they had been their practice in the past in order to conserve stocks.

Apart from the concerns expressed by respondents from both zones about marine parks and how this had intensified effort on the remainder of their fishing grounds, other comments were specific to the Central Zone.

General concern continues about illegal fishing within the Central Zone although there is also acknowledgement that it has reduced as a result of improved government resource allocation for enforcement operations. Although Western Zone divers observed substantially less illegal fishing than in the Central Zone most of this activity in their zone was shore-based rather than boat-based.

Respondents were requested to nominate those reefs where illegal activity was most prevalent. In the Western Zone 6 respondents nominated reefcode 3.07 (Watertower) and 4 nominated 3.11 (The Cutting). Reef codes 1.07 (Seal Caves), 2.07 (Yellow Rock), 2.09 (The Passage), 3.05 (The Crags) and 3.12 (Thunder Point) were each nominated by 2 divers. Relative ease of access, from the shore in most instances, is the common factor among these nominations.

In the Central Zone five divers nominated 13.01 (Cape Schanck to Bushrangers Bay), four nominated 12.03 (Sorrento Back Beach) and four nominated 12.06 (Fingal Beach to Cape Schanck) as having the most prevalent illegal abalone fishing. Over a broader scale 25 respondents nominated one or more among the Mornington Peninsula Back Beaches, 6 nominated Phillip Island, 5 nominate Port Phillip Bay and 7 nominated the West Gippsland coast including Wilson's promontory. Marine Parks featured among the code identified despite the absence of commercial fishing in these areas.

Ten out of 15 Western Zone respondents and 6 out of 16 Central Zone respondents had noticed substantial changes in the abundance of organisms other than abalone. Central Zone respondents identified abundant 11-arm sea stars in Port Phillip Bay, illegal harvesting and reduced kelp growth proximal to a sewage outfall as reasons for habitat degradation. All of the Western Zone respondents cited an increase in the abundance of 11-arm sea stars (*Coscinasterias muricata*), one believed that wrasses had increased whilst another that they had decreased in abundance and one diver suggested increases in crayfish abundance posed a predation a problem. One of the 6 Central Zone respondents who had noticed changes suggested that there had been substantial increases in the abundance of 11-arm sea stars and urchins, another that the abundance of cunjevoi had increased, 3 that the abundance of northern pacific sea stars had increased (presumably within Port Phillip Bay) whereas four believed that the abundance of wrasses had decreased.

Six out of 14 Western Zone respondents believed that these changes had had a negative effect on their catches via predation or denuding reefs. Central Zone divers believed that their catches had suffered from changes in the relative abundance of other organisms. Their perceptions were that increasing abundance of sea stars, and in one instance urchins, will have a negative effect but that decreases in reef fishes such as wrasses was beneficial. One opinion was that reduced vegetation cover would not have an effect but that loss of space to other sessile organisms such as cunjevoi would impact negatively on abalone.

Future prospects

Several divers believed that prospects for the fishery were good providing there is adherence to sound management practices, whereas a couple of their colleagues felt overwhelmed and disillusioned by government regulations and what they perceived to be government interference in the pursuit of a livelihood.

Reef-scale assessment workshops

Reef-scale assessment workshops were first trialled in the Western Zone using a training package developed by Assoc Prof Jeremy Prince. The package comprises a manual and workbook designed around national training competencies (Appendix 3B & C). These workshops were later extended to the Central Zone that then commenced to run a modified version under the supervision of the Executive Officer Mr Vin Gannon with assistance from Assoc Prof Prince. PIRVic developed a supporting reef report card system that collated available data summaries and statistics and captured industry input during their workshops (Figs. 1 & 2).

This process has now become integral to annual fishery assessments in Victoria with zone association workshops preceding the formal Abalone Fishery Assessment Group workshop each year. The Abalone Fishery Committee of the Fisheries Co-management Council now takes these workshops outputs into account when deliberating over its annual TAC advice to the Victorian Minister for Primary Industries. The use of reef report cards ensures that all data are available in a consistent and intelligible manner to all stakeholders. Much of the underpinning data are derived from the same datasets used for input to fisheries modelling at regional and zonal management scales so there is consistency between model-based and reef scale assessments.

The main issue of contention with the workshop process developed thus far is the application of shell morphometry and morphology as a surrogate for estimating the reproductive maturity of abalone populations on different reefs. This aspect requires validation, although if the hypothesis is refuted this will not invalidate the process of using workshops as an effective tool for industry engagement in assessment and management. Two current FRDC projects, 2004/019: Towards optimising the spatial scale of abalone fishery management and 2005/024: Abalone Industry Development: local assessment and management by industry, integrated into State zonal assessment, are examining this issue so it should be resolved during the next few years. Preliminary data, supported by anecdotal observations among abalone divers, indicate that mature abalone tend to have more convex shells and that this occurs at smaller lengths among slower growing populations. However, it is unclear how this relationship varies spatially among populations exposed to different environmental conditions.

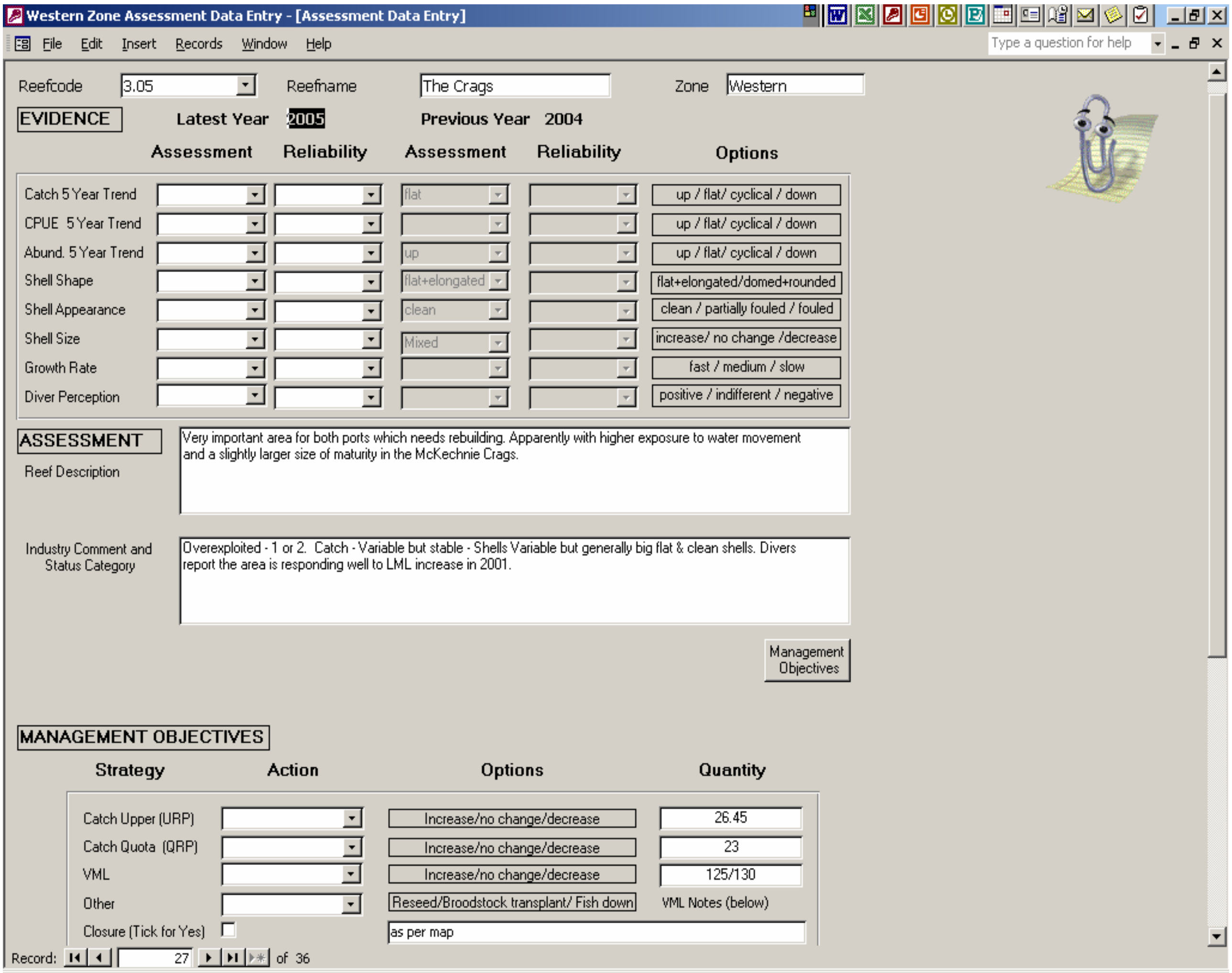

Figure 1. Access database Graphic User Interface for computer entry of industry assessment information and decisions during the reef scale workshops. The GUI allows a facilitator to efficiently update the previous year's assessment. The new assessment can then be readily uploaded

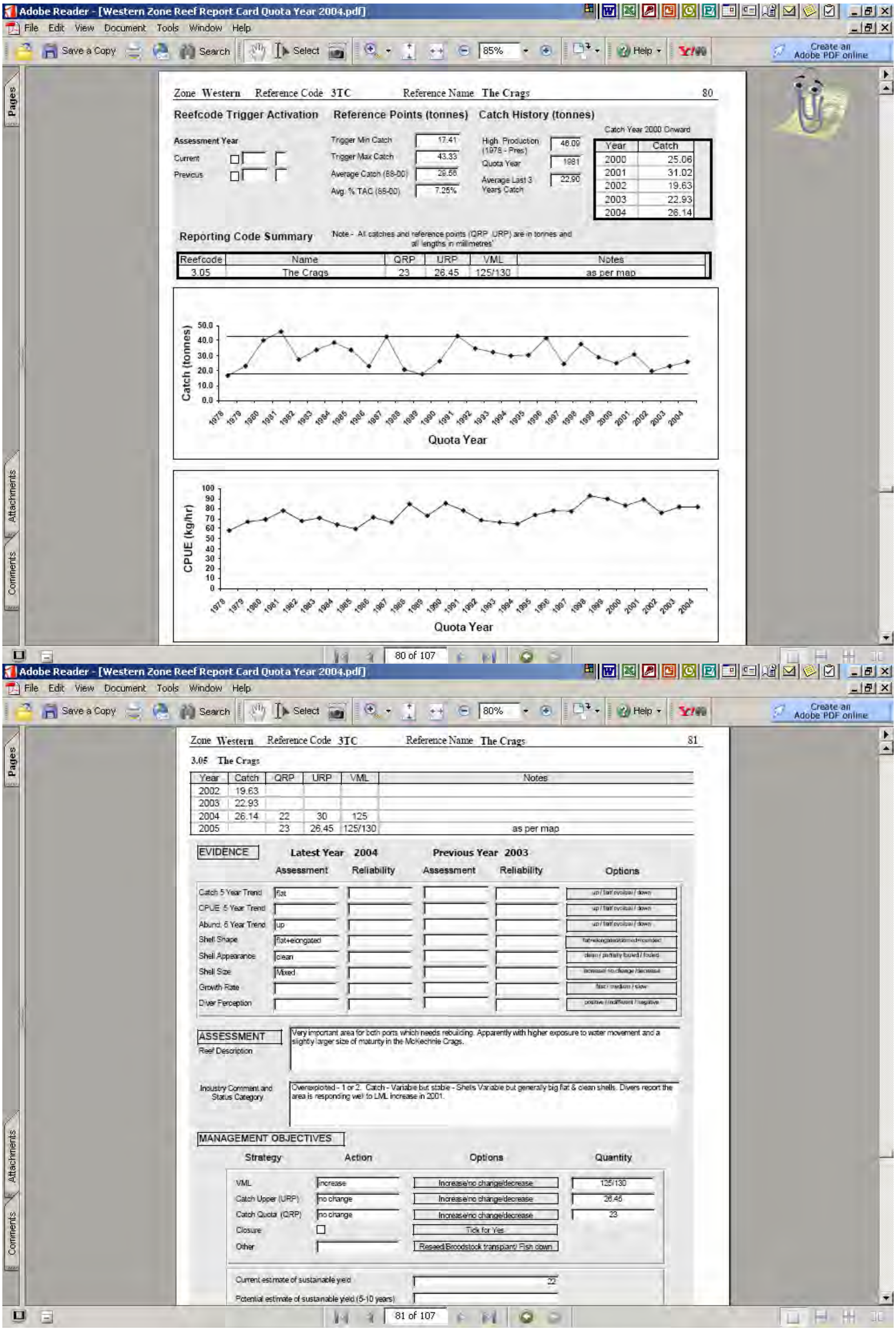

Figure 2. Outputs from the master database are distributed to workshops participants in the form of a reef report card pdf prior to each workshop. It is hoped that eventually these will be made available on-line via an industry reporting and communication website.

Primer on abalone biology

In response to requests from industry concern that they were unfamiliar with some aspects of biology and associated terminology used during assessment workshops and how the kinds of data they collected related to abalone productivity, it was decided to develop and trial a brief training session on abalone biology (see Appendix 3D for full presentation). This was delivered to Central and Western Zone divers and met with positive feedback. It is envisaged that eventually this will be used to induct new divers entering the fishery prior to their participation in the assessment workshops developed by Assoc Prof Jeremy Prince. Course objectives, delivery strategy and presentation outline are described below.

Aim

To provide abalone divers with some basic information about abalone life history & population biology of relevance to fishery assessment

Objectives

At the end of this session divers will be able to –

- Identify major anatomical features and their function
- Describe how some features are adapted to key environmental factors
- List key elements of abalone life history & reproductive biology
- Describe how abalone feed, what they eat & explain how this affects growth
- List some key sources of mortality & ecological competition
- Explain the importance of reproduction and growth for fishery assessments

Training method
- Powerpoint presentation
- Group discussion

Resources
- Notebook computer
- Digital projector
- Screen
- Handout notes

Time
1h 30min

Evaluation
- Participation
- Questions
- Group discussion

Exploring potentially under-utilised fishing grounds

Central Zone, Reefs east of Wilson's Promontory

Members of the Victorian Abalone Divers Association were keen to follow up on anecdotal information from a rock lobster fishermen about rocky reefs at diveable depths along the coast northeast of Wilson's Promontory. The nearby Seal Island Group offshore is well known as a region of productive abalone reefs, however little was known about whether harvestable quantities of abalone existed on inshore reefs to the north and east. Commercial abalone divers undertook spot dives from a chartered rock lobster boat searching for abalone along 23 Km of coast within Reef Code 18.9 during 18/07/2003–20/07/2003 (Appendix 3E). Divers took note of the habitat and collected specimens of biota that they were unable to identify underwater. After each dive a PIRVic staff member aboard the vessel interviewed the divers to record information about the abundance of abalone, habitat type and other biota observed. They also identified any samples that bad been collected.

The outcome for the divers was disappointing because no commercial quantities of abalone were found, however there were isolated individuals, which begs questions about how they got there and whether these low densities persist over time. Despite this result, the exploratory cruise yielded useful data about the reef ecosystems surveyed that has been added to PIRVic's GIS marine database and represents a valuable community contribution (Appendix 3E).

Western Zone, Julia Bank Reef

In the Western Zone the Western Abalone Divers Association was assisted by PIRVic to organise an experimental fish-down of blacklip abalone over an extensive reef area known as Julia Bank (Appendix 3F). Julia Bank is situated east of Portland Bay about 2 km offshore from Yambuk Lake between the mainland and Julia Percy Island. Julia Bank reefs are of generally low relief and the region is frequented by Great White Sharks. Divers believe that its abalone populations are stunted, a perception that is consistent a possibly poorer food supply this area is partially in the lee of the capes west of Portland Harbour. A permit was issued by Fisheries Victorian that allowed abalone to be harvested a minimum size of 90mm which is 30mm less than the legal minimum length (LML) that would otherwise apply. Because there had been virtually no catch reported from this reef code in the past decade it was agreed that the principle criterion for determining whether or not the Julia Bank populations were stunted was the size structure of abalone in the experimental catch. A criterion was established that no more than 15% of individuals sampled should be greater than LML of 120mm, as prima facie evidence that the study populations were stunted. No catch rate threshold was set because divers accepted the high probability that these would be much less than for other reefs within the Zone. Although catches of blacklip abalone were poor, those harvested were clearly stunted. Concurrent observations that there was approximately a fivefold ratio of greenlip to blacklip abalone led to a separate survey restricted to greenlip populations. Results from this second survey indicated that commercially acceptable catch rates were possible, however categorising these greenlip abalone populations as stunted was equivocal because the extent of stunting varied considerably among reefs.

Final recommendations from these surveys were for a reduced size limit of 110mm for blacklip abalone (existing LML = 120mm), and a fishing slot of 125 – 145 mm for greenlip abalone (existing LML = 130mm) within an annual quota of 500kg per fishery access licence i.e. greenlip abalone TAC = 7 tonnes.

Rehabilitating depleted reefs

Releasing hatchery reared juveniles in the Western Zone

The Western Abalone Divers Association (WADA) was keen to trial stock restoration by releasing hatchery-reared juvenile 'seed' blacklip abalone on two reefs in the Western Zone whose populations had become depleted, ostensibly from over fishing. Twenty-five thousand disease-tested abalone were released in specially fabricated modules at two reefs close to two of the three main ports in the Zone by commercial abalone divers in an operation co-ordinated by PIRVic's Abalone Scientific Extension Officer, Steve Michael (Appendix 3G).

Translocating mature adults in the Western Zone

Commercial abalone divers translocates several thousand abalone to selected reefs at Portland and Port Fairy. The necessary permits were issued by Fisheries Victoria and a follow-up survey incorporating searches at both re-seeding and translocation sites was conducted early during 2006 (Appendix 3H). Results from the follow-up survey suggest that although the translocation may have been successful in terms of broodstock survival, there is little evidence of benefit from the re-seeding to date (Appendix 3H).

Estimating growth, size at maturity & length frequency

Tagging was completed at two regions in the Central Zone and one in the Eastern Zone that have assumed greater importance since becoming subject to increased effort displaced by the introduction of no-take marine parks elsewhere within these zones. Hundreds of tagged abalone were released at several sites around Cape Liptrap west of Wilson's Promontory, west of Cape Otway between Moonlight Head and Peterborough, and in the vicinity of Cape Conran in East Gippsland. The principle reason for selecting these locations was to test the hypothesis that their relatively lower catch histories reflected slower growth rates. If this were true then harvesting might be sustainable at lower size limits which by increasing the available stock would help lessen the burden on Victoria's abalone resources that has arisen from the loss of productive grounds to marine parks. One of the challenges for this project was to address the issue of how best to analyse data where there was substantial heterogeneity within each dataset and where recapture rates also varied greatly among locations. The method for analysing these data was revised and then used to test the quality of the data fits for each sample dataset. These datasets were then ranked categorically to provide an indication about how well they described the growth for the the particular population to which they pertained (Appendix 3I). Size at maturity samples were also collected from many reefs to enable estimation of size limits that would ensure 50% of these populations would have at least two years of spawning potential prior to reaching the minium size for harvesting (Appendix 3J). Ninetieth percentiles were also estimated to provide a more conservative set of values for comparison. Where growth data specific to a particular reef were unavailable sensitivity analyses were completed using data from several reefs that differed substantially in growth rate.

In addition to acquisition of length-frequency data during this project's specific investigations, industry in all three zones also embarked on the application of electronic shellfish measuring machines to log samples of shell lengths from the commercial catch for as many reefs as possible (Appendix 3K). To date more than one million observations have been recorded using this equipment and provided valuable input to modelling the fishery as well as supporting the reef-scale assessment process. Acquisition and logging of geographic co-ordinates from the inbuilt GPS of the measuring machines for each shell length observation allows precise mapping of fishing effort patterns that occur during the sampling process (Appendix 3K).

Benefits

Benefits from this project will manifest in the short term as improvements in the information and processes for assessing abalone resources with greater spatial resolution than has occurred in the past. This will include a greater level of self-governance by industry as it assumes more responsibility for assessment and management decision-making. Given that divers directly observe what is happening on reefs every day that they harvest abalone, their involvement in assessment processes will contribute timely first-hand knowledge about the current status of abalone populations and their supporting ecosystems.

It is hoped that through these short term benefits longer term benefits of on-going resource sustainability will accrue to the whole community. This will be contingent on the preparedness of industry to review and refine their reef scale assessment and micro-management processes and their resolve to persist with practicing good governance in cooperation with all stakeholders.

The community at large will benefit as industry places less reliance on government to look after the resource for them and takes greater financial responsibility for managing their impact on sustainability.

Lastly, other states will benefit if, as has already been indicated by some of their abalone industries, they are willing to adopt the technology from this project.

Further Development

Further development is already underway as FRDC Projects 2004/019 'Towards optimising the spatial scale of abalone fishery management' and 2005/024 'Abalone Industry Development: local assessment and management by industry, integrated into State zonal assessment' pursue the validation of some of the key biological tenets upon which the reef-scale assessment process is based and refine the industry assessment workshop process. PIRVic is also undertaking a review of the process for producing and disseminating reef report cards. A project team under the auspices of the Geelong Quality Council's (GQC) Science & Technology in Industry Program 2005 was tasked with developing an industry-based data management and communication strategy. This is now being extended by a team of six 4th year software engineering students from the University of Melbourne who, based on recommendations from the GQC Science & Technology Industry Program team, are developing a web-based industry data capture and reporting package (Appendix 3L). The software package, scheduled for completion at the end of 2006, will be spatially structured to allow industry to utilise maps for data selection and drop down menus to select graphical templates and tables for display and printing of data summaries and reports. This web based facility will facilitate managed up-loading of data from a variety of sources and secure access for industry to generate their own up-to-date reports by selecting from a menu of statistical summaries, graphs and maps. Publications and newsletters in pdf format could also be posted on the site that will be maintained by a private consultant engaged at industry's expense, but operating under PIRVic's supervision to ensure the validity and integrity of the datasets.

FRDC Project 2006/029 'Using GPS technology to improve fishery dependent data collection in abalone fisheries' will extend the use of the GPS logging facility of the shellfish measuring machines to enable analyses of fine scale patterns of fishing effort that will improve the quantitative data available for reef scale assessment and provide valuable feedback to industry on the extent to which their management initiatives are affecting feet dynamics.

Planned Outcomes

Although relatively complex by virtue of the diverse avenues explored, this project has delivered significant outcomes including:

- Improvement in TAC setting arising from a broader range of inputs to fishery modeling
- Establishment of voluntary micro-management strategies in the from of larger minimum sizes, catch caps and daily boat limits for individual reefs
- Intervention by industry to rehabilitate depleted reefs
- Improved knowledge and access to seldom fished stocks via new management arrangements
- Better informed catching sector with respect to abalone biology and assessment
- A nucleus for future self-governance by Australia's abalone industry

The Victorian abalone industry has been empowered to contribute to the assessment of the resource upon which their livelihoods depend and this will foster increased resource stewardship in the future. Tangible evidence of the success of the project is the substantial provision of input data for fishery assessment on an on-going basis. Improved estimates of sustainable catches and appropriate size limits have already been made through the availability of spatially refined data and the synthesis and analysis that occurred during reef-scale assessment workshops. Broadly, by value-adding to existing FRDC investments in R&D, this project has made a substantial contribution toward maximising the return to the abalone industry and broader stakeholder community on these investments. It has contributed to the cycle of continual improvement in sustainable harvesting within the Australian abalone industry, necessary to satisfy community demands, for responsible marine resource stewardship, that are reflected increasingly among fisheries and environmental legislation.

Conclusion

Empowerment of abalone industries to contribute towards the sustainability of the resource that they depend upon for their livelihoods will only be realised if their engagement extends well beyond data acquisition. Divers can and licence owners must meaningfully participate in the synthesis and assessment of the acquired data. A codified process that provides both appropriate training and opportunities to use that training is needed for such participation to occur.

Questionnaires can provide useful information about how the industry is structured and how its members perceive the resource, but it is dependent on the quality of the questions posed, how the responses are sought and the level of willingness for respondents to be candid. Responses are often subjective and guarded in case the information is used by government to the perceived economic disadvantage of industry. Nonetheless, two zones willing participated in this component of the [project and are now using questionnaires annually or bi-annually to canvas their members' observations and opinions about abalone resource status and management needs.

Data collection is not free and although electronic technology may automate the acquisition process and reduce costs by minimising the extent of involvement required of divers and their deckhands, current applications are limited and further research is required before any expansion can occur. Tagging and gonad sampling are labour-intensive and costly. It is more effective to pay specialists to tag, release and recapture en masse than to rely on commercial divers to tag small quantities incidentally whilst engaged in fishing. A similar approach is needed for size at maturity sampling, however this is more amenable to organising several commercial abalone divers to collect samples from different reefs at the same time and then deliver these to a permit holding courier who can then convey the sample to a laboratory. For such an operation to occur in Victoria, the divers are not permitted to have any commercial catch aboard their boats whist collecting and transporting the samples thereby adding to the costs involved.

This project initiated a process that supports micromanagement by facilitating participation of industry stakeholders in a structured reef scale assessment process. Development of this process has been a driver to improve the accessibility of information to industry and a reef report card and database has been established for this purpose. Information supplied is comprehensive and consistent with that supplied to fisheries managers and other non-industry stakeholders.

The benefits of practical intervention by divers to rehabilitate depleted reefs have yet to be demonstrated and it will be several years before the success of the trial conducted during this project can be evaluated. Exploration of alternative fishing grounds to compensate for grounds lost to marine parks or depletion is an important endeavour if sustainable catch quotas are to be maintained without unacceptable risk. Out of the two surveys conducted to explore new territory for abalone harvesting during this project one was fruitful whilst the other was not. The unsuccessful search for harvestable quantities of abalone at least demonstrated a capacity for industry to gather new ecological data for posterity.

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Appendix 1: Intellectual Property

There is no intellectual property arising from this project to date that can be commercialised. Any existing or future intellectual property will be shared between PIRVic and FRDC.

Appendix 2: Staff

Name	Project Role	Position	Organisation
Ross McGowan	Principal Investigator	Executive Director	Seafood Industry Vic
Harry Gorfine	Co-investigator	Abalone Project Manager	PIRVic—MFS
Jeremy Prince	Workshop consultant	Managing Director	Biospherics
Cameron Dixon	Data analysis	Fisheries Scientist (abalone)	PIRVic—MFS
Steven Michael	Field extension	Field Scientist	PIRVic—MFS
David Bardos	Modelling consultant	Bio-mathematician	Ecological Dynamics
David Forbes	Field survey team	Research Diving Contractor	ARSS
Bruce Waters	Field survey team	Research Diving Contractor	ARSS
Jason Ciavola	Field survey team	Research Diving Contractor	ARSS & WADA
KP Sivakumaran	Data management	Fisheries Scientist	PIRVic—MFS

Appendix 3: Project Publications & Reports

A. Victorian Abalone Fishery Questionnaire for Divers, compiled by Harry Gorfine.

B. Developing Environmental Assessment & Management Decision Making Skills—A Course Developed for the Western Abalone Divers Association. Developed by Assoc. Prof. Jeremy D. Prince, Biospherics, October 2003.

C. Developing Environmental Assessment & Management Decision Making Skills Course Work Book —A Course Developed for the Western Abalone Divers Association. Developed by Assoc. Prof. Jeremy D. Prince, Murdoch University August 2003.

D. Abalone Biology—Primer for Commercial Divers, compiled by Harry Gorfine.

E. VADA Abalone Survey: Catch Reef Code 18.9 East 18/07/2003–20/07/2003.

F. Gorfine, H. 2005. Assessment of abalone fishing potential in the Julia Bank region of western Victoria. Report no. 62. Primary Industries Research Victoria, Queenscliff.

G. Release of juvenile blacklip abalone to rehabilitate depleted reefs in the Western Zone. Steve Michael, November 2004.

H. Monitoring results for industry re-seeding and translocation initiatives in the Western Zone of the Victoria abalone fishery. David Forbes, March 2006.

I. Improved analysis of growth increment data for Victorian abalone populations. Report for Abalone Project – Primary Industries Research Victoria David Bardos, Ecological Dynamics, March 2006.

J. Size at maturity surveys in Victoria during 2000-2003. Cameron Dixon, November 2003.

K. Commercial catch sampling length-frequency and effort patterns from Western Zone data logged using electronic shellfish measuring boards.

L. Web-based Abalone Reporting Project.

Victorian Abalone Fishery Questionnaire for Divers

Questionnaire No:______________________

Name:____

1. In what year were you born? 19_______

Western Zone divers' ages ranged from 34 to 76 years with an average of 48 years and a median of 42 years, whereas Central Zone had a range of 21 to 65 years with an average of 46 years and a median of 47 years.

2. Which category best describes your involvement in the fishery? (Circle all that apply)

a). Diver

b). Deckhand

c). Licence owner

d). Processor

All of the interviewees were or had been divers and many had more than one role in the fishery. In the Western Zone two divers, one of whom was also a licence owner, worked as deckhands. Another five divers were licence owners and one owner also identified themselves as a processor. Among those from the Central Zone who were interviewed, 11 only worked as divers. Two fitted the category of diver, deckhand and licence owner among the remaining three that identified themselves as deckhands two were also licence owners and one worked as a contract diver. There were three processors among the Central Zone group, one of whom also identified himself as belonging to all four categories and another who was a diver and licence owner.

3. If you are not a license owner, what is your relationship to the owner of the license on which you are nominated? (Circle all that apply)

a). Family member

b). Contractor

c). Ex deckhand

Among the non-owner divers two in the Western Zone and one in the Central Zone were members of a licence owner's family. Only one of the Western Zone divers compared with 10 of the Central Zone divers were ex-deckhands.

4. In which town do you reside?________________________________

In the Western Zone five of the divers resided in Port Fairy, three in Portland and two in Warrnambool with the remainder living away from the main ports, four of these outside the zone.

Seven of the Central divers lived on the Mornington Peninsula, two in West Gippsland, three on the Bellarine Peninsula, two in Cape Otway and one in the Western Zone.

5. What is the postcode of your residence?____________________________

See above.

6. With which zone(s) are you associated?

a). Eastern Zone

b). Central Zone

c). Western Zone

There were no respondents from the Eastern Zone, 17 from the Central Zone and 16 from the Western Zone. The Western Zone had the largest portion of respondents from its catching sector compromising 14 Fishery Access Licences. There are 23 Fishery Access Licences in the Eastern Zone and 34 in the Central Zone.

7. From which port do you usually operate? ____________________

Ten Western Zone divers operated primarily out of Port Fairy and six out of Portland. Six Central Zone divers regularly launched from, Stony Point, three from Flinders, two from Queenscliff, two from Apollo Bay, and one each from Sandy Point and Port Campbell.

8. Have you had experience abalone diving in another state? Yes/No

Six Western Zone and 7 Central Zone divers had interstate abalone diving experience.

If YES specify state ___________ & number of years ________

The majority had dived for abalone in NSW (5 Western Zone & 3 Central Zone) and Tasmania (1 Western Zone & 4 Central Zone) with one also having experience in South Australia and Western Australia. Although one diver had 11 years experience interstate the rest had less than 5 years experience elsewhere.

9. What do you consider to be an acceptable minimum daily catch on a typical day?

a) 750 kg

b) 500 kg

c) 350 kg

d) 250 kg

Catch (kg)	*Western Zone*	*Central Zone*
750	*0*	*0*
500	*5*	*7*
350	*10*	*7*
250-350	*-*	*2*
250	*1*	*2*

10. What would be your catch rate threshold for relocating to another reef?

a). 150 kg/hour

b). 100 kg/hour

c). 75 kg/hour

d). 50 kg/hour

e). 25 kg/hour

CPUE threshold (kg/h)	Western Zone	Central Zone
150	0	0
100	4	6
75	4	8
50-75	-	2
50	7	2
25	0	0

11. Are you involved in another fishery? Yes/ No

When asked whether they were involved in another fishery (other than abalone) similar proportions, 3 out of 16 Western Zone respondents and 4 out of 17 Central Zone respondents, from the two zones answered in the affirmative.

If YES then Specify. ___________________________

a In what capacity? ___________________________

b From which port do you usually operate? _______________________________

Among the three Western Zone divers, one skippered a long-liner operating out of Port Fairy, one was a periwinkle diver and the third was involved in abalone farming interstate. One of the Central Zone divers worked as a pearl diver, one owned an interstate fishing licence and the other two worked in abalone aquaculture, one a company director and the other as an employee.

12. Which reef code would you choose to dive in your zone under ideal weather conditions?

In the Western Zone reefs favoured under ideal weather conditions included reefs from Bridgewater Bay westward, Crags, Julia Percy I. and Levy's Point. There were no clear preferences in the Central Zone other than quite a few divers nominating the western region of the zone (west of Cape Otway).

13. Can you identify areas where lack of launching facilities restricts your ability to obtain good daily catches?

Launching facilities precluded ready access to reefs in the far west of each zone as well as around Lorne and between Inverloch and Cape Liptrap in the Central Zone.

14. Please list the 3 reef codes in your zone that you believe currently have the best stocks.

____

____

____

Western Zone – Crags (10), South Bridgewater-Bully Cove (6), Burnets (5), Blowholes (4) & The Tits (3) were nominated as having the best stocks in the Western Zone.

In the Central Zone – 12.6 (6), 4.2 (5), 12 nominated one or more reefs west of Cape Otway and 5 nominated at least one Phillip I. reefcode.

15. Please list the 3 reef codes in your zone that you believe currently have the worst stocks.

____

____

____

Horseshoe (9), The Passage (7), Mills (4), Julia Bank (4), Killer Waves to Cape Grant (3) in the Western Zone were nominated as having the worst stocks in the Western Zone.

Nine Central Zone divers nominated at least one reefcode from the Mornington Peninsula Back Beaches as having the worst stocks with 12.03 (Sorrento Back Beach) and 13.05 (Flinders Back Beach) each listed by 3 divers. Port Phillip Bay codes were nominated by 7 divers as having poor stocks.

16. Before you started diving did you work as a deckhand? Yes/ No

Seven Western Zone divers and 12 Central Zone divers worked as deckhands prior to taking up commercial abalone diving.

17. How many years have you been harvesting abalone?____________________

	Commercial abalone diving experience (years)			
	Av	Med	Max	min
Western Zone	16	11	39	1
Central Zone	13	13	40	1

18. In your zone how many reef codes do you fish?

a). All b). Most c). Few

	Proportion of reef codes fished (number of divers)		
Category	All	Most	Few
Western Zone	2	11	3
Central Zone	3	10	5

19. Given occupation health health and safety considerations, what depth are you prepared to dive to harvest abalone? _______ meters

	Maximum depth re: OH&S (m)			
	Average	Median	Maximum	Minimum
Western Zone	20	20	33	10
Central Zone	21	20	30	10

20. **Given weather considerations and availability of good stocks, What is the maximum depth to which you are prepared to dive to harvest abalone? _______ meters**

	Maximum depth re: weather & good stocks (m)			
	Average	Median	Maximum	Minimum
Western Zone	26	25	30	10
Central Zone	22	20	35	10

Vessel Information

1. **What type of vessel do you use?**
   a). Monohull runabout
   b). Twin hull runabout
   c). Displacement vessel

	Number of respondents			
Category	Monohull	Twin hull	Displacement	Mono & Twin
Western Zone	7	6	0	3
Central Zone	12	5	1	1 Mono & Dis

2. **Vessel length:** _________ **metres**

	Vessel length (m)			
	Average	Median	Maximum	Minimum
Western Zone	6	7	8	4.7
Central Zone	6.6	6.7	7.5	5.6

3. **Type of motors:**
   a). Twin outboards
   b). Single outboard
   c). Inboard
   d). Stern drive

Motor Type	Western Zone	Central Zone
Twin outboards	9	14
Single outboard	1	4
Inboard	1	
Stern drive	2	

4. **Total horsepower:** ___________ **HP**

Vessel power (HP)				
	Average	Median	Maximum	Minimum
Western Zone	268	265	500*	70
Central Zone	309	300	450	175

* single outboard max = 135 HP

5. **What instrumentation do you have aboard the vessel?** (Circle all that apply)
   a). Depth sounder
   b). GPS
   c). GPS plotter
   d). VHF radio
   e). HF radio
   f). Other

Instrument	Western Zone	Central Zone
Depth sounder	15	17
GPS	7	15
GPS plotter	5	10
VHF radio	7	13
HF radio	2	2
Other	0	5

Diving equipment

i) Do you use a breathing mixture other than air? YES NO

ii). If yes what mixture (specify %s) e.g. Nitrox/trimix ________________

iii) Do you use oxygen as an in-water decompression gas? YES NO

iv) Do you use oxygen as a topside decompression gas? YES NO

v) Do you use a gas delivery system other than hookah? YES NO

vi) If yes, specify e.g. Scuba, Cylinder bank, Rebreather ________________

vii). Do you use a shark protection device? YES NO

viii). If yes, specify ____

Diving equipment	Western Zone	Central Zone
Do you use a breathing mixture other than air?	2	0
If yes what mixture (specify %s) e.g. Nitrox/trimix	40% EAN_x	na
Do you use oxygen as an in-water decompression gas?	1	2
Do you use oxygen as a topside decompression gas?	10	8
Do you use a gas delivery system other than hookah?	3	2
If yes, specify e.g. Scuba, Cylinder bank, Rebreather	Cyl bank, SCUBA	Bail- out/pony
Do you use a shark protection device?	5 (only 11 responses)	2
If yes, specify	3 pods & 2 shields	ns

Fishing Effort

1. To what extent do processor requirements influence when you fish?

a). Never

b). Sometimes

c). Often

d). Always

	Processor influence on when to fish				
	Never	Sometimes	Often	Always	No response
Western Zone	3	7	1	0	5
Central Zone	1	9	4	3	0

2. To what extent do processor requirements influence where and how you fish?

a). Never

b). Sometimes

c). Often

d). Always

	Processor influence on where & how to fish				
	Never	Sometimes	Often	Always	No response
Western Zone	7	7	1	0	0
Central Zone	1	9	6	2	0

3. If you did not circle (a), what characteristic are you specifically seeking?

a). Small abalone

b). Large abalone

c). High meat recovery rate

d). Other (specify) ____________

	Characteristic among abalone targeted			
	Small	*Large*	*Meat recovery*	*Other*
Western Zone	*4*	*3*	*1*	*4*
Central Zone	*10*	*7*	*7*	*8*

4. How do you define your fishing time/effort?

a). Time spent at sea

b). Time spent at fishing location

c). Diver Time

d). Other (specify) ________________

	Definition of fishing effort			
	Time at sea	*Time on location*	*Dive time*	*No response*
Western Zone	*1*	*1*	*10*	*4*
Central Zone	*1*	*0*	*15*	*2*

Resource Status

1. How would you rate the resource overall compared to when you first entered the fishery?

a). Worse

b). Same

c). Better

	Overall rating of resource status relative to commencing in the fishery		
	Worse	*Same*	*Better*
Western Zone	*9*	*6*	*0*
Central Zone	*6*	*7*	*4*

2. Do you work closer to port than when you first started? Yes/ No

Western Zone divers responded unanimously that they were not working closer to port than when they started whereas one out of 17 Central Zone divers ventured that he now fished closer to port.

3. **How many reefs do you fish from compared to when you first started?**

a). More

b). Same

c). Less

	No of reefs fished relative to commencing in the fishery		
	More	*Same*	*Less*
Western Zone	*8*	*5*	*2*
Central Zone	*12*	*4*	*1*

4. **Were you finished prior to 1988?** Yes/ No

Four out of 11 Western Zone respondents (36%) were fishing prior to 1988 compared with only 2 out of 16 Central Zone respondents (13%).

5. **If yes, how did the introduction of quota change the number of reefs that you fished?**

a). More

b). Same

c). Less

	No of reefs fished relative to commencing in the fishery		
	More	*Same*	*Less*
Western Zone	*1*	*2*	*1*
Central Zone	*0*	*2*	*0*

6. **Has the size composition of abalone changed over the years since you began diving?** Yes/ No

Eight Western Zone divers (50% of respondents) believed the size composition had changed since they started diving for abalone as did a similar proportion of Central Zone divers (10 respondents or 50%).

7. **If Yes, How?**

a) Increase in abundance of smaller abalone

b). Increase in abundance of larger abalone

c). Other________________________________

Among Western Zone respondents 5 believed that the abundance of smaller abalone had increased whereas 2 thought that the abundance of larger abalone had increased. Among Central Zone respondents 7 suggested the abundance of smaller abalone had increased and 3 thought that the abundance of larger abalone had increased.

8. **How long is the stock taking to recover from fishing compared with when you first started?**

a Longer

b Same

c Shorter

	Stock recovery rate relative to commencing in the fishery		
	Longer	Same	Shorter
Western Zone	6	7	0
Central Zone	8	9	0

9. Do you fish more adverse weather conditions than you used to? Yes/ No

Five out of 16 Western Zone divers and 6 out of 17 Central Zone divers responded that they fish under more adverse weather conditions than they used to during the past.

10. If so, why? ______________________________________

Reasons given among those responding 'Yes' included catching more quota units than previously, the need to fish to patterns in market demand and variability in owners' needs for cash flow.

Reasons given among those responding 'Yes' included catching more quota units than previously, the need to fish to patterns in market demand and variability in owners' needs for cash flow.

11. Do you fish deeper than you used to? Yes/ No

Only 2 out of 11 Western Zone divers responding to this question said they fished deeper than during the past whereas 6 out 11 Central Zone divers now fished deeper.

Habitat/Ecosystem

1. Do you think abalone habitat has become degraded since you stated diving? Yes/ No

Half the divers in each zone (7 out of 14 Western Zone & 6 out of 16) thought that the habitat had become degraded since they had commenced commercial abalone diving.

2. If so, why?

a). Pollution

b). Reduced abundance of abalone,

c). Overgrowth of seaweed

d). Other ____________________

	Reason for habitat degradation			
	Pollution	Abalone depletion	Algal overgrowth	Other
Western Zone	0	1	5	Both b & c
Central Zone	5	2	1	*

Central Zone respondents identified abundant 11-arm sea stars in Port Phillip Bay, illegal harvesting and reduced kelp growth proximal to a sewage outfall as reasons for habitat degradation.

3. Have you noticed a substantial change in abundance of other organisms? Yes/ No

Ten out of 15 Western Zone respondents and 6 out of 16 Central Zone respondents had noticed substantial changes in the abundance of organisms other than abalone.

4. If so, which ones and have increased or decreased?

a. 11 arm sea stars Increased/decreased

b. white urchins Increased/decreased

c. black urchins Increased/decreased

d. wrasse Increased/decreased

e. others (specify) ____________________

All of the Western Zone respondents cited an increase in the abundance of 11-arm sea stars (Coscinasterias muricata), one believed that wrasses had increased whilst another that they had decreased in abundance and one diver suggested crayfish abundance had been a problem. One of the 6 Central Zone respondents answering the previous question in the affirmative suggested that there had been substantial increases in the abundance of 11-arm sea stars and urchins, another that the abundance of cunjevoi had increased, 3 that the abundance of northern pacific sea stars had increased (presumably within Port Phillip Bay) whereas four believed that the abundance of wrasses had decreased.

5. Has this had a negative affect on your abalone catches? Yes/ No

Six out of 14 Western Zone respondents believed that these changes had had a negative effect on their catches via predation or denuding reefs. Four out of 12 Central Zone divers responding to this question believed that their catches had suffered from changes in the relative abundance of other organisms.

6. Explain. ____________________

Their (Central Zone) perceptions were that increasing abundance of sea stars, and in one instance urchins, will have a negative effect but that decreases in reef fishes such as wrasses was beneficial. One opinion was that reduced vegetation cover would not have an effect but that loos of space to other sessile organisms such as cunjevoi would impact negatively on abalone.

General

1. **Estimate the number of illegal fishing incidents in the following categories that you have observed during the past year.**
   a Boat-based operators ____________
   b Shore-based operators ____________
   c Shell discarded on bottom ____________

	Number of illegal fishing incidents observed during past year		
	Average	*Maximum*	*Minimum*
Western Zone			
- boat based	*1*	*6*	*0*
- shore based	*4*	*12*	*0*
- UW shell	*5*	*20*	*0*
Central Zone			
- boat based	*11*	*30*	*2*
- shore based	*16*	*45*	*5*
- UW shell	*9*	*30*	*1*

2. **List the three reef codes in your zone where illegal activities are most prevalent**

____

____

____

Western Zone
Six respondents nominated reefcode 3.07 (Watertower) and 4 nominated 3.11 (The Cutting). Reef codes 1.07 (Seal Caves), 2.07 (Yellow Rock), 2.09 (The Passage), 3.05 (The Crags) and 3.12 (Thunder Point) were each nominated by 2 divers. Relative ease of access, from the shore in most instances, is the common factor among these nominations.

Central Zone
Five divers nominated 13.01 (Cape Schanck to Bushrangers Bay), four nominated 12.03 (Sorrento Back Beach and four nominated 12.06 (Fingal Beach to Cape Schanck) as having the most prevalent illegal abalone fishing. Over a broader scale 25 respondents nominated one or more among the Mornington Peninsula Back Beaches, 6 nominated Phillip Island, 5 nominate Port Phillip Bay and 7 nominated the West Gippsland coast including Wilson's promontory. Marine Parks featured among the code identified despite the absence of commercial fishing in these areas.

3. What impact has the implementation of Marine Parks had on the economics of your fishery?

a). High b). Medium c). Low

	Economic impact of implementing marine parks		
	High	Medium	Low
Western Zone	2	3	8
Central Zone	13	3	0

4. Comments: ____

A general comment for Western Zone respondents was that marine marks had caused a re-direction of fishing effort increasing pressure on the remaining fishing grounds. One diver suggested that whilst the impact across the Western Zone might not be great the personal impact on his abalone diving was high. Another suggested that it would not be until the impact of displaced effort on populations became apparent that the significance of the marine park introductions would be known. A thread diver criticised the choice of locations and suggested that a more protected section of coast such as within Bridgewater Bay would have been a better option for locating a marine park.

Among Central Zone respondents' comments on marine parks, several divers claimed that they had lost access to about two-thirds of the reefs from which they used to harvest abalone. For some it was the loss of access to reefs accessible for fishing during adverse weather that was the biggest impact. Central Zone respondents believed that not enough research had been done prior to introducing marine parks and there were concerns expressed about lost productivity due to quota reductions. Concerns were also expressed about the prevalence of illegal fishing within marine park boundaries and commercial divers' inability to now rotate fishing effort among reefs as they had been their practice in the past in order to conserve stocks.

General Comments

Apart from the concerns expressed by respondents from both zones about marine parks and how this had intensified effort on the remainder of their fishing grounds, other comments were specific to the Central Zone.

General concern continues about illegal fishing within the zone although there is also acknowledgement that it has reduced as a result of improved government resource allocation for enforcement operations. Several divers believed that prospects for the fishery were good providing there is adherence to sound management practices, whereas a couple of their colleagues felt overwhelmed and disillusioned by government regulations and what they perceived to be government interference in the pursuit of a livelihood. Respondents also commented that reefs within their zone that have been historically under-utilised were generally characterised by low catch rates.

B

Developing Environmental Assessment &

Management Decision Making Skills

A Course Developed for the

Western Abalone Divers Association

By

Assoc. Prof. Jeremy D. Prince

October 2003.

Biospherics P/L

062-458-093

Session Plan

Day 1 – Introduction to Basic Theory of Reef Scale Environmental Management of Abalone Reefs

Morning Session

Session 1 - Introduction to Training Workshop & Management of Localized Marine Resources

Lunch

Session 2 - Reef Assessment

Afternoon Session

Session 3 - Categorizing Exploitation Histories to Assess Status of Abalone Reefs

Day 2

Morning Session

Session 4 - Appropriate Environmental Management for each Exploitation Category

Lunch

Session 5 - Profiling Catch & Effort Histories of the Western Zone Reefs

Afternoon Session

Session 6 - Environmental Management Decision Making Matrices

Day 3

Morning Session

Session 7 - Designing Decision Making Matrix for Western Zone Abalone.

Lunch

Session 8 - Designing Decision Making Matrix for Western Zone Abalone continued …..

Afternoon Session

Session 9 - Summary & Reaffirmation of Decisions made during the Workshop

Session 1 - Introduction to Training Workshop

National Training Competencies Addressed by this Course

(RTD6502A) Review management plans and strategies

This competency standard covers the process of reviewing and assessing effectiveness of management plans and strategies. It requires the ability to determine mechanisms and criteria for reviewing management plans and strategies, analyse existing management plans and strategies, modify management plans and strategies, and implement modified management plans and strategies. Reviewing management plans and strategies requires knowledge of the interrelationship of geophysical, hydrological, biological and meteorological factors in an ecosystems, biodiversity, monitoring parameters and techniques utilised in biological monitoring, international, national and local standards and Codes of Practice, relevant cultural issues, and legislation under which enterprise operates.

(SFICOMP502A) Contribute to fisheries management

This unit involves being pro-active in fisheries management along with industry representatives, scientists, environmentalists, government and community representatives.

Managing Localised Marine Resources

In their overview of the 1998 North Pacific Symposium on invertebrate stock assessment and management Orensanz and Jamieson (1998) present a concise summary of the difficulties sedentary benthic invertebrates present for orthodox stock assessment and management. As our understanding of these marine resources grows it is becoming increasingly evident that they are characterised by their complex spatial structure.

The observation that many localized populations tend to be self recruiting was once thought to be restricted to abalone (Prince *et al.* 1987, 1988), but the evidence mounts that this may be true for many species. This feature by itself does not necessarily complicate assessment and management, but it does when combined with the variable patterns of growth and size of maturity that also characterise sedentary invertebrates.

When a broad scale management regime such as minimum or maximum size limits, or regional catch limits are applied to a resource with highly variable growth rates and size of maturity the impact of fishing pressure varies across the individual populations that comprise the resource. Catch limits or effort controls applied at a regional level over a spatially intricate resource have limited effect on the level of fishing pressure applied at the scale of component populations. Consequently the principle form of management becomes the LML used in the fishery. Local populations with a higher than average size of maturity may receive little if any protection from a regional LML, while populations with a smaller size of maturity remain lightly exploited. The application of an upper size limit also has a variable impact between local stocks; stocks with a low maximum size maybe unable to grow into the protection of the upper size limit, while fast growing populations which emerge at mature at a large size may be almost completely protected by the same maximum size limit.

This localized and variable impact of management is exacerbated by the tendency of divers to focus their fishing pressure on favoured dive sites; preferring to fish close to home ports, in shallow calm waters, and where the density of legal sized animals is greatest. Combined with a tendency for local populations to be self recruiting, variable exploitation patterns can cause the preferred pockets of resource to become locally extinct through recruitment overfishing, while stocks remain lightly exploited. As component areas of stock become locally extinct, fishing pressure transfers to remaining stocks which in their turn become the favoured focus of fishing effort and may in turn also decline and fail as fishing pressure escalates.

This spatial variability is extremely difficult for orthodox methods to assess and manage. Fishery dependent means of resource assessment (commercial catch rates) rarely reflect the density in depleted areas because fishers avoid wasting their time there. While the relatively few fishery independent surveys allowed by the scarce resources of government agencies may reflect the local conditions being surveyed without providing an accurate reflection of the broader resource. Even if there is an accurate appreciation of the many small scale trends occurring across the resource government management agencies are unable to implement and enforce management at the scale of kilometres and 10s of kilometres.

One of the main causes for the failure of stock assessment and fisheries management in fisheries for sedentary invertebrates and many apparently more mobile fish species is unrecognized spatial complexity and a consequent mismatch between the scale of assessment and management, and the scale of component units of stock within the fishery (Prince & Hilborn 1998). This so-called Tragedy of Scale makes it imperative for many fisheries to look beyond orthodox models of management and assessment, towards a future where fishermen are involved more completely in processes of fine scale data collection, stock assessment and management (Prince *et al.* 1998).

Recently the government agency heads charged with managing the abalone resources of southern Australia met and agreed that the priority of these fisheries was to foster the development of fine scale environmental management (micro-management or reef scale management) of abalone resources. This approach is in its infancy and needs substantial development. Key to its success will a much greater participation by the commercial divers and access licence holders as it is apparent that government agencies have limited abilities to monitor, assess and enforce management at the scales of individual abalone reefs.

Concerned at recent trends they have observed in their own resource the Western Abalone Divers Association (WADA) have been discussing ways of progressing this initiative in the Western Zone fishery, and have approached Assoc. Prof. Prince to begin providing the training required to underpin reef scale Environmental Management of their resource.

This fishery has a history of management initiatives flowing rapidly across the entire Australian fishery. The introduction of LMLs in the early 1960s, limited entry in the late 1960s, licence transferability in the mid-1970s and ITQs in the 1980s all began in a single jurisdiction but were taken by all states within several years. Beyond addressing the immediate concerns of WADA by equipping Western Zone divers and access licence holders to become more involved in their own program of Environmental Management, the impact of this training program is likely to flow rapidly through the other zones of Victoria and the other southern Australian states.

Session 2 - Reef Assessment

To start the process of reef by reef management it will be necessary to develop and agree some means of assessing the different reefs in the Western Zone. How else will we agree what management is appropriate to each area? At the core of any assessment method must be the examination of some indicators of the abundance of abalone stocks in each place – stock abundance indicators.

Indicators of Stock Abundance

Obviously the best way to track the abundance of abalone would be directly surveying the every abalone reef, but this will remain a pipe dream for some time to come. At least until we have had everyone equipped with measuring machines for several years. In the mean time we must agree some alternative proxy or indicator of stock abundance.

Traditionally in the field of fisheries assessment catch rates or CPUE are used extensively to provide an indicator (index) of stock abundance. However this is now widely accepted as being highly problematic for abalone and many other species. The principle reasons for this are:

1. Catch rate data are aggregated over too many abalone aggregations.
2. The visual nature of abalone diving and the high level of knowledge divers have about the location and abundance at each location;
3. Enables divers to accurate allocate diving time to differing aggregations in direct proportion to the amount of abalone in each aggregation.

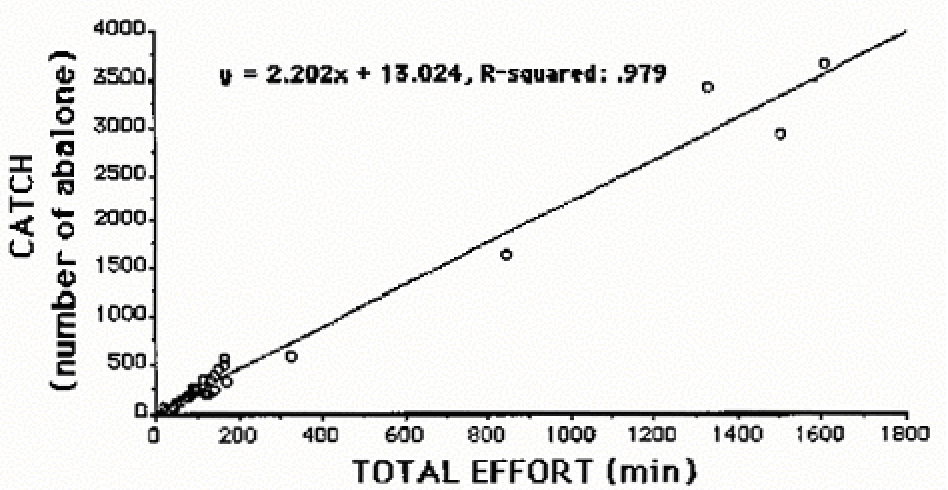

Figure 1. Linear relationship between catch and effort observed during the George III Rock fishdown experiment (Prince 1989).

The effect of this is to keep effort and catch proportional to each other which means that catch rates remain extremely stable even as a resource is depleted. This is demonstrated by figure 1 which was derived from a fishdown experiment conducted by Prince (1989) in

Tasmania and compares the amount of diving time (effort) allocated to differing 125 x 125m square areas of reef to the catch from each area. Note the direct relationship between effort and catch.

This direct relationship between catch and effort destroys the usefulness of CPUE but the underlying mechanism causing the relationship – the high level of knowledge divers have about the abundance of abalone each area - also provides an opportunity. Why not use the knowledge of the divers – or at least an index of their knowledge, the effort allocated to each area (or the catch), as the indicator of abalone abundance. If divers accurately allocate their effort according to the abundance of abalone in an area and usually take a proportional amount of catch why not use the amount of effort they are allocating (rather than the catch rate) as the indicator of abundance?

Figures 2 and 3 demonstrate that the idea of using effort (or catch) as an indicator of stock abundance is fundamentally sound. These figures are drawn from the same experiment as figure 1 and show that the population of abalone estimated to have been in each block (figure 2) was proportional to the level of effort the divers used in the fishdown experiment allocated to each block.

Obviously this will not work in all situations – any indicator of stock abundance other than direct reef by reef surveys will have some weaknesses. For instance if abalone abundance across all areas is very low but regional TACs remain relatively high divers will have to be combing through all the areas regardless of the fact that they know few legal sized abalone remain. But in this case we will expect a sharp decline in catch rates to provide a warning sign that this is happening, and we will probably still see most effort being directed to where divers expect the best catches to be made. Alternatively where a low TAC was applied to a reef code effort may be driven down but this will be evident in the management decision and to some extent should uncouple the previous relationship between catch and effort i.e. cause catch rates to rise.

In the current context the principle is sound – but we must stay aware of the fact that we are looking at indicators of stock abundance which, unlike direct population counts, will not hold up under all conditions.

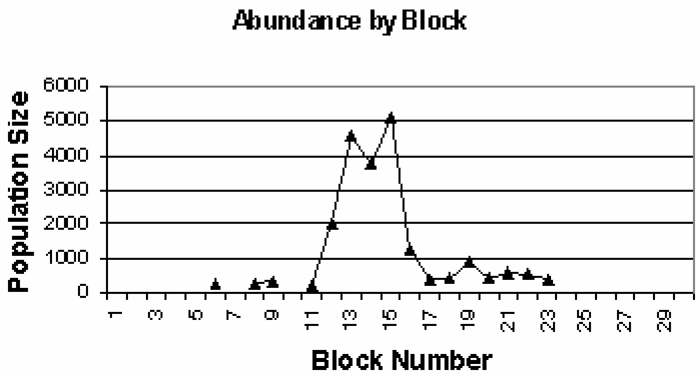

Figure 2 Estimated population of abalone by 125x125m block at George III Rock (Prince 1989).

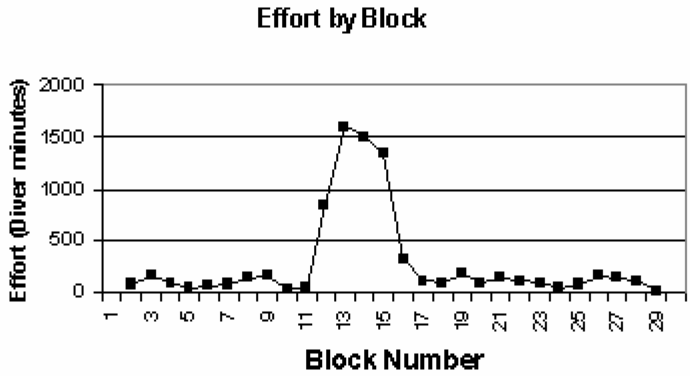

Figure 3 Effort in diving minutes allocated by 125x125m block at George III Rock (Prince 1989).

<u>Reading Abalone Shells</u>

As outlined in the methods section of my 2002 report to WADA qualitative observations about the nature of abalone shells can also be used to assess the status of an abalone population. I have previously discussed the biology underlying this several times with WADA members and it is also documented in my 2002 report and several published papers so I will not detail it again.

In summary, juvenile abalone remain hidden within the reef if at all possible until they mature. During this life phase their shells tend to be growing in length and are relatively thin and flat. Because they remain in the dark they also remain relatively free of fouling growth and so are clean. Upon maturity they move out of the cryptic habitat to join adult feeding and breeding aggregations, their shells become thicker and growth tends to be in volume rather than length, so the shells become higher and rounder. As mature animals they also sit out in the open and their shells become fouled by epiphytic growth.

In general upon maturing abalone take several years to attain full adult fecundity (egg production capacity) and should be allowed several years of breeding with their full adult potential before being harvested. So if breeding stocks are to be maintained at safe levels on each reef LMLs for each reef should be set to ensure they allow abalone to remain on the reefs for 5-6 years after they first mature and emerge. This means that the shells of the abalone being harvested should not be flat and clean in appearance, rather they should be high, rounded and covered with fouling growth. This gives us a second means of assessing the status of an abalone reef.

Point 1. - Use trends in catch and effort as one means of assessing the status of different Reef Codes.

Point 2. Use the nature and appearance of shell as a second means of assessing reef status. Clean flat shells in the catch means abalone are being caught before their breeding potential has been realized – meaning that a reef is being over-exploited. High, rounded shells covered with fouling growths indicates abalone are being allowed some years breeding before capture.

Session 3 - Categorising Exploitation Histories to Assess the Status of Abalone Reefs

Armed with the two qualitative assessment principles derived in the first session the workshop will need to conduct its own Reef by Reef assessment of the Western Zone. Because the assessment process will pave the way for making some hard management decisions about different areas of reef, there will be competing motives amongst the membership of WADA. Potentially this could become a source of tension and conflict between members which might undermine the association's ability to take corporate action.

Decision Trees

To counter this possibility it is important that the assessment process be structured, disciplined and transparent. This need is all the greater because of the lack of hard (quantitative) survey data on which to base the assessment. However, even with this type of qualitative information it is possible to structure decision making with an agreed decision tree, an example of which is shown in figure 4. Such a decision tree can be used to agree and then make transparent the basis by which each reef area is assessed.

The tree shown in figure 4 is not meant to be 'fixed in stone' rather it is just a 'first cut' and after consideration and some use could well need some adjustment. However it is important that adjustments are made:

1. By agreement of the association,
2. Before, or after (not during), an assessment.

This is to preserve the purpose of the decision tree which is to ensure structure, discipline and transparency. Changes made by select small groups, or 'on the fly' during an assessment will undermine the central purpose of using a decision tree.

The Decision Tree in figure 4 shows that the first level of assessment is made on the basis of long term (5-15 year) trends in the catch and effort statistics for each reef code. The first order decision will be; are catch and effort levels stable (remaining around the same level) or are they unstable (rising or falling over time)? Here we should note the changes that have occurred in the definition of reef codes over time, and the fact that any changes need to be taken into account when deciding what the history of an area has been. We should also note that in some areas catch and effort is applied spasmodically (in some years but not in others). Our interest here is not in year to year variability but longer term trends i.e. is the average for the last five years similar to the average of 5-10 years ago, and 10-15 years ago.

Unstable Catch and Effort Trends

If we decide that catch and effort trends are unstable for a reef code the second order assessment is; are catches and effort rising or falling?

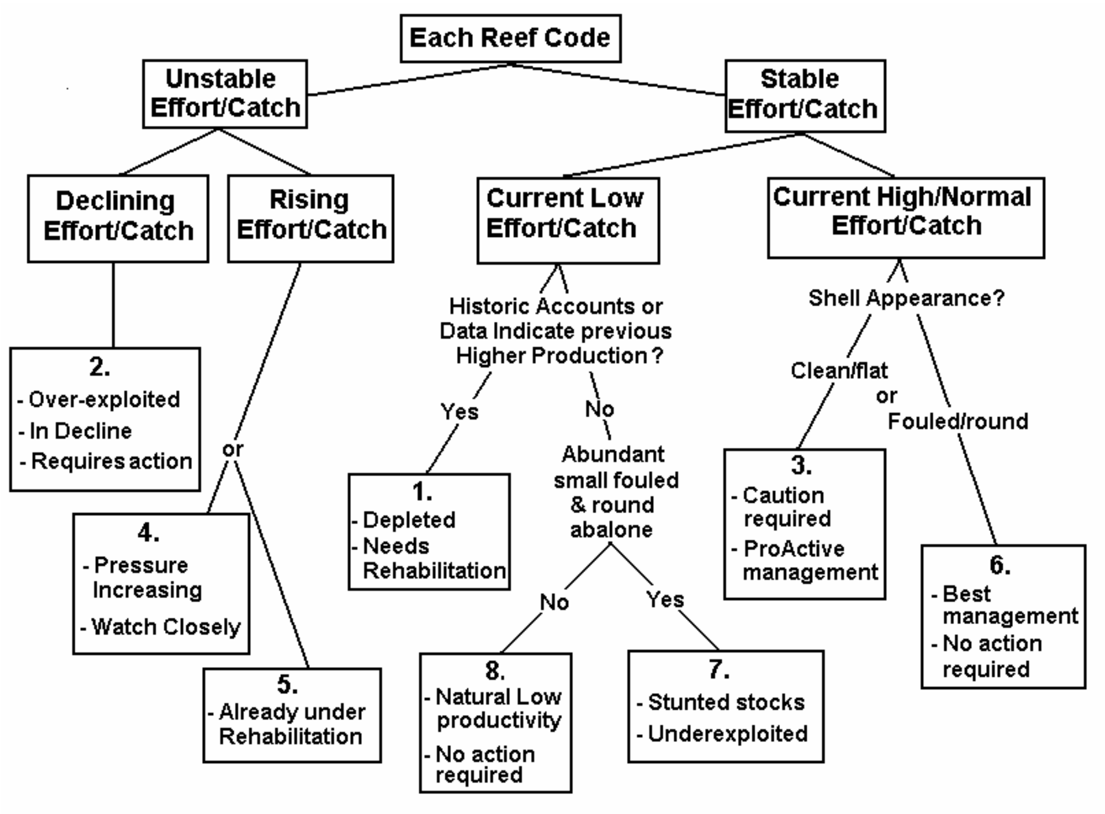

Figure 4. An example of an assessment 'decision tree' that can be used to structure, discipline and make transparent the reef by reef assessment process.

Where catch and effort continues to decline over some period of years the assessment is that a reef area is being overexploited (Category 2) and the population in that area has declined. This is an area that will require improved management to arrest and reverse the trend. Here let us note that, in the short term, tighter management might also cause catch and effort to decline. But management induced impact of this type should be short lived (1-2 years) and then the decline should be stabilized and hopefully be reversed.

Where catch and effort are rising two possibilities arise. Often this will be a cause for concern because it would indicate that effort displaced from elsewhere is being redirected and fishing pressure is intensifying (Category 4). Trends in such an area should be watched carefully because potentially this rising pressure could lead to a decline setting in. Warning of this should be provided by the size of the abalone declining, and an increase of flat clean shells in the catch. However, in some situations, where the LML is appropriate and previous fishing pressure was not too great a period of increasing catch and effort might be sustained, although no increase can ever be sustained indefinitely.

We should also expect catch and effort to rise when we have been successful with a management strategy aimed at rebuilding stock levels (Category 5). In this case we would expect the increases to be accompanied by reports of increasing abundance and size of abalone. In this case the proportion of shells that are flat and clean should be falling.

Stable Catch and Effort Trends

Where catch and effort trends are judged to be stable over time; the question to ask is whether they are stable at a high or low level? Is the area stable and productive, or stable but unproductive?

Where the judgment is that an area is stable but unproductive, historic accounts and data, and the observations on the quantity and appearance of abalone can be used to distinguish areas that were once productive from areas that have never been productive.

Every abalone fishery has areas that were productive in the early history of the fishery but were rapidly depleted and failed to recover (Category 1). Anecdotal information of retired divers from the early years of the fishery, historic data and the nature of the shell from these areas can be used to diagnose these areas. These areas often had a particularly large size of maturity, were close to home ports, or in relatively sheltered, or shallow water. For these reasons early fishing pressure focused in on these areas causing rapid overfishing of local brood stocks. These areas offer great promise for the long term increasing of catch levels if reef scale management can rehabilitate them.

Every abalone fishery also has areas that for some reason contain few abalone and have never been productive (Category 8) this might because of lack of suitable habitat, the wrong environmental conditions, or perhaps even because the limited dispersal power of abalone prevented colonization in the first place. In the long term some of these areas might offer scope for enhancing production but in the short term it is probably better to focus management effort on areas with proven production potential.

Variations on this latter category are areas of “stunted” or “shorty” abalone (Category 7). Here the problem is not a lack of abalone but that environmental conditions do not support growth through to the LML. These areas can at least be considered sustainable however suitable long terms aim maybe to increase access to these stocks.

Where the assessment is that catch and effort is stable and productive the third order assessment needed is between areas that are actually in slow decline (Category 3) and those that within the precision of our assessment process are sustainable (Category 6). Here the nature of the shell can be used to distinguish between the two areas.

Where shells are clean and flat the stock is operating at a low level of potential egg production, and in all likelihood future recruitment rates will decline. Extreme caution should be exercised with these stocks (Category 3) and a close watch maintained. The stability of catch and effort in these areas often masks actual declines that the divers will be seeing. The divers should be questioned about whether the size of aggregations and the size of abalone are declining? In all probability they will be, and if management is not improved catch and effort in these areas will begin to decline after some years. Pro-active management in these areas repays immediate dividends.

Where catch and effort trends are stable and the abalone in the catch are fouled, round and high (Category 6) management is about as good as it gets and we have grounds for hoping management is sustainable in these areas. Considering the other areas with demonstrably greater needs we should not rushing to change management in these areas. However, we must be aware that the system we are using is qualitative and relatively imprecise. The state of abalone science is such that there can be no guarantees that even the best managed areas are going to prove sustainable on a time scale measured in decades. However time is on our side in these areas.

Point 3 – Provisionally agree to use a Decision Tree to structure and discipline a reef by reef assessment process of the Western Zone.

Session 4 - Appropriate Environmental Management Responses for each Exploitation Category

In this session the aim is to continue developing and agreed framework for making hard management decisions. The aim is to maintain discussion at a theoretical level and agree on fundamental principles before engaging in the practical business of assessing the reef codes of the western zone and developing reef by reef management proposals.

The previous developed a Decision Tree by which catch and effort trends, the appearance of shell from an area, and historic accounts and data can be used to assess each reef code and place them into 8 Exploitation Categories. In this session we discuss briefly the appropriate management for each of these exploitation categories.

Category 1

These are areas with a stable trend of low catch and effort however historic accounts or data indicate that at some earlier time there was a higher level of productivity. These areas have been over-fished in the past and levels of breeding stock and recruitment have already been reduced to very low levels. A low level of continued fishing will prevent any recovery in these areas. These reefs will be the most depleted in the fishery. Normally this has occurred through a combination of focused fishing pressure (favored home ground and/or sheltered, shallow water) and relatively high size of maturity. The shell from these areas will often be clean and flat at a relatively large size, indicating the catch is comprised of young large abalone.

The immediate aim with these areas should be to rebuild levels of breeding stock. This could be achieved through closure (zero TAC) for some years or imposition of an extremely high LML. Where residual breeding stocks are extremely low or even locally extinct it may prove cost effective to reintroduce breeding stocks with translocations of adults or even reseeding.

Once the breeding stock has been rebuilt and fishing is again considered thought will need to be given to preventing a re-occurrence of the original over-fishing. These reefs will need particular protection through a high LML or Reef Code TAC. The LML or TAC should be set to a level which ensures the catch is principally comprised of shells that are high, rounded and heavily fouled.

Category 2

These are areas where effort and catch is declining over time indicating that stocks are declining through over-fishing. The shell from these areas will normally be clean and flat indicating the catch is primarily newly maturing animals recently emerged from the cryptic habitat. If the decline is not arrested over some years catch and effort will stabilize at some new low level and these areas will move into Category 1.

The immediate priority for these areas should be to stabilize and rebuild levels of breeding stock which can be achieved by increasing LMLs and/or reducing the reef code TAC. The LML or TAC should be moved towards a level which ensures the catch is principally comprised of shells that are high, rounded and heavily fouled.

Cost intensive interventions such as reseeding and translocation are unlikely to be cost effective in these areas because considerable breeding stocks already exist in these areas.

Category 3

In this category of reefs the catch and effort trend will be stable but this masks a declining stock abundance which the divers will probably be aware of even though it is not yet reflected in their catch and effort trends. The tell tale signs of the depletion will be a declining shell size in the catch and a predominance of flat clean shell in the catch. If the stock decline in these areas is not addressed at this stage, the next phase (Category 2) will see effort levels decline as divers recognize their inability to continue taking current catch levels.

These areas should be the focus of immediate proactive management aimed at stabilizing and rebuilding the level of breeding stock on these reefs. These areas will still have good levels of recruitment and can be expected to stabilize rapidly and rebuild productivity if management is improved. Increased LMLs and lower Reef Code TACs could be used to achieve this end.

Cost intensive interventions such as reseeding and translocation are unlikely to be cost effective in these areas because considerable residual breeding stocks already exist in these areas.

Category 4

These are areas with a trend of increasing catch and effort indicating that fishing pressure is increasing. In some rare cases this increase in fishing pressure may be sustainable. Where the catch is principally of high, rounded shells with a good cover of fouling this argument may be correct.

However no increase can be sustained indefinitely and given that there are now few lightly exploited abalone reefs left in any abalone fishery this indicator is normally a warning sign that an area is headed towards Category 3 and Category 2 status. This will certainly be the case where the size of shells is declining and flat clean shells are heavily represented in the catch indicating that pressure is increasing by taking younger, newly maturing abalone.

Where the appearance of shells suggests concern pre-emptive responses should be considered to prevent further increases in fishing pressure. This can be achieved by increasing LMLs and/or reducing the reef code TAC. The LML or TAC should be moved towards a level which ensures the catch is principally comprised of shells that are high, rounded and heavily fouled.

Cost intensive interventions such as reseeding and translocation are unlikely to be cost effective in these areas because considerable residual breeding stocks already exist in these areas.

Category 5

These are areas which have previously been rated as Category 1-4 and which have been the subject of a previous management decision. The unstable trend of rising catch and effort in this case is an indication that the previous management decision is working and breeding stocks and production is increasing. Their improving status should be confirmed by an increasing shell size in the catch, the proportion of high, rounded and fouled shells should also be increasing. The divers should also be observing more an improving cover of abalone across the reef.

No further management action is required in these situations.

Category 6

In these areas catch and effort trends are currently stable catch and effort and the catch is dominated by high round shells with a good cover of fouling. These are the best managed areas and may well be sustainable.

No further management action is required in these situations.

If catches are reduced in other areas by raising LMLs or reducing Reef Code TACs, without reducing the level of the zonal TACs these areas will be forced to take the brunt of transferred fishing pressure. This will push them into category 4. In some cases this may be sustainable, particularly in the short to medium term (1-5 years).

Category 7

This category of reef is currently unproductive but contains stocks of small high round shells with good covering of fouling. These are the stunted stocks which are sustainable because current LMLs preserve a high level of the original breeding biomass.

Reducing LMLs in these areas can increase the sustainable yield from these areas. The high level of breeding biomass in these areas ensures a high level of recruitment from the cryptic habitat in the short to medium term, this will make them robust to fishing pressure for 5-10 years. A regional plan for reef management should be seeking to transfer fishing pressure from categories 1-4 into these areas.

Category 8

These are areas with naturally low levels of productivity and probably should not be the focus of intensive management. This might result from a lack of suitable habitat, the wrong environmental conditions, or perhaps even because the limited dispersal power of abalone prevented colonization in the first place. These areas need to be distinguished from Categories 1 & 7 through the knowledge of divers both retired and current. To some extent the distinction between Categories 7 and 8 is arbitrary because this latter Category often contains some low level of stunted stocks.

In the long term some of these areas might offer scope for enhancing production but in the short term it is probably better to focus management effort on areas with proven production potential.

Putting it Together – The Depletion – Rehabilitation Process

As shown by figure 5 these different reef categories can be considered as forming a gradient of exploited or managed states. From underfished (Category 7) through well managed (Category 6) and recovering (Category 5) to declining (Categories 2-4) and depleted (Category 1). Clearly the purpose of reef management is to move all reefs towards the sustainable productivity typical of Category 5.

Inter-Reef Issues

Much of the discussion so far has treated the different Categories of reef as if they are independent units to be managed in isolation of each other. To a large extent this is the reality of the situation. However, we are all aware that currently these resources are being managed by zonal TACs which means the management of one reef code will have an impact on other reef codes.

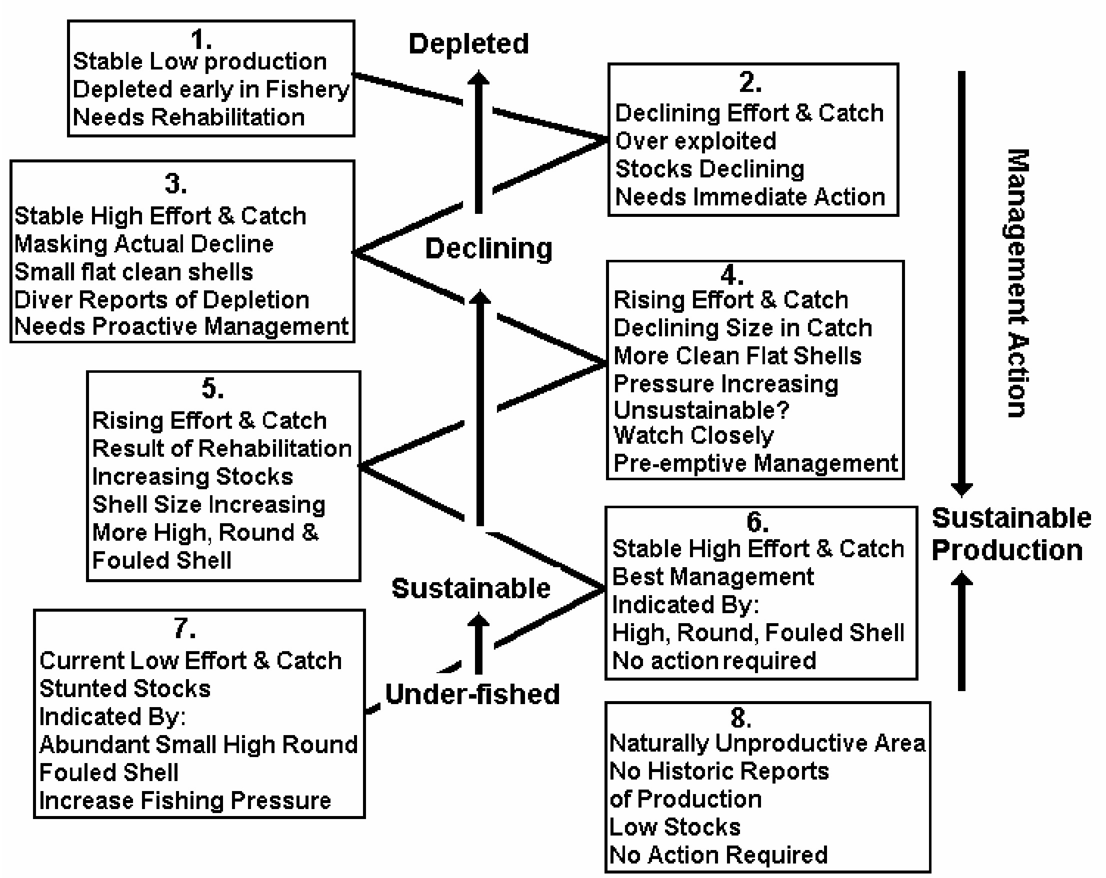

Figure 5. The Depletion – Rehabilitation process linking the different resource status categories.

The fact is that deciding to rebuild the breeding biomass in one area and reducing the catch from that area by increasing LMLs, temporarily closure, or introducing and lowering a reef code TAC will transfer catch and fishing pressure between areas. This must be recognized and addressed in a co-ordinated manner. To the some extent catch could be transferred into Reef Categories 6 & 7 (currently well managed and stunted stocks) but particularly in the case of the Category 6 (currently well managed) fine judgment will be required to ensure that this transfer of catch does not destabilize these areas. In many cases there will be insufficient capacity to absorb this transferred fishing pressure and Zonal TACs will need to be reduced in the short to medium term to allow rebuilding process to take place.

My own judgment of the Western Zone suggests to me that to be entirely certain of stabilizing and rebuilding stocks across the zone the Zonal TAC will need to be reduced for some years.

Session 5 - Profiling Catch & Effort Histories of the Western Zone Reefs

During this session the workshop will review through existing information on each of the Western Zones Reef Codes with the aim of categorizing each area. The meeting will have three main sources of information to review:

1. Statistical records of catch and effort.
2. Historical accounts collected from retired divers.
3. Observations made by current divers.

The criteria contained in the decision tree outlined in figure 4 will be applied to the information about each reef code and the rationale for each categorization will be documented. The categorization of each reef code provides the context and priority for making management decisions tailored to the stock status of each area.

Session 6 - Environmental Management Decision Making Matrices

Having categorized each reef code and before proceeding direct to discussing the management of each reef code it is necessary to introduce another decision making tool – the Decision Making Matrix.

Because of competing interests and motivations it is always extremely difficult for an Industry Association like WADA to make hard decisions. Any hard management decision will impact some people more than others which will cause tension within the association and make it hard to maintain unity of purpose. Having made a decision it then becomes hard to hold to that decision and tensions tend to escalate as one faction or another seeks to have the original decision reviewed, modified or over turned.

With the aim of controlling these natural tensions the purpose of the Decision Making Tree (Figure 4) is to make the process of resource assessment transparent and disciplined. In the same way Decision Making Matrices (Figure 6) created and agreed for each reef code can be used to make management decisions transparent, explicit and predictable.

Decision Making Matrices

A Decision Matrix should be designed to make every aspect of the management process explicit, transparent and predictable. The basic aim is to lay out the agreed decision rules by which management will occur in the future so that all stakeholders can engage and debate the management process, but also so they can anticipate what future management decisions will be made.

In this situation a Decision Matrix would be designed and agreed by WADA for each Reef Code being managed. Each Decision Matrix will be tailored to the assessed status of each reef code.

Figure 6 provides an illustrative example of a Decision Making Matrix created for an imaginary reef code # 345.

Reef Code	345	Category:	2 - Overexploited, declining stocks, requires immediate management action				
		Objective:	A.Stabilise & Rebuild Breeding Stocks				
			B. Rebuild catch and effort back to level of 1989 (25t/annum)				
			Different Annual Scenarios				
Lines of Evidence		Effort	Continued Decline	Stable	Stable	Increasing	Back to 1989 Level
		Catch	Continued Decline	Stable	Stable	Increasing	Back to 1989 Level
		Appearance of Shell	Flat Clean	Flat Clean	Inc. % Round, Hi & Foul	Inc. % Round, Hi & Foul	All Round, Hi & Foul
		Shell Size	Decreasing	No Change	Increasing	Increasing	Increasing
		Diver Accounts	Negative	Negative	Positive	Positive	Positive
Management Decisions		LML	Increase Another 2mm	Increase Another 2mm	No Change	No Change	No Change
		Reef TAC	Decrease Another 15%	No Change	No Change	No Change	Increase 5%

Figure 6. An illustrative Decision Making Matrix.

This imaginary reef has been assessed as Category 2 – that is it is overexploited with declining stocks as evidenced by a declining trend of catch and effort, flat clean shells of decreasing size and negative reports from divers. A decision has been made to implement and initial LML increase and to reduce the TAC for the reef code by 15%. This Decision Making Matrix has been agreed as the basis of the future management strategy for this reef and will be used annually to review management.

The Decision Making Matrix contains:

1. A statement of the assessed status of the reef code.
2. The objective of long term management: rebuild breeding biomass and, effort and catch to the level of 1989 which on the basis of historic statistics appears to be a reasonable sustainable level.
3. The Lines of Evidence (stock indicators) that will be used each year to evaluate the progress of management: Effort and Catch Trends, Shell Appearance and Size, and the anecdotal accounts of the divers.
4. The various scenarios (combinations of stock indicators) that it is anticipated could be encountered from year to year.
5. The range of management actions that will be used to manage the stock: LML and reef code TAC adjustments.
6. The pre-agreed management actions that will be taken in each expected scenario.

Session 7 & 8 - Designing Decision Making Matrices for Western Zone Abalone.

It is not anticipated that time and energy reserves will permit much progress in designing Decision Making Matrices within this workshop. The main aim of this workshop is to introduce the concept and uses of these matrices and decision rules. Depending on the time remaining this aim will be consolidated by beginning the design of matrices for one, or several, of the reef codes assessed as being of highest priority for management action. These discussions will provide experience with these concepts and provide feedback so that draft matrices could be prepared out of session, for finalization and agreement at a future WADA workshop.

Session 9 - Summary & Reaffirmation of Decisions made during the Workshop

The final session will be used to summarize the material covered during the workshop and to re-affirm decisions made by the group.

C

Developing Environmental Assessment & Management Decision Making Skills

Course Work Book

A Course Developed for the

Western Abalone Divers Association

By

Assoc. Prof. Jeremy D. Prince

Murdoch University

August 2003.

Biospherics P/L

062-458-093

Session Plan

Day 1 – Introduction to Basic Theory of Reef Scale Environmental Management of Abalone Reefs

Morning Session

Session 1 - Introduction to Training Workshop & Management of Localized Marine Resources

Lunch

Session 2 - Reef Assessment

Afternoon Session

Session 3 - Categorizing Exploitation Histories to Assess Status of Abalone Reefs

Day 2

Morning Session

Session 4 - Appropriate Environmental Management for each Exploitation Category

Lunch

Session 5 - Profiling Catch & Effort Histories of the Western Zone Reefs

Afternoon Session

Session 6 - Environmental Management Decision Making Matrices

Day 3

Morning Session

Session 7 - Designing Decision Making Matrix for Western Zone Abalone.

Lunch

Session 8 - Designing Decision Making Matrix for Western Zone Abalone continued …..

Afternoon Session

Session 9 - Summary & Reaffirmation of Decisions made during the Workshop

Session 1

Introduction to the Management of Localized Marine Resources

(Competency: RTD6502A/01/02 & SFICOMP502A)

1. What are the three factors which make current management plans and strategies for localized marine resources problematic?

A) …………………………………………………………………………………

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B) …………………………………………………………………………………

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C) …………………………………………………………………………………

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2. What is meant by the Tragedy of Scale?

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3. What change is needed to existing management plans and strategies?

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Session 2

Reef Assessment

(Competency: RTD6502A/01/02 & SFICOMP502A)

4. Why are traditional forms of stock assessment problematic for abalone stocks?

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5. What are the two principle types of information proposed as an alternative basis for assessing the status of abalone populations in differing reef codes?

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B) …………………………………………………………………………………

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Session 3

Categorising Exploitation Histories to Assess the Status of Abalone Reefs (Competency: RTD6502A/01/02 & SFICOMP502A)

6. What is the purpose of using a Decision Tree to assess reef codes?

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7. What are the two primary criteria used in the Decision Tree?

A) ………………………………………………………………………………………

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B) ………………………………………………………………………………………

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8. What are the four secondary criteria used in the Decision Tree?

A) ………………………………………………………………………………………

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B) ………………………………………………………………………………………

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C) ………………………………………………………………………………………

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D) ………………………………………………………………………………………

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Session 4

Appropriate Environmental Management Responses for each Exploitation Category (Competency: RTD6502A/02/03 & SFICOMP502A)

9. What are the main characteristics of the eight exploitation categories used to assess reef codes?

Category 1 ……………………………………………………………………………

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Category 2 ……………………………………………………………………………

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Category 3 ……………………………………………………………………………

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Category 4 ……………………………………………………………………………

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Category 5 ……………………………………………………………………………

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Category 6 ……………………………………………………………………………

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Category 7 ……………………………………………………………………………

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Category 8 ……………………………………………………………………………

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Session 5

Profiling Catch & Effort Histories of the Western Zone Reefs

(Competency: RTD6502A/02/03 & SFICOMP502A)

10. Using the profiles of catch and effort histories provide a Western Zone example of each of the eight exploitation categories?

Category 1 ……………………………………………………………………………

Category 2 ……………………………………………………………………………

Category 3 ……………………………………………………………………………

Category 4 ……………………………………………………………………………

Category 5 ……………………………………………………………………………

Category 6 ……………………………………………………………………………

Category 7 ……………………………………………………………………………

Category 8 ……………………………………………………………………………

Session 6

Environmental Management Decision Making Matrices

(Competency: RTD6502A/02/03 & SFICOMP502A)

11. What is the purpose of using a Environmental Decision Making Matrix?

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12. What are the six components of an Environmental Decision Making Matrix?

Component 1 …………………………………………………………………………

Component 2 …………………………………………………………………………

Component 3 …………………………………………………………………………

Category 4 ……………………………………………………………………………

Category 5 ……………………………………………………………………………

Category 6 ……………………………………………………………………………

Session 7 & 8

Designing Decision Making Matrices for Western Zone Abalone. (Competency: RTD6502A/02/03 & SFICOMP502A)

13. On the attached blank matrix draft a Decision Matrix for a Western Zone Reef Code of your choice.

Reef Code:	Category:					
	Objective:					
		Different Annual Scenarios				
Lines of Evidence	Effort					
	Catch					
	Appearance of Shell					
	Shell Size					
	Diver Accounts					
Management Decisions	LML					
	Reef TAC					

D

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Topics

- Functional Anatomy
- Life cycle processes
  - Reproduction
    - Spawning
    - Larval dispersal & population recruitment
  - Feeding and growth
  - Ecological interactions
    - Mortality - predators, diseases & parasites
    - Competition

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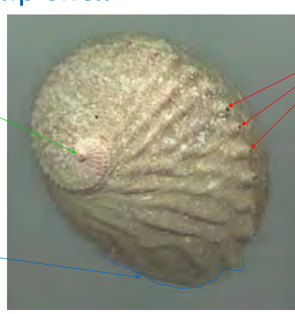
Blacklip shell



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Fractal representation of helical shell

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Other Victorian species

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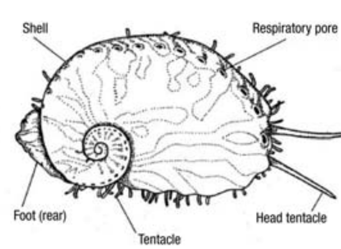
Morphology



Source: R Fallu, All About Abalone, Rural Press, 1994

Downloaded from www.disease-watch.com/documents/CD/index/images/ab-Dorsal view of anatomy of abalone

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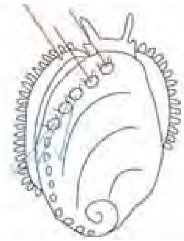
Water flow in & out of tremata



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Calcium carbonate shell

The interlocking brickwork of microscopic, limestone-like crystals and thin sheets of proteins makes this shell 3,000-times stronger than the crystals alone, while the precision of its biological "nanofabrication" (control of structure on an ultra-small scale) far exceeds the present capabilities of human engineering

Recent interest in commercial applications

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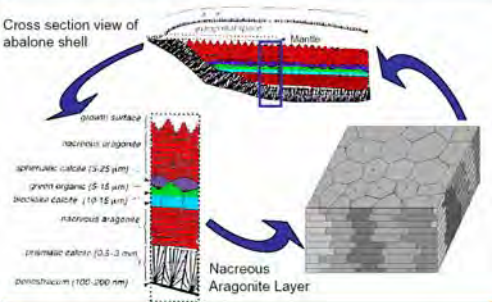
‡ Image source: Screw Dislocations and Spiral Growth in Abalone Shell Nacre
Alexander Epstein
Princeton University, Solid State and Materials Chemistry REU 2005, August 5

Structure of the Abalone Shell



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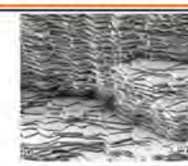
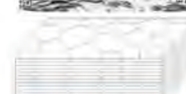
Structure and Properties of Nacre‡

1. The nacreous layer of sea-shells is composed of 95 vol.% $CaCO_3$, and 5% organic matrix (proteins, poly-saccharides, and water).
2. Each aragonite crystal is a polygonal platelet, about 0.5 μm thick and 5-8 μm wide. The platelets are close-packed and organized into a layered structure. The organic matrix, about 20 nm thick, separates adjacent platelets.
3. The work-of-fracture of nacre is 3 orders of magnitude higher than monolithic $CaCO_3$. The fracture toughness is comparable to that of modern ceramics.





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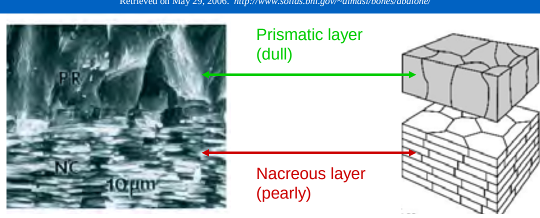
Images after: E. DiMasi, J. L. Jordan-Sweet , & M. Sarikaya 2000. *Orientation of Microcrystals in Abalone Shell near the Nacre-Prismatic Boundary.*
Retrieved on May 29, 2006. *http://www.solids.bnl.gov/~dimasi/bones/abalone/*



The prismatic and nacreous layers have different optical properties due to differences in crystal habit. The prismatic layer (composed mostly of blocky prisms of calcite or aragonite) tends to be weakly translucent to opaque.

The nacreous layer (composed mostly of plate-like tablets of aragonite), is shiny, translucent and often very colourful.

The smooth surface of the nacreous layer allows mantle tissue to slide against the shell without being damaged.

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Screw Dislocation Theory ‡

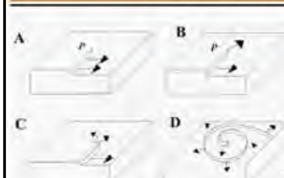

Figure 1

Figure 1:

Screw dislocation leading to spiral growth.

Figure 2:

Growth Step, the center region will be the nucleus for crystallization as well as the region where etching starts.

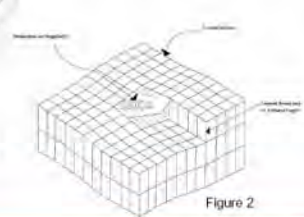

Figure 2

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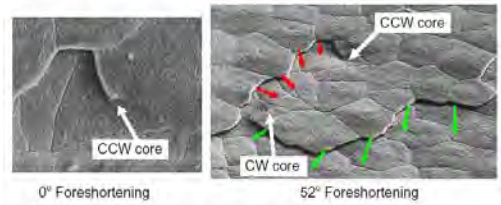
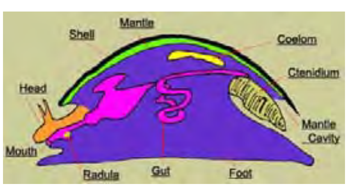
Spiral Growth of Nacre Platelets ‡



A center-singularity core (left) shows the emergent layer rising counterclockwise. The growth step that starts at this core extends out as the growth front for corresponding counterclockwise spiral sheet growth (right). Spiral growth domains can intersect, at right with a clockwise domain originating from a clockwise core.

Anatomy – lateral (side) view



Earth Sciences 089G: Lecture Resources
http://instruct.uwo.ca/earth-sci/089g/motherofpearl.ppt

Anatomy – dorsal view

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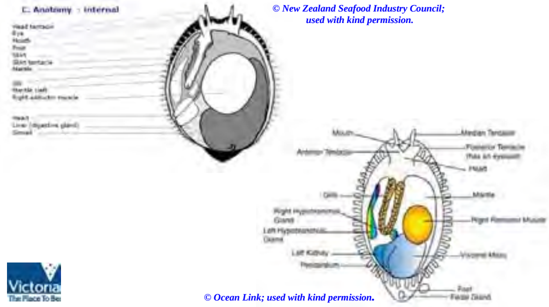

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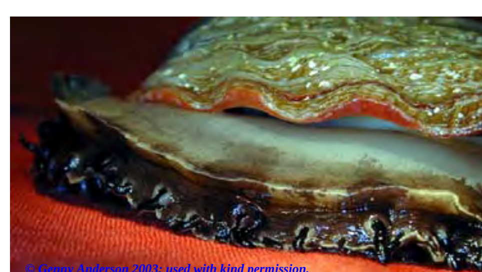

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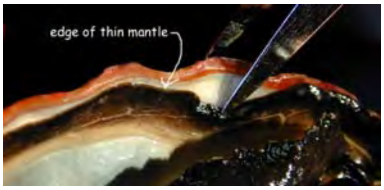

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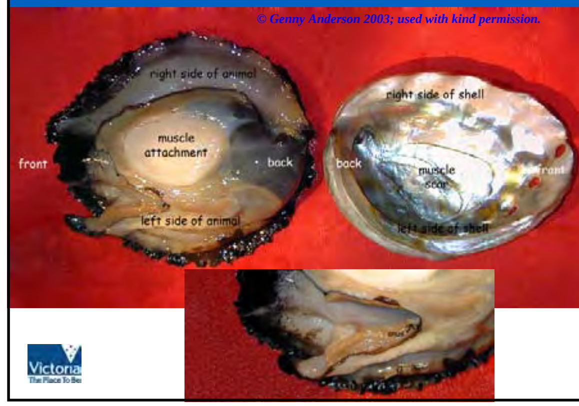

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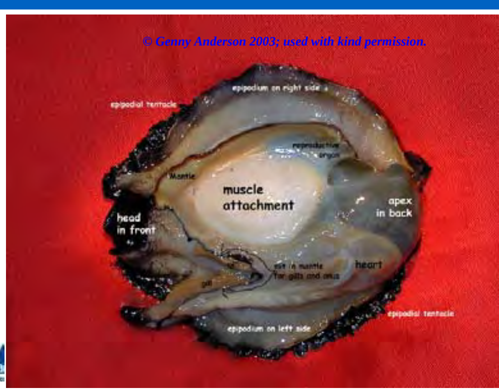

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Separate sexes For permission, contact

Female ovary | Male testis

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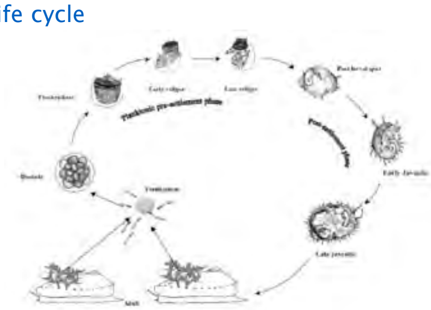
Life cycle



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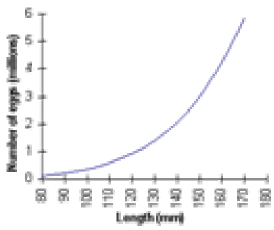
Spawning (green eggs & sperm)

- Size and shape of the gonad are the only readily available indicators of the stage of gonad development
- Eggs have own yolk sac = energy reserves
- Foot acts as an energy storage organ for glycogen
- Readiness or condition depends on Effective Accumulated Temp (EAT)
- Spawning occurs mostly during the summer months and multiple events during one season are possible.
  - Cues elevated water temperature
  - high wave action
  - photoperiod
  - lunar cycle, and
  - presence of abalone gametes
- Some species (*H. scalaris*, *H. roei*) spawn throughout the year.
- Spent adults can be difficult to sex

Egg production v. length (weight)



Role of weather

- when conditions are relatively constant and mild, abalone will serially spawn during the reproductive season
- if peak stress events occur, in the form of extreme weather, all abalone near condition will spawn.

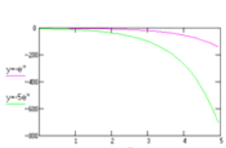
Adverse environmental conditions

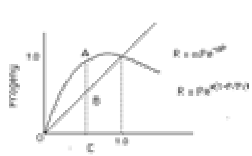
Atresia – female resorb their eggs presumably to ensure their own survival rather than attempt to produce off-spring

Gonad Index Scale

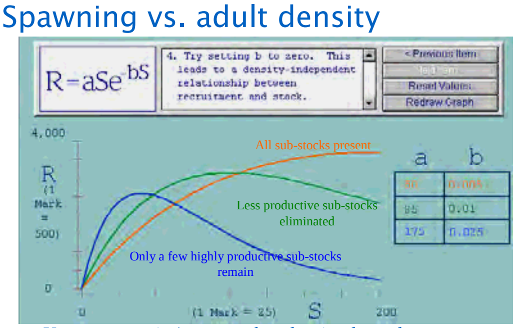
Broadcast spawning

- Eggs ejected into water via respiratory pores
- This triggers males to eject sperm in the same way
- Fertilisation takes place in the water column
- Rates dependent on proximity among aggregations





Spawning vs. adult density



Key: a = recruits/spawner; b = density dependence

Adapted from: Montgomery, I & Hood, G. 2000. Quantitative training in fisheries. Software Ver. 3.00. FRDC & IME (Syd Uni.)

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Egg release (several million)

Downloaded from www.lib.noaa.gov/.../abalone.files/fsdyh003.gif

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Sperm release (zillions)

Abalone spawning article in *Science* - a landmark paper by Dr. Dan Morse. The cover shows an abalone spawning (it is a male as the spawn is beige). Cover photo of Science magazine by Larry Jon Friesen.

After cover of Science©, 15 April 1977, downloaded from http:// www.biosbcc.net

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Human comparison

- Unlike men, who produce new sperm daily (400,000 per ejaculation) throughout most of their lifetime (12 trillion sperm!), women are born with a finite number of undeveloped eggs -- around one to two million -- in their ovaries.
- When women reach puberty and start menstruating, only about 300,000 immature egg cells, or follicles, remain. Some of these begin to develop with each monthly cycle, but during this time, only one follicle matures into an ovum (egg) and bursts from an ovary into the fallopian tubes, initiating ovulation. Through a process known as atresia, many of the follicles that don't develop into mature egg cells degenerate. As a result, only a few hundred remain at menopause, which usually begins at around forty-five or fifty years of age; however, because of the hormonal changes that accompany menopause, the remaining follicles are unlikely to mature and become viable eggs.
- Say, (50-15) x 12 = only 420 eggs!

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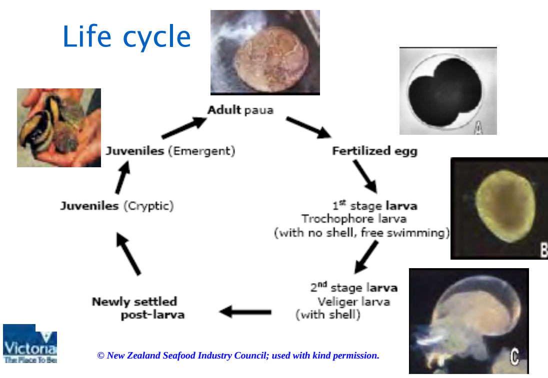
Life cycle



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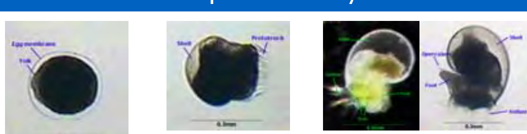
Lifespan 15-20 yrs



Fertilised egg — 24 h Trochophore — 48 h Veliger (180°)

2-3 weeks Spat — 1-3 months Juvenile — 4+ yrs Mature adult

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Larval distribution & settlement

- Generally localised, limiting ability to re-populate depleted reefs
  - vulnerability to water movement can be rapidly 'diluted'
  - concentration of densities in eddies and beneath kelp canopy critical
  - will swim upwards off unsuitable surfaces
  - once on suitable bottom lose ability to swim so start to crawl & graze
- Settle mostly on encrusting pink coralline algal plates
  - contains an attractant (GABA)
  - growth form of coralline important e.g. smooth v. warty
  - slime from large sub-adults and adults may also play a role (peptides & bacteria = attr. or food) wrt. threshold densities
  - high post settlement mortalities

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Lifespan

- Commercial species are long lived and slow growing
- 15 and 30 mm in their first year
- 100 mm in about 3-6 years according to species and locality
- Large specimens are estimated to be between 10 to 50 years old.

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Coralline Algae

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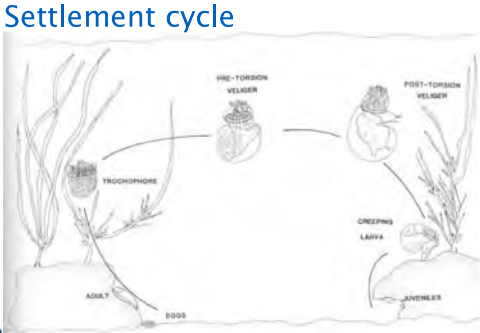
Settlement cycle



After McShane, P.E. 1992. In Abalone of the World. Blackwell: Oxford p.123

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Spat on CCA

Image: L. Tong

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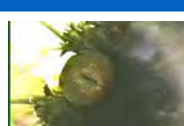
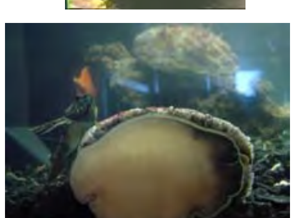
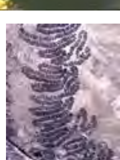
Feeding







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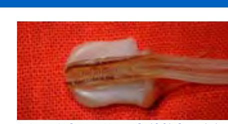
Feeding mechanism



Mouth showing teeth and rasp

Cartilage blocks ‘teeth’ top & radula with real teeth = rasp

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Radula

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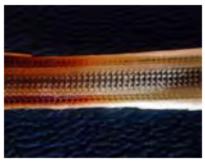

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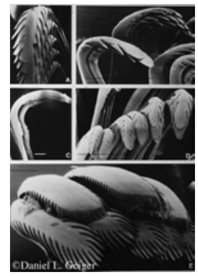
Radula



Used with kind permission of D. Geiger

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Food preferences

- Consume about 5% of body weight daily
- Over a 12 month period abalone typically may consume 45-80% red algae, 7-15% brown algae and <5% green algae.
- Depends on availability & water movement = drift
- Clear preference for red algae - higher protein content ~ 20% (some reds have toxic compounds)
- Brown algae lower protein = 12-15% and many in Oz e.g. crayweed, are rich in polyphenolics = unpalatable
- Preferences similar between blacklip & greenlip
- Small juveniles (smaller mouths) graze on microscopic plants (turf) or diatoms (and the substances they exude) and ingest and utilise a range of bacteria (including those growing on abalone mucous) and microscopic organisms (sometimes toxic algae called dinoflagellates).

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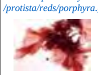
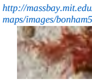
Food seaweed

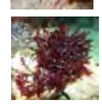
www.ucmp.berkeley.edu /protista/reds/porphyra.gif

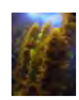


www.cryptogamicbotany.com/images/oa_rhodo/Dasya_baillouviana_01_08_05_C_353 x550.jpg

http://massbay.mit.edu/exoticspecies/exoticmaps/images/bonham5.jpg







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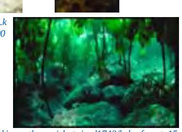
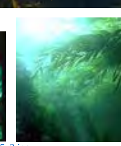
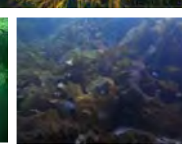
www.animalls.co.kr/img_gds/000000 1501_1.jpg







www.ianskipworth.com/photo/pcd1742/kelp_forest_15_2.jpg

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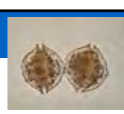
Unpalatable & toxic algae



www.nsf.gov/news/mmg/media/images/Alexandrium_tam2_f1.jpg

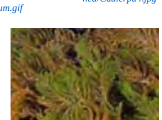
www.uio.no/miljoforum/m_alge/img/alexandrium.gif

www.science.org.au/scientists/images/sj7.jpg

http://swr.nmfs.noaa.gov/hcd/Caulerpa4.jpg

www.sb-roscoff.fr /Enseignement/img/_PC.jpg

www.ifremer.fr/francais/produits/thau/alexandrium.gif



www.scuba-equipment-usa.com/marine/JUN04/thumbs/Caulerpa_flexilis.jpg

www.niwa.cri.nz/ncabb/abb/2002-01/green1_large.jpg

www.bilyap.com.tr/images/sra169.jpg

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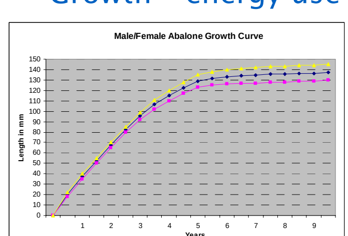
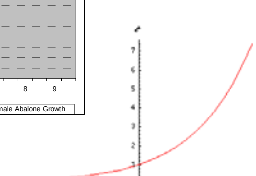
Growth – energy use





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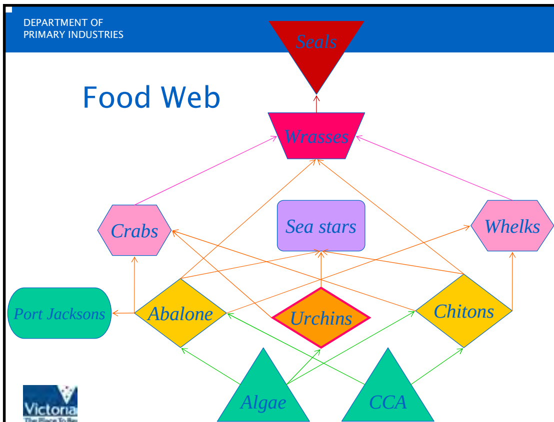
Food Web



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Abalone are habitat responders

Urchins are habitat modifiers = keystone?

No obvious higher order predators dependent on abalone

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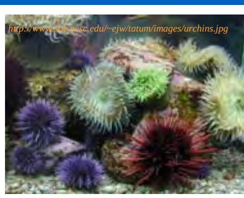
Habitat Competitors



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Mortality

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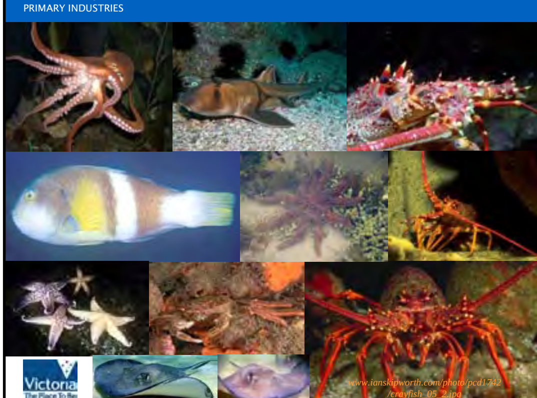

Predators

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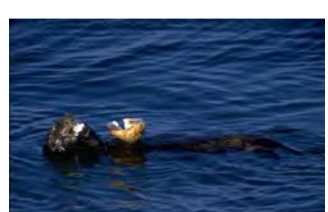
Sea otters

- Central California



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Down loaded from <donb.furfly.net/photo_cd/f/b47.html>

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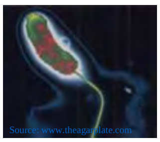
Parasites & diseases

- Virus = *Vibrio*
- Bacterium = Rickettsia
- Protozoan = *Perkinsus olseni*
- Polychaete worm =*Terebrasabella heterounicinata*
- Carnivorous snail = *Thais*
- Sponge = *Cliona celata*

http://www.sierraclubbooks.ucpress.edu/books/pages/8355/115.html



Shell Parasites

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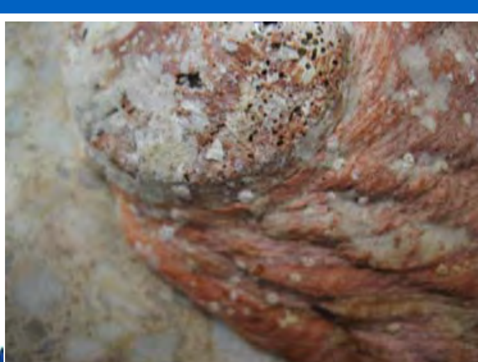
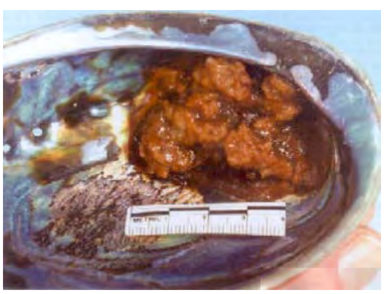


Mudworm blisters (*Polydora websteri*)

Shell lesions (fungi)



Foot disease

Tinea pedis

Perkinsus olseni infection in greenlip

Because this parasite can survive freezing (-60 °C) in abalone tissue for 197 days, its potential for being spread is high in relation to processing plants.

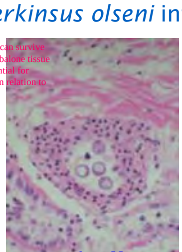


Image: G Burreson

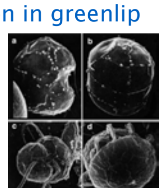


Image: D. Callinan

Source: www.disease-watch.com.

Herfort, A. (2004). *Aquatic Animal Diseases Significant to Australia: Identification Field Guide. Australian Government Department of Agriculture, Fisheries and Forestry. Canberra.*

Withering syndrome

Clinical signs of disease in an infected animal

- atrophy of the foot muscle
- wasting of body mass
- high predation

Source: www.disease-watch.com.

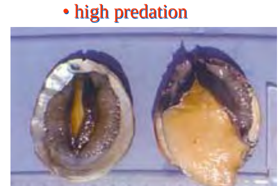


Image: J. Moore.

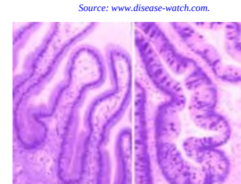


Image: J. Moore.

- **Disease agent**
- Withering syndrome is caused by the intracellular bacterium *Candidatus* Xenohaliotis californiensis of the family Rickettsiaceae.

Herfort, A. (2004). *Aquatic Animal Diseases Significant to Australia: Identification Field Guide. Australian Government Department of Agriculture, Fisheries and Forestry. Canberra.*

Herpes-like virus

- Highly virulent.
- Mortality from ganglioneuritis within 4 days of infection.
- Transmitted via water column.
- Withstands freezing.

Cultured Haliotis laevigata

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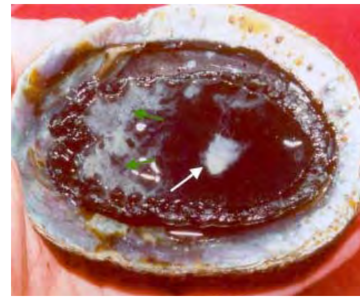
Pustular lesion from knife wound



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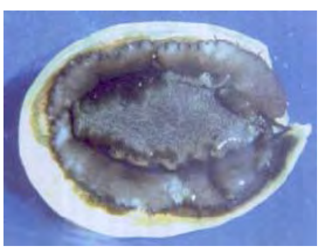
Haplosporidosis (white lesions on skirt)



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VADA ABALONE SURVEY – 18/07/2003 – 20/07/2003
Catch Reef Code 18.9 East.

Vessel details:
Make - Steber
LOA – 14.4m
HP- 2x450 Diesle

Present
Niel Blunden – Skipper
Wayne – Deck Hand
Divers:
  Peter Johnson
  Toby Hoskins
  Lou Panetti
  John Purdie
Steve Michael – Observer

Day 1: 18/07/03
Depart Port Albert @ 0900
@1157 Location #1 / 38 44.035 S 146 49.390 E
@1533 Location #8 / 38 39.124 S 146 59.045 E
Return Port Albert @ 1730
No abalone located.
Reef locations yielded an abundance of sea life with varied relief. Predominance of sponge on honeycombed sandstone/sand patches.

Day 2:19/07/03
Depart Port Albert @ 0745
@ 0945 Location #1 / 38 38.163 S 146 59 .347 E
@ 1552 Location #7 / 38 27.057 S 147 07 .980 E
Anchor @ 1800.
10 abalone located.
Reef locations generally yielded medium sea life with more sand patches. Sandstone shelves with *Ecklonia radiata* and some bubble weed. Visibility was poor/water borne sediment.

Day 3: 20/07/03
@ 0812 Location #1 / 38 12.314 S 147 26.600 E
@ 1330 Location #7 / 38 29.310 S 147 05 601 E

Vada Survey of abalone Reef. Reef code 18.9 East.
Sample ID (1=present)

	18/07/2003								19/07/2003							20/07/2003						
Site details	Site#01	Site#02	Site#03	Site#04	Site#05	Site#06	Site#07	site#8	Site#01	Site#02	Site#03	Site#04	Site#05	Site#06	Site#07	site#01	site#02	site#03	site#04	site#05	site#06	site#07
Phylum Phaeophyta													abort									
Brown algae, brown seaweeds																						
Ecklonia radiata	1	1	1	1			1	1	1	1	1	1		1	1	1	1	1	1	1	1	1
Sargassum sp.								1	1	1	1			1		1					1	
Zonaria turneriana								1	1	1				1		1						
Phylum Rhodophyta																						
Red algae, Red seaweeds																						
Plocamium sp.			1				1	1	1	1	1						1	1			1	
Filamentous red algae								1	1	1	1						1	1			1	
Coralline red algae	1		1		1			1	1	1	1			1		1			1		1	
Phylum Porifera																						
Sponges																						
Mycale mirabilis	1		1		1			1	1	1	1	1		1	1	1			1	1	1	1
Spongia sp	1		1		1			1	1	1	1	1		1	1	1	1	1	1	1	1	1
Dendrilla rosea			1		1			1	1	1	1			1		1			1	1	1	
Thorecta sp.								1	1	1	1			1		1				1	1	
Sponges attached with Bryozoans.								1	1	1	1			1	1	1				1	1	
Phylum Cnidaria																						
Gymnangium ascidioides	1		1					1		1	1	1									1	1
Other samples unable to ID			1		1					1		1										1
Order Pennatulacea																						
Sea pens																						
Sarcoptilus grandis										1						1				1		1
Phylum Bryozoa																						
Bugularia dissimilis	1	1					1	1		1						1						1
Phylum Chordata																						
Family Pyuridae (Sea tulip)																						
Pyura australis							1	1														
Pyura gibbosa							1	1														
Family Styelidae																						
Polycarpa clavata							1															
Order Alcyonacea																						
Corals Gorgonians																						
Mopsella klunszingeri					1			1														
Phylum Mollusca (Bivalves)																						
Electroma georgiana							1	1	1	1	1			1	1	1	1	1	1	1	1	1
Pecten fumatus (King scallop)	1	1		1	1				1			1								1		1
Lima lima	1	1	1	1																1		
Phylum Echinodermata																						
(Sea Urchins)																						
Centrostephanus rodgersii	1	1	1						1	1	1			1	1		1	1	1		1	
Heliocidaris erythrogramma	1	1	1						1	1	1			1	1		1	1	1		1	
Family Comasteridae																						
(Feather stars)																						
Cenolia trichoptera	1								1		1				1	1	1	1	1	1	1	
Comatula purpurea			1				1		1		1				1	1	1	1	1	1	1	
Family Oreasteridae																						
Nectria ocellata			1																			
																				1		
Family Ophiotrichidae																						
Ophiothrix caespitosa (Brittle stars)	1		1				1		1		1					1	1	1	1	1	1	1
Ophiothrix spongicola							1		1		1					1			1	1	1	
Sparsely Spotted Ray											1						1					
Red Cod																						
Common Sea dragon										1												1
Barber Perch				1	1		1	1	1		1				1	1	1	1	1	1	1	1
Magpie Perch										1						1				1		1
Blue Throat Wrasse									1	1								1		1		
Wrasse (genral)					1		1	1	1	1					1	1	1	1				
Sweep (general)										1						1	1					
Crayfish - Rock Lobster	1	1	1	1	1					1						1					1	
Hermit Crab										1						1						
Crab (general)				1	1					1						1	1	1				
Abalone									1	1	1							1			1	

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Assessment of abalone fishing potential in the Julia Bank region of western Victoria

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Assessment of abalone fishing potential in the Julia Bank region of western Victoria

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Executive Summary

The region known as Julia Bank located along the coast of western Victoria between Port Fairy and Portland Bay is a complex of reefs that has seldom been fished for abalone during the past two decades. Perceptions that abalone populations on these reefs are stunted and atypically patchy are among reasons proffered by industry for the lack of fishing in this region.

Recent quota reductions in the Western Zone fishery and attempts to implement a more planned pattern of sustainable fishing effort throughout have resulted in industry no longer having the luxury of leaving potential stocks un-accessed. In response to this need, surveys of blacklip and greenlip abalone populations were conducted by commercial abalone divers in conjunction with government fisheries agency personnel and scientific divers to determine whether or not Julia Bank abalone should be classed as stunted and to obtain information about their fishing potential at a reduced size limit.

The small proportion of blacklip abalone larger than the legal minimum length of 120mm among populations sampled on Julia Bank given the negligible catch history for this region is *prima facie* evidence that these stocks are stunted. Reducing the LML to 105mm would provide divers with access to half to two-thirds of the population. At a LML of 110mm 40% of blacklip abalone 90mm and larger would be available for capture and about half the mature biomass would be conserved.

In contrast, amongst greenlip abalone about half are available for capture at the current LML of 130mm and a reduction of 5mm would allow 60% to be fished but reduce the protection of mature biomass to 25%. Consequently, it would be problematic to classify Julia Bank greenlip stocks as stunted.

A recommendation that the LML for blacklip abalone be reduced to 110mm seems reasonable, especially when considering that abundance of this species within the study area was not high. Reducing the LML for greenlip abalone to 125mm in conjunction the introduction of an upper size limit of 145mm on Julia Bank and raising the LML to 135mm for greenlip abalone elsewhere within the Western Zone should provide overall protection of 50% of the mature biomass. This strategy would be consistent with resource conservation objectives espoused by biologists who have studied greenlip abalone populations extensively.

Fishing mortality rates at the prevailing size limits will depend on growth rates among pre-recruits and fishing intensity. Consequently, no quantitative advice based on this study can be provided about sustainable catch levels until growth and abundance have been monitoring during several years of conservative fishing.

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Introduction

Legal minimum lengths (LMLs) constitute one of the main management tools for limiting fishing mortality among Victorian abalone resources (Fisheries Victoria). The use of LMLs has been a traditional management strategy to protect the recruitment process of fish populations generally (Hillborn and Walters 1992) and in particular, Prince and Guzman del Próo (1993) have stressed the need for conservative LMLs to protect abalone breeding stock. However, conservative size limits applied generically along expansive stretches of the southern and central Californian coastline were insufficient to prevent stock collapses among several species (see Parker et al. 1992 and Tegner et al. 1989).

In theory, fast-growing abalone populations, whose maximum meat yield may precede reproductive maturity, require protection with larger size limits, whereas so-called stunted populations can be sustainably harvested at smaller LMLs without compromising egg production (McShane 1992). The situation in reality is more complex with influences from environmental and habitat factors affecting recruitment. Nonetheless, high variability in growth and size at maturity repudiates the one-size-fits all approach to setting minimum sizes for capture.

Uniform LMLs, presumptive of uniform growth rates, have the disadvantage of prohibiting divers' access to areas supporting populations of slow-growing abalone whilst leaving fast-growing abalone vulnerable to recruitment over-fishing (Troynikov and Gorfine 1998). Different LMLs already exist at a regional scale within the different management zones of the Victorian abalone fishery (Fisheries Victoria 2002), but these fall well short of matching the spatial variability in growth and size at maturity among populations. Areas that have been labelled as slower-growing or stunted, have generally been identified as such based on anecdotal information rather than biological assessments.

Although, stunted is a widely used term when discussing apparently slow-growing abalone populations, its usage is often without definition. Use of the term should be restricted to those populations that have relatively low expected maximum shell lengths rather than slow growth rates *per se*. It is important to differentiate truly stunted populations from those whose production is limited by growth over-fishing. This implies that stunting arises from some limitation to growth (Wells and Mulvay 1995), mediated for instance by nutrition when food availability is limited or by energy expenditure when parasitic organisms stimulate abalone to engage in substantial shell repair (Grindley et al. 1998, McDiarmid et al. 2004).

Wells and Mulvay (1995) studied commercially exploited greenlip abalone populations in Western Australia that industry classified as occupying 'good' and 'bad' fishing areas, the latter term being a euphemism for stunted. They found that the 'bad' areas had only 5% to 16% of their populations larger than the LML compared with 31% to 51% in areas classed as good. The smallest proportion of legal sized abalone in an area classed as good was 31%. Size at maturity did not vary between good and bad areas, however mature abalone in bad areas were less fecund per unit length.

Hooker et al 1997 studied abalone (*H. iris*) growth in the Leigh Marine Reserve, New Zealand, over a 6–year period following two decades of protection from fishing. Their study showed that the abalone grew rapidly to 80mm over three years then slowed abruptly to the extent that few were above the LML of 125mm that prevailed outside the Reserve.

It is reasonable to surmise that reef specific rather than generic size limits offer better protection of abalone populations subject to sustained fishing pressure. Consequently, those populations where environmental conditions limit the average maximum shell length are best fished at lower size limits provided output is also controlled.

The region known as Julia Bank located along the coast of western Victoria between Port Fairy and Portland Bay is a complex of reefs that has seldom been fished for abalone during the past two decades. Perceptions that abalone populations on these reefs are stunted and atypically patchy are among reasons proffered by industry for the lack of fishing in this region. Previous surveys conducted during 1972, 1973, 1987 and 1998 on populations within Portland Bay showed that greenlip abalone on these reef areas were abundant but mostly below the LML of 130mm (Gorfine and Dixon 2000a).

Although Victorian greenlip abalone populations are at the easternmost limit of their distribution and consequently tend to be fragmented and less resilient to fishing mortality, stock depletion caused by overfishing has been largely restricted to the Port Phillip Region and adjacent coastal reefs in the Central Zone and has not an issue in the Western Zone. Specific restrictions on access to greenlip abalone introduced during the early 1990s and pursuant recommendations in the Victorian Abalone Fishery Management Plan for a separate greenlip abalone total allowable catch set at zero were generic responses to the poor state of the resource in geographically specific parts of the Central Zone. Expediency and low catch quantities motivated selection of a generalised approach in lieu of something more spatially explicit.

Amendments to Victorian fisheries legislation in 2005 provides for separate quota management arrangements for blacklip and greenlip abalone for the first time. Coupled with the shift towards more formalised reef scale management during the past few years, these amendments present an opportunity for a more strategic approach to the harvesting of greenlip abalone stocks.

Recent quota reductions in the Western Zone abalone fishery and attempts to implement a more planned pattern of sustainable fishing effort throughout mean that industry no longer has the luxury of leaving potential stocks un-accessed. In response to this need, exploratory surveys of blacklip and greenlip abalone populations were conducted by commercial abalone divers in conjunction with government fisheries agency personnel and scientific divers to determine whether Julia Bank abalone populations should be classed as stunted and to obtain information about their sustainable fishing potential at reduced size limits.

Material and Methods

Field sampling

The surveys were conducted within the Julia Bank catch reporting reef code (Reef Code 2.14) bounded by lines running to seaward from the shore at S38 17.199 E141 38.905 and S38 20.436 E142 02.472. A map grid of 1 km x 1 km cells was created using Arcview GIS software and overlayed onto an electronic nautical chart of the region (Figure 1). This provided a crude illustration of the bottom topography that assisted in the selection of a sub-set of grid cells for sampling.

Potential locations likely to harbour commercially viable abalone stocks within the defined region were identified by canvassing Western Zone divers, especially those who pioneered the development of the fishery. This information was used in conjunction with hydrographic charts to select areas that warranted further investigation.

Blacklip abalone survey

It was decided to initially focus on blacklip abalone populations within a relatively shallow region charted as relatively complex reef extending from about two to six kilometres offshore from the Fitzroy River (Figure 2).

The LMS for the blacklip feasibility survey was set at 90mm and a permit issued by Fisheries Victoria accordingly.

Six commercial abalone boats supporting 11 divers, with a maximum of two divers per vessel, were each randomly allocated two 1km^2 cells from a fourteen-cell grid overlayed on the selected survey area (Fig 2).

Within each survey cell a central co-ordinate in WGS84 was established as a way-point to which the assigned vessel would navigate using a GPS. Upon arrival at the way-point divers attempted to locate potentially suitable habitat in the immediate vicinity. During diving operations the vessel remained approximately within a 500m radius of the way-point.

An observer (mostly fisheries officers) was posted aboard each of the participating vessels to ensure adherence to the survey design and to measure and record catch details and environmental observations. Observers were specifically responsible for ensuring that their assigned vessel remained within 500m of its assigned way-point(s) and that field data sheets (Appendix) were fully completed.

Data that were collected aboard each vessel included the:

- Vessel and diver details
- Weather conditions and sea state
- GPS co-ordinates for each dive or change in vessel location within an assigned cell.
- Individual shell lengths for all abalone – using an electronic shellfish measurer and data logger &/or callipers.
- Observations of bottom habitat
- Time and location for each bin of abalone

A separate set of observations was recorded every half-hour throughout the day's diving and an identification tag was used to make each bin traceable at the post-landing weigh-in.

Samples of the catch from each vessel were set aside for reproductive studies, including size at maturity, conducted by students from the University of Melbourne.

The weight of each bin landed was to be recorded against the catch time sequence noted on the observation data sheet. However, delays in landing the catch left insufficient time to weigh most individual bins before transport to processing factories. Individual weights and harvesting duration were recorded for individual bins from grid cells #64 and #94 only.

An *a priori* specified criterion for determining whether or not the surveyed populations were stunted was that an aggregate of at least 85% of the abalone collected must be smaller than the current LML of 120mm. This seemingly arbitrary reference point is consistent with the results of Wells and Mulvay 1995.

Greenlip abalone survey

This survey focussed largely on the same reef areas as the blacklip abalone survey (Table 1, Figure 2). Several pioneer divers as well as those and those with contemporary experience fishing Julia Bank were consulted to ensure that potentially productive greenlip abalone reefs were not excluded. This information was used in conjunction with qualitative observations of greenlip abalone abundance made during the blacklip abalone survey to select specific grid cells in which to search. Initial boat-based surveys of chosen cells were made using a submersible video camera. Based on the camera results a subset of cells was chosen for subsequent survey by divers. Two inshore cells (#11 & #23) that were dived were not included in the blacklip abalone survey. Unlike the blacklip abalone survey, the work was conducted by contract scientific divers, one of whom is also a Western Zone abalone diver familiar with the region. Dive surveys involved attempting to collect 100 abalone and recording the time elapsed during collection. One haphazardly selected site was dived within each nominated grid cell. No size limit was imposed for these collections and all abalone were transported to the surface and individual shell lengths measured to the nearest millimetre using an electronic shellfish measurer and data logger &/or callipers. At the conclusion of these measurements all abalone were returned to the bottom and carefully replaced on the reef by hand to minimise incidental mortality from predators.

Laboratory measurements

Blacklip and greenlip abalone samples were frozen soon after landing and transported to the University of Melbourne for reproductive studies undertaken by post-graduate students. Amongst a suite of measurements, macroscopic gonad index scores, based on a 5-stage scale illustrated by a series of photographic images, and shell lengths to the nearest mm were recorded and used in this study.

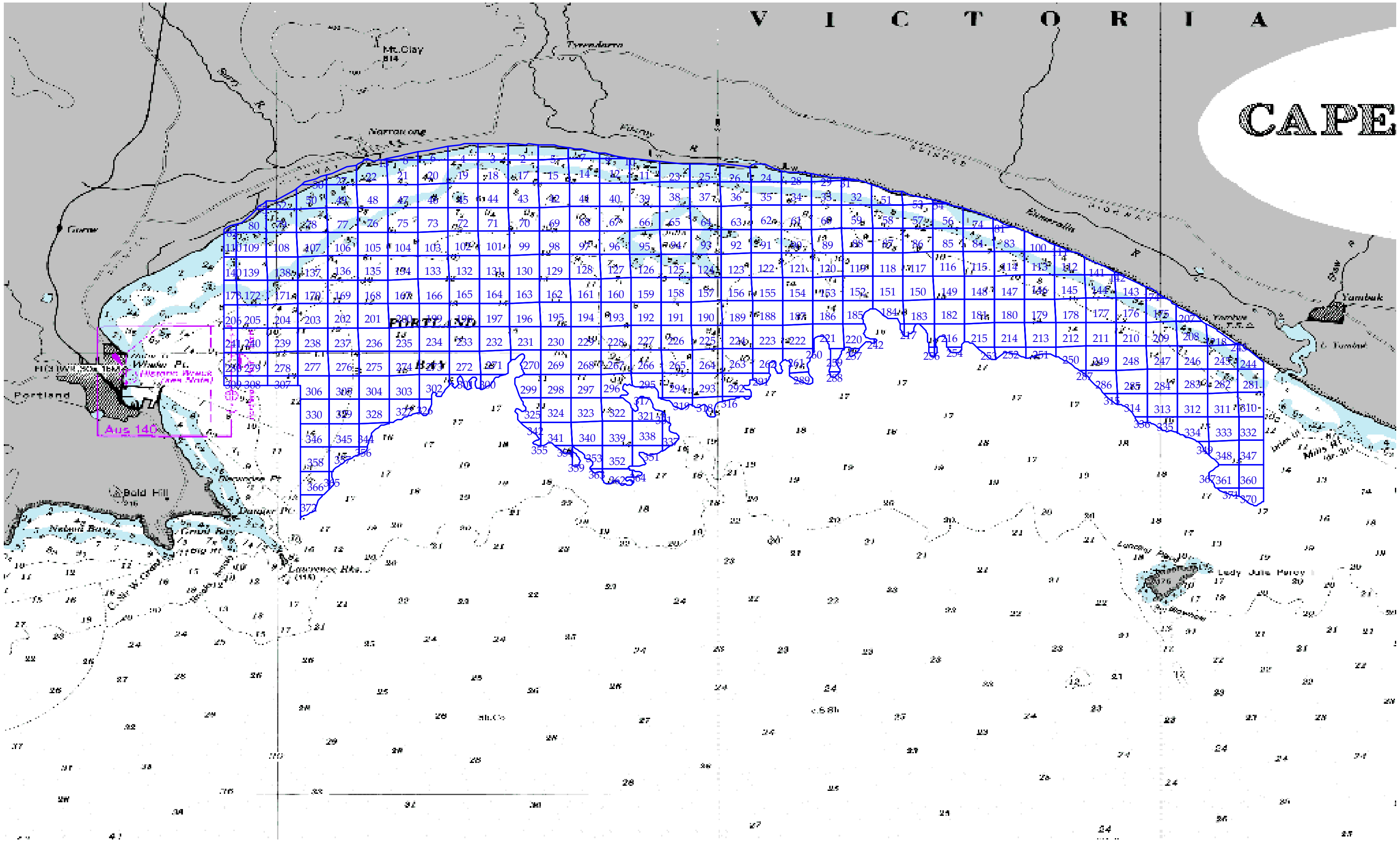


Figure 7. Map showing the entire Julia Bank catch reporting reefcode with blue numbered sampling grid overlayed.

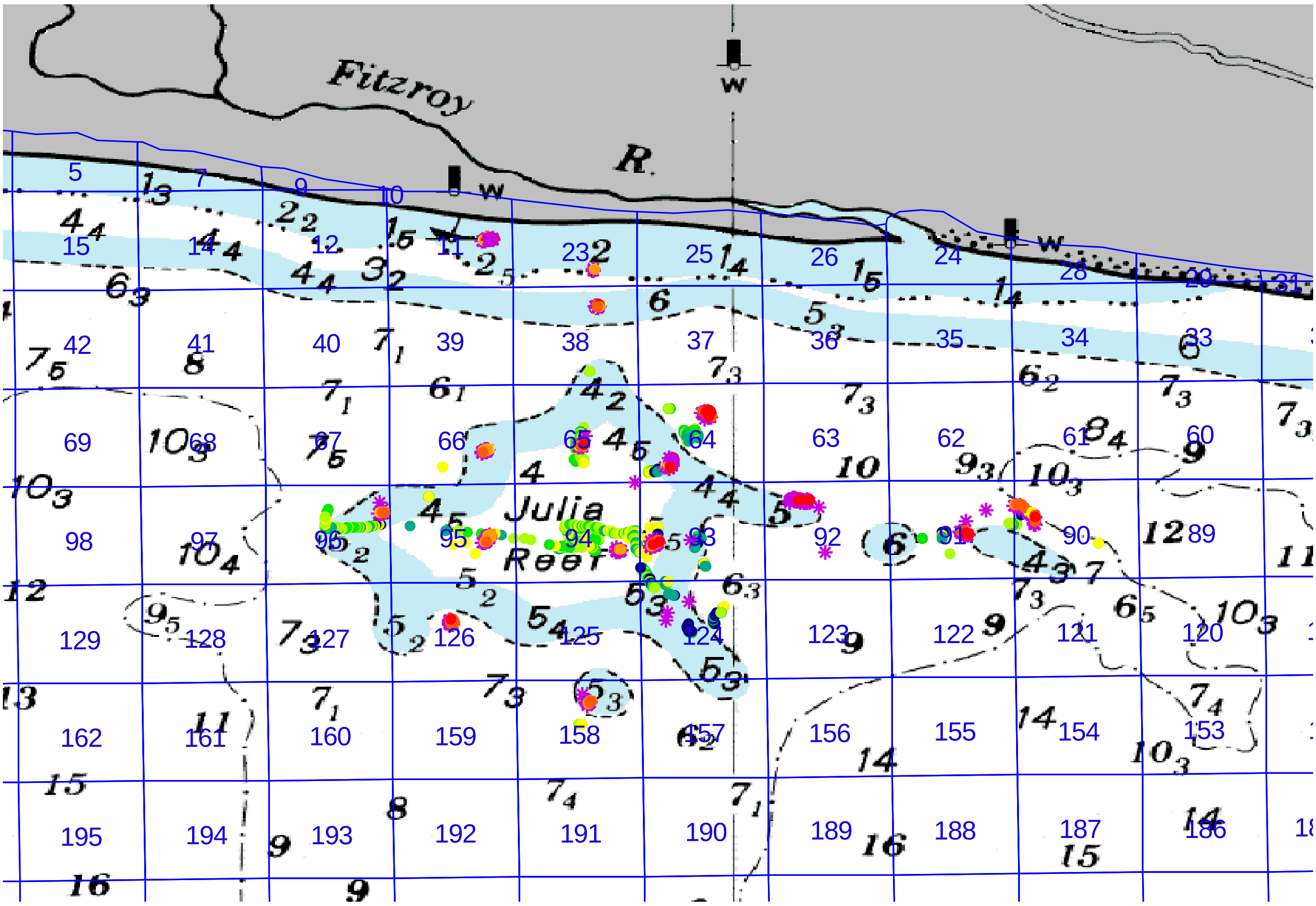


Figure 8. Sampling grid (1km x 1km) showing cell identification numbers in blue and fishing effort pattern, depicting shell lengths on increasing scale from yellow through green to blue (dark green and blue dots represent shell lengths larger than 113mm) for blacklip abalone and yellow through orange to red (dark orange and red dots represent shell lengths than 133mm) for greenlip abalone, overlayed on a nautical chart of Julia Bank. Purple asterisks represent survey sites where no abalone were observed.

Data analysis

Length frequency data were downloaded from loggers and processed in MSExcel®. Processed data were then uploaded into Arcview® via their co-ordinates and merged with a shapefile to assign the appropriate experimental grid cell number to each observation. The observations were then exported and re-loaded into MS Excel® where for each cell in the grid length was converted to an individual weight using the relationship $W = aL^b$. The parameters a and b were initially nominated as those estimated for blacklip abalone from Boulder Point by McShane and Smith (1988) because this site is closest to the survey region. The same parameter values were used for both species because values estimated in the past for blacklip abalone from Julia Percy Island (McShane and Smith 1988) and greenlip abalone from Portsea (Gorfine and Dixon 2000a) were quite similar. The total live catch weight from the conversion was then calibrated to the actual catch weight via small arbitrary adjustments to the parameter b, such that $a = 0.000512$ and $b = 2.8075$.

Table 7. Geographic coordinates (WGS 84) for grid cells surveyed for blacklip (B) and greenlip (G) abalone within the Julia Bank reefcode area.

Grid cell	Latitude		Longitude		Species
#	Deg	Min	Deg	Min	
3	38	15.3360	141	45.0012	G
11	38	15.7590	141	48.4512	G
18	38	15.7794	141	45.0060	G
23	38	15.7860	141	49.1208	G
24	38	15.8124	141	51.1788	G
38	38	16.2924	141	49.1268	B & G
64	38	16.8282	141	49.8186	B & G
65	38	16.8330	141	49.1328	B & G
66	38	16.8378	141	48.4470	B & G
90	38	17.3544	141	51.8826	B & G
91	38	17.3592	141	51.1968	B & G
92	38	17.3640	141	50.5110	B & G
93	38	17.3694	141	49.8246	B & G
94	38	17.3742	141	49.1388	B & G
95	38	17.3790	141	48.4530	B & G
96	38	17.3832	141	47.7666	B & G
124	38	17.9100	141	49.8312	B & G
125	38	17.9148	141	49.1448	B
126	38	17.9196	141	48.4584	G
158	38	18.4554	141	49.1508	B & G

The Julia Percy Island parameters were not chosen for the initial length to weight conversion because they were considered less likely to reflect the environmental conditions at Julia Bank than the Boulder Point parameters and would have required more scaling to calibrate to the true catch weight. However, this decision was inconsequential to the final result.

Weights for each grid cell were then divided by their respective effort values, estimated from times recorded on field data sheets, to calculate catch rates in $Kg.h^{-1}$. Although catch rates are generally regarded as a poor indicator of trends in abundance, the high spatial variability that characterises abalone distributions makes these estimates useful as a relative measure among survey sites. Shell length frequency histograms were plotted as absolute frequency and cumulative relative frequency for each grid cell separately and for data pooled among cells. The proportions below the LML and of the total catch were also calculated.

Gonad index scores for each species were plotted against shell length and the proportion mature at current LMLs and several alternative size limits were estimated from the data. For the purposes of this study abalone with scores less than four were classed as immature and a score of five was required for classification as fully mature.

Results

Three thousand six hundred and fifteen blacklip abalone and 1360 greenlip abalone were collected during the surveys, corresponding to total weights 953Kg and 529Kg respectively.

Abundance

Blacklip abalone

Experimental catches of blacklip abalone showed that abundance was highly variable with two grid cells (#s 92 and 125) yielding no abalone despite two hours of effort expended in searching and four cells (#s 64, 65, 94 and 124) producing between 150 and 200 Kg representing about two thirds of the catch (Table 2). Within many grid cells there were some dives that did not yield any abalone and the amount of reef area covered by divers within a cell tended to reflect its abalone abundance (Figure 2). Among cells contributing to the days' catch per unit effort ranged from 9 to 136 $Kg.h^{-1}$ with an average of 50 ± 10 $Kg.h^{-1}$. Four of these 12 cells had more than the pre-specified 15% of abalone at or larger than the legal size limit of 120mm. With the exclusion of cell #64 which had 82% of its catch below the LML, the remaining three cells that met the criterion for stunting accounted for about one third of the total catch (Table 2).

Catch per unit effort per bin was relatively high and variable for cell #94, ranging from 22–242 $kg.h^{-1}$ and high but less variable for cell#64, ranging from 80– 83 $kg.h^{-1}$ (Table 3).

Table 8. Comparison of experimental blacklip abalone catches among grid cells surveyed on Julia Bank.

Grid cell #	Number harvested	Estimated weight (Kg)	Catch proportion (%)	Effort (min)	CPUE ($Kg.h^{-1}$)	% < LML
38	333	77	8.1	?	?	95
64	474	136	14.2	60	136	82
65	736	176	18.5	130	81	98
66	5	1	0.1	1	52	100
90	171	41	4.3	60	41	97
91	58	17	1.8	15	67	72
92	0	0	0.0	179	0	na
93	376	118	12.4	144	49	64
94	777	184	19.3	189	58	94
95	106	27	2.9	80	20	92
96	60	15	1.5	10	87	92
124	508	160	16.8	192	50	72
125	0	0	0.0	122	0	na
158	11	2	0.2	12	9	100
Total	3615	953	100	1194	-	-
Mean (SE)	-	-	-	-	50 (10)	88 (3)

Greenlip abalone

Greenlip abalone were generally more abundant and less variable than blacklip abalone among the cells surveyed. Catch rates ranged from 41–159 $kg.h^{-1}$ and averaged 92 ± 9 $kg.h^{-1}$. Proportions of greenlip abalone below the LKML of 130mm varied ranging between 7–91% with an average of 60 ± 7% (Table 4). Thirteen out of the 16 cells surveyed had more than the pre-specified 15% of abalone at or larger than the legal size limit of 130mm.

Table 9. Catch, effort and CPUE for individual bins of blacklip abalone harvested from grid cells #64 and #94 of the area surveyed on Julia Bank.

Grid cell #	Bin #	Weight (Kg)	Effort (min)	CPUE (Kg.h^{-1})
64	1	39.9	30	80
64	2	41.5	30	83
94	1	40.3	10	242
94	2	38.2	104	22
94	3	38.4	22	105
94	4	40.4	20	121
94	5	39.2	33	71

Size structure

Overall, the 85th percentile among shell lengths was 120mm among blacklip abalone and 145 mm among greenlip abalone samples. Respective median values were 107mm and 128mm (Table 5). Although the shapes of the pooled length frequency histograms for both species appear to approximate normal distribution (Figures 3 and 4) the histograms for individual cells show many instances of skewed distribution (Figures 5 and 6), especially among the greenlip samples (Figure 6). In some instances the proportion smaller than the LML was high because of relatively higher abundance of small abalone less than about 100mm rather than low abundance of legal-sized greenlip abalone (Figure 6).

Table 10. Comparison of experimental greenlip abalone catches among grid cells surveyed on Julia Bank.

Grid cell #	Number collected	Estimated weight (Kg)	Catch proportion (%)	Effort (min)	CPUE (Kg.h^{-1})	% < LML
3/18	0	0		15		
11	94	39	7.4	24	99	51
23	10	2	0.3	15	7	10
24	0	0	-	15	-	-
38	98	30	5.7	20	90	66
64	99	52	9.8	28	112	22
64a	92	47	8.8	19	145	27
65	97	39	7.5	21	115	58
66	99	30	5.6	11	159	91
90	80	21	3.9	30	41	78
91	104	44	8.3	28	94	47
92	69	49	9.2	31	94	7
93	99	48	9.0	23	127	18
94	94	34	6.5	20	101	70
95	88	24	4.6	22	67	90
96	70	17	3.2	19	55	91
124	1	0	-	20	-	-
124a	0	0	-	15	-	-
126	102	34	6.5	20	104	69
158	57	19	3.6	20	58	77
Total	1360	529	100	416	-	-
Mean (SE)	-	-	-	-	92 (9)	60 (7)

Maturity

Among the 52 blacklip abalone sampled for reproductive study 57% were female, whereas 41% of the 73 greenlip abalone were female (Figure 7). One third of the blacklip and one quarter of the greenlip abalone gonads could not be scored because of the condition of their tissues.

Assuming abalone with maturity scores less than 4 were immature, 58% of the blacklip and 82% of the greenlip abalone sampled could be considered as mature. Six percent of the blacklip were scored as fully mature and compared with 21% of the greenlip abalone being scored at stage 5. There were no immature blacklip abalone larger than 104 mm and immature greenlip abalone were all smaller than 116 mm.

If the blacklip abalone sample is assumed to be representative of blacklip abalone populations within the study area generally then examination of the distribution of gonad index scores among length classes indicated that a size limit of 111mm would protect about half the mature biomass. This estimate was based on assuming that 37% of abalone with shell lengths within the range 90–104 mm and 100% larger than 104mm were mature.

Similarly, assuming that the greenlip abalone sample is generally representative of this species within the study area, then examination of the distribution of gonad index scores among length classes indicated that a size limit of 135mm would protect about half the mature biomass, and the current size limit of 130mm protects 36% of the mature biomass. These estimates were based on assuming that 62% of abalone with shell lengths within the range 90–115 mm and 100% with shells larger than 115mm were mature. A size limit of 125mm would protect 24% of the mature biomass, however in combination with a maximum size limit of 145mm protection for 50% of the mature biomass could be achieved.

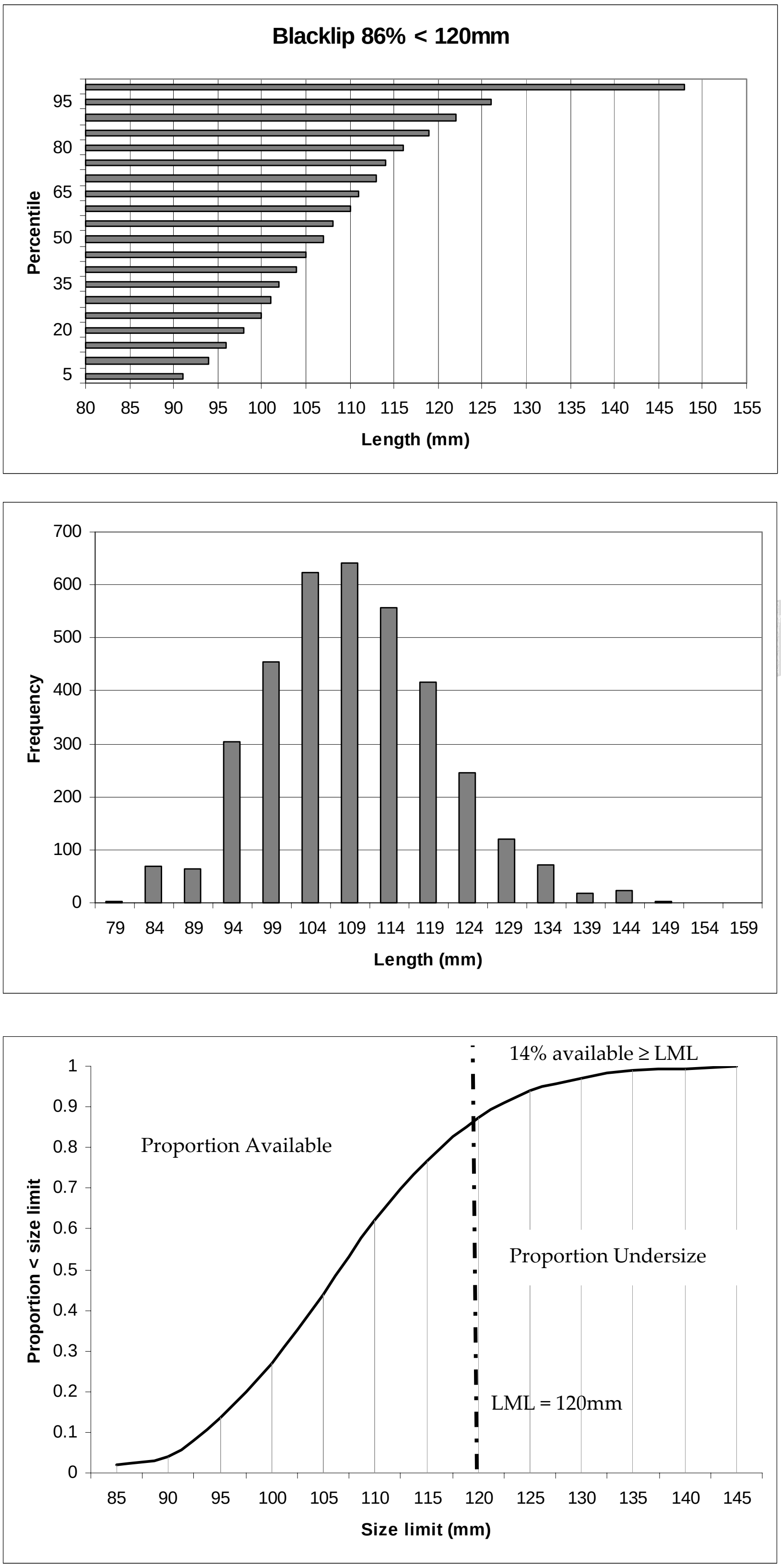


Figure 9. Cumulative distribution, frequency and proportion relative to alternative size limits for pooled maximum shell length data from blacklip abalone populations on Julia Bank in western Victoria.

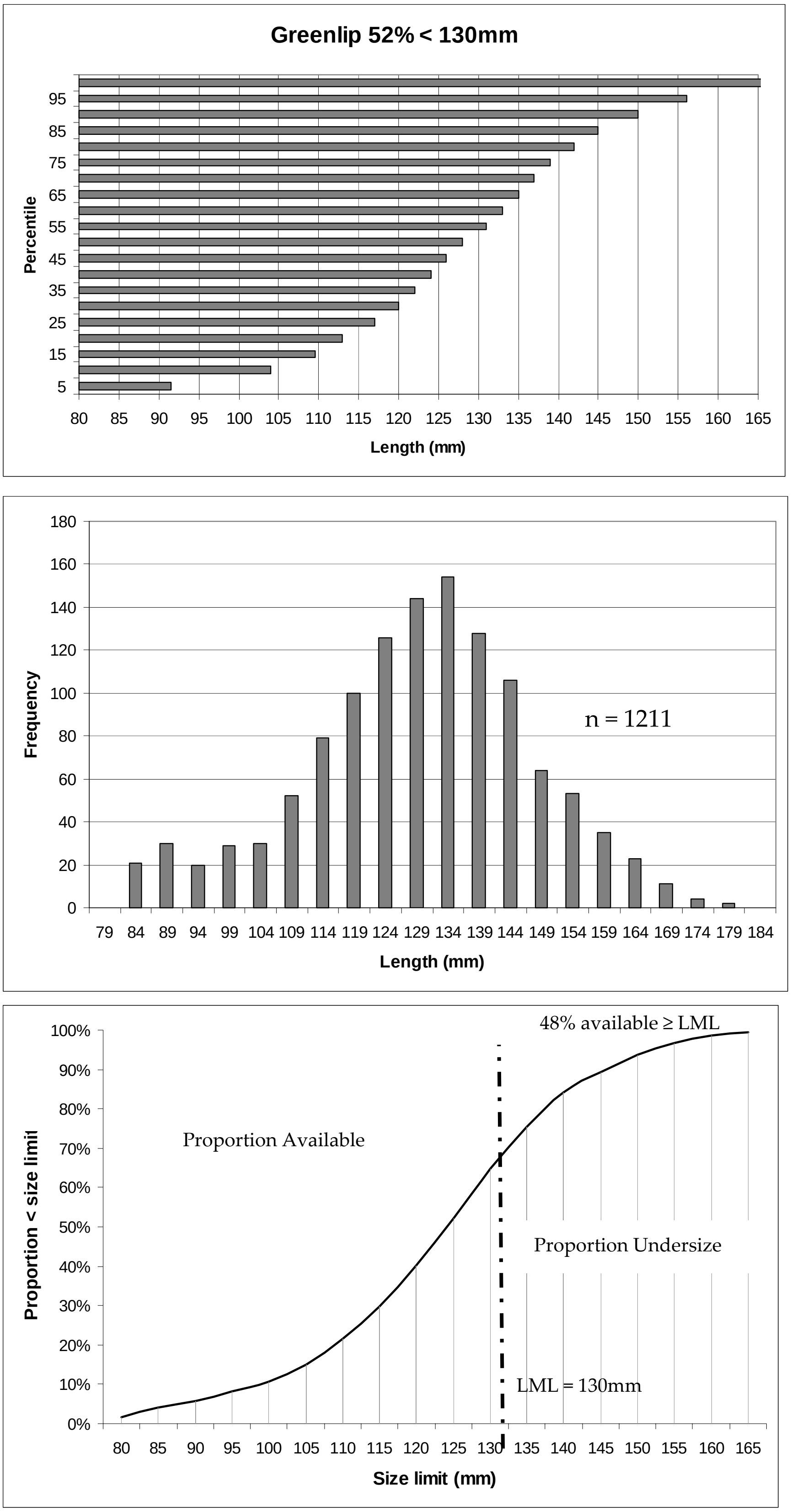


Figure 10. Cumulative distribution, frequency and proportion relative to alternative size limits for pooled maximum shell length data from greenlip abalone populations on Julia Bank in western Victoria.

Table 11. Percentile values from shell length distributions of blacklip and greenlip abalone sampled from Julia Bank.

Percentile	Length (mm)	
	Blacklip	Greenlip
5	92	92
10	94	104
15	96	110
20	98	113
25	100	117
30	102	120
35	103	122
40	104	124
45	106	126
50	107	128
55	109	131
60	110	133
65	112	135
70	113	137
75	115	139
80	117	142
85	120	145
90	122	150
95	126	156
100	148	177

Discussion

The small proportion of blacklip abalone larger than the legal minimum length of 120mm among populations on Julia Bank given the negligible catch history for this region is *prima facie* evidence that these stocks are stunted. Reducing the LML to 105mm would provide divers with access to half to two-thirds of the population. At a LML of 110mm 40% of abalone 90mm and larger would be available for capture and about half the mature biomass would be conserved. In contrast, amongst greenlip abalone about half are available for capture at the current LML of 130mm and a reduction of 5mm would allow 60% to be fished but reduce the protection of mature biomass to 25%. Consequently, it would be problematic to classify all Julia Bank greenlip stocks as stunted. Indeed, examination of the results for individual grid cells revealed substantial variation in the proportion of greenlip abalone that were larger than the LML, with a range of 9–93%. One quarter of the cells contained less than 15% legal sized greenlip abalone, whereas in almost half the cells at least 40% were larger than the LML. Previous studies of reefs further west within Portland Bay during 1972, 1973, 1987 and 1998 showed similar variation in the proportion of legal-sized greenlip abalone ranging from 14–33% (Gorfine and Dixon 2000a).

The patchiness in distribution across reefs observed among the Julia Bank abalone populations will produce lower rates of fertilisation among mature spawning abalone of both species (Andrew et al. 1997, Babcock and Keesing 1999, Wells and Mulvay 1995) and consequently lower levels of population recruitment. Divers tend to target the more mature animals owing to their larger size. Unlike juvenile abalone, the mature fraction of the population tends to have naturally low mortality rates (Beinssen and Powell 1979, Shepherd and Breen 1992, Shepherd and Godoy 1989, Shepherd et al. 1982). A corollary to this is that abalone diving imposes an unnaturally high level of mortality on adult abalone. It is these features, as well as some other aspects of their biology, that render abalone populations with low abundance particularly vulnerable to recruitment overfishing and subsequent collapse.

Stunted blacklip abalone populations, such as those on Julia Bank, are likely to have less potential to sustain fishing mortality than more productive populations located on reefs elsewhere in the Western Zone (see Andrew et al 1997). However, at the current LML of 120mm few abalone are large enough to be fished and without fishing this is unlikely to change. A reduction in LML is the only way that commercial catches can be obtained from this region, however because of the patchiness of aggregations the potential overall productivity from Julia Bank is small and only relatively low levels of fishing mortality will be sustainable.

Greenlip abalone populations were clearly more abundant than blacklip abalone on Julia Bank and this is reflected in experimental catch rates that were on average almost twice those for blacklip abalone. Although these observed catch rates compare favourably with average rates across the Victorian abalone fishery generally (see Gorfine and Dixon 2000b), they were principally estimated for comparative purposes and, because they include abalone across the entire size range sampled, should not be considered to be predictive of the actual catch rates likely during commercial abalone fishing. Commercial divers fishing this region at a reduced LML would have to reduce their daily catch expectations and tolerate lower hourly catch rates for blacklip abalone. This disincentive to harvest blacklip abalone may be offset by the more viable quantities of greenlip abalone observed during this study. It is likely that reductions in abalone densities within aggregations that result from fishing will stimulate improved growth and reproductive output (Bardos et al. accepted, Dixon and Day 2004). However, improvements in these parameters are unlikely to overcome environmental constraints to population growth e.g. food availability and suitable habitat (Wells and Mulvay 1995). Consequently, substantial improvement in abundance of abalone resources within the Julia Bank region is improbable.

Although this study indicates that an LML of 135mm would be required to protect 50% of the mature biomass overall, increasing the size limit would render many of the more stunted aggregations of greenlip abalone inaccessible. In this instance there would be little incentive for divers to fish Julia Bank. Introducing a maximum size limit in conjunction with a reduced legal minimum length would be a potentially effective compromise that allows divers to access the more stunted populations whilst providing increased protection for aggregations of large greenlip abalone. An upper limit of 145mm in combination with a reduced LML of 125mm is numerically equivalent to a general LML of 135mm in its level of biomass protection yet has the advantage of increasing the commercial viability of abalone diving on Julia Bank.

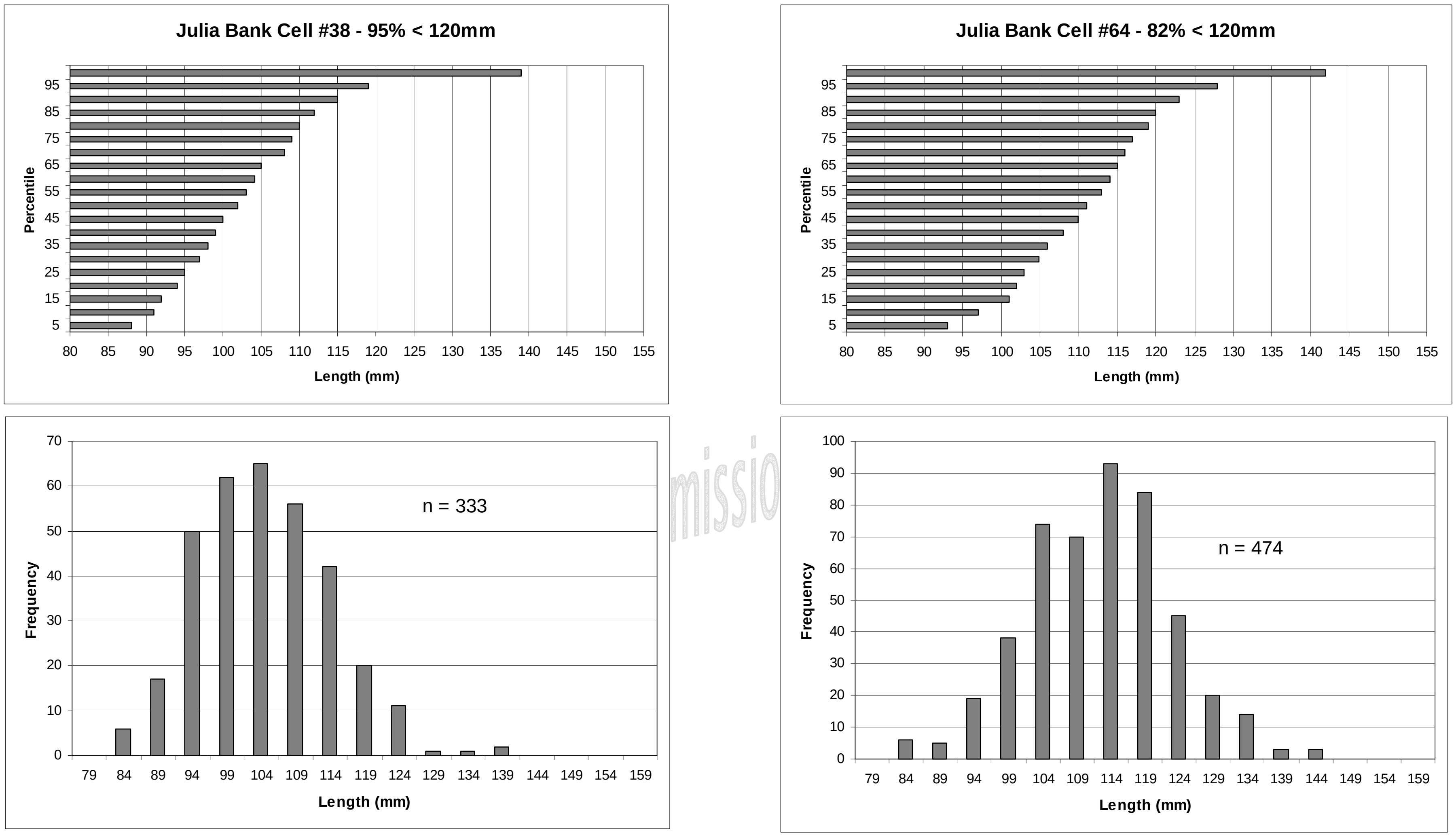
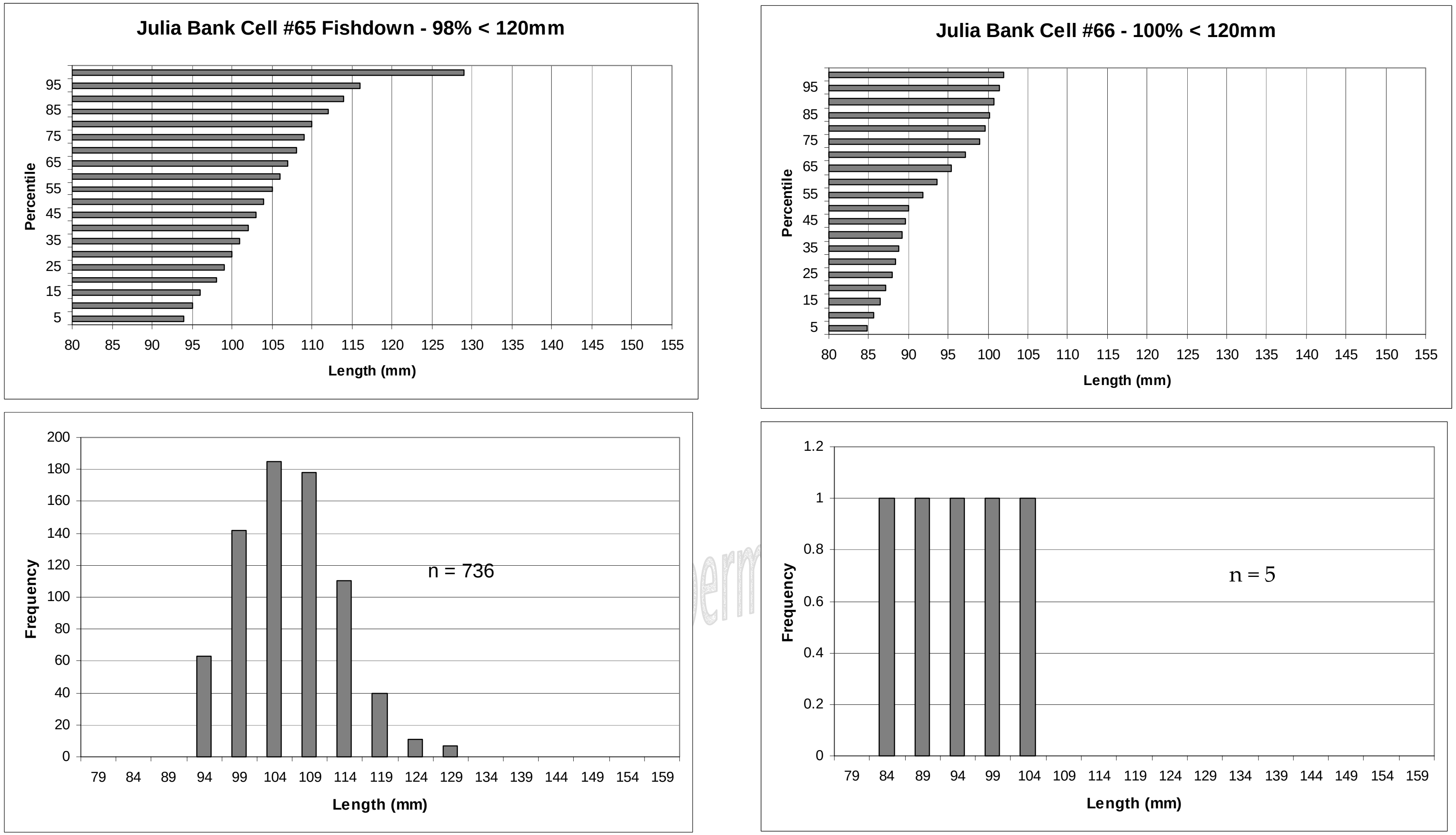


Figure 5. Cumulative and frequency distrbutions of maximum shell lengths for blacklip abalone from grid cells sampled on Julia Bank in western Victoria.



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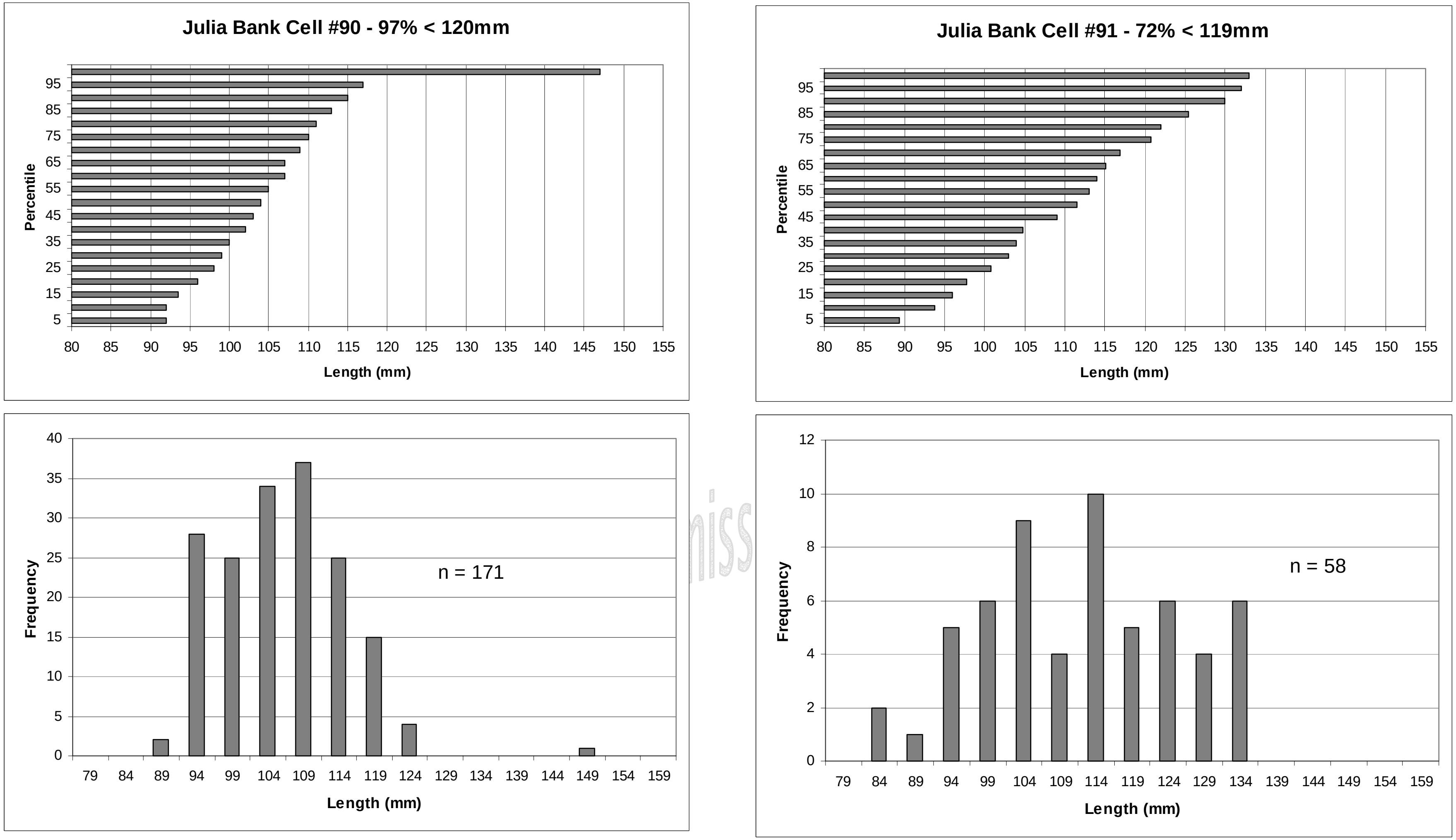

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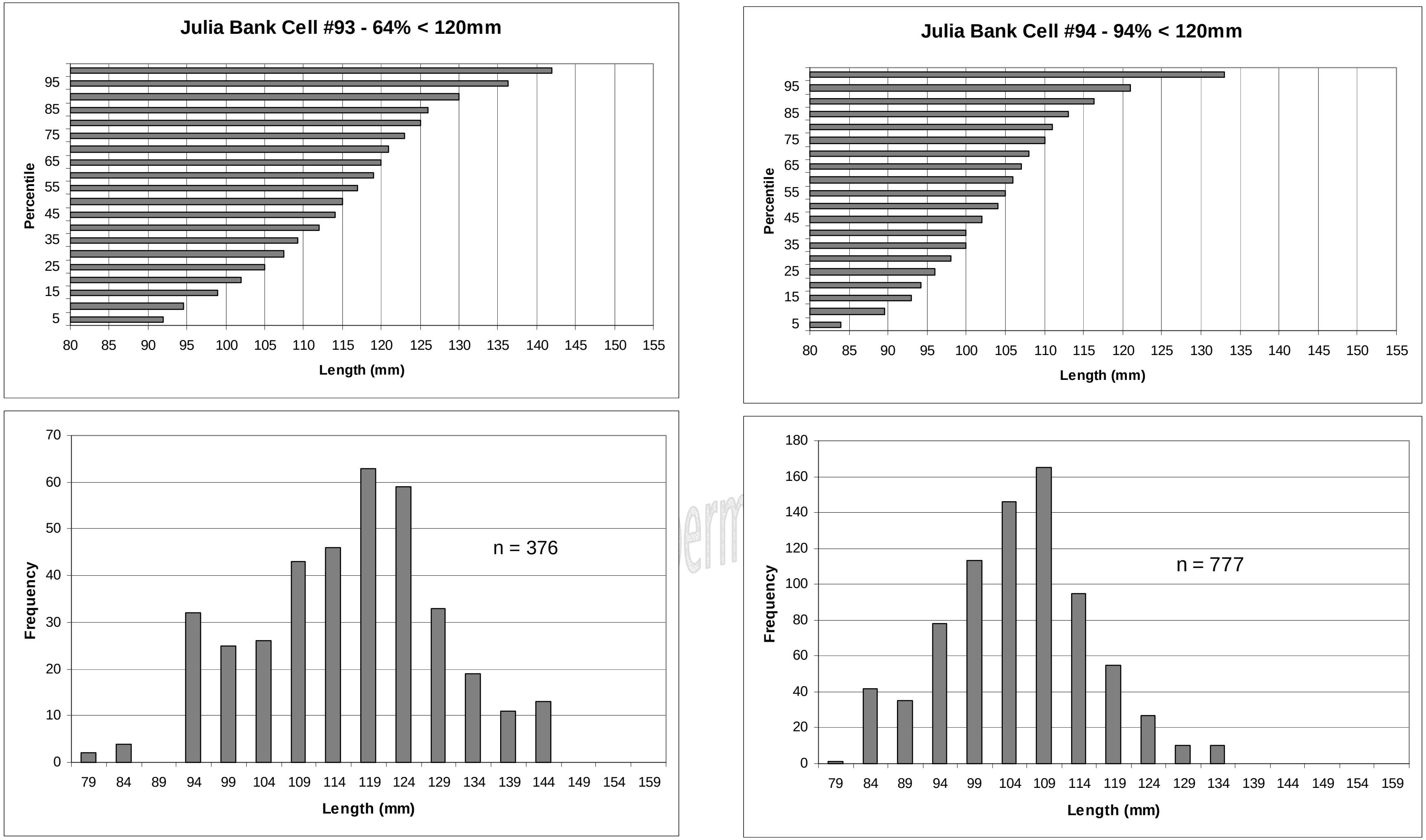

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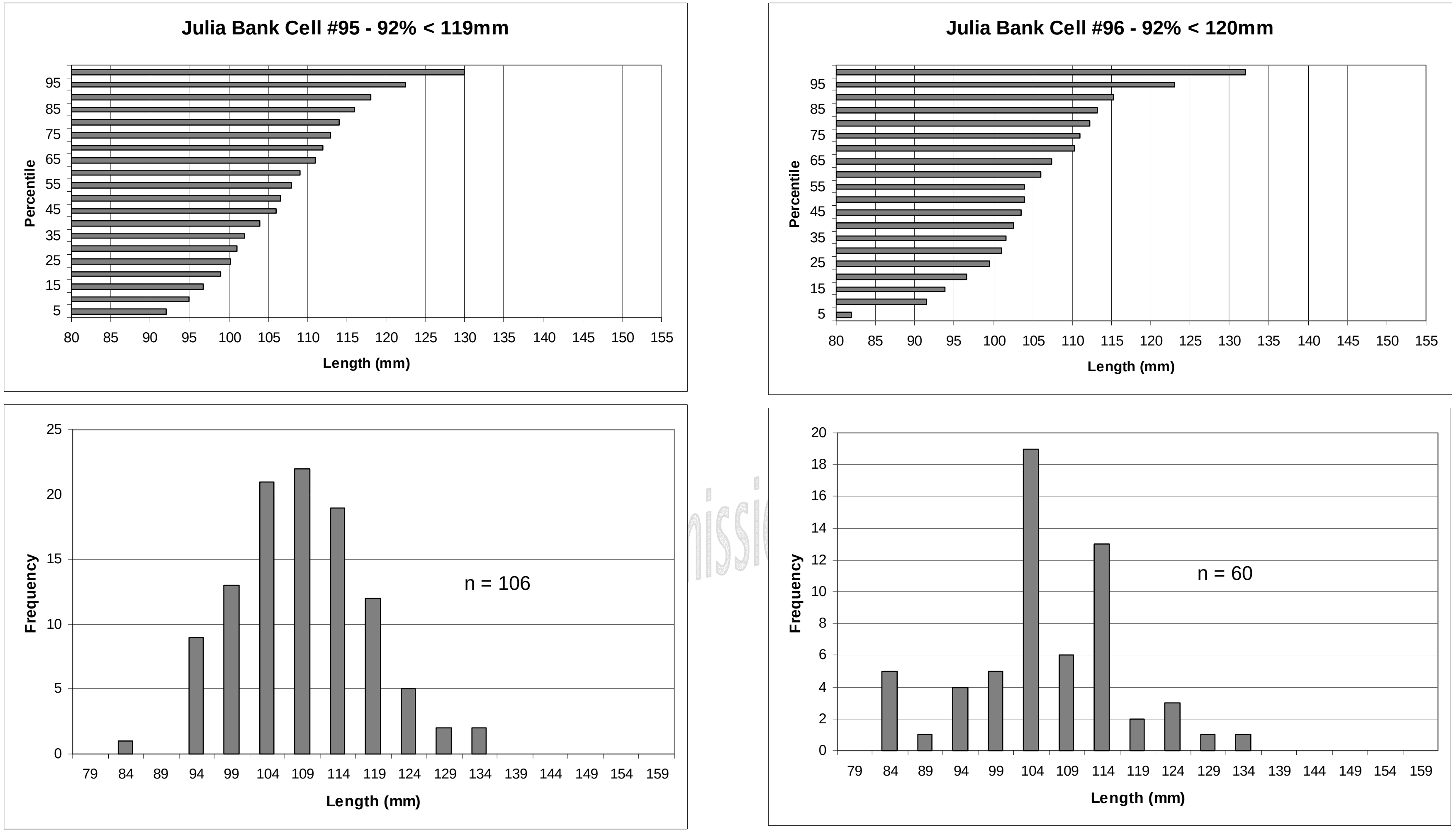

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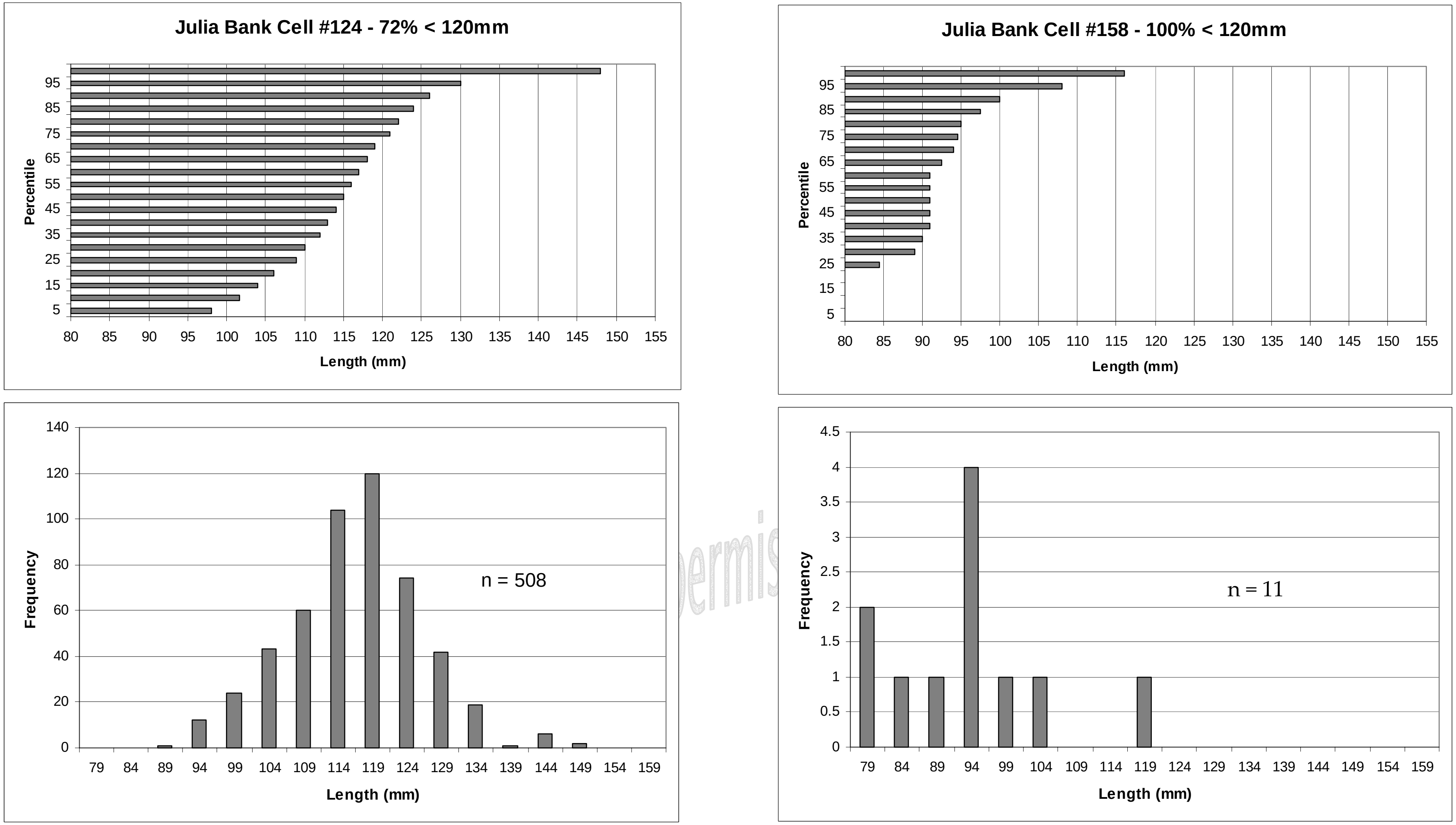

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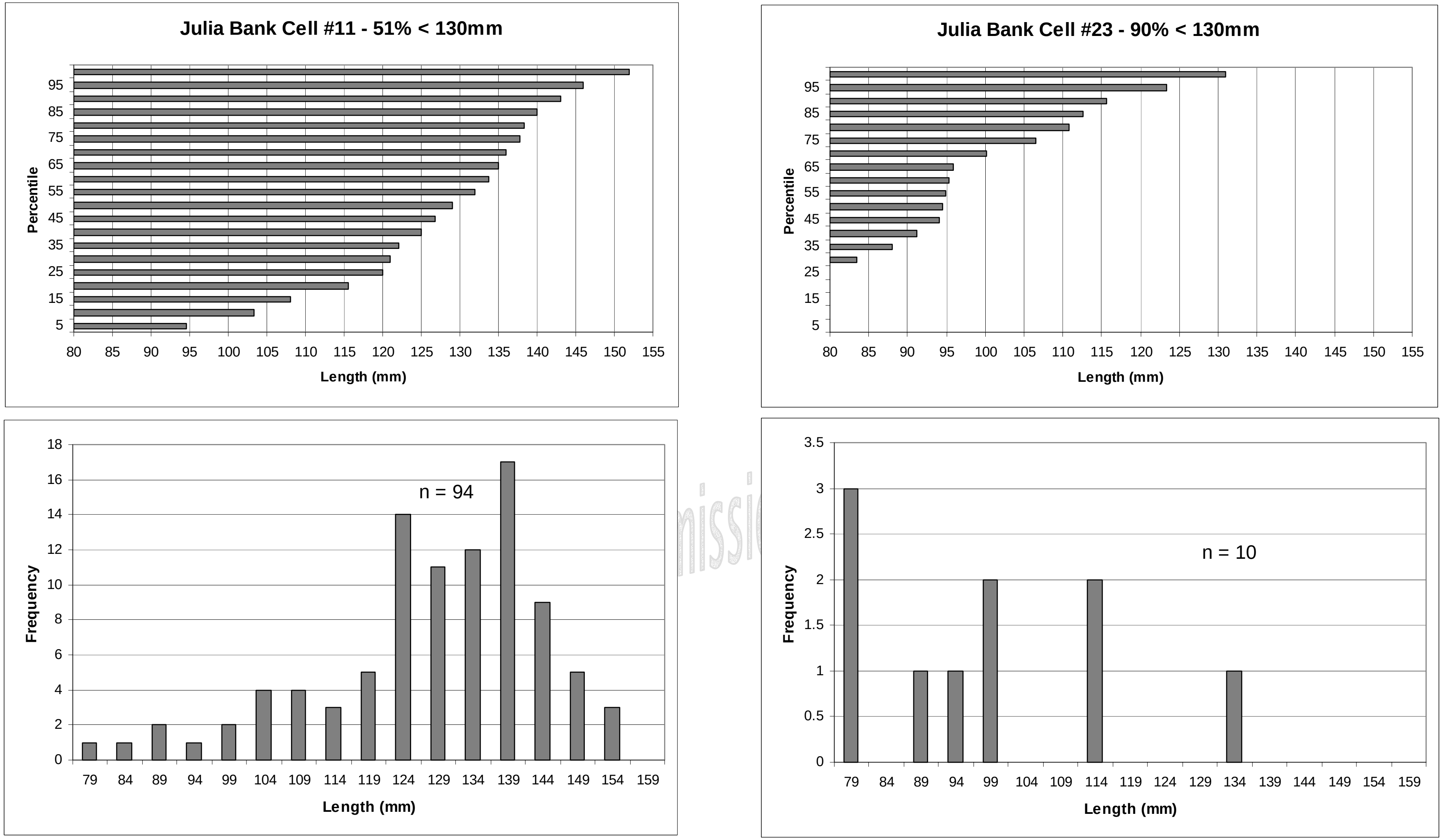
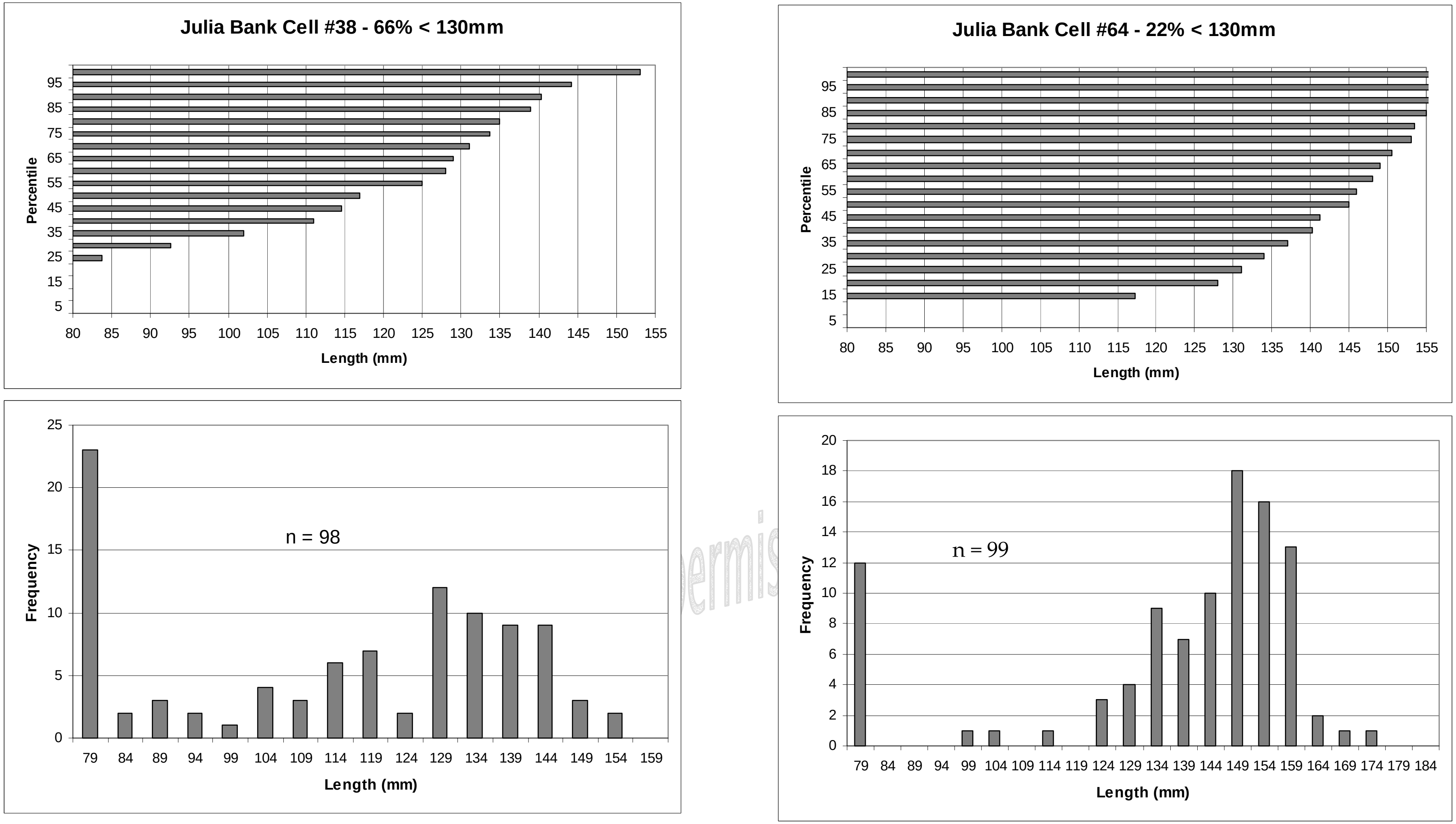


Figure 6. Cumulative and frequency distributions of maximum shell lengths for greenlip abalone from grid cells sampled on Julia Bank in western Victoria.



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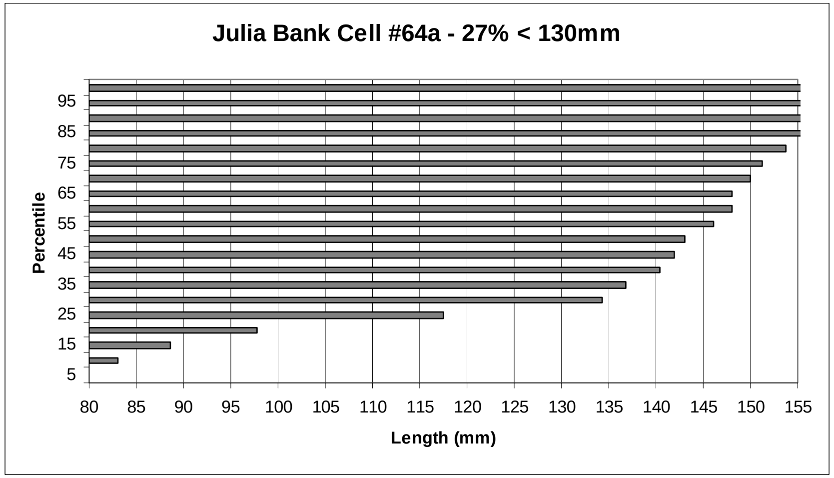

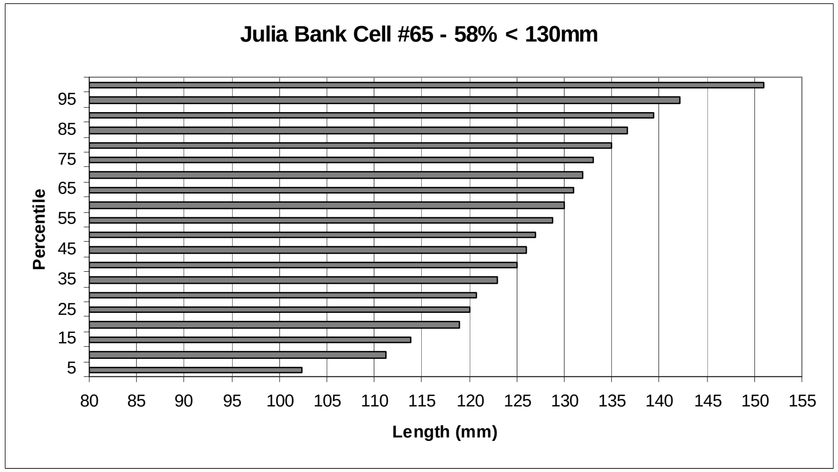

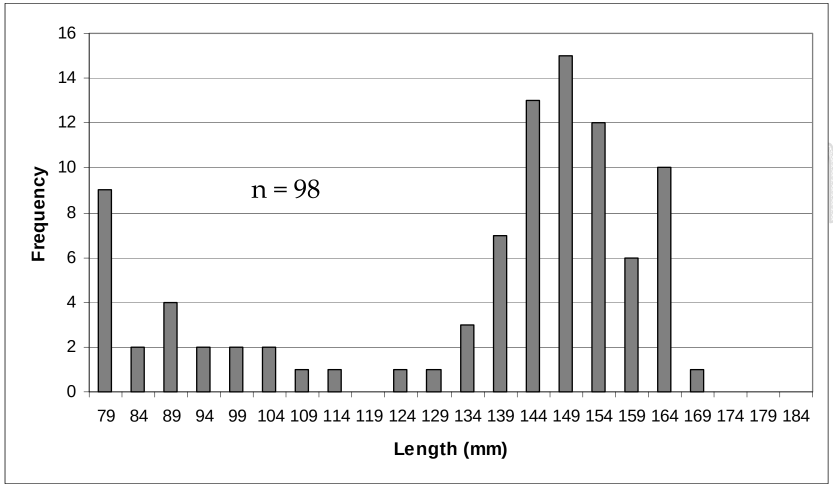

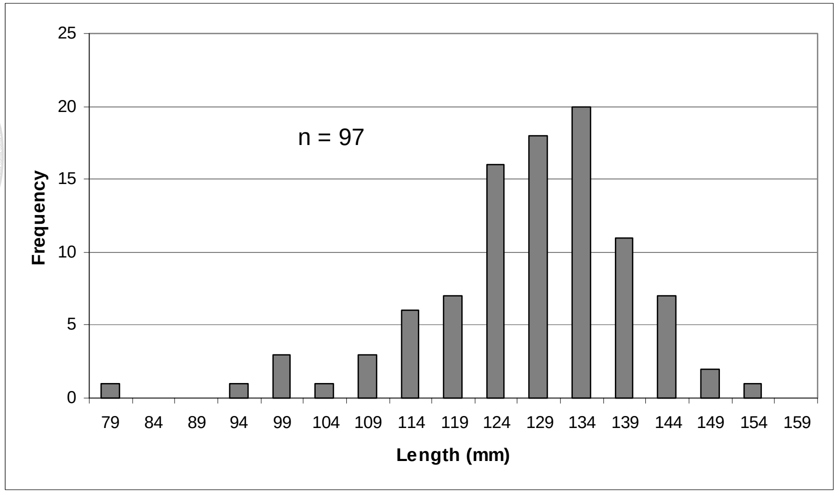

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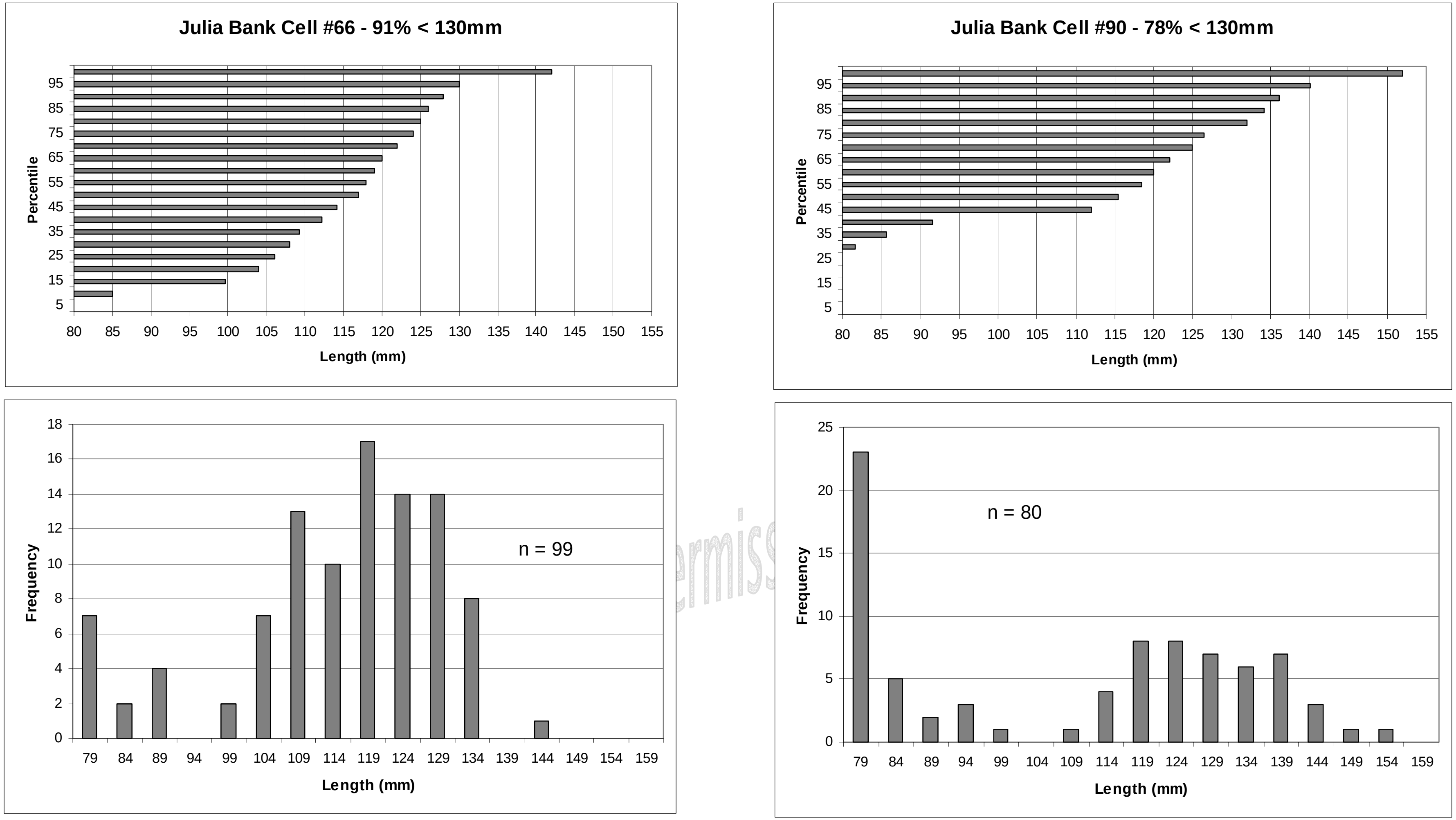

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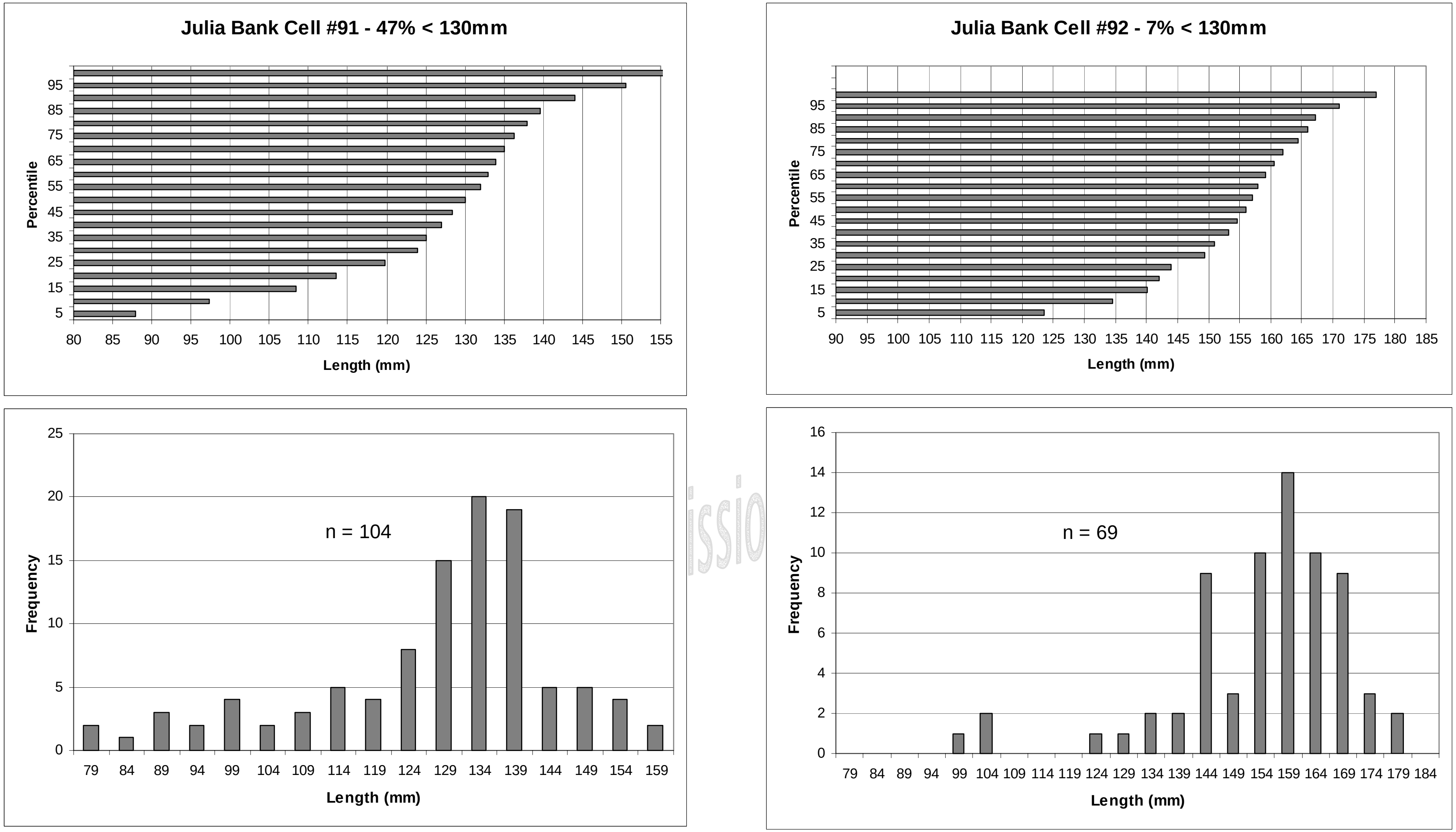

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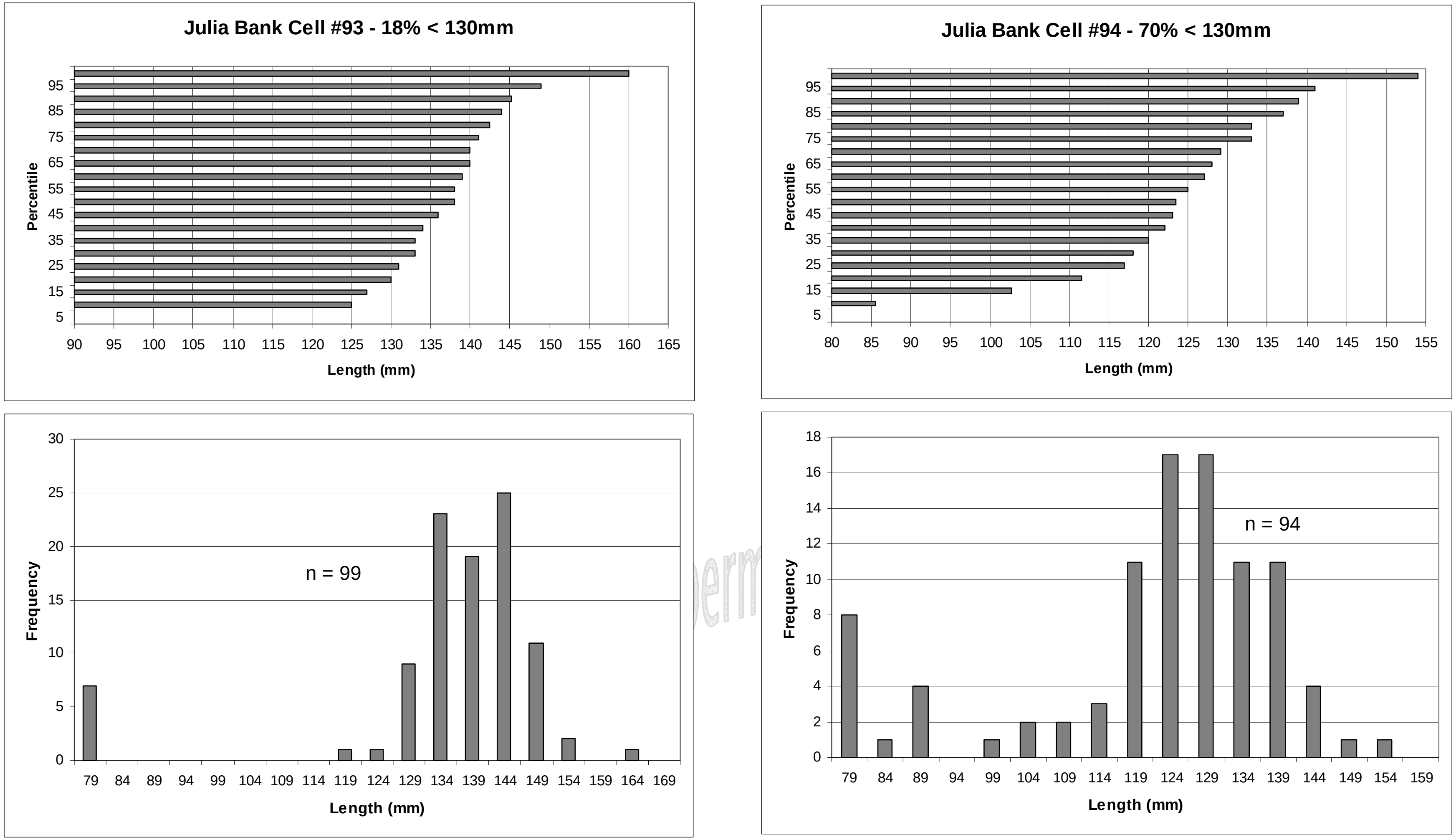

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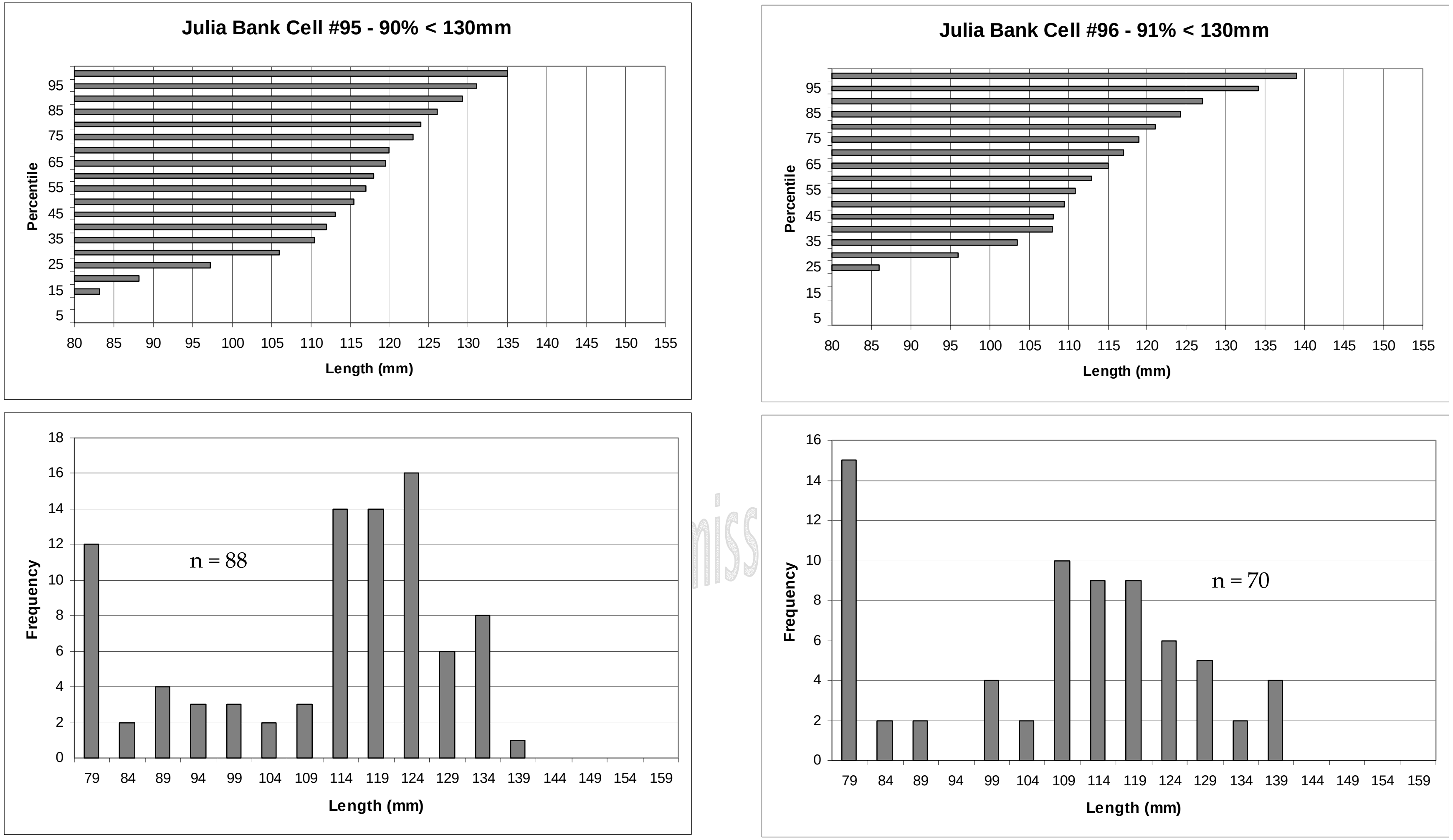

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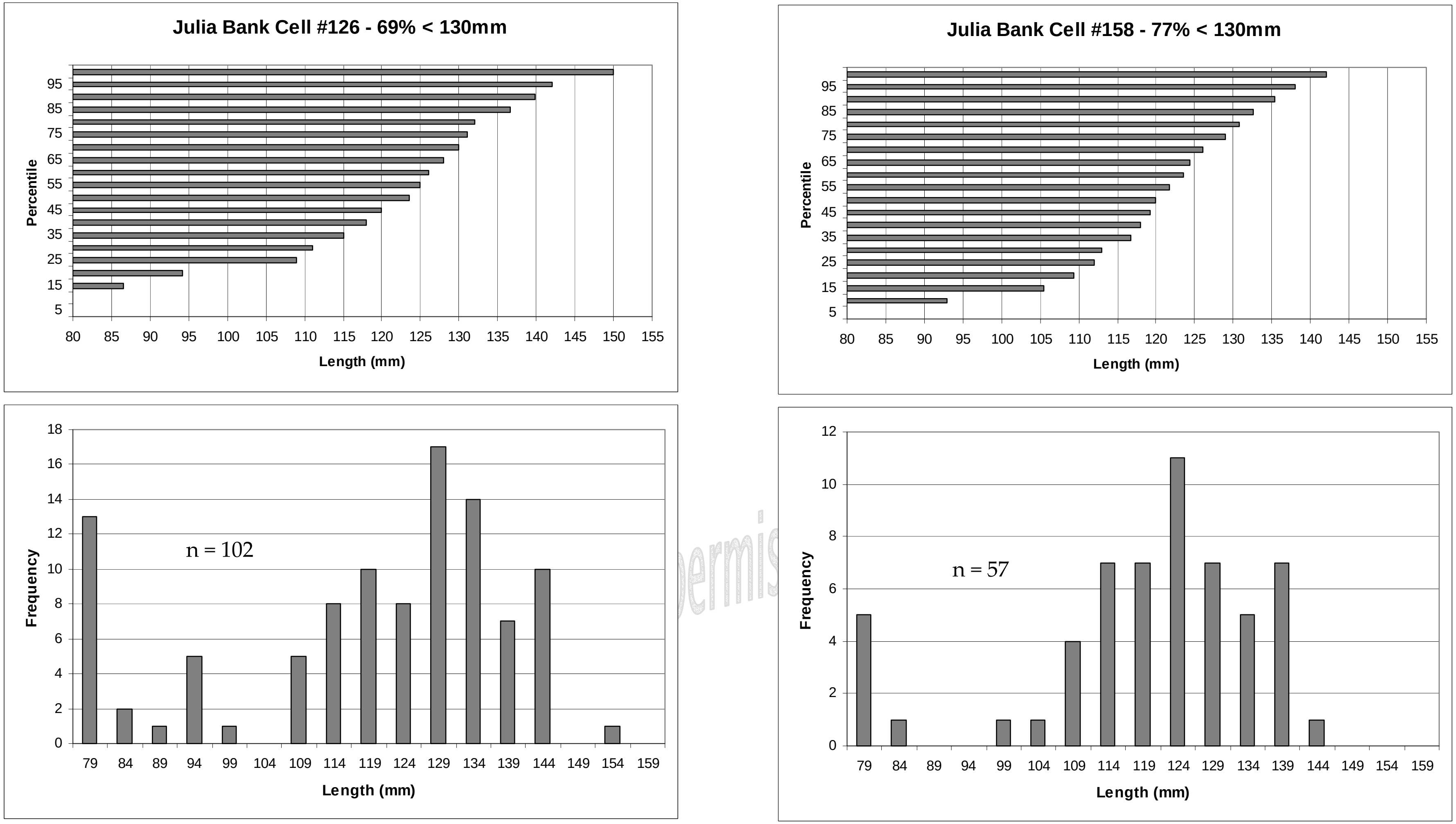

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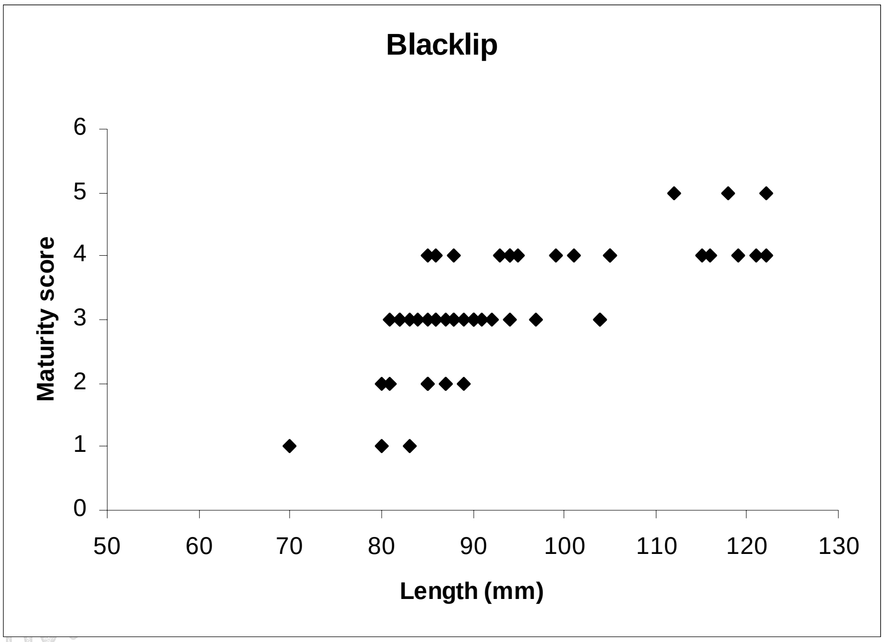

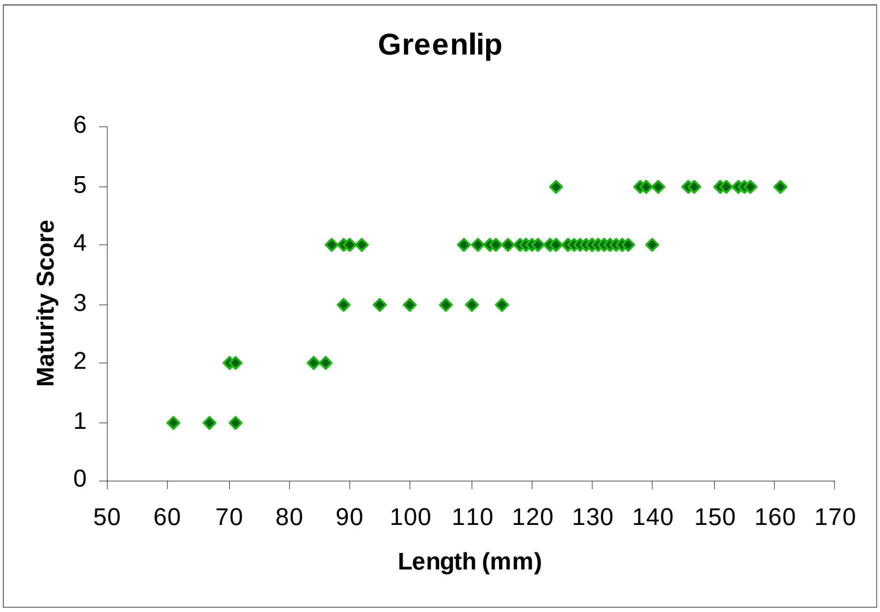

Figure 7. Maturity score versus length for samples of blacklip and greenlip abalone from Julia Bank in western Victoria.

Conclusions

Deciding how much of the Julia Bank abalone populations to conserve should form the basis for size limit selection. However, there is scant information about what proportion of mature biomass (or egg production) should be conserved for abalone generally, although some abalone researchers have advocated values of 50% (Shepherd and Baker 1998, Shepherd et al. 2001). It is more likely that the amount of unfished mature biomass that is optimal for long-term sustainability will vary among populations. Although abalone mature with age rather than size (Nash 1992), they nevertheless mature within a range of ages and the proportion mature in any given year, as determined by gonad indices, will vary seasonally and with inter-annual differences in environmental conditions.

This study has shown that a size limit (SL) of 100mm would protect 25% of the blacklip abalone above 90mm from fishing, a SL = 105mm would protect 45% and a SL = 110mm would protect 60%. For greenlip abalone a SL = 120 would protect 27% and 38% would be protected at SL = 125mm. Only about 36% of mature greenlip abalone biomass is protected by the current LML, whereas 50% of the mature blacklip abalone biomass would be protected if the LML was reduced by 10mm.

A recommendation that the LML for blacklip abalone be reduced to 110mm seems reasonable, especially when considering that abundance of this species within the study area was not high. Reducing the size limit to 125mm for greenlip abalone on Julia Bank would carry a greater risk of unsustainable fishing and is a less conservative option than maintaining status quo. However, if a maximum size limit of 145mm is introduced concurrently then the effect on biomass would be numerically equivalent to increasing the LML to 135mm, a more conservative option than the current strategy. Anecdotal information from divers and commercial catch sampling data (unpublished) indicate that greenlip abalone populations on other Western Zone reefs tend to have substantial proportions of larger abalone well above the current LML of 130mm. It follows that protection of Western Zone greenlip abalone could be even further enhanced by increasing the LML applying to reefs outside of the Julia Bank reef code area to 135mm.

Fishing mortality rates at prevailing size limits will depend on growth rates among pre-recruits and fishing intensity. Consequently, no quantitative advice based on this study can be provided about sustainable catch levels until growth and abundance have been monitoring during several years of conservative fishing. It is recommended that three fixed monitoring sites be established on Julia Bank to be surveyed annually using the well established techniques used to assess blacklip abalone populations throughout Victoria (Gorfine et al. 1998).

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Special thanks also go to Harry Peeters, Executive Officer WADA, for organising the industry participation and lastly but certainly not least, Steve Michael who co-ordinated and supervised the experimental fishing and data collection.

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Appendix

Field data sheet used for surveys of Julia Bank abalone populations:

Date: ______ Diver: ______ Observer: ______

Location: ______ Depth: ____ m

Latitude: ______ Longtitude: ______

Wind speed: ____ kn Wind direction: ______

Swell height: ____ m Swell direction: ______

Arrival time: ____ h Departure time: ____ h

Site description: ______

Diver Observations

U/W Visibility		Poor	Fair	Good	Excellent	
Surge		None	Light	Moderate	Heavy	
Current		None	Light	Moderate	Heavy	
Water temperature		Cold	Moderate	Warm		
Geology	Igneous		Sedimentary		Metamorphic	
	Basalt	Granite	Sandstone	Limestone	Mudstone	Shale
Sand patches		None	Few	Many		
Relief/Terrain		Low <1m	Medium 1-3m	High >3m		

	None	Low	Medium	High
Proportion of Urchin Barrens				
Cryptic Habitat (crevices, under boulder)				
Amount of reef buried under sand				
Crayweed				
Bull kelp				
Seastars				
Periwinkles				
Wrasses				
Rays				
Banded Morwong				
Crabs				
Crayfish				
Other(specify): ______				

Diversity of Marine Life	High	Medium	Low	
Polluted?	Yes	No	Partly	
Recovery rate after fishing?	Fast	Medium	Slow	
Number of times have dived this site	Never visited before	Few	Regular	Favorite
Comparison of habitat with last visit		Better	Same	Worse

Abalone assessment

Proportion undersize	High	Medium	Low	None
Juvenile abundance (< 50mm)	High	Medium	Low	None
Cryptic abalone (visible but inaccessible)	High	Medium	Low	None
Empty shell abundance	High	Medium	Low	None
Shell appearance	Clean		Fouled	
Shell shape	High &/or rounded		Flat &/or elongated	
Overall shell size	Large		Small	
Stock status rating	Good	Indifferent	Poor	Collapsed
Weather access rating	All conditions	Moderate swell	Choppy	Calm only

Logger used?	YES	NO

Bin #	Time	Beach weight (kg)

G

Release of juvenile blacklip abalone to rehabilitate depleted reefs in the Western Zone

Steve Michael

November 2004

Introduction
The Western Abalone Divers Association (WADA) was keen to trial stock restoration by releasing hatchery-reared juvenile 'seed' blacklip abalone on two reefs in the Western Zone whose populations had become depleted, ostensibly from over fishing. Twenty-five thousand abalone (minumum), that had been disease-tested, were released in specially fabricated modules at two reefs close to two of the three main ports in the Zone. This was done by commercial abalone divers in an operation co-ordinated by PIRVic's Abalone Scientific Extension Officer for the project, Steve Michael.

Method
Following the preliminary survey and discussions with Mark Gervis from Southern Ocean Mariculture a meeting was held with WADA members. The divers were keen to participate and a program to release hatchery-reared stock (20,000 x juvenile abalone of 20–50mm shell length) was developed that included design and construction of release modules, disease testing (see Appendix), grading of seed at the hatchery, loading the seed into the modules and transporting them from the hatchery, placing the modules on selected reefs and developing an industry-based on going monitoring program.

The program was to be implemented in two phases, with the first phase involving the reseeding of 'The Patches' at Port Fairy with about 10,000 abalone. This site was considered less vulnerable to rough sea conditions than the other candidate site at the 'Passage' in Portland and the operation could be trialed and assessed to assist the second phase.

The chosen module design (Fig. 1) resulted from testing various materials and systems including tank tests at PIRVic using stock samples. Sixty release modules were built at PIRVic using 65mm PVC pipes x 400mm long attached to concrete pavers 500mm x 350mm x50mm. Four PVC pipes were strapped to the pavers with strips of inner tube on a bed of Sicoflex® adhesive (Fig. 2).

Upon completion the modules were transported to Southern Ocean Mariculture in Port Fairy on 29th August. Abalone (100 x 20-40 mm) were placed in one of the pipes and placed in a tank to monitor distribution within the pipe to test the suitability of the design. This resulted in 80% mortality due to abalone moving to the ends of the pipe and restricting water flow. The transition from darkness to a sunlit environment may have stressed the abalone thereby contributing to these mortalities.

Local divers Phil and Glen Plummer ran trials modifying the pipes by cutting a series of 3mm slots longitudinally and using perforated inserts to allow more water flow. It was anticipated that this would substantially reduce mortality rates. Sam Askew and Peter Riddle further secured the pipes to the pavers with wire incorporating a loop at the top to attach parachutes for ease of manoeuvring when placing on the reef.

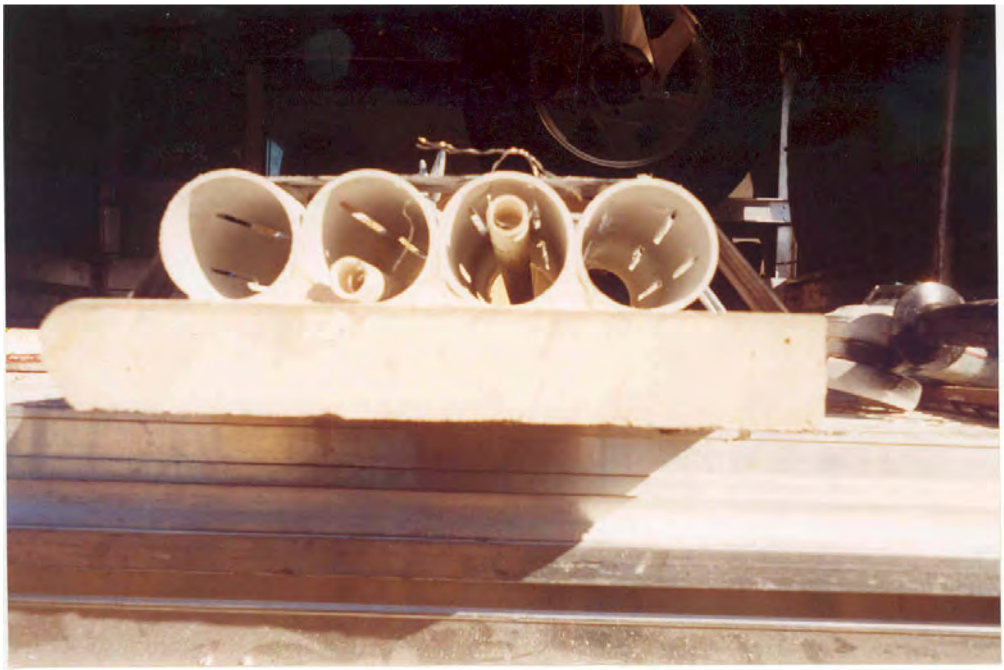

Figure 1. Completed release modules.

Figure 2. PVC deployment modules strapped to concrete paving bricks.

Trials proved successful and the rest of the modules were modified for the project.

Phase 1 - The Patches Port Fairy

During the afternoon on Tuesday 9th of September an estimated 6,000 abalone were anaesthetised (Fig. 3) using magnesium sulphate and placed in nets in the Southern Ocean Mariculture hatchery's nursery tanks (Fig. 4). The following morning the procedure was repeated and loading the release modules commenced (Fig. 5).

Figure 3. Removal of juvenile blacklip abalone from tanks following anaesthetisation.

Figure 4. Sorting anaesthetised hatchery-reared juvenile blacklip abalone

Figure 5. Placing hatchery reared juvenile abalone into deployment modules.

Participants were: **Phil Plummer, Glen Plummer, Simon McCall, Sam Askew, Gerard Gleeson, Mark Gervis, Steve Michael.**

An estimated 15,000 juveniles were placed in 44 modules. The ends of the pipes were secured with nylon mesh to contain the abalone and the modules were placed in a holding tank while the task was completed (Fig. 6).

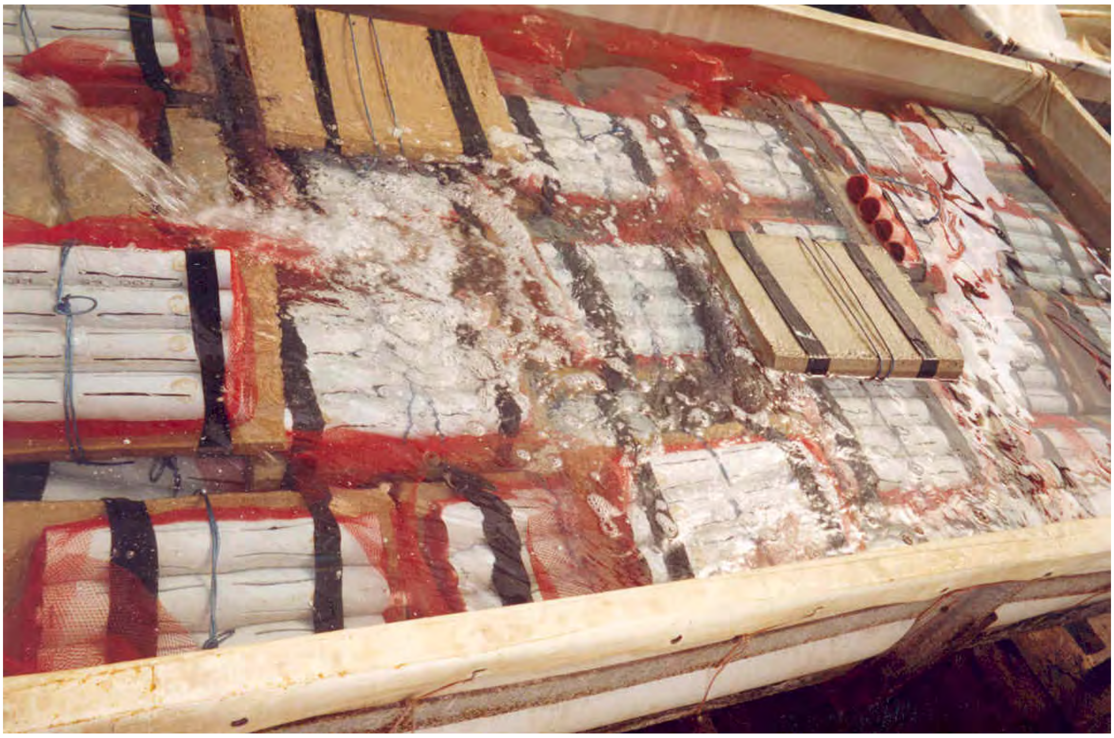

Figure 6. Modules in holding tank.

The modules were loaded on to utility vehicles, covered with wet carpet strips and transported to the boat ramp at Port Fairy. They were carefully loaded on to two vessels (Fig. 7) and taken out to the designated site.

Figure 7. Modules on deck of commercial abalone boat.

Figure 8. Commercial abalone boat at anchor at The Patches, Port Fairy, Western Victoria.

The vessels were anchored on The Patches site at 1400hrs and the work of placing the modules began (Fig. 8). The divers were Glen and Phillip Plummer.

The nylon mesh was taken off and retrieved and each module was attached to a parachute to assist manoeuvring over the reef (Fig. 9). Visibility was poor and there was a moderate surge.

Figure 9. Lowering deployment module into the sea with parachute attached.

Figure 10. Retrieving parachute bag from surfacing diver.

The deployment exercise was completed at 1600hrs (Fig. 10) and the vessels returned to the boat ramp.
NB 22 modules were placed base down/22 base up. Took place on a full moon.

Phase 2 - The Passage Portland

The second phase of the seeding project began at 0830hrs Sunday 12th October 2003 at Southern Ocean Mariculture, Port Fairy.

Additional modules had been built prior to this to make up a shortfall. (A decision had been made to leave the modules that had been placed at 'The Patches' in place to give the abalone more time to establish on the reef). Some of these modules were larger than the original module and it was estimated that a potential 15,000 abalone could be accommodated.

The same procedure (refer Seeding Report 1) was used to remove the abalone and fill the modules. Participants were **Phil Plummer, Glen Plummer, Maurice Dalton, Simon McCall, Dave Forbes, Jason Ciavola and Eddie Morrissy.** Special thanks to Eddie as he came along and helped without having any direct involvement in the project.

Dave Forbes cleared the drains of surplus abalone (estimate 10,000) and this combined with an under estimate of remaining stock provided an estimated total in excess of 30,000 abalone to be released.

The 42 filled modules were loaded on to a 1 tonne open tray truck, covered with wet carpet and a tarpaulin and driven by Maurice to Portland boat ramp.

Rodney Harris, Blue Grant and Dave Forbes provided vessels**.** Rod and Blue with deckhands helped complete a rapid transfer of the modules from the vehicle to the vessels (Fig. 11).

Figure 11. Transferring deployment modules from utility to commercial abalone boat at Portland boat ramp.

Figure 12. Modules on deck of commercial abalone boat covered with Hessian bags and irrigated with sea water to promote survival of juvenile abalone.

Once aboard the boats the modules were covered with wet Hessian bags and irrigated with sea water to minimise hypoxic stress from exposure to air (Fig. 12).

The passage site (38° 23.86' S and 141° 38.76' E in the WGS84 GPS mode or 38° 23.57' S and 141° 38.41' in AMD66 GPS) was located at approximately 1430hrs (Fig. 13) and Blue, Dave and Rod began placing the modules on the reef (Fig. 14).

Figure 13. Commercial abalone boats at anchor at The Passage, Portland, Western Victoria.

Figure 14. Commercial abalone diver placing modules in suitable location on reef in The Passage.

The vessels returned to the Portland boat ramp at 1630hrs marking the completion of the WADA reseeding exercise.

Figure 15. Some of the commercial abalone diver participants at Portland boat ramp.

As a follow-up, Dave Forbes returned to the site three days later and after 40 minutes of underwater searching detected only several empty shells. The abalone appeared to have established on the reef successfully and approximately 90% had exited the modules. About 12 months later Glen Plummer visited the Port Fairy site and reported that few if any of the released seed were now detectable. A structured industry-based monitoring program has been established to record results over the next 4 to 5 years to gauge the success of the project. Datasheets to ensure a systematic acquisition of data have been produced (see Appendix).

Appendix:

Disease testing report.

Site monitoring datasheet for commercial divers.

A Q U A T I C V E T E R I N A R Y S E R V I C E S
A . B . N . 41 339 742 732

Client: Abalone Program
Marine and Freshwater Research Institute
Weroona Parade
Queenscliff, 3225
Victoria, Australia

Species: Abalone Submission Date: 1 October 2003

History: Sixty ~25mm abalone were submitted for histological analysis and observation for mudworm. The abalone will be assessed histologically for the presence of bacterial, protozoan and fungal disease.

These abalone were the randomly selected from the small grade of the population. The population are to be provided to DPI Abalone Program for reseeding in natural waters.

Mud Worm Assessment: The sixty abalone shells were visually assessed for the presence of mud worm. Six showed signs of mudworm infestation. Five of the six were only slightly affected by mudworm while one demonstrated moderate to severe mudworm development on the interior of the shell around the gonad area.

Histological examination: There were no significant findings in the histological examination. No pathogenic organisms were seen.

Overall, the gills were in good condition, with no evidence of thickening or mucous cell enlargement, indicating that the gills had not been irritated in any way. Three submissions did show discrete localised thickening of the gill lamellae, however, no pathogenic organisms were seen at these sites. This type of thickening can occur as a result of irritation by suspended organic material (food particles, faeces and /or silt).

The foot musculature of these abalone showed no evidence of pathogenic infection. Food was evident in all of the sections of the gastro-intestinal tract. No abnormalities were noted in any of the other organs.

Discussion: In my opinion, these abalone were healthy at the time of sampling, furthermore, the presence of mud worm doesn't present a threat to the wild population as mud worm is already endemic in the environment

Alistair Brown B.Sc., BVMS, Cert.FHP, MACVSc.

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WADA Reseeding project — site monitoring datasheet

BOULDER SEARCHES

BOULDER SIZE COUNT

Small ____________________

Medium ____________________

Large ____________________

NO. OF JUVENILES

Hatchery ____________________

Wild ____________________

NO. OF ADULTS

____

TIME SEARCHING BOULDERS

____

CREVICE SEARCHES

CREVICE SIZE COUNT

Small ____________________

Medium ____________________

Large ____________________

NO. OF JUVENILES

Hatchery ____________________

Wild ____________________

NO. OF ADULTS

____

TIME SEARCHING CREVICES

____

UNDERSTORY % COVER

Crustose Coralline Algae ____________

Caulerpa spp. ____________

Percentage Brown Algae ____________

Percentage Red Algae ____________

Percentage Green Algae ____________

KELP CANOPY % COVER (Columns should tally to 100%)

Phyllospora ____________

Macrocystis ____________

Durvillaea ____________

Ecklonia ____________

Cystophora/Sargassum ____________

No Algal Cover ____________

PREDATORS/COMPETITORS

Red Crabs ____________

Crayfish ____________

Rays ____________

Wrasses ____________

Morwong ____________

Sea star ____________

Pests ____________

Monitoring results for industry re-seeding and translocation initiatives in the Western Zone of the Victoria abalone fishery.

David Forbes

March 2006

I. WADA Translocation Site
"The Patches" – Port Fairy

Survey Date: 23/02/06

Background

No formal preliminary surveys were conducted within the area prior to translocation, so no temporal comparison is possible at this stage.

On 20/03/05 Diver B translocated 3000 mature abalone, 450 of which were tagged, from Mills Reef to the Patches.

During a 2 hour, follow up survey on 08/07/05, Diver B found 45 tag mortalities and reported *"…the reef in general is far more active and in abalone numbers now resembles an area like Pelican Reef rather than a desolate patch of weed…."*

Method:

A transect array was deployed in the very centre of the patch, and because of the limited area it was decided that transects would have to be reduced in length from the usual 30 to 15 metres.

Two divers (A & B) entered the water with three random compass directions each. After arriving at the centre of the transect array each diver set an underwater compass to the first of their three randomly allocated bearing, attached a sample bag and began their first transect.

Each diver swam close to the reef surface (among the kelp stipes) and counted each abalone encountered within a one metre wide strip along the length of each transect. Each abalone was visually gauged as either under or over 120 mm. When there was uncertainty the diver used a measuring gauge to determine the size of the abalone in question. While counting abalone the diver also counted sea-urchins, turbo and 11-arm sea stars, as well as recording the geology, over-storey kelp cover, under-storey floral cover, the abundance of predators and competitors and the suitability of the site for juvenile abalone.

At the end of each transect the divers recorded all information gathered on an arm slate and then commenced a timed collection of the first 25 abalone encountered. These abalone were transported to the vessel for measurement.

Given that the primary objective of these surveys was to determine the success of translocations, additional time was also spent in the search for juveniles and tagged abalone. Tagged abalone were also collected if encountered along each transect.

Results

Abundances of abalone among pre-recruit and legal size classes were relatively high, no juveniles were observed and few predatory 11-arm sea stars were encountered (Table 1). The length frequency distribution of abalone sampled from the survey area showed that proportions of abalone above and below the legal minimum length for harvesting were similar, but only four abalone were smaller than 100mm in shell length (Fig. 1). Up to one quarter of the substrate was covered in sand (Table 1).

Table 1. Abalone and 11-arm sea star abundance (no./transect) at the Patches translocation site, Port Fairy, Western Victoria.

Transect Dir. (deg)	Diver	Abalone counts			Mortality	11-arm seastars	Time to collect 25 abalone (min)	Sand Cover (%)
		<80 mm	<120 mm	>120 mm				
240	A	0	23	17	0	0	2.20	25%
90	A	0	13	4	3	0	6.02	20%
150	A	0	7	4	2	0	6.05	0%
300	B	0	17	10	4	1	5.15	10%
30	B	0	45	20	3	1	5.05	25%
60	B	0	21	5	4	3	5.30	25%

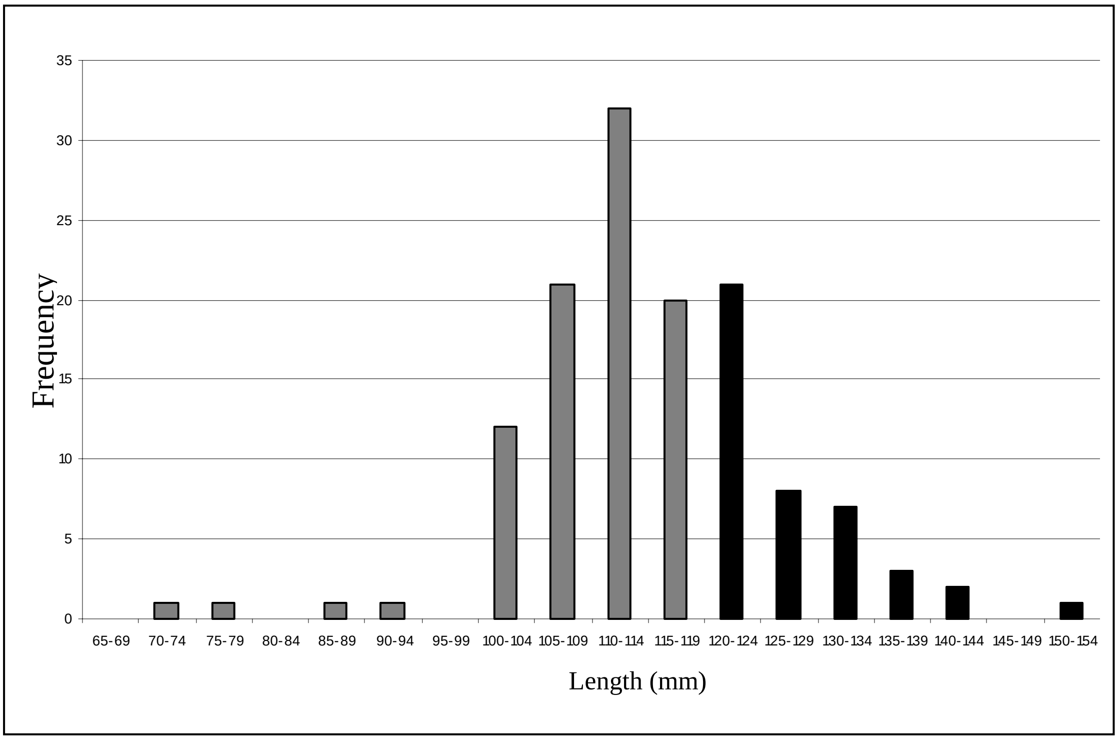


Figure 1. Length-frequency distribution of blacklip abalone collected from the Patches translocation site, Port Fairy, Western Victoria (n=151; grey bars = undersized, black bars = legal sized).

Fifteen live tagged abalone (Table 2) and four tagged mortalities (Table 3) were collected and in all instances annual growth increments were relatively small ranging from -1mm (shell chipped or measurement error) to 11mm.

Both divers reported *Phyllospora comosa* (cray weed) as 100% of the upper-storey kelp cover. Within the areas of sandy substrate (Table 1), *P. comosa* was “growing” out of sand, indicating that the reef was recently covered by sand.

Table 2. Shell lengths at release and recapture and growth increments at the Patches translocation site, Port Fairy, Western Victoria.

Red Tag No	Release length (mm)	Recapture length (mm)	Growth increment (mm)	**Red Tag No**	Release length (mm)	Recapture length (mm)	Growth increment (mm)
2202	130	131	1	**2565**	126	126	0
2207	105	105	0	**2570**	102	113	11
2212	138	142	4	**2659**	110	110	0
2226	122	123	1	**2676**	104	111	7
2227	122	122	0	**2807**	114	118	4
2241	134	135	1	**2813**	138	138	0
2242	119	120	1	**2817**	110	112	2
2272	122	122	0	**2818**	121	121	0
2273	134	133	-1	**2822**	120	121	1
2409	127	127	0	**2830**	118	120	2
2440	131	131	0	**2850**	118	118	0
2479	131	131	0	**2851**	123	123	0
2503	118	117	-1	**2873**	111	115	4
2506	103	108	5	**2878**	123	122	-1
2546	104	103	-1	**2897**	121	123	2

Table 3. Mortality among tagged abalone released at the Patches translocation site, Port Fairy, Western Victoria.

Tag No (red)	Release length (mm)	Recapture length (mm)	Growth increment (mm)	Comment
2264	120	121	1	Recent mortality
2281	114	114	0	Old mortality
2403	125	129	4	Old mortality
2485	122	123	1	Old mortality

Discussion

The abundance of abalone encountered within the 15 metre transects (average of 21 unders and 10 overs) if doubled to roughly represent 30 metre transects (42 under-sized and 20 over-sized) are very high by any comparison and indicative of a healthy abalone population.

There were two distinct morphotypes and sizes of abalone found on the collections, those above 135mm were flat, relatively clean and with fast growth characteristic (i.e. large spacings between shell ridges). It seems that these individuals were native to the area and existed prior to the translocation. Abalone of the second morphotype were obviously translocated.

Vigilant topside supervision ensured that both divers “completely” covered this patch of reef during transect sampling, timed collections and further searches, fro a combined searching time of two hours and fifteen minutes. More tag recaptures were expected on an isolated patch of reef such as this than the number that was recovered.

Given the percentage of translocated abalone (both tagged and untagged) that were over or approaching the legal size limit, it would appear that the area might have experienced some recreational harvesting.

Mortalities in any removal, translocation and especially tagging exercise are to be expected and the percentage encountered to date is typical of this expectation.

Sand encroachment on the reef is of concern and may have accounted for a proportion of the observed mortalities.

This site has benefits as an experimental plot because it is isolated. However, it’s suitability as a site for commercial regeneration is most questionable. Sand movement, proximity to a possible pollution source (the Moyne River) and easy accessibility for recreational harvesters, as well as the capacity for a single commercial diver to remove all adult stock, limits it’s potential for successful rehabilitation.

II. WADA Reseeding Site
“The Patches” – Port Fairy

Survey Date: 23/02/06

Background

No formal preliminary surveys were conducted within the area prior to translocation, so no temporal comparison is possible at this stage.

Estimates of the precise number of release modules that were placed on the reef and the quantity of juveniles that they contained were also unavailable. However, most of the modules had been recovered for possible re-use.

Method:

Information about the location, layout and history of the reseeding efforts was obtained in advance from a commercial abalone diver with extensive knowledge of reefs around Port Fairy. In accordance with his recommendations, the site was located and the transect array deployed on the sand edge at the tip of “*the horseshoe in the reef* ”. Random 30 metre transect bearings were assigned to two divers, assignments that would have covered 100% sand were discarded and replaced by bearings that were substantially over rocky reef. The remainder of the method is as described above.

Results

Abundances of abalone among all size classes were relatively low and few predatory 11-arm sea stars were encountered (Table 4). The length frequency distribution of abalone sampled from the survey area showed a large proportion of abalone above the legal minimum length for harvesting (Fig. 2). Sand coverage was relatively low in all transects (Fig 2).

After an initial survey of the area, one tag and no hatchery juvenile were found, consequently the search was continued, turning boulders and searching as thoroughly as practicable during a total search time of 2 hours and 5 minutes. During this time a total of 13 release modules were found, three additional tagged abalone, one living and one dead hatchery abalone (Table 7) and 37 natural juveniles (size range 13–48 mm).

Table 4. Abalone and 11-arm sea star abundance (no./transect) at the Patches re-seeding site, Port Fairy, Western Victoria.

Transect bearing (deg)	Diver	Abalone counts <80 mm	Abalone counts <120 mm	Abalone counts >120 mm	Mortality	11-arm seastars	No. abalone collectedin 5 min.	Sand Cover (%)	Deployment modules found
0	C	2	2	5	0	0	7	10%	1
270	C	0	0	3	3 (juv)	1	9	5%	1
150	C	1	1	4	0	0	16	0%	0
330	B	0	0	2	0	0	13	10%	0
240	B	2	1	2	2	0	5	5%	1
180	B	0	2	7	0	2	11	0%	0

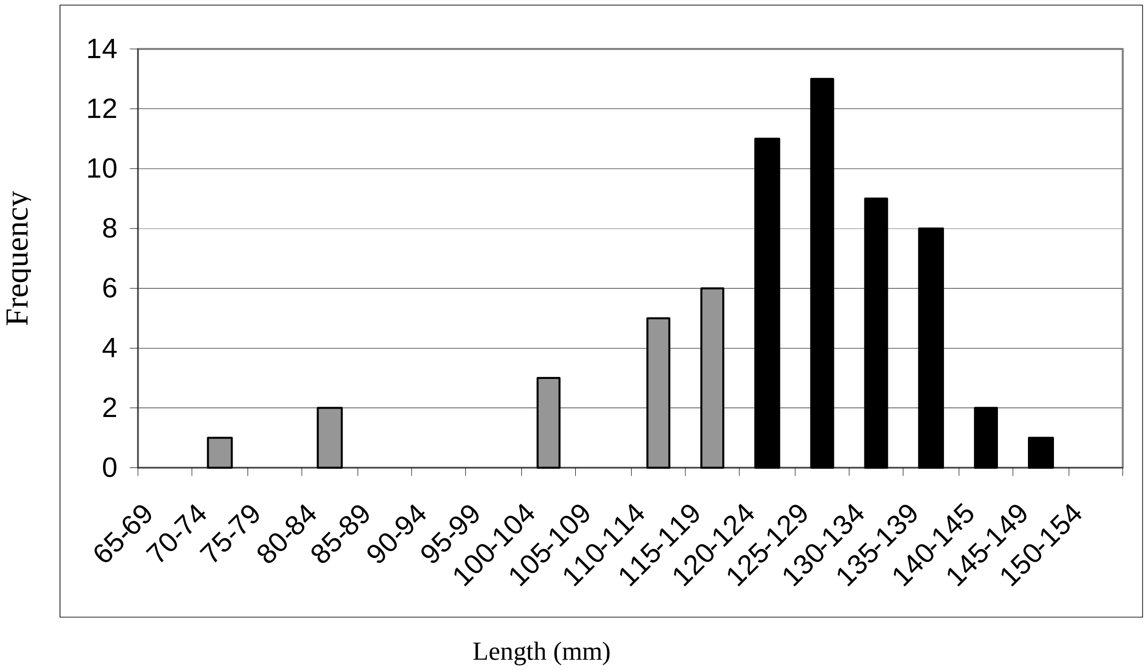


Figure 2. Length-frequency distribution of blacklip abalone collected from the Patches re-seeding site, Port Fairy, Western Victoria (n=61; grey bars = undersized, black bars = legal sized).

The five juvenile abalone encountered on the transect surveys were either from natural settlement or unable to be assessed due to their inaccessible locations within the reef topography (Table 4).

Shell appearance indicted that three juvenile abalone collected and measured aboard the boat were from a natural settlement event (Table 4).

Given the lack of obvious re-seeded abalone, the divers continued their searches for re-seeded juveniles, for a total searching time 2.5 hours. During this time one living hatchery juvenile was recovered, it measured 82 mm and was approximately 34 mm at time of release (growth increment = 48 mm). Eight abalone shells from hatchery-reared juveniles that had died were located with most showing substantial annual growth 37 ± 6 (s.e.) mm (Table 5).

Table 5. Mortalities, lengths and growth increments among hatchery-reared juvenile abalone re-seeded at the Patches, Port Fairy, Western Victoria.

Length at release (mm)	Length at death (mm)	Growth before death (mm)	Approx time of death
35	43	8	Long time ago
42	55	13	Some time ago
33	73	40	Some time ago
29	69	40	Some time ago
39	79	40	Some time ago
38	87	49	Quite Recent
30	89	59	Quite Recent
37	86	49	Very Recent

Discussion

Having since received clearer information about where the releases occurred, our survey may have been better positioned in the centre of the southern half of this reef, however apparently the *"horseshoe in the reef"* was the site for many of the release modules and it would be reasonable to assume that the abalone would disperse equally in both directions.

One of the local Port Fairy abalone divers has had better success during earlier *ad hoc* surveys, possibly indicating that either the abalone have become more cryptic over time, the "hatchery marker" is becoming more difficult to see, or that mortality may be increasing for some unknown reason.

This site, at time of this survey, appears to be almost completely unsuitable for re-seeding. Sponge and ascidian cover on the reef surface is almost 100% and the crevices present are relatively wide and provide no protection for juvenile abalone. The boulders / rocks that occurring here are either on the sand edge and sand-blasted clean by wave action or are covered in sponge and interspersed with sand, thereby providing little or no cryptic habitat.

Sand movement appears to be a problem for monitoring and possibly survival. At the time of the survey, reef on the seaward side had recently been uncovered, after previously being covered with sand, leaving the reef surface with only dead-looking coralline algae only on. This sand appears to have moved across the reef, being deposited in many of the gutters, crevices and around boulders in its path and then burying the reef on the shoreward side. This inshore area of the reef appeared to be sand but there was live *P. comosa* protruding from the sand.

Again this site may be useful as a test site, only because of its isolation, but is certainly unsuitable as a site for commercial regeneration.

Adult abalone were observed to be larger, older individuals that have survived historic fishing pressure (commercial and recreational) and the harsh environment at this location.

III. WADA Reseeding and Translocation Site "The Passage" – Portland

Survey Date: 25/02/06

Method:

The reseeding site was located and 30 metre transects completed by research divers using the method described above.

Background

No formal preliminary surveys were conducted within the area prior to translocation, so no temporal comparison is possible at this stage.

On 12/10/03 42 release modules were placed at this location (area less than 100m diameter) containing well in excess of 30,000 hatchery juveniles, and on 22 and 26/02/05 approximately 3000 mature abalone from Murrells were translocated to the Passage reef, of these approximately 400 were tagged.

Initial expectations were that the translocated abalone (tagged or not) would be placed at the reseeding site. Upon beginning this process one commercial abalone diver made the following observations ……"*I felt that the site was not very suitable because it was generally flat terrain, interspersed with shell grit-sand holes and the wrong type of flora. Suitable sitting sites for abalone were hard to find……*" and …" …*Finding suitable reef to relocate the abalone onto was very slow going (taking a lot longer than harvesting) Clean rocks, gutters and general good sitting sites are at a premium as some habitat change has taken place.*" To this end approximately two bins (100 - 300) of tagged abalone were placed at this location.

Past surveys have located many of the release modules, and re-located 22 hatchery juveniles on 05/02/04 in 25 minutes searching and 7 hatchery juveniles in 40 minutes searching on 01/08/4.

Comments by abalone diver on 05/02/*04* "……*I do not have much faith in this site, the reasons for which are:*

- *The solid reef is relatively flat, there are no cracks, crevices etc in it's surface and I am sure that sand would just flow up it during a sea. It has that typical flat bull kelp bottom appearance. This type of bottom is very seldomly productive*
- *There are no or very few overhangs, ledges or cracks around the base of the solid reef. The major features of which are squarish undulations.*
- *The boulders in general have been "cemented" into the bottom by sand and shell grit.*
- *Those boulders that are sitting on the bottom are generally sitting in areas where they look like they could move and roll around or be sanded up in a sea.*

Basically there is very little cryptic habitat, if these hatchery juveniles have found shelter it is going to be very hard to relocate them in any numbers*.*

And following the survey on 01/08/04 the following comment was made
"…I still have very little faith in this site. The fact that natural juveniles are using the underside of our release modules as habitat should give some support to my observations…"

Results

Abundances of abalone among all size classes were relatively low, no mortalities were observed within transects and few predatory 11-arm sea stars were encountered (Table 6). Despite the small numbers the length frequency distribution of abalone sampled from the survey area showed a pattern typical of blacklip abalone populations generally (Fig. 3). Sand coverage was variable but in all instances was less that the area of rocky substrate (Fig 3).

After an initial survey of the area, one tagged and no hatchery juvenile were found, consequently the search was continued, turning boulders and searching as thoroughly as practicable during a total search time of 2 hours and 5 minutes. During this time a total of 13 release modules were found, three additional tagged abalone, one living and one dead hatchery abalone (Table 7) and 37 natural juveniles (size range 13–48 mm).

Table 6. Abalone and 11-arm sea star abundance (no./transect), abalone mortality and sand cover at the Passage translocation & reseeding site, Portland, Western Victoria.

Dir.	Diver	Juv	Under 120 mm	Over 120 mm	Morts	11 arms	Abs in 5 mins	% Sand Cover	Deployment Modules Found
270	DF	0	3	4	0	1	2	15%	0
150	DF	2	0	0	0	0	14	0%	3
30	DF	0	3	7	0	0	7	0%	1
120	BW	0	0	1(Tag)	0	1	4	5%	1
60	BW	0	2	6	0	0	13	25%	0
300	BW	0	1	9	0	3	12	0%	1

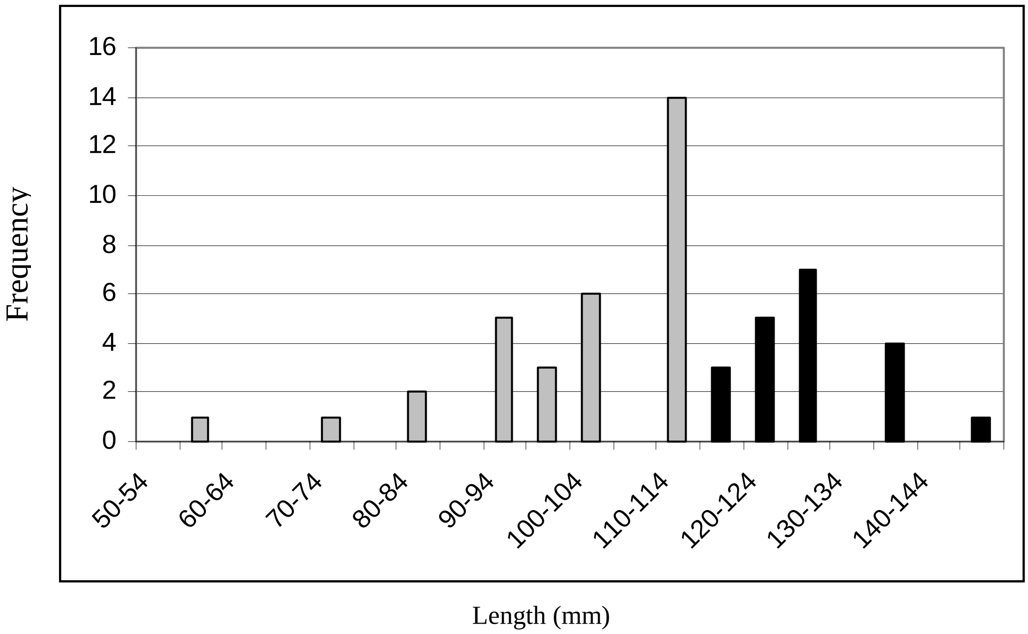


Figure 3. Length-frequency distribution of blacklip abalone collected from the Passage translocation site, Portland, Western Victoria (n=52; grey bars = undersized, black bars = legal sized).

Among the 400 translocated abalone that were tagged prior to release one year earlier, the four that were recaptured during this survey showed annual growth increments in shell length of 2–12mm (Table 8). In contrast the single living hatchery reared abalone recaptured showed an increment of 51mm which was consistent with juvenile growth patterns.

Table 7. Shell lengths, growth and survival of hatchery-reared juveniles recaptured at the Passage, Portland, Western Victoria.

Size at Release (mm)	Size at Recapture(mm)	Growth increment (mm)	Survival
36	37	1	dead
33	84	51	alive

Table 8. Lengths at release and recapture among tagged translocated abalone recovered from the Passage, Portland, Western Victoria.

Blue Tag No	Release length (mm)	Recapture length (mm)	Growth (mm)
4457	115	121	6
4472	122	127	5
4539	120	122	2
4590	111	123	12

Discussion

The abundances of abalone encountered within transects (average of 1.5 undersize and 4.5 legal size) were low when compared to typical commercially fished reefs, and these estimates follow the introduction of both hatchery juveniles and translocated stock.

The amount of recent natural recruitment that was observed by turning over boulders, was encouraging, but the survival rate for these juveniles is unknown.

The lack of abalone shell (natural or introduced) in the naturally occurring shell deposits on this reef suggested mortality rates were low and prospects for survival should be good.

Possibly this site was unsuitable as a test site, due to the lack of suitable habitat in the immediate vicinity and that the release area is a small section of a very large reef complex across which abalone could freely disperse beyond the survey area.

As one experienced diver commented, *"…Inshore of reseeding site. More suitable habitat…..2-3 metre high cryptic boulders, bull kelp on the tops interspersed with Phyllospora. Few resident abalone..."*

The abalone might have behaved as desired in a commercial rehabilitation effort, in so far as they dispersed and colonised suitable habitat.

Improved analysis of growth increment data for Victorian abalone populations

David Bardos

Ecological Dynamics

March 2006

<u>Report for Abalone Project – Primary Industries Research Victoria</u>

Summary of growth data analysis procedure

Evaluation of Gompertz fit to tagging data with varied times-at-liberty.

1. Use Estimatrix to fit tagging data and obtain parameter estimates.
2. Obtain an L_∞ value for each data point (using its l_1, Δl and Δt values and the fitted estimate for g) via Equation 10 from the Gompertz paper, i.e.

$$L_\infty(\Delta l) = \left[(l_1 + \Delta l) l_1^{-e^{-g\Delta t}} \right]^{\frac{1}{1-e^{-g\Delta t}}}$$

3. Choose a convenient time-at-liberty (Δt) to which all increment data will be standardized. For example, choose $\Delta t = 1\mathrm{Yr}$.

4. Using the individual L_∞ and l_1 values, the convenient Δt from step 3 and the fitted estimate for g, obtain a standardized increment from each data point using Equation 3 from the Gompertz paper, i.e.

$$\Delta l(\Delta t) = L_\infty \left(\frac{l_1}{L_\infty} \right)^{e^{-g\Delta t}} - l_1$$

5. Generate forward simulations of growth increments from the Gompertz model using the fitted parameter estimates, over a relevant range of l_1 values, using the same Δt as in step 4.

6. To evaluate the fit, plot the simulated increments from step 5 alongside the standardized data from step 4 and compare.

Table 1. Evaluation of quality of length increment datasets for different reefcodes throughout the Victorian abalone fishery.

	1	**very good**
	2	**good**
Quality key:	**3**	**fair**
	4	**poor**
	5	**very poor**

Sites with substantial numbers:

site	# of recaptures	Quality Score	3 year growth from 90 mm	3 year growth from 100mm	Fitted growth too high for small animals	Fitted growth too high at 50 mm
3JP (Julia Percy)	40	3	118.151	121.18		
3WR (Leavy's Beach)	41	4	112.424	115.951	Y	??
3KN (Killarney)	44	3	113.01	117.036		
1WS (Watersprings)	51	1	116.208	120.492		
3LR (Lighthouse)	59	2	107.513	114.309		
24LR (Little Rame)	61	2	109.07	113.073		
24SR Benedore	61	1	134.613	136.876		
3TC (The Craggs)	77	2	115.399	118.996		
13BR (Bushrangers)	79	5	114.505	117.206	Y	Y
24TS (Skerries)	92	4	138.579	139.241	??	Y
7	94	2	120.103	122.717		
24GU (Gabo Island undersized)	96	4	127.817	129.886	??	??
23BR (Big Rame)	102	1	142.594	144.495		
23PH (Pt. Hicks)	106	1	115.442	122.276		
23IP (Island Point)	118	1	131.672	133.705		
24BP (Bastion Pt)	138	4	118.293	122.749	Y	??
24SP (Sandpatch)	157	1	133.093	136.116		
13FB (Flinders)	175	3	102.306	109.012		
23PP (Petrel Pt)	230	1	127.762	130.206		
"tulla" (Tullaberga)	239	1	107.922	112.062		
"cent" (Seal Rocks)	350	1	104.872	110.559		
Pt Cook (old)	439	1	107.873	112.687		
11PC (Pt Cook)	508	1	107.415	111.84		
"west" (Boulder Pt)	531	1	112.68	117.913		

(note: 11PC overlaps heavily with the old Pt Cook dataset)

Sites with small numbers:

site	# of recaptures
1HS	1
2PS	1
11SO	2
11FF	3
11KP	3
18 (East side of Prom)	3
24TH (Cape Howe)	3
1SC	3
17NI (Norman I)	4
17NS (Norman South)	4
22BR (Beware Reef)	6
24IR (Iron Prince)	7
24TI (Tullaburge Is)	7
17GG (Glennies)	8
17A (Anser I)	9
24AE (Aerodrome)	9
14N (Nobbies)	12
14WR (Woolami)	12
12PB (Portseas BackBeach)	13
23LR (Little Rame)	13
14PR (Pyramid Rock)	14
17WN (Waratah North)	15
24GI (Gabo Is)	16
1WB (Whites Beach)	16
2ON (Outside Nelson)	19
1SB (South Bridgewater)	20
12CS (Cape Schank)	27
2IN (Nelson Inshore)	32

A measure of growth speed (i.e. an alternative to the g estimate)

1. Apply Estimatrix to tagging data to obtain a fitted growth matrix (i.e. a matrix derived from the fitted Gompertz parameters).

2. Use the growth matrix to time-evolve a population initially concentrated in a single size class. Calculate the mean size after a suitably chosen number of time-steps.

We use 2mm size-classes with a time-step of $\Delta t = 1\text{Yr}$. Three different initial populations are studied, concentrated in 52mm, 80mm and 90mm classes respectively, with mean size evaluated after 3 time-steps. The distribution of each population amongst the various size classes is displayed for 5 time-steps as a density plot (Fig. 1).

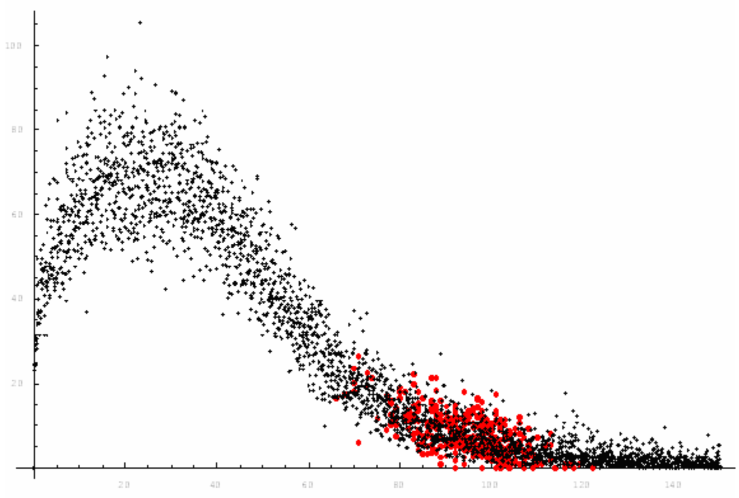
Application of the procedure to evaluate the quality of Victorian abalone growth datasets

The above procedure was applied to available tag-recapture growth increment data for different reef codes and the dataset for each reefcode was assigned a value from 1-5 representing an arbitrarily defined range from very good to very poor (Table 1). Only those reefcodes where there were 40 or more observations were included in the quality ranking. Fifty percent of the 24 datasets with sufficient recaptures were assigned a very good ranking of 1 (Table 2). Five of the datasets were assigned a poor to very poor ranking. In six instances the growth was fitted too high (Table 1).

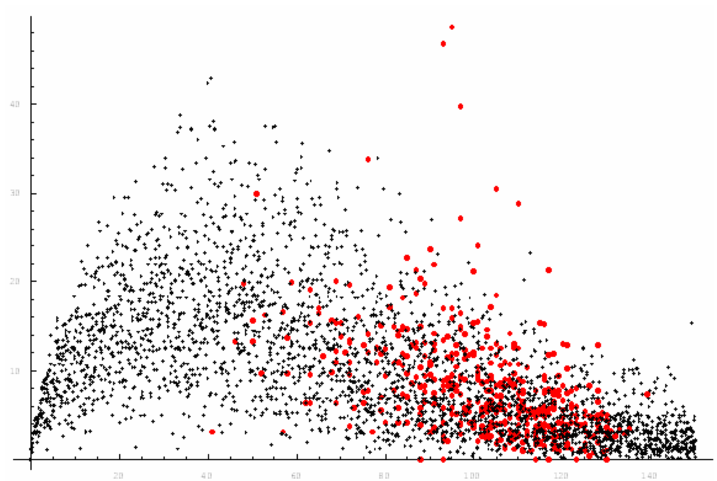
Table 2. Frequency of reefcodes with different growth data quality scores.

Quality score	Number of reefcodes
1	12
2	4
3	3
4	4
5	1

i)



ii)



iii)

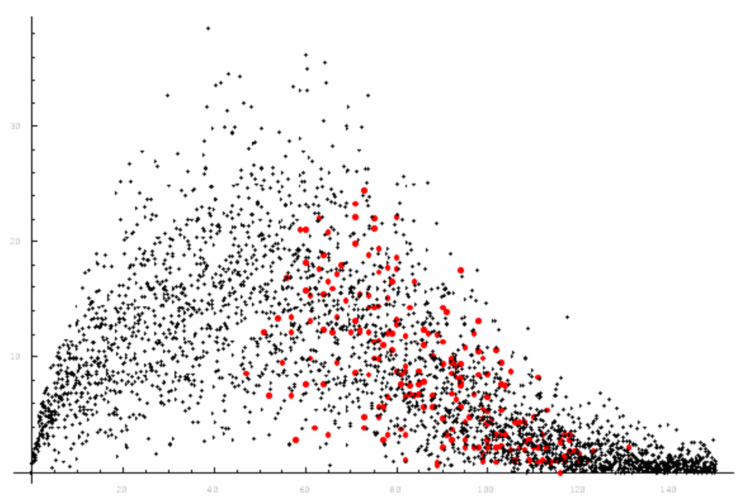


Figure 1. Examples of fits to growth for data sets from i) Central, ii) Western and iii) Eastern Zones.

Design analysis for abalone recapture experiment: surface-tagging versus bottom-tagging

The usual “surface tagging” method employed in abalone recapture experiments, in which stress due to insertion of the tag is compounded by removal to the surface, can reasonably be expected to retard the very growth of the animal that the tagging is intended to measure. Since growth data resulting from recapture experiments is an important input for the stock assessment modelling used in managing the fishery, an experiment has been proposed to assess the magnitude of any retardation of growth resulting from surface tagging. The proposed experiment calls for a substantial number of abalone to be tagged in-situ (“bottom-tagging”), whilst a control group of similar size is to be tagged by the customary surface-tagging method.

If it were found that removal to the surface for tagging causes a substantial decrease in the subsequently measured growth, then an appropriate adjustment could be made to recapture data obtained from surface tagging, prior to its use in assessment modelling.

One of the dominant features of abalone growth data is the strong observed variability in growth amongst individuals of similar initial lengths, even within populations restricted to a small locale (and thus subject to similar environmental factors). The possibility arises that even a substantial difference in growth between surface and bottom tagged animals could be masked by the strong variability usually seen in abalone growth.

This study investigates the feasibility of detecting a surface versus bottom tagging effect via the proposed experiment, given certain assumptions on the size of the effect and the expected number of recaptures.

Simulated truth

Our aim is to estimate the probability P_D of detecting an effect for a range of plausible effect sizes, effect model types, experimental numbers (assuming a 10% recapture rate) and growth variance scenarios.

We express the true effect size x_T as a fraction of the surface-tagged growth, i.e. we assume

$$\overline{\Delta l_b} = (1 + x_T)\overline{\Delta l_s}, \qquad (1.1)$$

where $\overline{\Delta l_s}$ and $\overline{\Delta l_b}$ are respectively the means of surface and bottom-tagged growth increments.

We consider two types of effect, both of which affect the average growth as described above, but differ in their effect on the variability in growth increments. In one case, denoted variance model 1 (VM=1), the standard deviations of surface and bottom tagged growth increments are identical,

$$\sigma_s = \sigma_b \qquad (1.2)$$

whilst in the second case, denoted variance model 2 (VM=2), increased growth due to bottom-tagging is accompanied by a reduction in standard deviation:

$$\sigma_b = \frac{\sigma_s}{1 + x_T} \qquad (1.3)$$

The rationale for the latter assumption is that surface tagged animals are subjected to two perturbing effects and may respond to each in a highly variable manner, so that the variability in the resulting increments is a compounding of two sources of variability. In contrast, only one of these is present for the bottom-tagged animals, which therefore could be expected to display correspondingly less variability. Note that both variance models imply that the standard deviation as a fraction of the mean, i.e. the ratio

$$r = \frac{\sigma}{\overline{\Delta l}} \qquad (1.4)$$

is smaller for bottom tagging than for surface tagging. We consider two values (i.e. two "variance scenarios") for this ratio when simulating surface tagging data: $r_s = 0.4$ and $r_s = 1.0$. These values span the range typically observed in growth increment data in the central zone. The ratio r_b for simulated bottom tagged data will depend on effect size x_T and on the variance model in accordance with equations (1.1 - 1.3).

Expressed in percentage terms, we consider effect sizes of $x_T = 5, 10,15,20 \text{ and } 25\%$, along with the null scenario $x_T = 0$.

Simulated growth increment datasets of size $n = 40,80 \text{ and } 160$ (that is, containing n simulated increments) were generated for all combinations of the above scenarios, with 10 batches of 100 simulated "replicate" datasets generated in each case to simulate a range of experimental outcomes.

Thus we obtain a total of 1000 datasets for each combination of x_T, r_s n and VM, giving a total of 72000 simulated datasets. For the purpose of referring to a particular simulated truth scenario with effect strength x_T, we will use the notation $\boldsymbol{\theta}_T = \{x_T, n, r_s, \text{VM}\}$, whilst $\boldsymbol{\theta}_0 = \{0, n, r_s, \text{VM}\}$ represents the null (zero-effect) scenario with all other parameters identical to $\boldsymbol{\theta}_T$.

On the assumption that equal numbers of surface (i.e. $x_T = 0$) and bottom tags are done experimentally, the above datasets with $n = 40,80 \text{ and } 160$ provide simulations of experiments involving 800,1600 and 3200 experimental tags respectively, (assuming a uniform recapture rate of 10%).

Estimated truth

We now treat the datasets as if they were from real experiments, i.e. as if we are in possession of the data, but not of the true means and variances used to generate them. Each of the simulated "true" datasets is estimated by a simple Bayesian model, assuming the increments to be gamma distributed. Estimation in performed in the WinBUGS package, employing the Gibbs sampling variant of Markov Chain Monte Carlo (MCMC), yielding posterior distributions of the mean increment for each dataset. This estimation is performed on batches of 100 simulated datasets for each value of x_T simultaneously.

Now for each dataset size n, variance scenario r_s and variance model VM, we then have batches of 100 posterior distributions $p_{i,x_T}(Y)$ for each true effect size x_T, where Y denotes a dummy probability variable for the mean growth increment $\overline{\Delta l}$ and $i \in \{1, 2, \ldots 100\}$ is the label identifying a particular simulated dataset within the batch. Each distribution $p_{i,x_T}(Y)$ can be paired with each of the 100 corresponding posterior distributions $p_{j,0}(Y)$ for the control datasets. From every such pair, a cumulative probability distribution function (CDF) can be derived

$$P_{\boldsymbol{\theta}_T}^{i,j}(X) = \iint p_{i,\boldsymbol{\theta}_T}(Y)\, p_{j,\boldsymbol{\theta}_0}(Z)\ \mathrm{H}(Y - Z - XZ)\, dYdZ, \qquad (1.5)$$

where X is a dummy probability variable for the effect size x_T, i.e. for the fractional difference between the true distribution means estimated from simulated bottom dataset i and simulated surface dataset j, whilst H is the Heaviside step function:

$$H(y) = \begin{cases} 1, & y > 0 \\ 0, & y < 0 \end{cases}. \qquad (1.6)$$

Instead of obtaining the cumulative distributions $P_{\boldsymbol{\theta}_T}{}^{i,j}\left(X\right)$ by performing the double integral (1.5) over the posterior distributions, we instead obtain them directly from the WinBUGS MCMC runs by evaluating

$$P_{\boldsymbol{\theta}_T}{}^{i,j}\left(X\right) \simeq \frac{1}{N}\sum_{k=1}^{N} H\left(y_k - z_k - X\, z_k\right), \qquad (1.7)$$

where y_k and z_k are the MCMC iterates for $\overline{\Delta l_b}$ and $\overline{\Delta l_s}$ from datasets i and j respectively and N is the number of MCMC iterates.

Thus for each scenario we obtain batches of 10000 distributions for the effect size, with each distribution $P_{\boldsymbol{\theta}_T}{}^{i,j}\left(X\right)$ resulting from estimation of a simulated "experiment". Each of these distributions can be used for hypothesis tests, in which we specify an effect-size hypothesis x_h to be tested (i.e. we test for $x_T > x_h$), and a confidence-level probability p_{CL} to be used in the hypothesis tests. That is, the outcome of the hypothesis test applied to $P_{\boldsymbol{\theta}_T}{}^{i,j}\left(X\right)$ is the binary detection index $d^{i,j}$ given by

$$d^{i,j}(\boldsymbol{\theta}_T, x_h, p_{CL}) = H\left(P_{\boldsymbol{\theta}_T}{}^{i,j}\left(x_h\right) - p_{CL}\right), \qquad (1.8)$$

where once again H represents the unit step function. Thus $d^{i,j} = 1$, signifying detection, if the posterior probability that "the effect size is greater than x_h" exceeds the confidence level probability p_{CL}, while $d^{i,j} = 0$ otherwise.

We will always set x_h to be smaller than x_T, rather than simply putting $x_h = x_T$ (i.e. rather than using a hypothesis test asking "is the effect size at least x_T?"). A hypothesis test with $x_h = x_T$ would be uninformative: even with a large dataset, we wouldn't expect to obtain a probability much greater than 50%, because the posterior density for effect-size will be centred on x_T, so there will be roughly as much probability below x_T as above it.

Design analysis

The design parameter over which we have direct control is the number of tagged abalone, which provides reasonable control over the number of recaptures, subject to variability in recapture rates. The purpose of the design analysis is to evaluate the likely performance of experiments providing n recaptures, given a true effect size x_T, some assumptions about the variance of the increments (specified in the parameter r_s) and the impact of surface vs. bottom tagging on the variance (specified in the variance model VM), all of which are summarised in the truth scenario label $\boldsymbol{\theta}_T$. Experimental performance for a range of truth scenarios is evaluated under a range of hypothesis-testing parameters (x_h and p_{CL}) that might be applied to analyse real experimental data. Design performance is expressed as a detection probability p_D for which an estimate p_D^m, resulting from batch number m for scenario $\boldsymbol{\theta}_T$, is provided by

$$p_D^m(\boldsymbol{\theta}_T, x_h, p_{CL}) = \frac{1}{10000}\sum_{i=1}^{100}\sum_{j=1}^{100} d^{i,j}(\boldsymbol{\theta}_T, x_h, p_{CL}), \qquad (1.9)$$

i.e. the fraction of the 10000 simulated experiments yielding positive hypothesis test results.

Error analysis

Each estimate p_D^m resulting from a particular batch of simulated data can be considered to be derived from a Monte Carlo procedure that begins with the pseudorandom generation of data, proceeds via MCMC estimation of posterior distributions from that data and concludes with an aggregation of hypothesis tests performed on these distributions. The associated Monte Carlo error will decrease with batch size, however in order to control the eventual error we maintain a constant batch size and take the mean of a sufficiently large number N_B of batches. Thus for our final estimate of p_D, we calculate

$$\overline{p_D} = N_B^{-1} \sum_{m=1}^{N_B} P_D^m \qquad (1.10)$$

along with a sample standard deviation

$$\widehat{\sigma_D} = \sqrt{N_B^{-1} \sum_{i=1}^{N_B} \left(P_D^i - \overline{p_D}\right)^2} \quad . \qquad (1.11)$$

Although the distribution for p_D^m resulting from the Monte Carlo procedure may be non-normal, the Central Limit Theorem guarantees that the mean $\overline{p_D}$ is normally distributed with standard deviation σ_D approaching $\left(N_B\right)^{-1/2}\ \widehat{\sigma_D}$ for large numbers of batches, i.e.

$$\sigma_D \rightarrow \frac{\widehat{\sigma_D}}{\sqrt{N_B}} \quad \text{as} \quad N_B \rightarrow \infty \, . \qquad (1.12)$$

In practice we simply employ $\left(N_B\right)^{-1/2}\ \widehat{\sigma_D}$ as an error estimate for $\overline{p_D}$, with $N_B = 10$ (where each batch comprises 10^4 simulated experiments) proving adequate for the present purpose.

Results

Two different approaches are taken in selecting effect-size hypotheses x_h:

a) In the first, we specify a series of fixed values $x_h = 0.05, 0.1, 0.15$ and 0.2. Thus the experimental design analysis amounts to asking, "how likely is it that a specific effect-size x_h will be detected for a true effect size x_T". Since the true effect sizes investigated range from $x_T = 0$ through to $x_T = 25\%$, the fixed effect-size hypotheses are not always substantial relative to x_T, but nevertheless always exceed 5% of the surface-tagged growth, which might be considered a minimum effect-size of interest from a fisheries viewpoint. Results are presented in the form of separate array-plots for each combination of variance ratio r_s and variance model VM. For each plot there are two remaining free parameters within $\boldsymbol{\theta}_T$, namely x_T and n, so that the detection probability p_D is displayed as a function $p_D(x_T, n, x_h, p_{CL})$ of four parameters:

b) In the second approach, we specify x_h as a fraction f of the true effect size, i.e. $x_h = f\,x_T$, so that the experimental design analysis amounts to asking "how likely is it that an effect-size of at least $f\,x_T$ will be detected, given a true effect size x_T". The proportions investigated are $f = 0.5$ and $f = 0.8$, corresponding to substantial fractions of the true effect size, i.e. somewhat below the true effect-size but large enough to constitute a biologically meaningful outcome. The detection probability p_D is once again displayed as a function of four parameters, in this case $p_D\left(x_T, n, f, p_{CL}\right)$, for each combination of variance ratio r_s and variance model VM.

Results for the $r_s = 0.4$, VM=1 scenario are presented in Figure 1 in the form of 2-dimensional array-plots, themselves nested in a 2-dimensional array, with the colour of each cell representing the value of p_D. This presentation might prove less than illuminating for a typical 4-dimensional function, however in the case of $p_D(x_T, n, x_h, p_{CL})$ we expect simple systematic behaviour as a function of each parameter. That is, we would theoretically expect p_D to increase monotonically with x_T and n (increasing true effect size and recapture numbers being favourable for detection), while conversely we expect p_D to decrease monotonically as x_h and p_{CL} increase, since stricter hypothesis-testing criteria should reduce the likelihood of detection.

The outer axes in Figure 1 represent x_T and n, whilst the inner axes (the axes for each nested array) represent x_h and p_{CL}. As expected, we see that detection improves consistently with distance from the outer origin, corresponding to better experimental conditions, whilst within each nested array, detection improves in the opposite direction, corresponding to milder hypothesis testing.

The fact that there are no exceptions to the outer trend suggests that sufficient numbers of Monte Carlo simulations have been performed. To confirm this, however, we examine the error estimate $\left(N_B\right)^{-1/2}\ \widehat{\sigma_D}$ for all combinations of truth ($\boldsymbol{\theta}_T$) and hypothesis-testing (x_h and p_{CL}). These estimates for the magnitude of error in $\overline{p_D}$ never exceeded 0.021, with most being substantially smaller. Since values of $\overline{p_D}$ that are of practical interest are of order 0.5 or higher, this indicates that sufficient Monte Carlo convergence had been obtained for our purposes here.

The variance ratio $r_s = \dfrac{\sigma_s}{\overline{\Delta l_s}}$ specified in the truth scenarios can of course be achieved with any choice of value for the mean increment $\overline{\Delta l_s}$, provided the standard deviation is in the correct proportion to it. We have assumed throughout the work that for any specified ratio r_s, the actual choice of $\overline{\Delta l_s}$ is unimportant to the question of how easily a certain percentage change in mean increment can be detected. That is, we assume it is the shape of the increment distribution (broad for larger r_s or sharply peaked for small r_s) that is important. For the simulations, we chose $\overline{\Delta l_s} = 10$ and thus for $r_s = 0.4$ we have $\sigma_s = 4$ and for $r_s = 1.0$ we have $\sigma_s = 10$. In order to test the assumption that only the ratio is important, the simulations for Figure 1 ($r_s = 0.4$, VM=1) were repeated using $\overline{\Delta l_s} = 1$ and $\sigma_s = 0.4$. As expected, the difference in p_D estimates for the two simulated datasets was minor, never exceeding 0.027, and for most cases (i.e. most of the cells in the array-plots) the difference was substantially less than that. Furthermore, the pattern of differences comprised a scattering of both magnitudes and signs across the outer axes (see Fig A below) indicating no consistent effect.

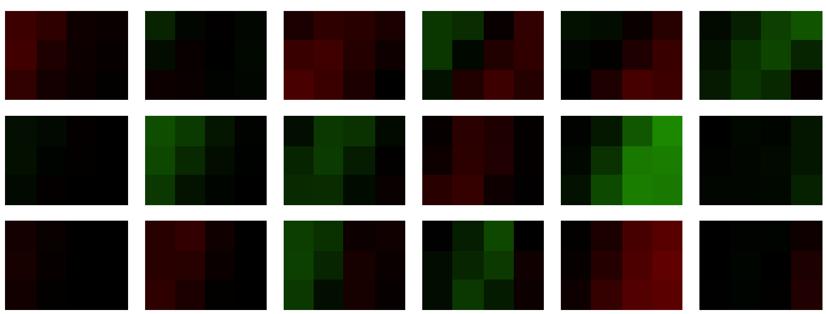


Figure A: Array-plot with axes corresponding to Fig. 1 (a), displaying differences in detection probabilities $\Delta p_D = p_D^{(\overline{\Delta l_s}=1, \sigma_s=0.4)} - p_D^{(\overline{\Delta l_s}=10, \sigma_s=4)}$ with red representing $\Delta p_D < 0$ and green representing $\Delta p_D > 0$. Colour intensity is proportional to $|\Delta p_D|$, with the strongest intensity representing $|\Delta p_D| = 0.027$.

Trends are of course visible within each nested array, in which the same simulated datasets are subjected to varying hypothesis-testing criteria. Thus, we conclude that only the ratio r_s, representing the shape of the distribution, is important. Additionally, if we accept this conclusion, the results in Fig. A provide another test of MCMC convergence and are consistent with the error estimates discussed earlier.

Although this level of MCMC error is small enough to ensure that substantial trends can be observed, it is still large enough to occasionally cause a cell (eg. in Fig. 1) to be incorrectly colour-coded, as would be true for any non-zero error level. It is extremely unlikely, however, that the colour coding will be in error by more than 1 gradation, and also very unlikely that more than a few cells per array are affected.

Results presented in Fig. 1 suggest a high likelihood of detecting substantial effects when the true effect size is 20 or 25% and also of detecting a small effect when the true effect size is 15%.

In Fig. 2 the same scenarios are represented as in Fig. 1, except that the second variance model (VM=2) is employed. Whilst a small number of cells differ between the two models (mainly indicating easier detection for VM=2), the effect is not pronounced. We conclude that although the additional signal in the second variance model does slightly enhance detection, it will have little practical impact.

Figures 3 and 4 repeat the scenarios of Figures 1 and 2 respectively, except that here the variance ratio is now $r_s = 1$. Once again, we observe a slight improvement in detection for the second variance model, however there is clearly a dramatic loss in detection probability at $r_s = 1$ compared with $r_s = 0.4$. The evident strong impact of variance on detection probability is consistent with an intuitive picture of the difficulty commonly posed by variance when attempting to draw scientific conclusions from abalone growth data.

The r_s values considered here have been chosen to represent a range of ratios typically observed in abalone increment data; the question arises as to which end of this range is more relevant, eg. for the central zone, since this ratio clearly has a major impact on the viability of an experiment.

A number of factors converge to suggest that it would be reasonable to conduct surface vs. bottom tagging experiments at locales for which large recapture datasets already exist:

1. The strong impact of r_s on the feasibility of an experiment suggests the use of existing data to try to choose a site and length range so as to minimise r_s.

2. The possibility that an experimental dataset will yield data that would be of marginal value in isolation, but which may yield useful conclusions when combined via Bayesian techniques with large existing (surface-tagged) datasets.

3. In the event that the experimental dataset does yield a clear conclusion in isolation, the credibility of this conclusion would be bolstered if a comparison with existing data suggested that the new dataset was consistent with previous data (accumulated over many years) and thus representative of the site in question. That is, a large existing dataset provides some ability to test the new data against the possibility of a systematic error (eg. something going awry in the experimental methods or an unusual environmental event).

Pursuing point (1) above, we examined the ratio r_s as a function of initial abalone length for two large recapture datasets from the central zone: Seal Rocks and Point Cook. The analysis proceeds in three stages:

a) The recapture data is fitted to the probabilistic Gompertz model using Estimatrix.
b) The resulting model parameters are imported along with the dataset into Mathematica and used to renormalise the dataset to a single time-at liberty ($\Delta t = 1\text{Yr}$). Additionally, a simulated increment dataset is generated by forward simulation of the probabilistic Gompertz model (using the fitted parameters).

c) The renormalized increment data is then used to investigate r_s as a function of initial length l_1. For each value of l_1, all Gompertz-renormalized increments having initial lengths within a specified distance Δl_1 (eg. 5mm) of l_1 are collected and the ratio $r_s(\bar{l}_1)$ calculated for that sample, where $\bar{l}_1$ is the mean initial length within the sample. Then the "sampling window" is advanced by 1mm and a new $r_s(\bar{l}_1)$ calculated for the new $\bar{l}_1$ value. The same procedure is also applied to the simulated increment dataset.

Thus two statistical pictures of $r_s(l_1)$ are developed: one from the actual dataset, renormalized via the fitted Gompertz model to 1Yr increments, while the second is derived purely from the fitted model. Here we have employed a sampling window of width 10mm (corresponding to $\Delta l_1 = 5\text{mm}$) and have sampled increments with initial lengths in the range 80-120 mm (i.e. the sampling windows were centred on 85mm through to 115mm). The resulting plots are shown in Fig. 5. The two different pictures of $r_s(l_1)$ utilise the information content of the original datasets in different ways, with the renormalized data giving more emphasis to the data points lying in the displayed l_1 range, so it is unsurprising that the results differ. The plots derived purely from the fitted model are smoother because a large number of forward simulations were used and the underlying Gompertz model is itself a smooth function of l_1. In contrast, the renormalized-data plots are based only on the data lying within the displayed l_1 range. Nevertheless, despite the evident differences, a clear trend emerging from the plots is that $r_s(l_1)$ is an increasing function in the range of interest.

Experimentally, it would therefore be advantageous if the tagging effort could be directed to the smaller size range. However, the typical scarcity of emerged abalone in the smaller l_1 range indicates a trade-off in experimental effort, so that it may be unrealistic to expect an average l_1 value below 100mm. It therefore appears, on the basis of Fig. 5 (giving equal weight to all plots), that an experimental dataset will at best yield a value of r_s intermediate between 0.4 and 1.0, so that the problematic scenarios (Figs. 3 and 4) could prove to be realistic. However, some further investigation of the Pt. Cook dataset, working directly with the data (segregated by time-at-liberty) rather than with renormalized data, would be worthwhile, since it appears to offer the best chance of minimising r_s.

In view of the poor detection probability for the $r_s = 1.0$ scenario with $n = 160$ (corresponding to 3200 experimental tags with a 10% recapture rate), we have investigated the effect of a further doubling in experimental numbers for the $r_s = 1.0$, VM=1 scenario. This could be construed as an actual doubling of experimental numbers to 6400 tags. Alternatively, 3200 tags could be assigned to bottom-tagging and existing datasets could be sampled for control (surface-tagged) data. Obviously the latter suggestion carries risks inherent in using old data as a control and a good case would have to be made, based on specific knowledge of the site, that the data are comparable.

The results depicted in Fig. 6. show some improvement in going from $n = 160$ to $n = 320$, particularly for the 25% effect size, however the limited nature of the improvement further emphasises the importance of directing effort, as far as is practical, toward reducing initial capture lengths and thus reducing r_s.

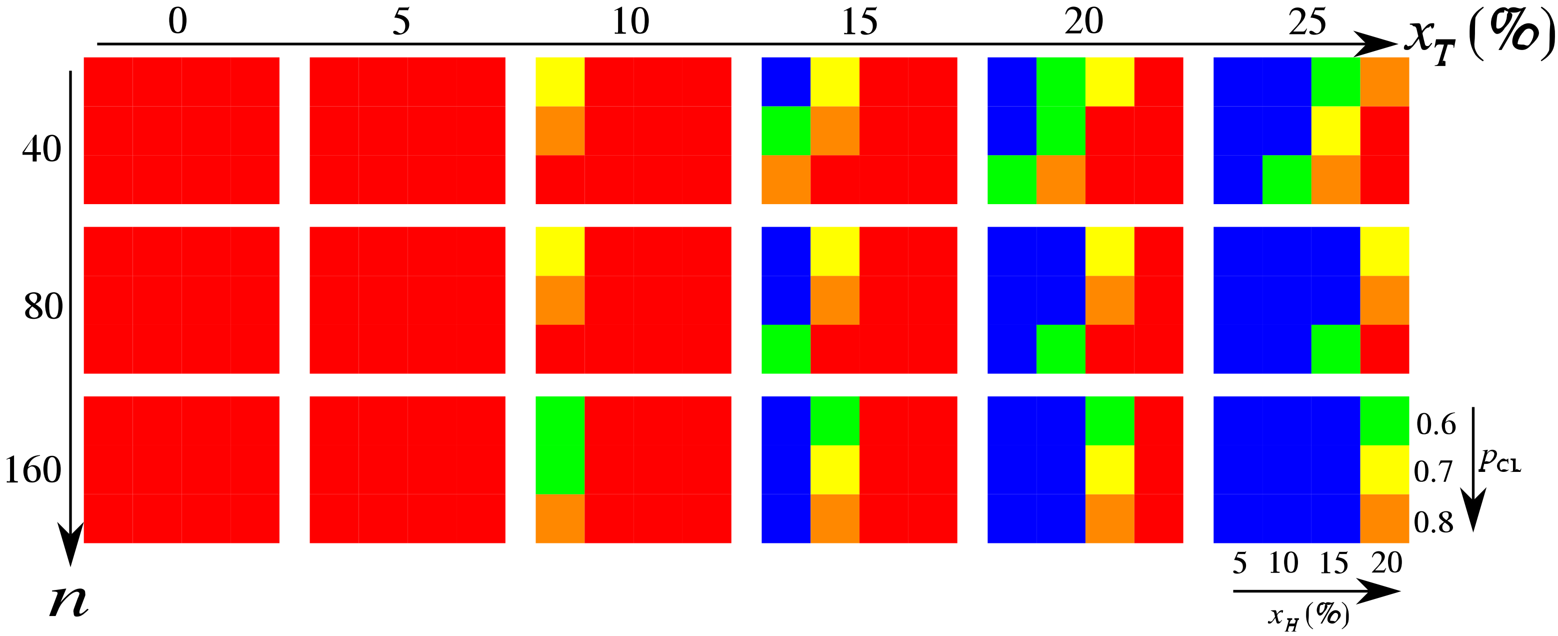
Figure 1. Variance ratio: $r_s = 0.4$, Variance Model 1

Probability of detection p_D as a function of:

x_T = true effect size (% additional growth)
n = number of data points (recaptures)
x_H = effect-size hypothesis, i.e. test for $x_T > x_H$
p_{CL} = confidence level probability employed in hypothesis tests

- Red: $p_D < 0.5$
- Orange: $0.5 \le p_D < 0.6$
- Yellow: $0.6 \le p_D < 0.7$
- Green: $0.7 \le p_D < 0.8$
- Blue: $0.8 \le p_D$

(a) Detection probability $p_D(x_T, n, x_H, p_{CL})$:



(b Detection probability as a function $p_D(x_T, n, \frac{x_H}{x_T}, p_{CL})$ of the effect-size hypothesis relative to the true effect size:

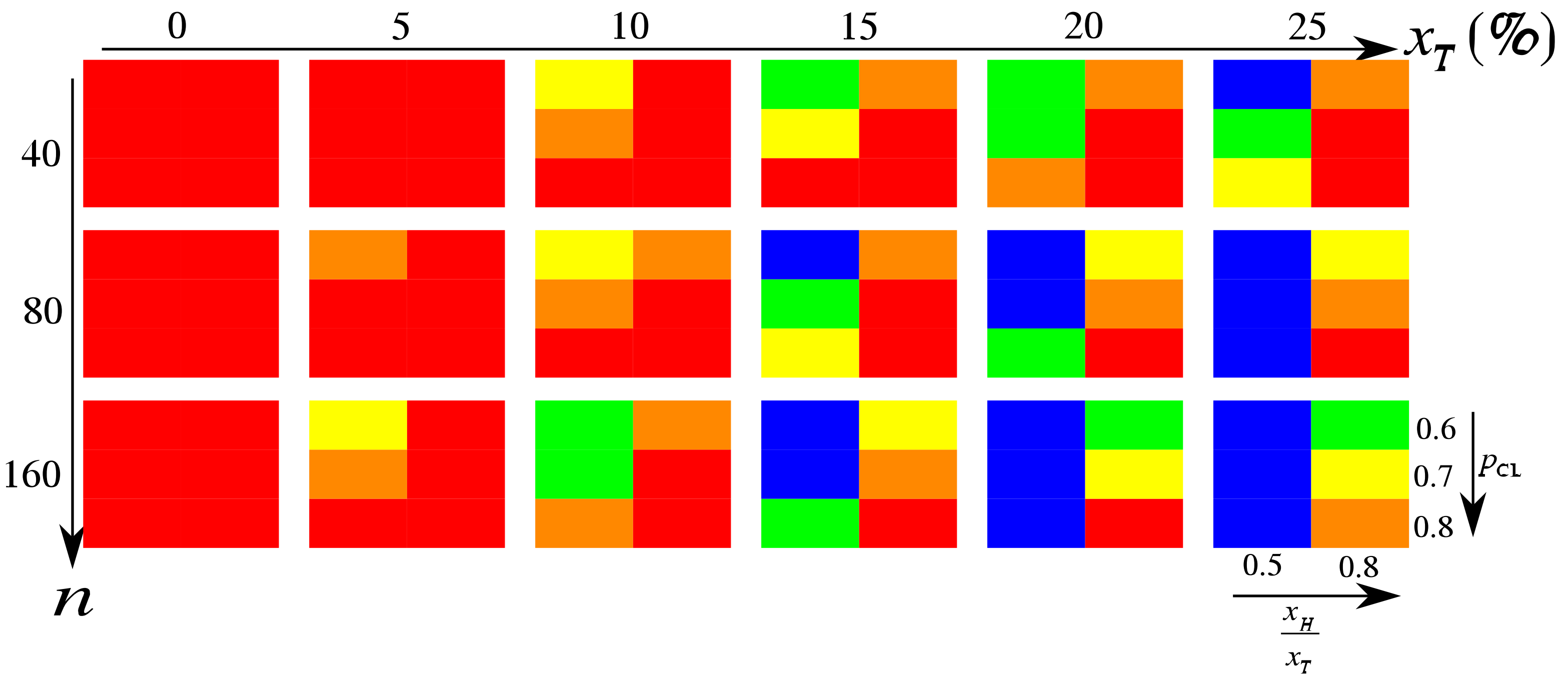
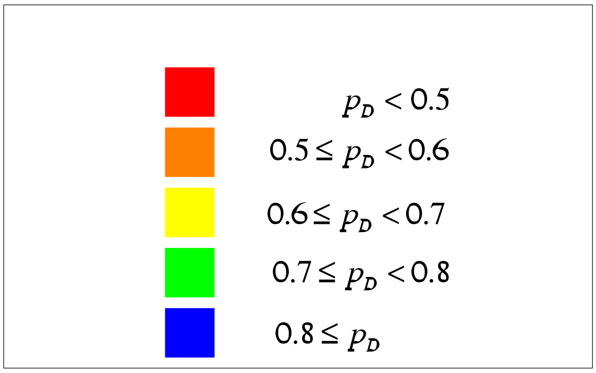


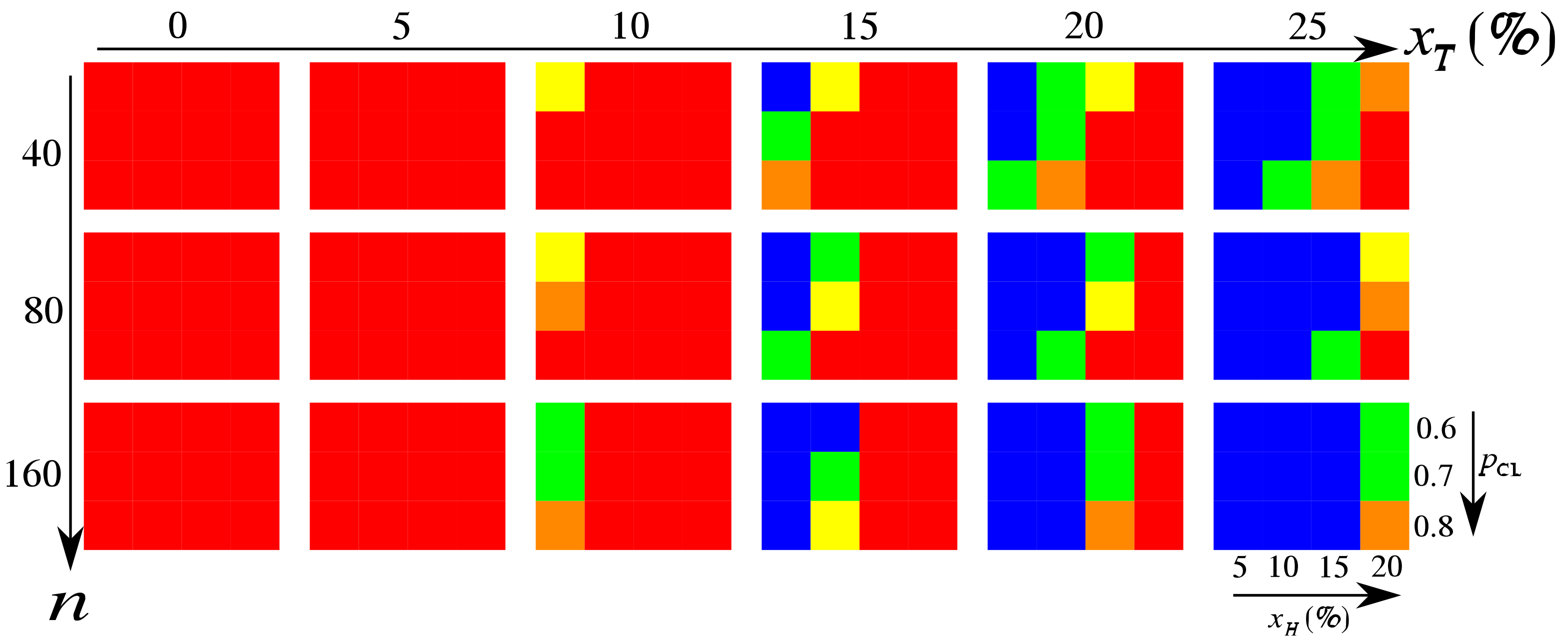
Figure 2. Variance ratio: $r_s = 0.4$, Variance Model 2

Probability of detection p_D as a function of:

x_T = true effect size (% additional growth)
n = number of data points (recaptures)
x_H = effect-size hypothesis, i.e. test for $x_T > x_H$
p_{CL} = confidence level probability employed in hypothesis tests



(a) Detection probability $p_D(x_T, n, x_H, p_{CL})$:



(b) Detection probability as a function $p_D(x_T, n, \frac{x_H}{x_T}, p_{CL})$ of the effect-size hypothesis relative to the true effect size:

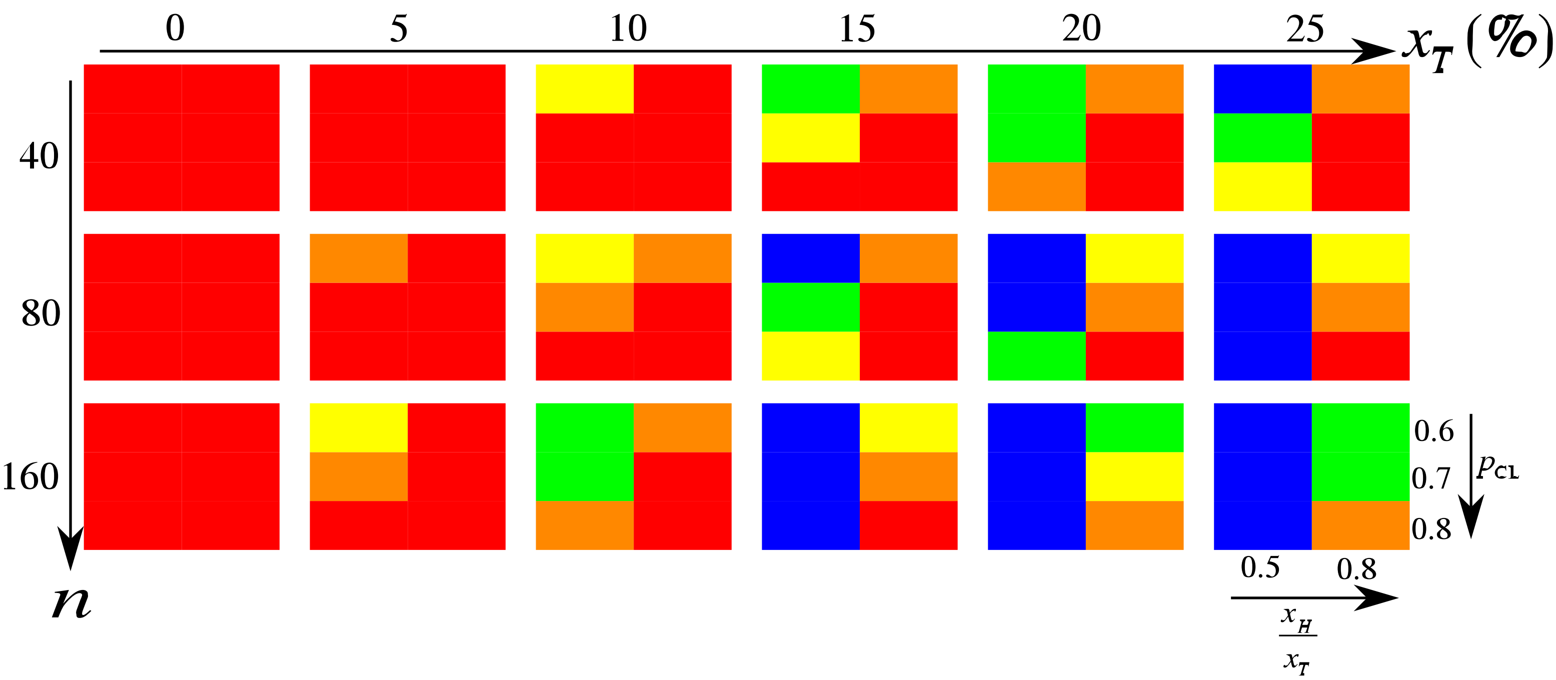
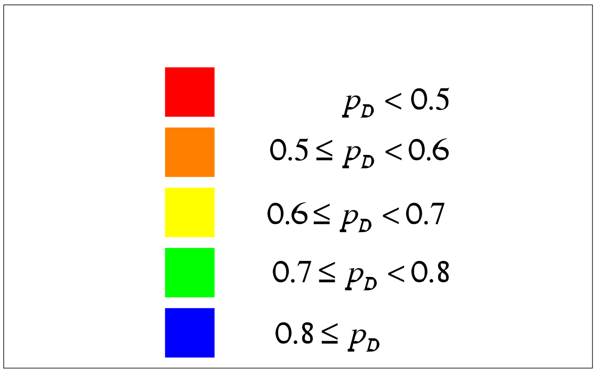


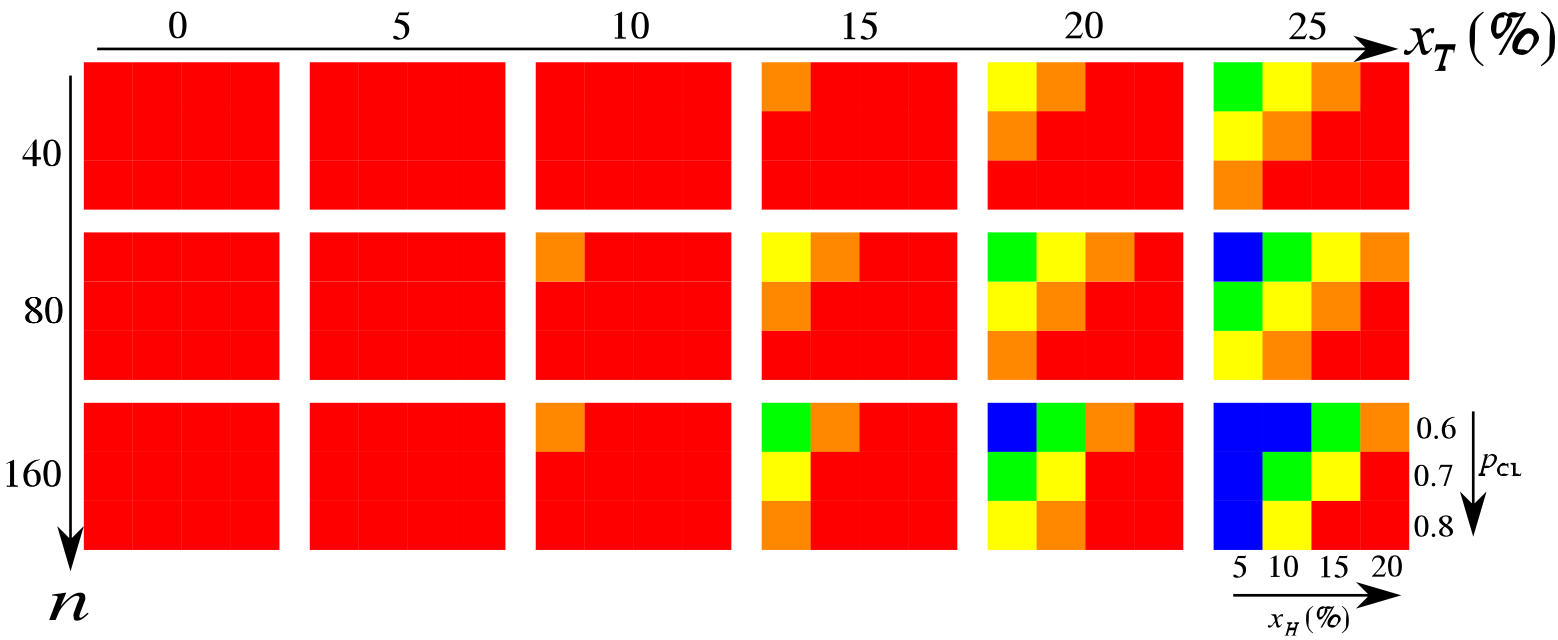
Figure 3. Variance ratio: $r_s = 1.0$, Variance Model 1

Probability of detection p_D as a function of:

x_T = true effect size (% additional growth)
n = number of data points (recaptures)
x_H = effect-size hypothesis, i.e. test for $x_T > x_H$
p_{CL} = confidence level probability employed in hypothesis tests



(a) Detection probability $p_D(x_T, n, x_H, p_{CL})$:



(b) Detection probability as a function $p_D(x_T, n, \frac{x_H}{x_T}, p_{CL})$ of the effect-size hypothesis relative to the true effect size:

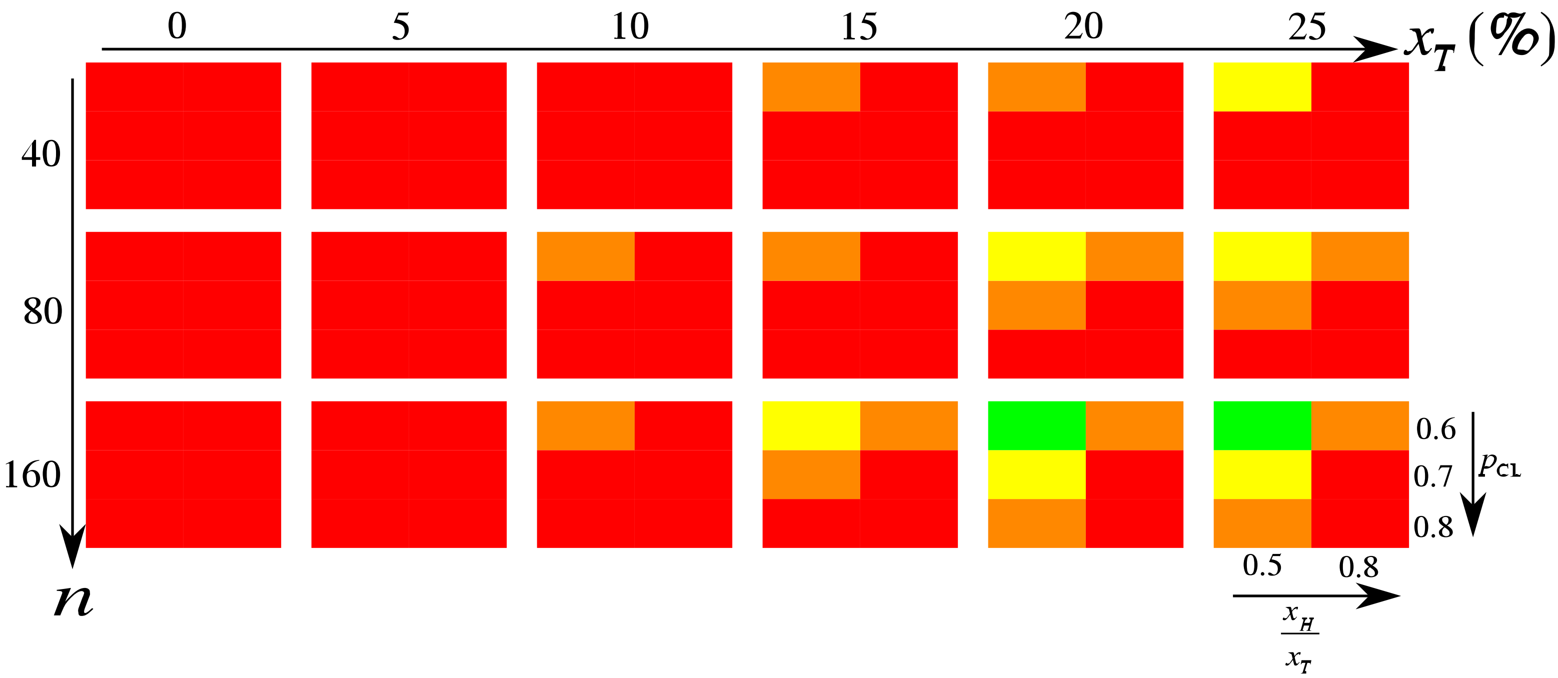
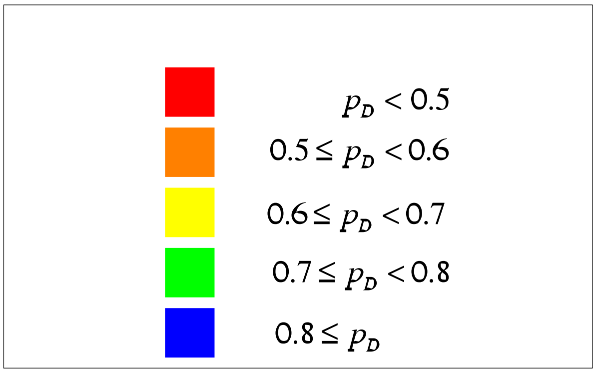


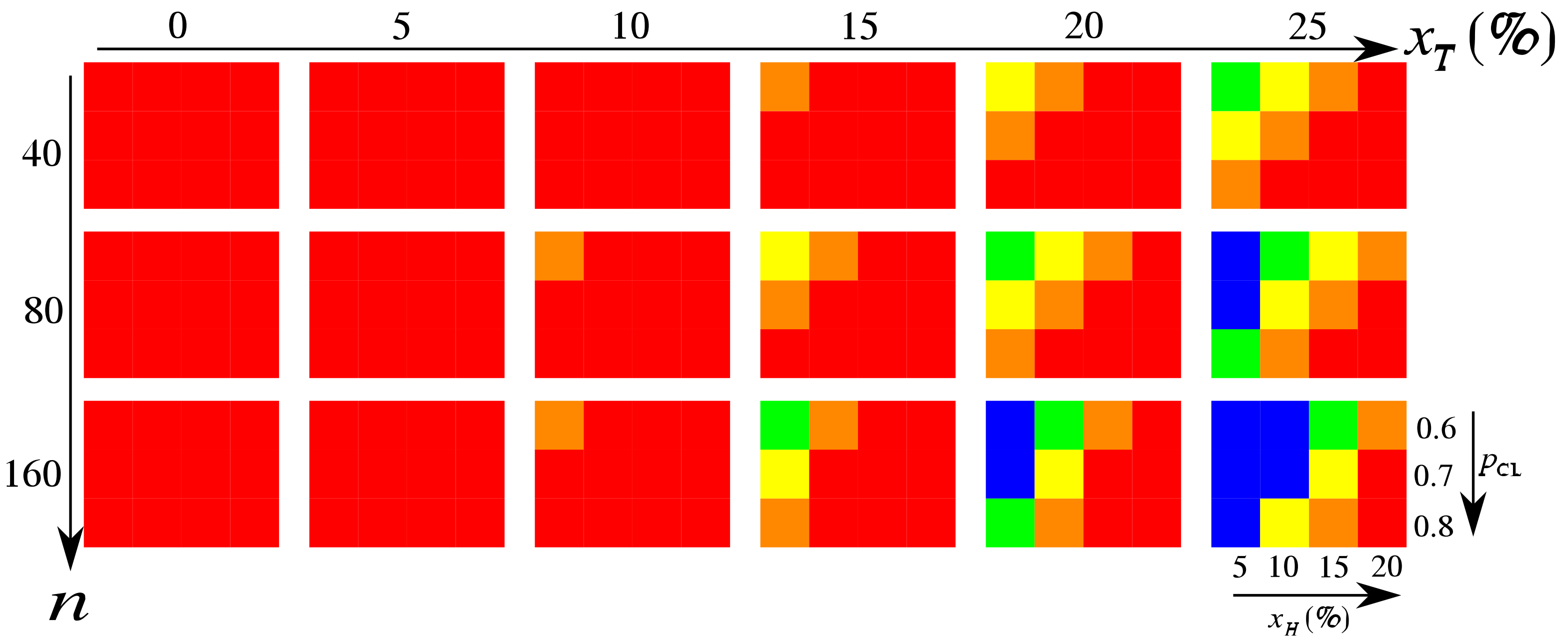
Figure 4. Variance ratio: $r_s = 1.0$, Variance Model 2

Probability of detection p_D as a function of:

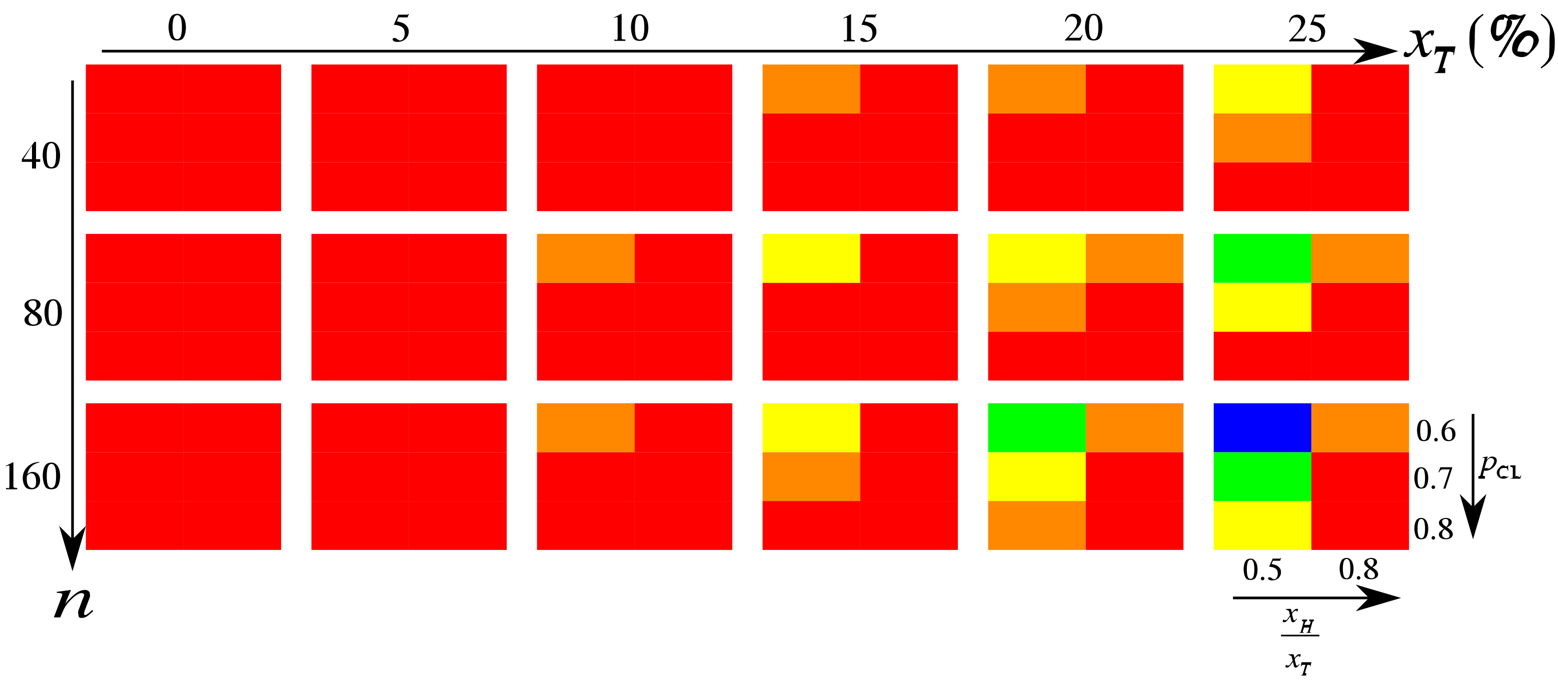
x_T = true effect size (% additional growth)
n = number of data points (recaptures)
x_H = effect-size hypothesis, i.e. test for $x_T > x_H$
p_{CL} = confidence level probability employed in hypothesis tests



(a) Detection probability $p_D(x_T, n, x_H, p_{CL})$:



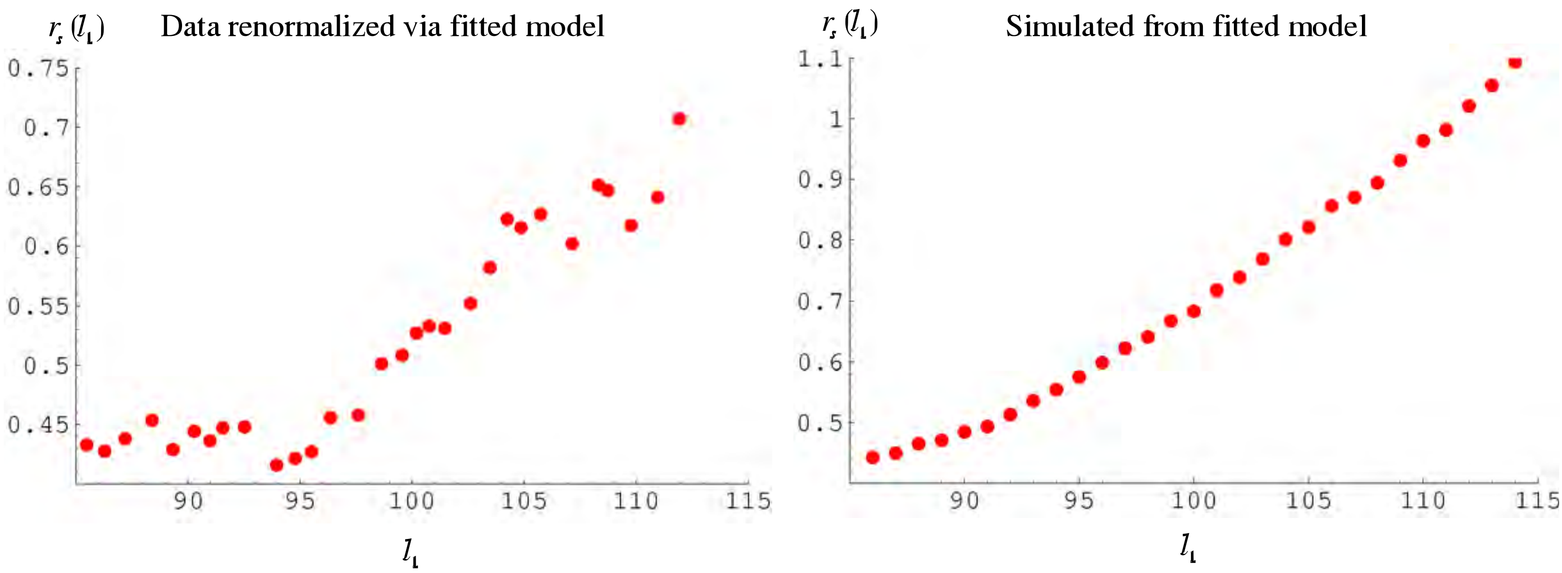
(b) Detection probability as a function $p_D(x_T, n, \frac{x_H}{x_T}, p_{CL})$ of the effect-size hypothesis relative to the true effect size:



Variance ratio r_s as a function of initial length l_1

Figure 5.

Pt. Cook



Seal Rocks

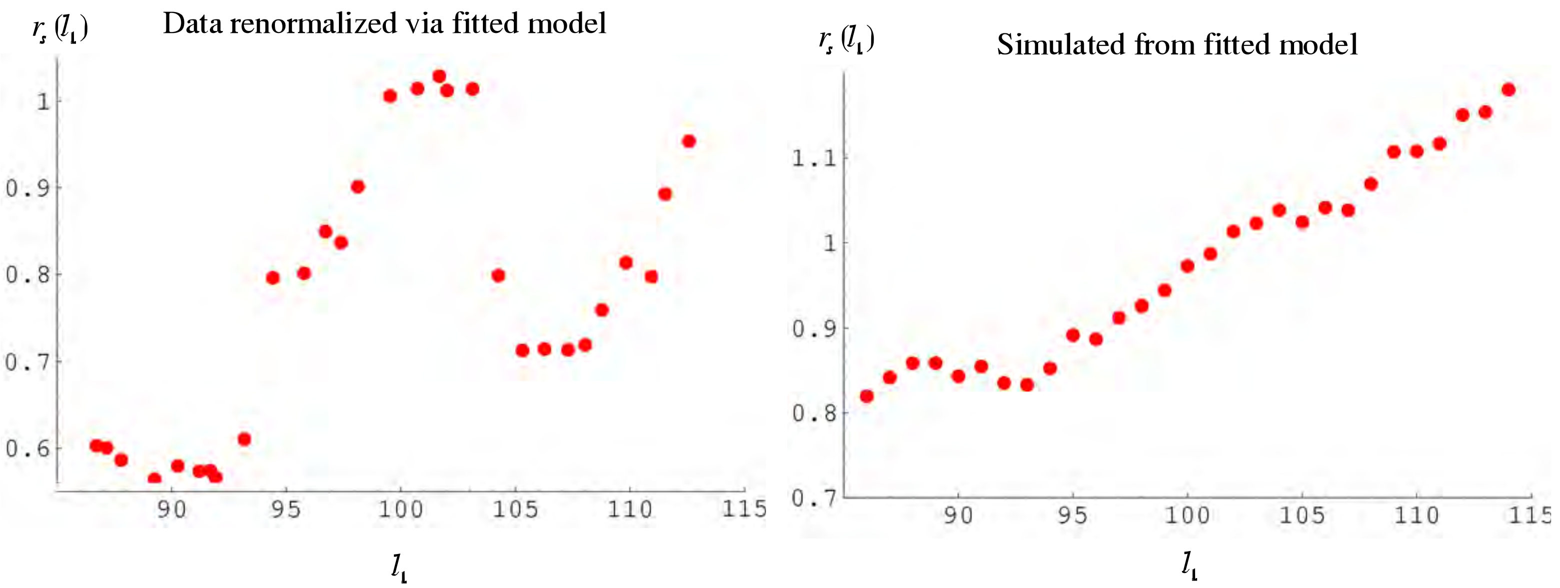
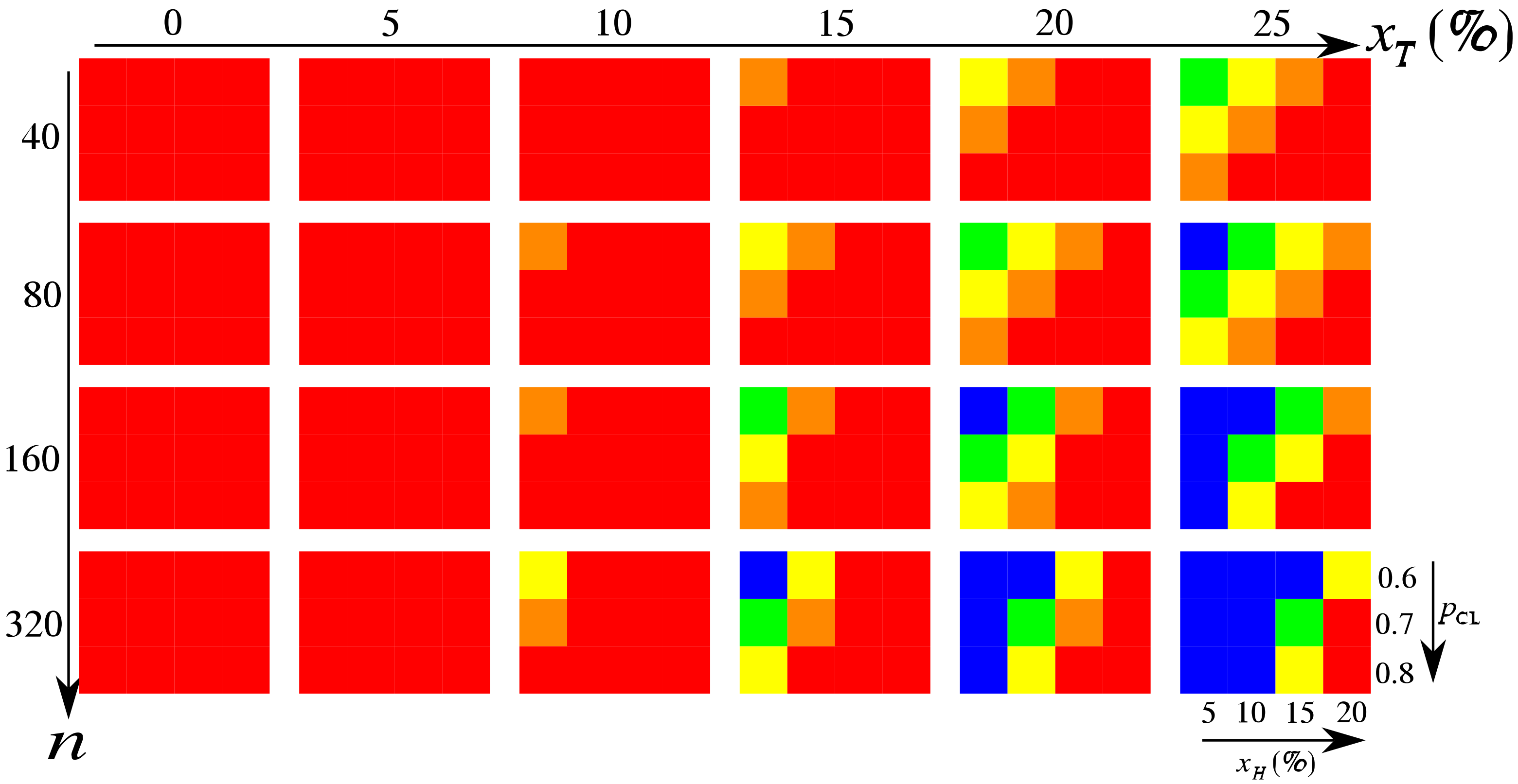
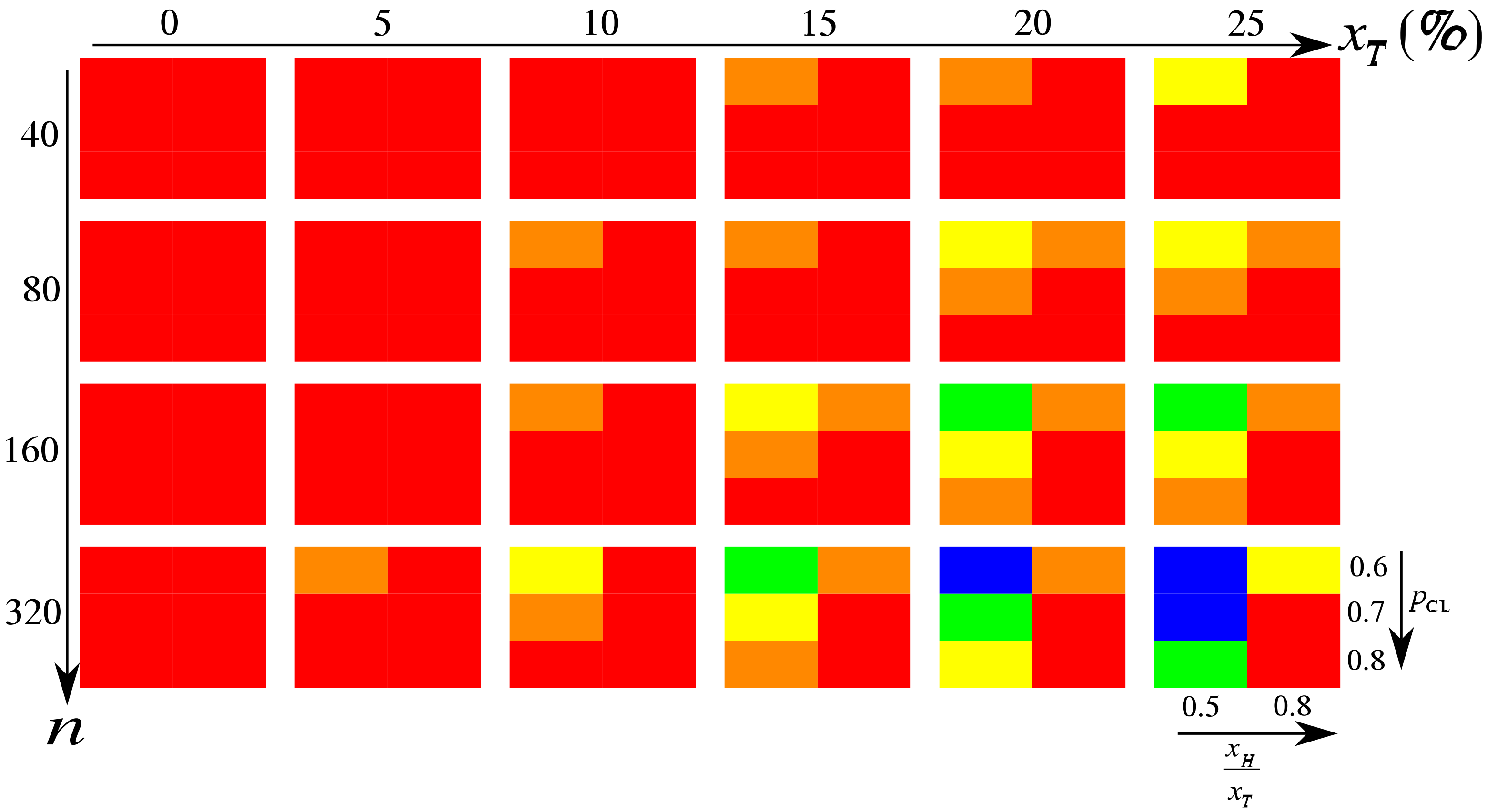


Figure 6. Variance ratio: $r_s = 1.0$,   Variance Model 1

(a) Detection probability $p_D(x_T, n, x_H, p_{CL})$:



(b) Detection probability as a function $p_D(x_T, n, \frac{x_H}{x_T}, p_{CL})$ of the effect-size hypothesis relative to the true effect size:



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Size at maturity surveys among Victorian abalone populations during 2000-2003

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Internal Report: Not for Citation

Introduction

The size at first maturity (L_{50}) is the size (shell length) in a population where you are likely to find 50% of the abalone mature and 50% immature. In other words, if you collected an abalone at the L_{50} length, it would have a 50% chance of being mature. Size at maturity is an important biological parameter for fishery management, particularly when considering the viable egg production of a fished population.

Unfortunately assessment of gonad tissue can only be performed with destructive sampling. Furthermore, complete enumeration of egg production from an individual is incredibly time consuming, and is therefore impractical for comparisons over large temporal and spatial scales. Visual gonad indices provide a fast and efficient tool for estimation of size at first maturity, but as the calculation of L_{50} is based on presence/absence of gonad tissue, it is critical to establish a clear definition of 'what is mature?'

Currently very little is known about the reproductive capacity of abalone during the onset of maturity. Abalone with only a thin veneer of gonad tissue can produce viable gametes, but the likelihood of successful spawning or the relative contribution to overall spawning success is likely to be insignificant. During these studies we used five categories of gonad maturity, enabling us to change the definition of maturity if future studies suggest.

Recent studies in Tasmania have shown that estimates of size at first maturity vary greatly within and between years for the same population. At Sterile Island in Tasmania's southeast, maturation studies were undertaken every month for two years and showed that L_{50} varied by up to 20mm in eight months (Tarbath 2003). This is most obvious in faster growing populations where predominately one year-class of abalone are in the transitional phase leading into maturation. During the period of increasing L_{50}, the change in L_{50} will equal the growth during that period, until a new year-class of immature abalone are available for capture and the L_{50} decreases rapidly.

This plasticity in L_{50} creates difficulty in interpreting results. Comparison of results from region to region should be treated with caution, as spatial differences in factors such as water temperature and food availability are likely to increase variation (Tarbath 1999). Therefore, regardless of the time of sampling, we compare results only from within regions that were sampled at similar times.

Methods

Between November of 2000 and June 2003 size at maturity studies were conducted at 20 different locations in the Eastern Zone. During January and February 2002 surveys were conducted at 11 sites in the Western Zone and 18 sites in the Central Zone that were selected by divers to best represent the fishery.

Gonad development was graded into five categories (Figure 1). Abalone that showed no visible signs of gonad were assigned to Category 1. Abalone in Category 2 were determined to be in a transitional phase as they showed the first signs of gonad development. For analyses these were defined as immature as they were considered unlikely to contribute greatly toward the egg production of the population. Abalone were considered mature in Categories 3, 4 and 5 as substantial gonad production was clearly visible. This approach is similar to the categories and rationales applied by Tasmanian researchers. Further studies that include fecundity analysis should be made before determining the most likely cut-off point to determine the contribution to egg production.

In most instances abalone were collected within a size range of approximately 60 mm to 130 mm. This range was selected because it was believed that at 60 mm all abalone would be immature and at 130 mm all abalone would be mature. The selection of sizes varied depending on expectations of maturity from the site, however the final size structure often varied due to the lack of availability of smaller size classes.

Figure 1. Five categories of maturity. Categories 1 and 2 are considered immature, 3, 4 and 5 are considered mature. All gonads shown are male.

A simple probit analysis was used to estimate the shell lengths at 50% and 90% of reproductive maturity from the probability distribution of the gonad indices for each population sampled.

Results

At Flinders, Pyramid Rock and Seal Rocks in February 2002, some gonads appeared to be affected by the unusually high water temperatures at the time. These abalone were not categorised, but were considered as mature in both scenarios of maturity.

Eastern Zone data reported as November 2001 were collected from two samples, one in Nov 2001 and one in March 2002. During November collections were biased towards mature individuals because expectations of results from the previous year suggested we target a specific size range. The differences in observed maturity meant further collections of smaller individuals were required in March 2002. This was likely to have resulted in more variation around the estimates of average size at maturity.

To calculate rankings for Mallacoota sites, 2001 values were standardized based on the differences observed at Gabo Island North and Sandpatch Point. At both sites the difference in L_{50} was approximately 15%, thus all values for 2000 were unchanged and

2001 values were increased by 15%. At Gabo Island North in 2002 the results were consistent with 2000 values and therefore remained unchanged.

Table 1. Proportion mature, average length, smallest mature and largest immature size of abalone sampled for size at maturity in the Western Zone.

Western Zone Region	Site	Date	No. sample	% Mature	Smallest mature	Largest immature	Mean Length
Portland	Killer Waves (Inside Nelson)	30-Jan-02	96	32	87	102	86
Portland	Murrells	01-Feb-02	103	38	67	110	83
Portland	Outside Nelson	30-Jan-02	99	29	87	105	84
Portland	The Passage	30-Jan-02	96	28	89	110	90
Portland	Whites Inside	01-Feb-02	118	22	75	100	77
Portland	Whites Outside	01-Feb-02	94	29	80	108	91
		Sub-Total	**606**	**30**	**81**	**106**	**85**
Port Fairy	Killarney	29-Jan-02	96	40	75	113	92
Port Fairy	Lady Julia Percy Island	01-Feb-02	107	59	81	116	94
Port Fairy	Lighthouse	29-Jan-02	110	35	75	126	87
Port Fairy	Mills Reef	29-Jan-02	104	62	85	102	91
Port Fairy	The Craggs	15-Feb-02	120	43	84	113	98
		Sub-Total	**537**	**47**	**80**	**113**	**93**

Six sites were sampled at Portland and five sites sampled at Port Fairy in January and February of 2002. The proportion of mature abalone was particularly low at Portland, but as the number sampled was around 100, enough mature abalone were sampled for a confidence analysis (Appendix 1). The low proportion of mature abalone was reflected in the relatively low mean length of most Portland samples. At Port Fairy the largest mean size was at The Craggs, which was also the only site to be sampled at a different time, two weeks after most other sites. The smallest mature abalone at Portland was found at Murrels where also the equal largest immature abalone was found, along with The Passage. Murrels showed the greatest variability in maturity when considering the range of sizes from smallest mature to largest immature, and the site at Outside Nelson had the smallest range. At Port Fairy the smallest mature abalone was found at both Lighthouse reef and Killarney. Clearly the largest immature abalone was found at the Lighthouse, giving this site the greatest variability. The smallest range was clearly at Mills reef. In general Port Fairy had a larger size of immature abalone than Portland (Table 1).

Table 2. Proportion mature, average length, smallest mature and largest immature size of abalone sampled for size at maturity in the Central Zone.

Central Zone Region	Site	Date	No. sampled	% mature	Smallest mature	Largest immature	Mean Length
Shipwreck	Mutton Bird Island	26-Jan-02	103	25	81	118	85
Shipwreck	Rotten Point	25-Jan-02	110	38	80	120	93
Shipwreck	Schomberg	26-Jan-02	100	38	75	104	79
Shipwreck	The Arch	26-Jan-02	99	27	75	114	79
		Sub-Total	**412**	**32**	**78**	**114**	**84**
Cape Otway	The Tide	25-Jan-02	93	41	69	110	92
Cape Otway	West Otway	25-Jan-02	100	38	78	118	96
		Sub-Total	**193**	**39**	**74**	**114**	**94**
PPB	Kirks Point	09-Jan-02	134	54	57	88	70
PPB	Point Cook	09-Jan-02	136	74	57	85	74
		Sub-Total	**270**	**64**	**57**	**87**	**72**
Morn. Pen & P.I.	Bush Rangers Bay	10-Jan-02	106	14	78	106	80
Morn. Pen & P.I.	Cape Schanck	10-Jan-02	102	29	83	105	85
Morn. Pen & P.I.	Flinders	07-Feb-02	115	63	84	118	98
Morn. Pen & P.I.	Portsea Back Beach	10-Jan-02	58	47	82	111	92
Morn. Pen & P.I.	Pyramid Rock	07-Feb-02	100	69	83	100	95
Morn. Pen & P.I.	Seal Rocks	07-Feb-02	98	58	77	115	96
		Sub-Total	**579**	**47**	**81**	**109**	**91**
Wilsons Prom.	Glennie Island	15-Feb-02	104	38	77	109	93
Wilsons Prom.	Kanowna Island	15-Feb-02	104	33	81	121	94
Wilsons Prom.	Norman Island	15-Feb-02	101	27	84	122	93
Wilsons Prom.	Tounge Point	15-Feb-02	110	28	86	115	91
		Sub-Total	**419**	**32**	**82**	**117**	**93**

Four sites were sampled on the Shipwreck Coast, two at Cape Otway and Port Phillip Bay, six from the Mornington Peninsula and Phillip Island and four sites from Wilsons Promontory, during January and February of 2002. The proportion of immature abalone was high at Shipwreck, Cape Otway and Wilsons Promontory and low in Port Phillip Bay (Appendix 2). The variable proportion immature abalone at Mornington Peninsula and Phillip Island appears to reflect the mean size of abalone sampled ie. populations with 70% or greater proportion immature have a mean size 85mm or less, populations with less than 53% immature have mean sizes greater than 92 mm (Table 2). Samples within each region were taken at approximately the same time in all cases. Size ranges of smallest mature and largest immature were generally similar at Cape Otway and Shipwreck Coast, slightly narrower on the Mornington Peninsula and Phillip Island, larger at Wilsons Promontory and much smaller in Port Phillip Bay.

Table 3. Proportion mature, average length, smallest mature and largest immature size of abalone sampled for size at maturity in the Eastern Zone.

Eastern Zone Region	Site	Date	No. sampled	% Mature	Smallest mature	Largest immature	Mean Length
Marlo	Cape Conron	05-Jun-03	74	54	83	112	97
Marlo	Pearl Point	05-Jun-03	76	20	98	107	91
Marlo	Point Ricardo	05-Jun-03	76	41	91	118	99
Marlo	Yeerung	05-Jun-03	75	60	86	115	100
		Sub-Total	**301**	**44**	**90**	**113**	**97**
Mallacoota	Bastion Point	17-Nov-00	53	68	92	104	101
Mallacoota	Big Rame	17-Nov-01	139	76	89	106	107
Mallacoota	Gabo Harbour	15-Nov-00	57	47	88	105	95
Mallacoota	Island Point	17-Nov-01	138	80	77	97	100
Mallacoota	Little Rame	17-Nov-00	50	70	97	108	104
Mallacoota	Gabo Island (NE)	17-Nov-00	51	57	101	116	108
Mallacoota	Gabo Island (NE)	17-Nov-01	85	66	89	96	96
Mallacoota	Gabo Island (NE)	27-Nov-02	67	51	99	118	102
Mallacoota	Gabo Island (NE2)	27-Nov-02	52	37	85	105	91
Mallacoota	Gabo Island (NE3)	27-Nov-02	49	45	76	102	93
Mallacoota	Gabo Island (NE4)	27-Nov-02	53	47	92	110	95
Mallacoota	Petrel Point	17-Nov-01	140	75	90	97	100
Mallacoota	Point Hicks	17-Nov-01	145	75	74	99	106
Mallacoota	Sandpatch Point	15-Nov-00	43	67	103	112	108
Mallacoota	Sandpatch Point	17-Nov-01	84	63	85	103	98
Mallacoota	Tullaberga Island	14-Nov-00	68	44	79	101	91
		Sub-Total	**1274**	**65**	**89**	**105**	**100**

Four sites were sampled at Marlo during June of 2003, and 16 samples have been taken at Mallacoota between November 2000 and November 2002 from 10 different locations. Samples were taken from the same location at Sandpatch Point and Gabo Island during November 2000 and 2001 and also during November 2002 at Gabo Island. Three other samples were taken at Gabo Island during November 2002 within 2km of the original site. The proportion of immature abalone was variable at Marlo and generally low at Mallacoota (Appendix 3). The mean size of abalone sampled from the Eastern Zone was generally larger than other zones. Samples within each region and year were taken at approximately the same time in all cases and at Mallacoota all samples were taken during November of each year, with the exception of the 2001 samples. Sampled shell lengths varied depending on research diver experience and availability of small abalone. Size ranges of smallest mature and largest immature varied greatly between years and sites at Mallacoota, although in general the ranges in the Eastern zone were slightly narrower than most other regions of the Central and Western Zones (Table 3).

Table 4. Sex ratios from all abalone that were able to be sexed (categories 2 – 5) during size at first maturity studies.

Zone	Region	% Female	No. Sampled
Western	Portland	41	264
Western	Port Fairy	38	330
	Sub-Total	***39***	***594***
Central	Shipwreck	26	267
Central	Cape Otway	22	187
Central	PPB	41	219
Central	Mornington Peninsula & Phillip Island	52	347
Central	Wilsons Promontory	37	249
	Sub-Total	***37***	***1269***
Eastern	Marlo	47	173
Eastern	Mallacoota	47	862
	Sub-Total	***47***	***1035***
	Grand total	**41**	**2898**

The mean sex ratio of all samples able to be sexed (categories 2–5) from Victoria was approximately 60% males and 40% females (Table 4). This ratio was reflected in all samples from the Western Zone, but was closer to 50% in the Eastern Zone. Results from the Central Zone were highly variable, with a very low proportion of females (25%) from the Shipwreck Coast and Cape Otway, average proportions (40%) from Port Phillip Bay and Wilsons Promontory and 50% from the Mornington Peninsula and Phillip Island. Shell lengths among samples tended to be large in all instances.

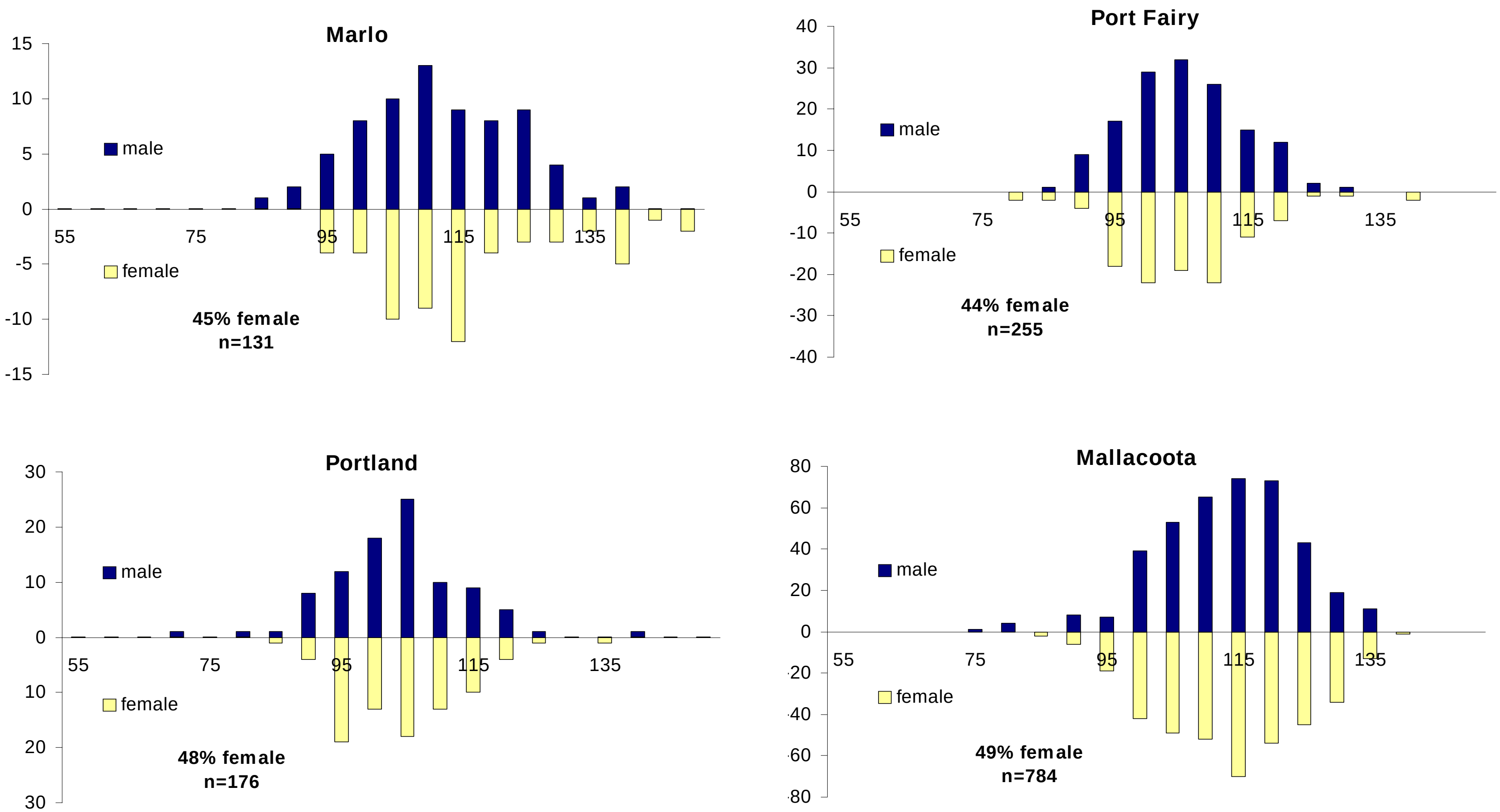

Figure 2A. Size distribution of male and female mature abalone (categories 3-5) in the Western and Eastern Zones.

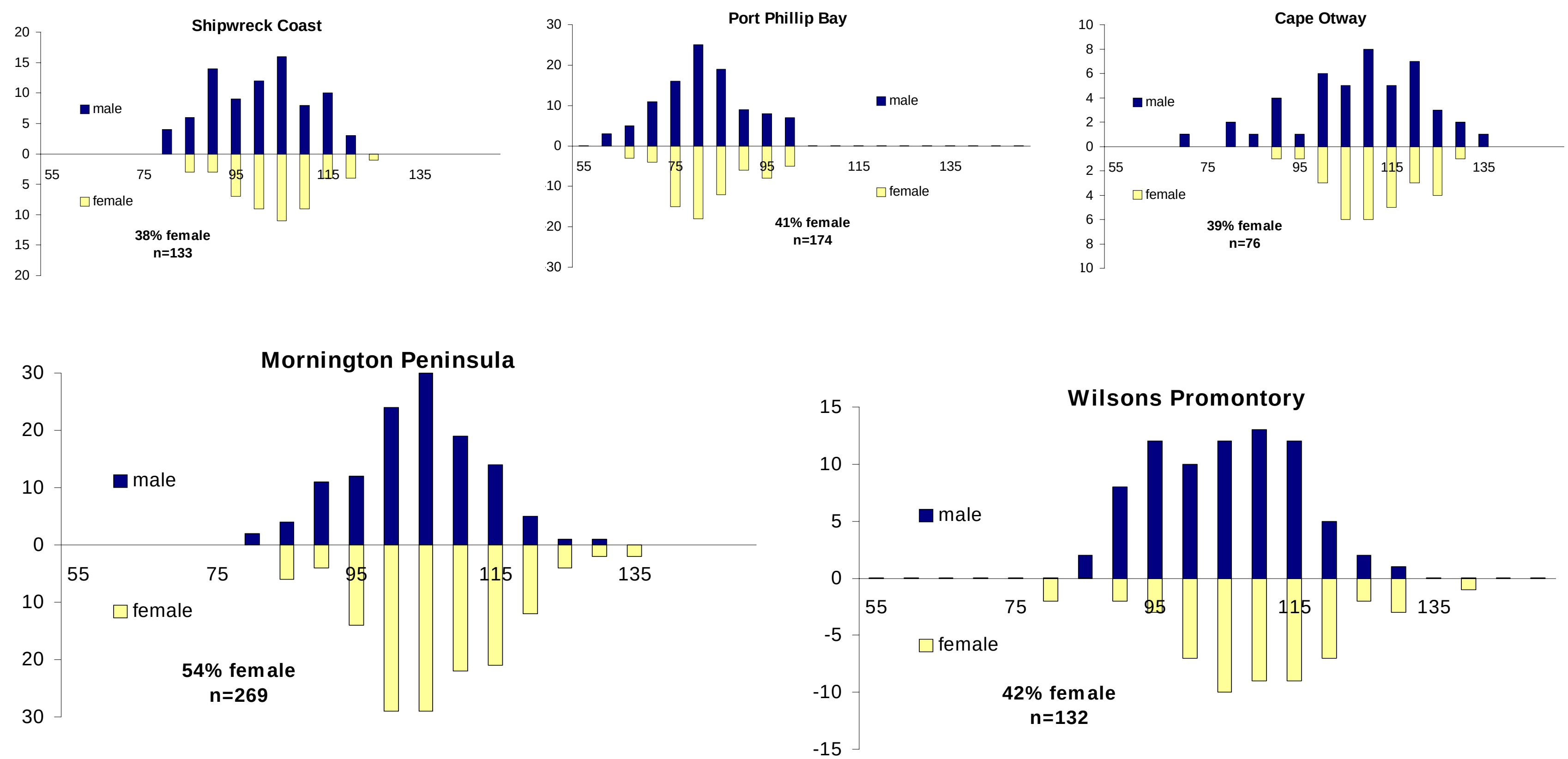

Figure 2B. Size distribution of male and female mature abalone (categories 3-5) in the Central Zone.

The sex ratio of mature abalone (categories 3–5) ranged between 38–54% female (Figs 2A and B), though on only the one occasion was the proportion of females greater than that of males at any location. On average only 45% of all mature samples were female.

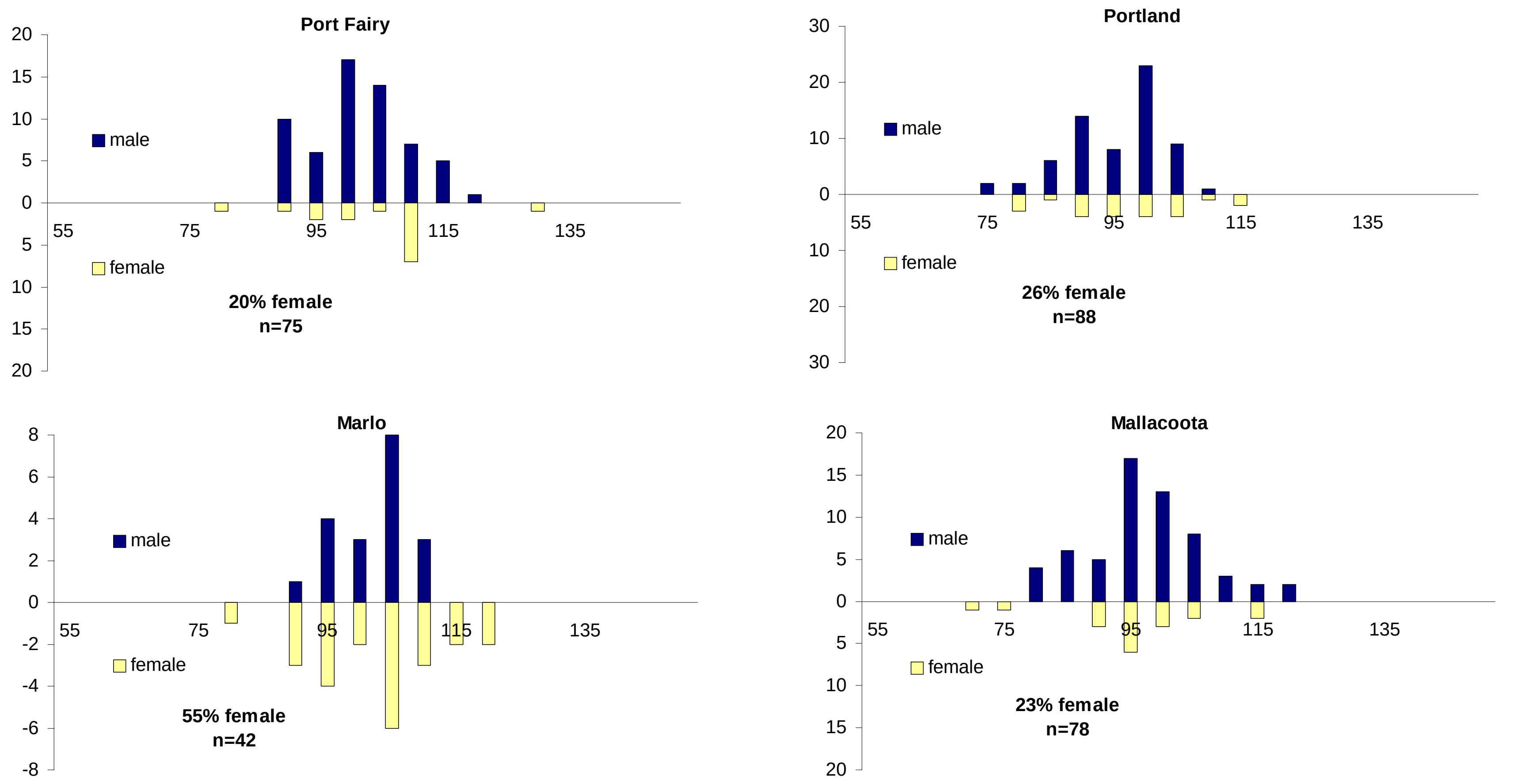

Figure 3A. Size distribution of male and female transitional abalone (Category 2) in the Western and Eastern Zones.

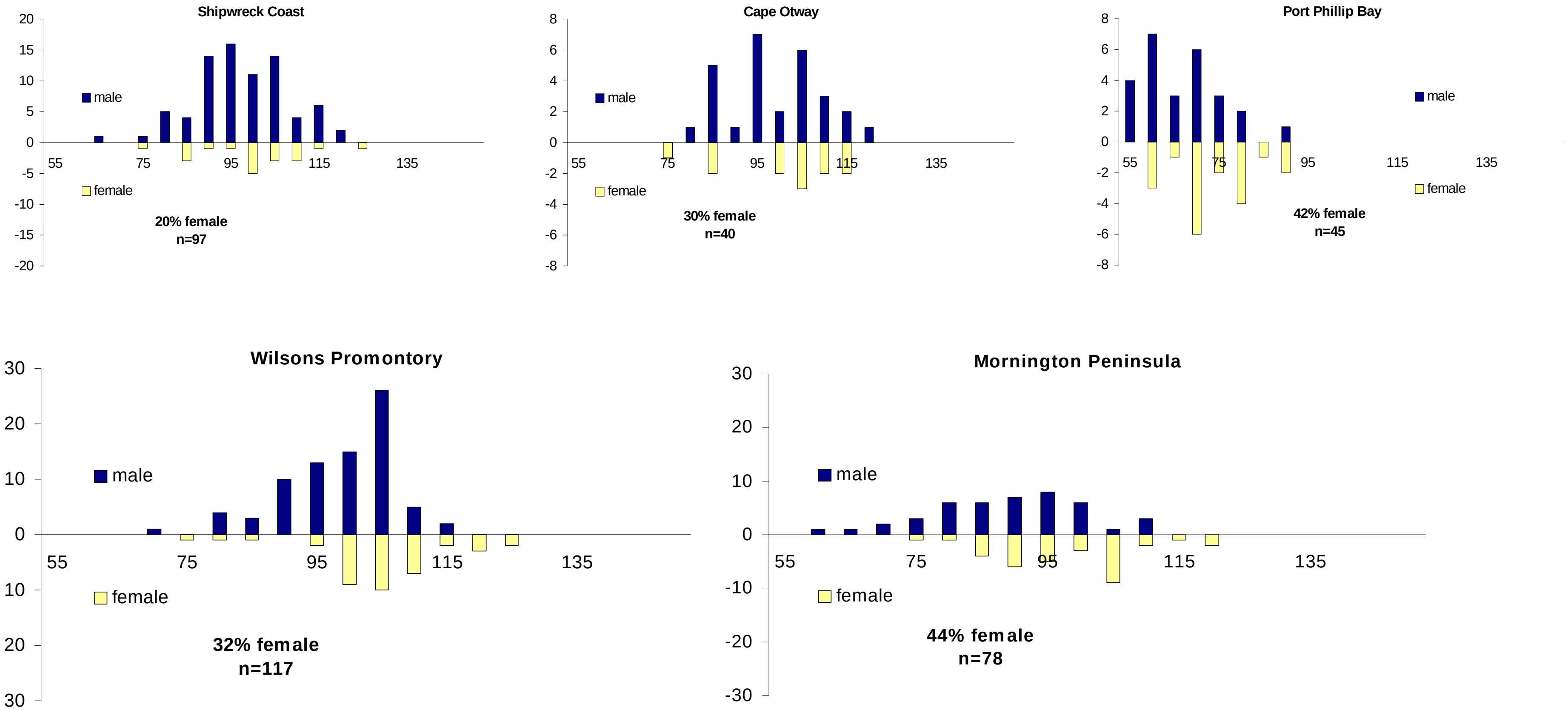

Figure 3B. Size distribution of male and female transitional abalone (Category 2) in the Central Zone.

On average only 30% of transitional abalone were female, ranging from 20% at Port Fairy and Shipwreck to 55% at Marlo. At Port Phillip Bay, Mornington Peninsula and Wilsons Promontory there appears to be a difference between sexes in the size distribution, with fewer small females and more large females.

Table 5. The month surveys were conducted and the proportion of abalone in various categories of maturity.

Location	Month surveyed	No. sites	Maturity category (1– 5)			Total sample
			No gonad (1)	Transitional (2)	Mature (3 – 5)	
Portland	Jan - Feb	6	55%	15%	30%	606
Port Fairy	Jan - Feb	5	39%	14%	47%	537
Shipwreck Coast	Jan - Feb	4	44%	24%	32%	412
Cape Otway	Jan - Feb	2	40%	21%	39%	193
Port Phillip Bay	Jan - Feb	2	19%	17%	64%	270
Morn. Pen & Phillip I.	Jan - Feb	6	40%	13%	47%	579
Wilsons Promontory	Jan - Feb	4	41%	28%	32%	419
Marlo	June	4	43%	14%	44%	301
Mallacoota	November	16	29%	6%	65%	1274

The proportion of abalone in the transitional phase of maturity (Category 2) ranges from 6–28% (Figs. 3A & B). At Mallacoota all samples were taken during November and despite the large number of sites surveyed, the proportion of abalone in the transitional phase was the smallest (6%). Samples taken at Marlo during June consisted of more than twice the proportion of transitional abalone than at Mallacoota in November. The proportion of transitional abalone taken from the Central and Western Zones during January and February was equal or greater than the proportion at Marlo. In Port Phillip Bay during January and February there were almost as many abalone sampled that were in the transitional phase of maturity as the number that were immature.

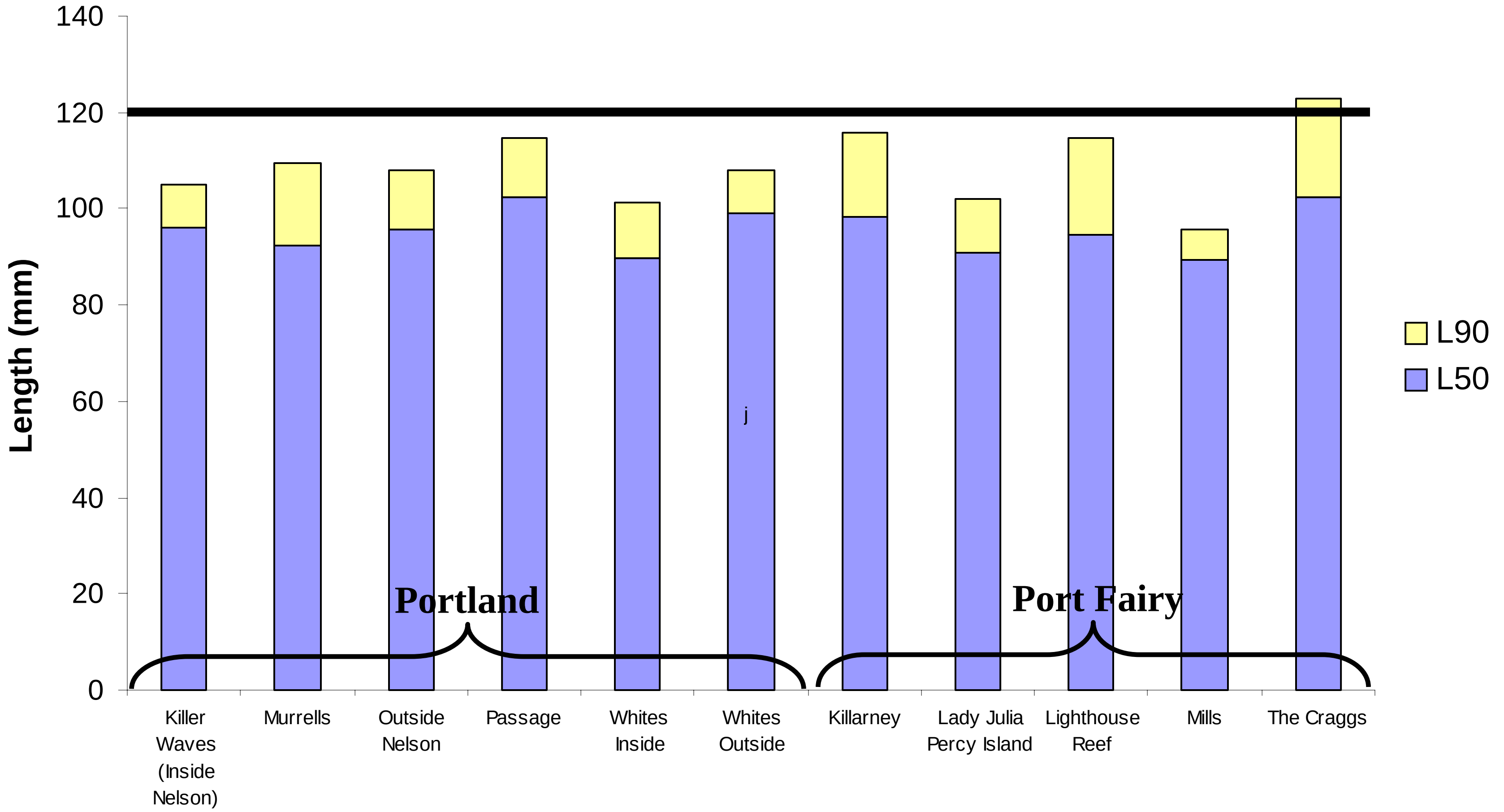

Figure 4. Sizes at 50% and 90% maturity in relation to Legal Minimum Length (LML) at sites in the Western Zone.

In all cases L_{50} was well below the LML of 120 mm. At The Craggs L_{90} was larger than the LML. At Murrels, Whites Inside, Lady Julia Percy Island and Mills L_{50} was well below LML. In the Western Zone L_{50} and L_{90} was lowest at Mills (Fig. 4).

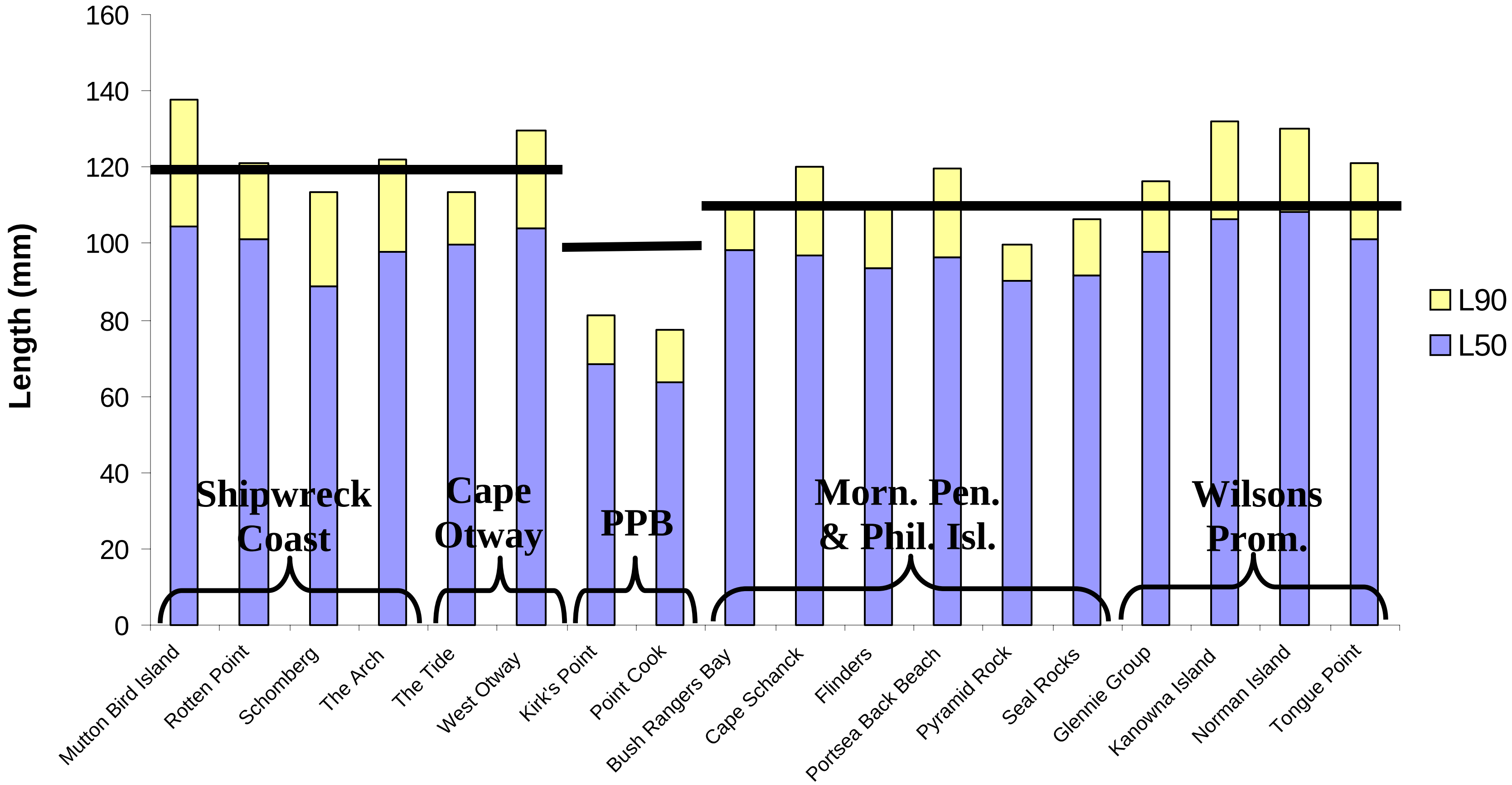

Figure 5. Sizes at 50% and 90% maturity in relation to Legal Minimum Length at sites in the Central Zone.

In all cases L_{50} was below the appropriate LML, however it was very close at the Wilsons Promontory sites of Norman and Kanowna Islands. In Port Phillip Bay L_{90} was well below LML but in all other instances except Schomberg, The Tide, Pyramid Rock and Seal Rocks, L_{90} was greater than the LML (Fig. 5).

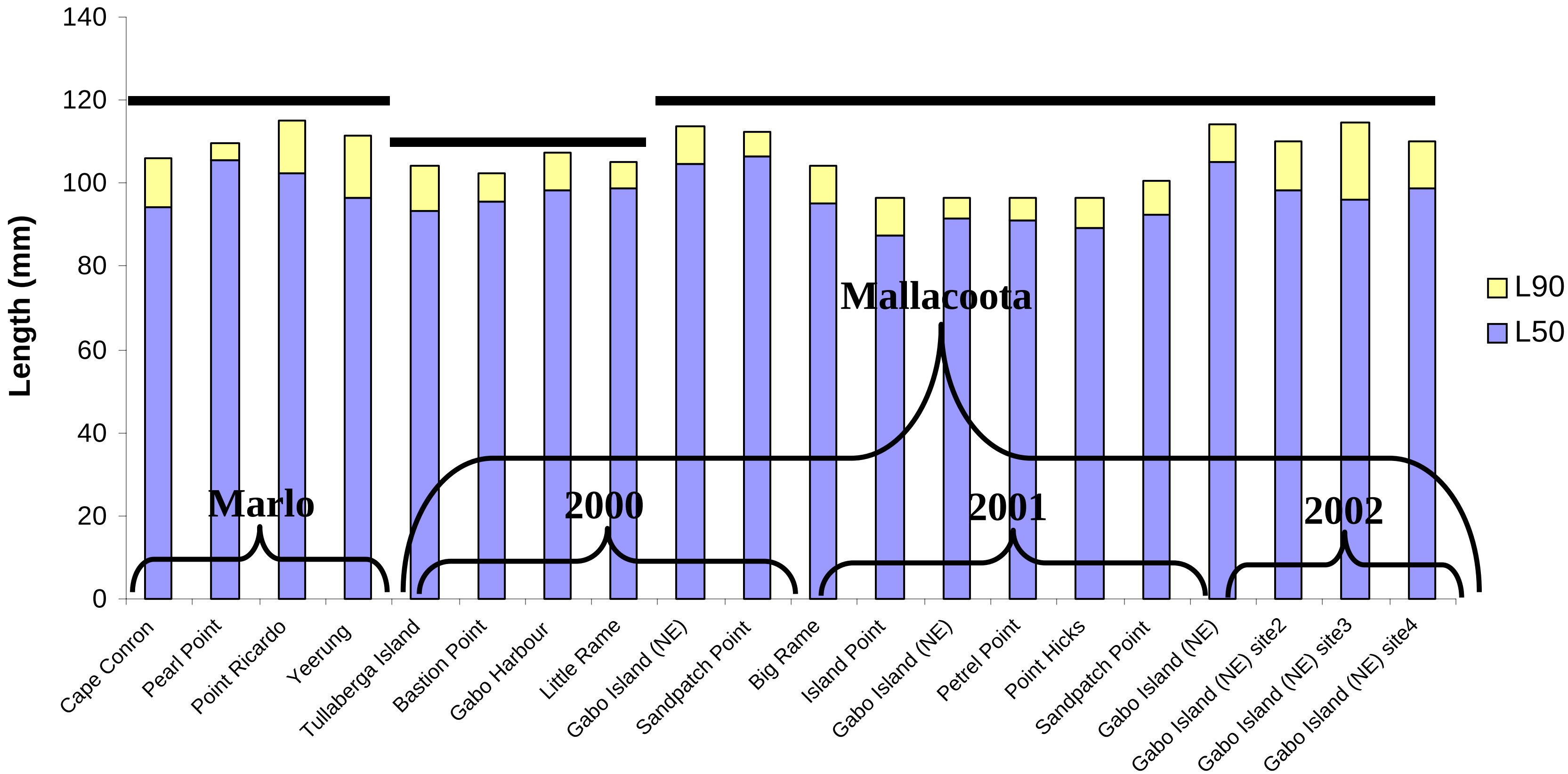

Figure 6. Sizes at 50% and 90% maturity in relation to Legal Minimum Length at sites in the Eastern Zone.

In all cases L_{50} and L_{90} was below the LML of 110mm or 120mm for Marlo and Mallacoota. At Marlo L_{50} and L_{90} was the lowest at Cape Conron and although Pearl Point had the highest L_{50} there was very little difference between L_{50} and L_{90}. Comparisons between years at Mallacoota suggest that 2001 was the year with the lowest size at maturity (Fig. 6).

Table 6. Rank of sites in the Western Zone based on size at 50 and 90% mature.

Portland

Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
Whites Inside	Feb-02	89.9	101.1	1	1	1
Killer Waves (Inside Nelson)	Jan-02	95.9	105.1	4	2	2
Murrells	Feb-02	92.5	109.3	2	5	3
Outside Nelson	Jan-02	95.8	108.1	3	4	4
Whites Outside	Feb-02	99.2	108.1	5	3	5
Passage	Jan-02	102.3	114.8	6	6	6

Port Fairy

Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
Mills	Jan-02	89.5	95.6	1	1	1
Lady Julia Percy Island	Jan-02	90.7	102.2	2	2	2
Lighthouse Reef	Jan-02	94.4	114.5	3	3	3
Killarney	Jan-02	98.3	115.9	4	4	4
The Craggs	Feb-02	102.3	123.0	5	5	5

Rankings at Portland show that Whites Inside has the lowest size at maturity and The Passage the highest. Whites Outside is the second highest ranked site. Killer Waves was the second lowest overall ranked although had the fourth highest L_{50} value. Port Fairy rankings were consistent across all three maturity levels, with Mills being the lowest ranked and The Craggs clearly the highest ranked maturity level (Table 6).

Table 7. Rank of sites in the Central Zone based on size at 50 and 90% mature.

Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
Shipwreck Coast						
Schomberg	Jan-02	89.0	113.6	1	1	1
The Arch	Jan-02	97.9	121.8	2	3	2
Rotten Point	Jan-02	101.1	121.3	3	2	3
Mutton Bird Island	Jan-02	104.5	137.6	4	4	4
Cape Otway						
Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
The Tide	Jan-02	99.8	113.5	1	1	1
West Otway	Jan-02	104.0	129.5	2	2	2
Port Phillip Bay						
Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
Point Cook	Jan-02	63.5	77.5	1	1	1
Kirk's Point	Jan-02	68.5	81.0	2	2	2
Mornington Peninsula and Phillip Island						
Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
Pyramid Rock	Feb-02	90.4	99.8	1	1	1
Seal Rocks	Feb-02	91.7	106.4	2	2	2
Flinders	Feb-02	93.8	110.6	3	4	3
Portsea Back Beach	Jan-02	96.2	119.8	4	5	4
Bush Rangers Bay	Jan-02	98.2	109.4	6	3	5
Cape Schanck	Jan-02	96.7	120.3	5	6	6
Wilson's Promontory						
Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
Glennie Group	Feb-02	97.8	116.6	1	1	1
Tongue Point	Feb-02	101.3	120.8	2	2	2
Kanowna Island	Feb-02	106.3	132.1	3	4	3
Norman Island	Feb-02	108.5	130.1	4	3	4

Shipwreck Coast rankings showed that Schomberg was the lowest ranked and Mutton Bird Island clearly the highest ranked. At Cape Otway the West Otway site has higher ranked than The Tide and in Port Phillip Bay, Kirk’s Point had a clearly higher maturity than Point Cook. Mornington Peninsula sites were more highly ranked than Pyramid Rocks and Seal Rocks at Phillip Island. Bush Rangers Bay had the highest L_{50} ranking but was not the overall highest. At Wilsons Promontory the Glennie Group had the lowest size at maturity and there was little difference between Kanowna Island and Norman Island as the highest (Table 7).

Table 8. Rank of sites in the Eastern Zone based on size at 50 and 90% mature.

Marlo Site	Date	L_{50}	L_{90}	Rank L_{50}	Rank L_{90}	Overall Rank
Cape Conron	Jun-03	94.4	106.2	1	1	1
Yeerung	Jun-03	96.7	111.5	2	3	2
Pearl Point	Jun-03	105.6	109.6	4	2	3
Point Ricardo	Jun-03	102.2	115.3	3	4	4

Mallacoota		Raw		Standardised		Rank		Overall Rank
Site	Date	L_{50}	L_{90}	L_{50}	L_{90}	L_{50}	L_{90}	
Tullaberga Island	Nov-00	93.5	104.3	93.5	104.3	1	2	1
Bastion Point	Nov-00	95.8	102.2	95.8	102.2	2	1	2
Gabo Harbour	Nov-00	98.2	107.2	98.2	107.2	4	4	3
Little Rame	Nov-00	98.5	105.1	98.5	105.1	6	3	4
Gabo Island (NE) site2	Nov-02	98.2	110.2	98.2	110.2	5	5	5
Gabo Island (NE) site4	Nov-02	99.0	110.3	99.0	110.3	7	6	6
Gabo Island (NE) site3	Nov-02	96.1	114.6	96.1	114.6	3	14	7
Point Hicks	Nov-01	89.2	96.4	102.6	110.9	9	8	8
Island Point	Nov-01	87.5	96.7	100.7	111.2	8	10	9
Gabo Island (NE)	Nov-01	91.3	96.4	105.0	110.9	12	7	10
Petrel Point	Nov-01	91.2	96.6	104.9	111.1	11	9	11
Gabo Island (NE)	Nov-02	104.6	113.7	104.6	113.7	10	12	12
Gabo Island (NE)	Nov-00	105.0	114.1	105.0	114.1	13	13	13
Sandpatch Point	Nov-00	106.3	112.5	106.3	112.5	15	11	14
Sandpatch Point	Nov-01	92.3	100.4	106.2	115.5	14	15	15
Big Rame	Nov-01	95.2	104.1	109.5	119.7	16	16	16

At Marlo, Cape Conron is the lowest ranked site and although Pearl Point is the highest ranked L_{50} site, Point Ricardo has the highest overall rank. At Mallacoota all 2001 values have been increased by 15%, in accordance with the differences in L_{50} observed between 2000 and 2001 at Gabo Island and Sandpatch Point. The lowest ranked sites at Mallacoota are consistent with the regions within the Airport area; Tullaberga Island, Bastion Point, Gabo Harbour and Little Rame. The next three lowest ranked sites were the additional sites surveyed on the North East of Gabo Island during 2002. Of the remaining sites, clearly Big Rame has the highest standardized size at maturity (Table 8).

Discussion

The staging of gonads into five categories has enabled flexibility in determining appropriate definitions of maturity. Complete enumeration of egg production from females is extremely time consuming and whilst good relationships exist to determine gonad volume from cross sectional areas of gonad, dramatically reducing the time required for analysis, some complete enumeration is still required to ensure that the assumed relationship is valid. Although such studies were outside the cost and objectives of this study, future projects may be able to establish a broad relationship between fecundity and the visual indices we have used, giving greater value to the existing data. Furthermore, by creating five categories for our visual gonad index we have provided the opportunity to change the definition of maturity. A more conservative approach may be to consider only categories 4 and 5 as mature. The consequences of such changes could be considered in a risk framework.

Sampling design aimed to minimize sample sizes to reduce the impact on abalone stocks, while targeting a spread of size classes with approximately two-thirds of abalone mature. Most samples from the Western and Central Zones in 2002 had a greater than desirable proportion of immature abalone (up to 70% in many instances), but as the number sampled at each site was around 100, enough mature abalone were sampled for a confidence analysis. The high proportion of immature abalone was reflected in the relatively low mean length of most samples. This was most likely due to the greater availability of smaller abalone in the Western and Central Zones compared to the Eastern Zone, where all previous studies had been conducted. Mean lengths of all Eastern Zone samples were generally 10 mm larger than Central and Western Zone samples. In the Eastern Zone, sample sizes of approximately 50 abalone provided results that appeared consistent with expectations. However if the ratio of mature to immature abalone is imbalanced as in the other zones, results may have been poor and therefore minimum sample sizes of 75 are suggested for future studies.

Reporting the length where different proportions of abalone are mature gives an indication of the variability within a site. We chose to present two scenarios, L_{50} and L_{90}, equal to the lengths where 50% and 90% of abalone are mature. Appendices 1, 2 and 3 give 95% confidence intervals around each of the values for all sites, which shows the variability around each estimate. As these calculations are based on a logistic curve, estimation of lengths with greater than 90% proportion mature are not likely to provide useful results. If it is required to determine the size where 100% of abalone are likely to be mature, the size of the largest immature abalone in the sample should be used. Obviously large sample sizes would be required to be reasonably confident of this figure.

The estimates obtained for size at first maturity are satisfactory for comparison of sites within a region at the same time, but not for comparisons over larger spatial or temporal scales. Comparison of results at Sandpatch Point and Gabo Island taken exactly one year apart show dramatic differences that are consistent between the two sites. To obtain a clear understanding of size at maturity at any one site, monthly surveys are required over extended periods of time, as have been conducted in Tasmania. Whilst this is impractical to achieve over many sites, it is plausible that monthly studies at one site in a region could be used to link results from all other sites within a region. If this is attempted, consideration should be given as to the appropriate size of each region. Studies in the Eastern Zone have shown that consistent results were obtained between years at Gabo Island and Sandpatch Point, approximately 30 kilometers apart.

The range of sizes of immature and mature abalone provided interesting and unexpected results. Whilst it was not surprising that the smallest mature abalone were found at Murrels and Lighthouse reef in the Western Zone (believed to be relatively ‘stunted’ sites), it was not anticipated that the largest immature abalone for their respective regions would also be found at these sites. As the onset of maturity is strongly linked to growth, this suggests that growth at these apparently ‘stunted’ sites in the Western zone is highly variable, or that some other mechanism has delayed the onset of maturity, or production of gonad tissue in any one year, for some abalone.

Other unexpected results were obtained when sex ratios of samples were compared. Overall sex ratios of abalone, where sex was positively identified (categories 2–5), showed that only 40% of abalone were female. In general it is believed that sex ratios of abalone are approximately 1:1, however some literature has shown slight biases toward males. Only in the Eastern Zone and on the Mornington Peninsula of the Central Zone were results close to 1:1. Clearly in the Western Zone both regions had approximately 40% of females in all samples, as too did Port Phillip Bay and Wilsons Promontory in the Central Zone. However most alarming was the extremely low proportion of females in samples from the Shipwreck Coast and Cape Otway, 26% and 22% respectively.

Further exploration of the data showed that of mature abalone sampled (categories 3 – 5), less than 45% were female. The alarming results of the Shipwreck Coast and Cape Otway were less pessimistic at 38% and 39% respectively. Comparisons of the sex ratio of transitional abalone (Category 2) showed that an extreme bias toward males existed in almost all regions, resulting in an average of only 30% females in all transitional abalone sampled. A likely explanation for this bias may be that at this stage of maturity it is difficult to ascertain the difference between sexes. Histological studies may prove to be the only way to determine if such bias is real or identification error. If the bias is true it may be caused by differences in the time it takes for males and females to move through the transitional phase of maturity to become mature. Until such studies are completed, estimates of sex ratio should only include abalone in categories 3 – 5.

The time of year that studies were conducted greatly influenced the proportion of abalone that were determined to be in a transitional phase (Category 2). During November at Mallacoota, when abalone were close to spawning, samples over a three year period averaged only 6% in the transitional phase. During June at nearby Marlo, the proportion in the transitional phase was more than doubled (14%), and in the Central and Western Zones with samples taken after spawning in January and February, transitional proportions ranged from 13% - 28%. There may be several reasons why the proportion of transitional abalone is greater during non-spawning periods. One possibility is that after spawning visual appearance of the gonad is greatly reduced. If this means abalone that would have been in Category 3 prior to spawning, appear to be in Category 2 after spawning, this could have a dramatic effect on estimates of L_{50}. Although it is not always possible, it would appear that the best time to conduct 'one-of' maturity studies would be just prior to spawning.

One common theory for unbalanced sex ratios is difference in growth rates between sexes. In our case female abalone would grow faster and would therefore be less likely to be captured in a sample of a targeted size range. Evidence exists that this may occur to some extent. The size distributions of abalone in Category 2 appear shifted to the right for several regions in the Central Zone. Close examination shows that on several occasions there are fewer small females and clearly more large females when compared to males. The existence of more large females is more compelling given that there are far fewer females in each of these samples. The evidence for these patterns in the mature samples are more tenuous, though can be inferred in some regions. As these abalone are larger and therefore growth increments are smaller, it is expected that such patterns are more difficult to detect.

Based on such small sample sizes and such inconclusive evidence, differences in growth rates of the sexes should not be explicitly inferred from this information. Future growth studies should always note the sex of the individual upon its capture. For many mature abalone this can be achieved satisfactorily during non destructive sampling, but in most growth studies abalone are retained and sex identification should be collected as a matter of course.

Whilst some previous studies have found differences in growth rates between the sexes, many others have not. A lack of statistical difference in the growth rates does not mean that differences do not exist, more so that the sample sizes were not large enough to detect such small differences. It is uncertain how much of a difference in growth rate between sexes would be required to cause an imbalance in the sex ratio of abalone populations. One thing that is certain, faster growth rates of females would mean that they would be younger when they were available for fishing, and therefore would have a higher selective fishing pressure, reducing the viable egg production of the population.

The implications of unbalanced sex ratios are difficult to predict. Undoubtedly sex ratios will influence estimates of egg production that are based on abundance indices, and may possibly influence outputs of the Victorian stock assessment model. However before further consideration is given to possible impacts, the existence of this relationship should be confirmed by further studies. One possibility is the collection of sex ratio data from the commercial catch. Recent analysis of catch data from the Mexican white abalone fishery showed that there was alarming variance in sex ratios along the coast of Baja California. The proportion of males in the commercial catch over a 20-year period increased from 50% in the south to almost 80% in the north. Whether this phenomenon contributed to the demise of this fishery is unknown.

The importance of sex ratios for the fertilization success of a population is likely to be strongly affected by local abalone densities and aggregative behaviour. Obviously unbalanced sex ratios will have a greater influence in areas with low density or areas where abalone are less aggregated. Work on greenlip abalone in South Australia has shown that a critical maximum distance of approximately one metre is required for fertilization success. Other recent studies have shown that the concentration of sperm in relation to egg size is also important in fertilization success. At low sperm concentrations, large eggs are preferentially fertilized whilst at high concentrations of sperm, smaller eggs are fertilized. The size of eggs within a female is variable, but does change depending on shell size and level of maturity. Given this information, a possible mechanism for unbalanced sex ratios may be a difference in average size of eggs that produce male or female gametes.

In all instances L_{50} was below the legal minimum size limit (LML) at each site, however at Norman and Kanowna Islands at Wilsons Promontory, L_{50} was very close to LML. In many instances in the Central Zone and at The Craggs in the Western Zone, L_{90} was larger than LML. This suggests that a reasonable proportion of the stock is available for capture before having the opportunity to spawn. The fact that in all other instances L_{90} did not exceed the LML does not preclude these other regions from a similar fate. In fact it is highly likely that if several more estimates of L_{50} and L_{90} were made, more pessimistic results would be obtained. In Tasmania the period where L_{50} peaked two years in a row was April, two months after the Central and Western Zone samples were collected. In Tasmania the difference in L_{50} between February and April was approximately 8 mm.

The ranking of sites provides a useful comparison of within region variability. In general slower growing sites should have a lower size at maturity although as previously discussed, some stunted sites have greater variability in maturity and therefore L_{90} may be ranked higher than anticipated. In recent years voluntary increases in size limits have been made in the Eastern and Western Zones. Ranking of the data in this manner can be a useful way to determine the appropriateness of voluntary increases in size limits.

In the Eastern Zone consistent differences were observed between years at two sites, North Gabo Island and Sandpatch Point. At both sites the difference was approximately 15%, thus enabling an increase of 15% to be applied to all sites in 2001, allowing for comparison between all sites and years. As expected the lowest ranked sites were those in the airport areas, and the highest ranked sites Sandpatch Point and Big Rame. These results were consistent with expectations from growth data. A lack of growth data at this point means that similar comparisons in the Central and Western Zones are not possible.

Port Phillip Bay stands out as the region with remarkably different results, with an L_{50} more than 20 mm less than any other site. Despite its low size limit of 100 mm it appears to have the greatest gap between onset of maturity and availability to fishing when compared with all other regions. Although Kirk's Point had a higher size at maturity than Point Cook, the differences were not great and were consistent with increasing proportion of maturity. Of all fished regions within Victoria, Port Phillip Bay also has clearly the lowest emergent size and the highest rate of natural mortality.

Results from the November surveys of 2002 show that large variability in size at maturity can exist on very small spatial scales. At the request of the Eastern Zone industry, surveys were conducted at four sites within a small section of Gabo Island. This shows that careful site selection is required for these studies and that care should be taken when applying these results in a management context.

In general, recaptures consisted of only emergent abalone. It is widely believed that abalone become emergent at the onset of maturity and whilst this may be true, clearly a small proportion of abalone that are emergent are not yet mature. The largest immature abalone in each sample was almost always greater than 100 mm, and was occasionally larger than existing size limits. Particularly in instances of knife-edge fishing a small proportion of the stock may not have had the opportunity to spawn prior to fishing. To further explore the relationship of emergence and maturity, future studies could compare the differences in observed maturity between emergent and cryptic populations. To explain the apparent time lag of emergence and maturity, it may be that food requirements for maturity are greater than is available with cryptic behaviour. Gut analysis concurrent to maturity studies may prove valuable.

In recent years size at maturity data has been used in conjunction with growth data to determine appropriate minimum size limits in the Eastern Zone. Recently in the Western Zone alternative approaches have been used to determine minimum sizes. Clearly size at maturity can provide important information to determine egg production from a population, and for conservative approaches such as an increase in minimum legal size limit, this tool may be ideal as there is little risk of harm to the fishery if the estimate is biased. However in scenarios such as determining an appropriate reduction in minimum size for stunted stocks, great caution should be taken to ensure that size at maturity is not a point estimate, and that the implications of variability in maturity are fully considered. Ideally, size at maturity should be used as one of a suite of indicators in order to make management decisions.

References

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Tarbath, D. 2003. Population parameters of the blacklip abalone (*Haliotis rubra* Leach) at the Acteons in south-east Tasmania. PhD Thesis, University of Tasmania.

Appendix 1.

95% Confidence intervals for mean size at 50% and 90% maturity in the Western Zone.

Zone	Region	Site	Sample size	Date	L_{50} ± 95% C.L.			L_{90} ± 95% C.L.		
					low	mean	high	low	mean	high
West	Portland	Killer Waves (Ins. Nels.)	96	Jan-02	94.6	95.9	97.4	102.7	105.1	109.3
West	Portland	Murrells	103	Feb-02	90.3	92.5	94.6	105.4	109.3	115.5
West	Portland	Outside Nelson	99	Jan-02	94.0	95.8	98.2	104.4	108.1	114.6
West	Portland	Passage	96	Jan-02	100.6	102.3	104.3	111.6	114.8	119.6
West	Portland	Whites Inside	118	Feb-02	88.1	89.9	92.1	97.9	101.1	106.0
West	Portland	Whites Outside	94	Feb-02	97.9	99.2	100.6	105.9	108.1	111.3
West	Port Fairy	Killarney	96	Jan-02	96.3	98.3	100.9	110.9	115.9	124.3
West	Port Fairy	Lady Julia Percy Island	107	Jan-02	89.0	90.7	92.2	100.1	102.2	105.1
West	Port Fairy	Lighthouse Reef	110	Jan-02	92.4	94.4	96.7	109.8	114.5	122.2
West	Port Fairy	Mills	104	Jan-02	87.4	89.5	91.0	94.2	95.6	97.4
West	Port Fairy	The Craggs	120	Feb-02	100.3	102.3	104.4	118.0	123.0	131.5

Appendix 2.

95% Confidence intervals for mean size at 50% and 90% maturity in the Central Zone.

Zone	Region	Site	Sample size	Date 2002	L_{50} ± 95% C.L. low	mean	high	L_{90} ± 95% C.L. low	mean	high
Central	Shipwreck	Mutton Bird Island	103	Jan	99.9	104.5	111.1	126.6	137.6	158.6
Central	Shipwreck	Rotten Point	110	Jan	99.1	101.1	103.4	116.5	121.3	129.0
Central	Shipwreck	Schomberg	100	Jan	86.2	89.0	92.1	107.6	113.6	123.6
Central	Shipwreck	The Arch	99	Jan	94.2	97.9	103.4	113.6	121.8	136.8
Central	Cape Otway	The Tide	93	Jan	97.6	99.8	102.0	110.2	113.5	118.6
Central	Cape Otway	West Otway	100	Jan	100.9	104.0	108.0	122.3	129.5	141.7
Central	PPB	Kirk's Point	134	Jan	67.0	68.5	69.8	79.3	81.0	83.1
Central	PPB	Point Cook	136	Jan	61.2	63.5	65.2	75.5	77.5	80.2
Central	M.Pen. & P.I.	Bush Rangers Bay	106	Jan	96.3	98.2	101.0	105.5	109.4	116.6
Central	M.Pen. & P.I.	Cape Schanck	102	Jan	94.1	96.7	100.9	112.8	120.3	134.5
Central	M.Pen. & P.I.	Flinders	115	Jan	90.4	93.8	96.2	107.8	110.6	114.6
Central	M.Pen. & P.I.	Portsea Back Beach	58	Jan	91.3	96.2	100.9	111.5	119.8	142.2
Central	M.Pen. & P.I.	Pyramid Rock	100	Jan	87.5	90.4	92.3	98.3	99.8	101.8
Central	M.Pen. & P.I.	Seal Rocks	98	Jan	89.2	91.7	93.8	103.6	106.4	110.4
Central	Prom	Glennie Group	104	Jan	95.5	97.8	100.6	111.6	116.6	124.5
Central	Prom	Kanowna Island	104	Jan	103.2	106.3	110.8	123.9	132.1	148.1
Central	Prom	Norman Island	101	Jan	104.8	108.5	114.2	122.1	130.1	145.3
Central	Prom	Tongue Point	110	Jan	98.9	101.3	104.6	115.2	120.8	130.3

Appendix 3.

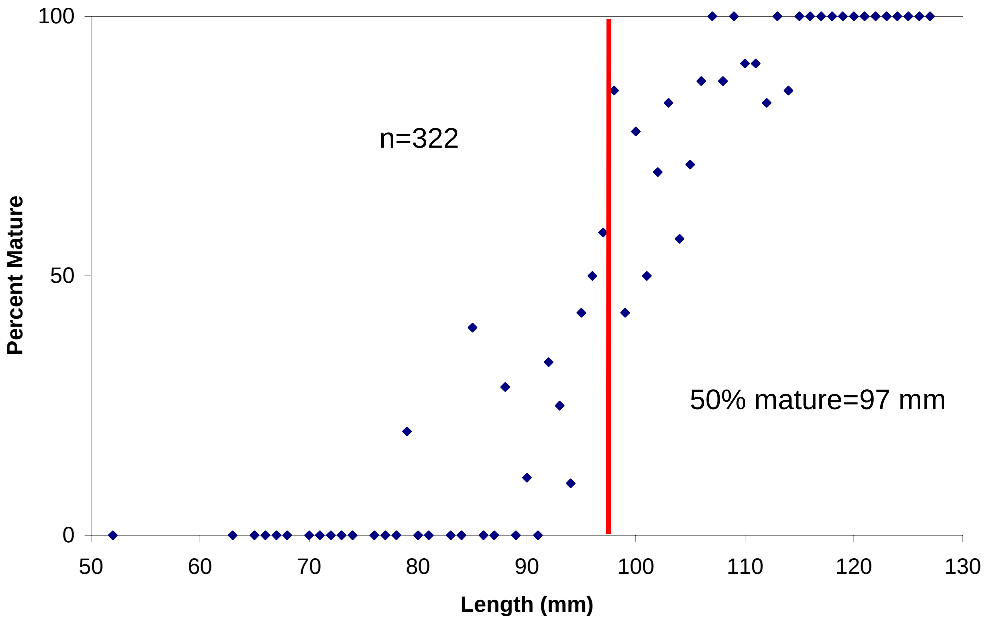
95% Confidence intervals for mean size at 50% and 90% maturity in the Eastern Zone.

Zone	Region	Site	Sample size	Date	L_{50} ± 95% C.L. low	mean	high	L_{90} ± 95% C.L. low	mean	high
East	Marlo	Cape Conron	74	Jun-03	92.0	94.4	96.8	102.8	106.2	111.7
East	Marlo	Pearl Point	76	Jun-03	104.2	105.6	108.5	107.3	109.6	118.2
East	Marlo	Point Ricardo	76	Jun-03	99.8	102.2	105.1	111.1	115.3	122.5
East	Marlo	Yeerung	75	Jun-03	93.5	96.7	99.1	107.7	111.5	118.8
East	Mallacoota	Bastion Point	53	Nov-00	94.1	95.8	97.3	100.1	102.2	106.0
East	Mallacoota	Big Rame	139	Nov-01	93.4	95.2	96.7	102.5	104.1	106.3
East	Mallacoota	Gabo Harbour	57	Nov-00	95.4	98.2	101.2	103.6	107.2	114.6
East	Mallacoota	Island Point	138	Nov-01	85.0	87.5	89.3	95.3	96.7	98.5
East	Mallacoota	Little Rame	50	Nov-00	95.8	98.5	100.6	102.8	105.1	109.7
East	Mallacoota	Gabo Island (NE)	51	Nov-00	101.5	105.0	108.0	110.8	114.1	120.5
East	Mallacoota	Gabo Island (NE)	85	Nov-01	89.2	91.3	92.8	94.8	96.4	98.9
East	Mallacoota	Gabo Island (NE)	67	Nov-02	102.4	104.6	106.5	111.0	113.7	118.7
East	Mallacoota	Gabo Isl. (NE) site2	52	Nov-02	95.4	98.2	101.2	106.2	110.2	117.6
East	Mallacoota	Gabo Isl. (NE) site3	49	Nov-02	92.0	96.1	100.4	107.7	114.6	133.0
East	Mallacoota	Gabo Isl. (NE) site4	53	Nov-02	96.1	99.0	101.1	106.7	110.3	119.0
East	Mallacoota	Petrel Point	140	Nov-01	89.2	91.2	92.5	95.5	96.6	98.2
East	Mallacoota	Point Hicks	145	Nov-01	85.4	89.2	93.7	92.2	96.4	104.0
East	Mallacoota	Sandpatch Point	43	Nov-00	102.1	106.3	108.8	109.9	112.5	117.8
East	Mallacoota	Sandpatch Point	84	Nov-01	89.2	92.3	94.8	97.8	100.4	104.3
East	Mallacoota	Tullaberga Island	68	Nov-00	91.5	93.5	95.5	101.2	104.3	109.5

Appendix 4

Explanation of size at first maturity, L_{50}.

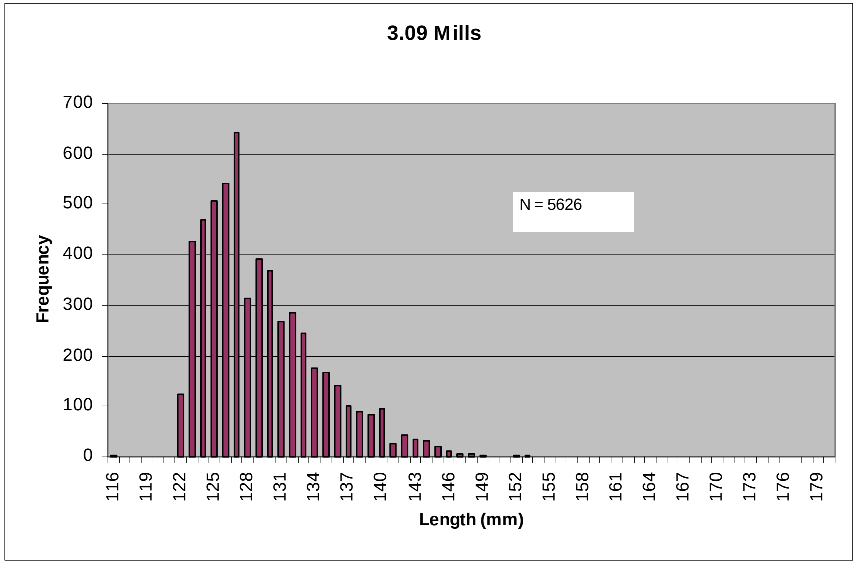
The onset of abalone maturity is not directly related to its size. Because growth is variable, we can expect that there will be variability in the size that abalone will first reach sexual maturity. To quantify the size at first maturity we use the value L_{50}, the size (shell length) in a population where you are likely to find 50% of the abalone mature and 50% immature. In other words, if an abalone was collected at the L_{50} length, it would have a 50% probability of being mature. Figure 1 shows a graph of the data collected at Mallacoota in November 2000. It shows the proportion of abalone mature (y-axis) at a particular size (x-axis). Below 78 mm all abalone were immature and above 116 mm all abalone were mature. The size where 50% of abalone were mature and 50% immature was 97 mm.

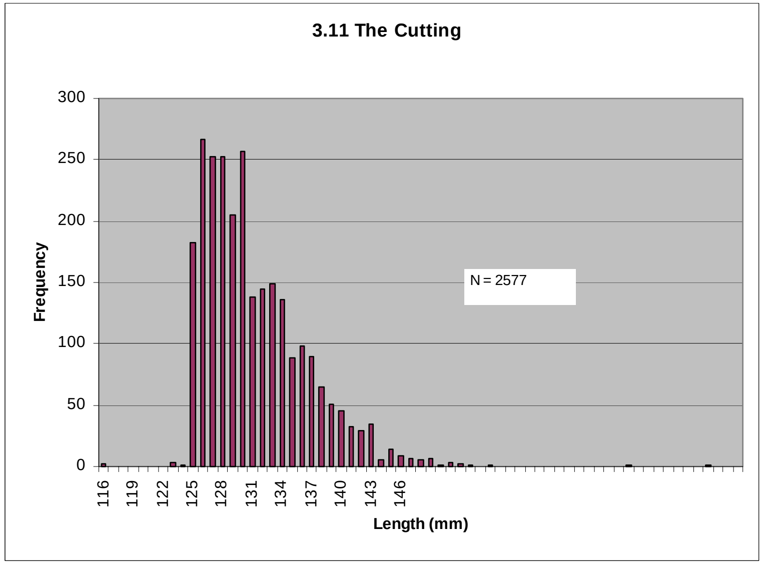


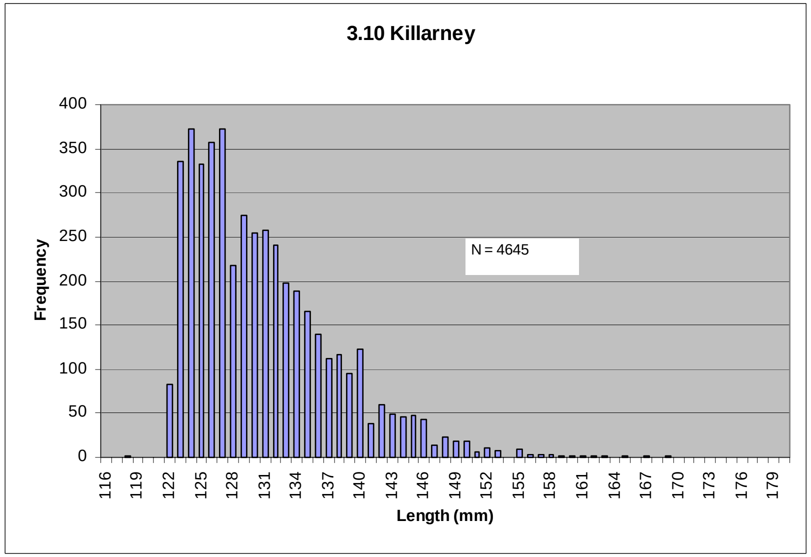
Size at 50% maturity for all sites at Mallacoota in November 2000.

K

Commercial catch sampling length-frequency and effort patterns from Western Zone data logged using electronic shellfish measuring boards


3.09 Mills
700
600
500
400
300
200
100
0
Frequency
N = 5626
116 119 122 125 128 131 134 137 140 143 146 149 152 155 158 161 164 167 170 173 176 179
Length (mm)


3.11 The Cutting
300
250
200
150
100
50
0
Frequency
N = 2577
116 119 122 125 128 131 134 137 140 143 146
Length (mm)


3.10 Killarney
400
350
300
250
200
150
100
50
0
Frequency
N = 4645
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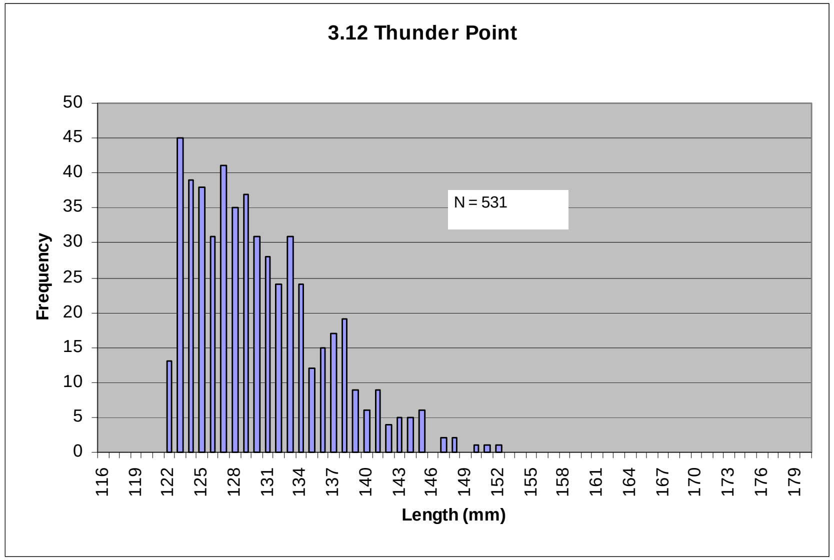
Length (mm)


3.12 Thunder Point
50
45
40
35
30
25
20
15
10
5
0
Frequency
N = 531
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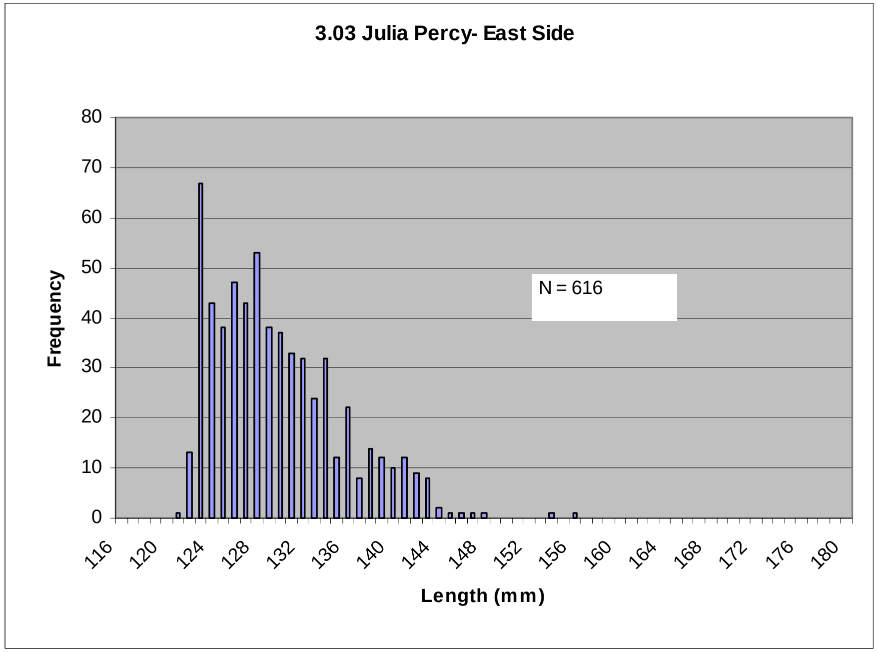
Length (mm)


3.03 Julia Percy- East Side
N = 616
Frequency
Length (mm)
0
10
20
30
40
50
60
70
80
116
120
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132
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140
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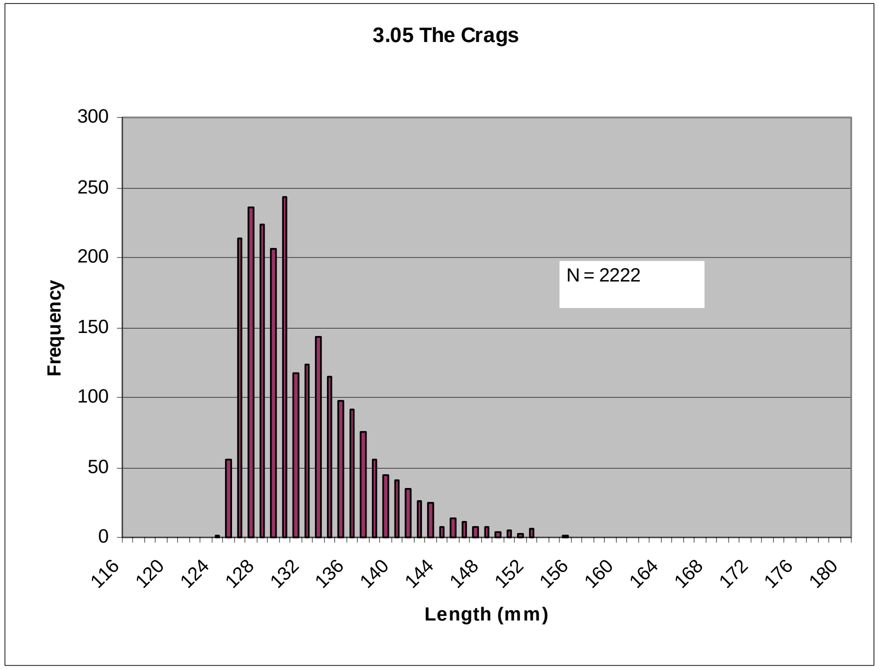
164
168
172
176
180


3.05 The Crags
N = 2222
Frequency
Length (mm)
0
50
100
150
200
250
300
116
120
124
128
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140
144
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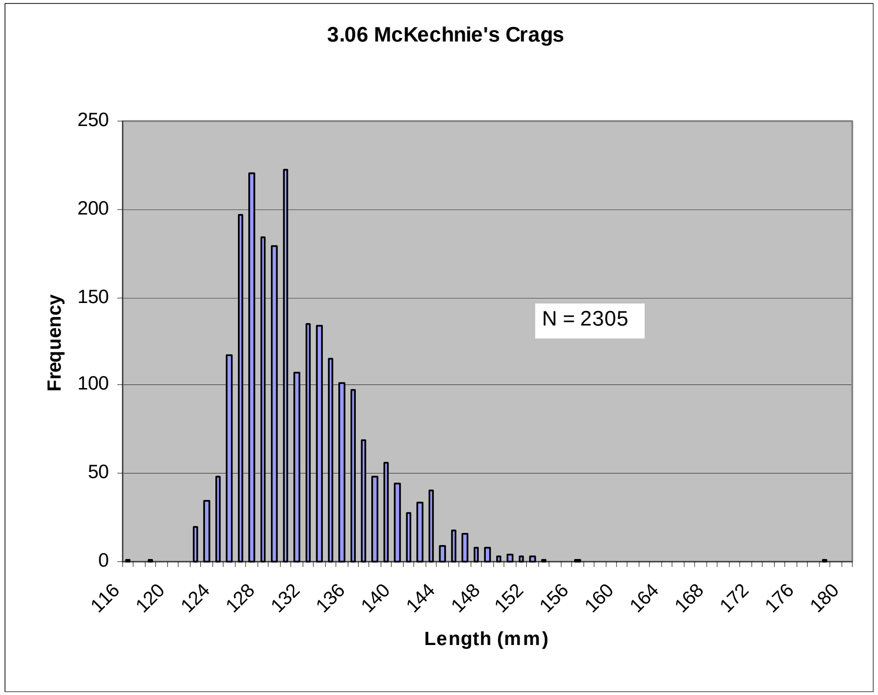
152
156
160
164
168
172
176
180


3.06 McKechnie's Crags
N = 2305
Frequency
Length (mm)
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50
100
150
200
250
116
120
124
128
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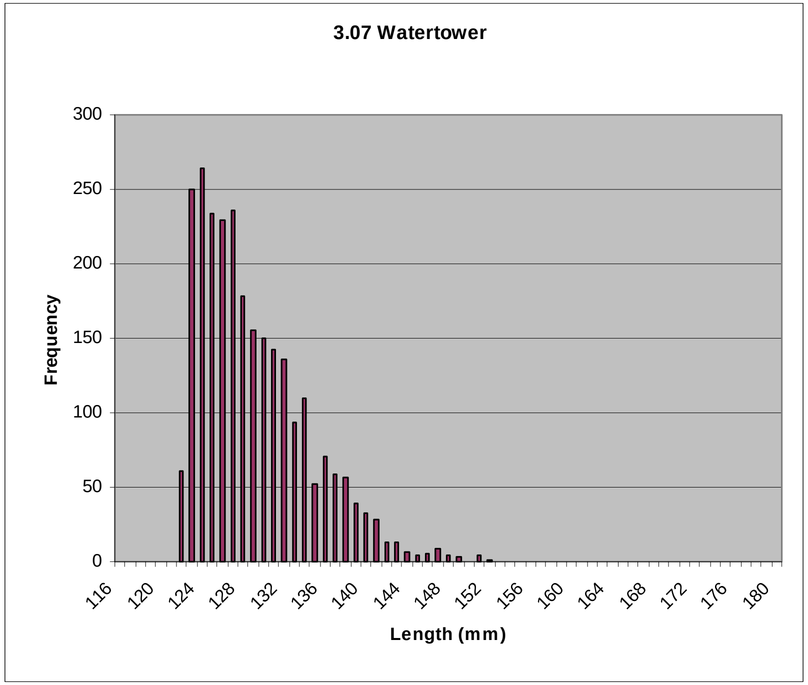
164
168
172
176
180


3.07 Watertower
Frequency
Length (mm)
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50
100
150
200
250
300
116
120
124
128
132
136
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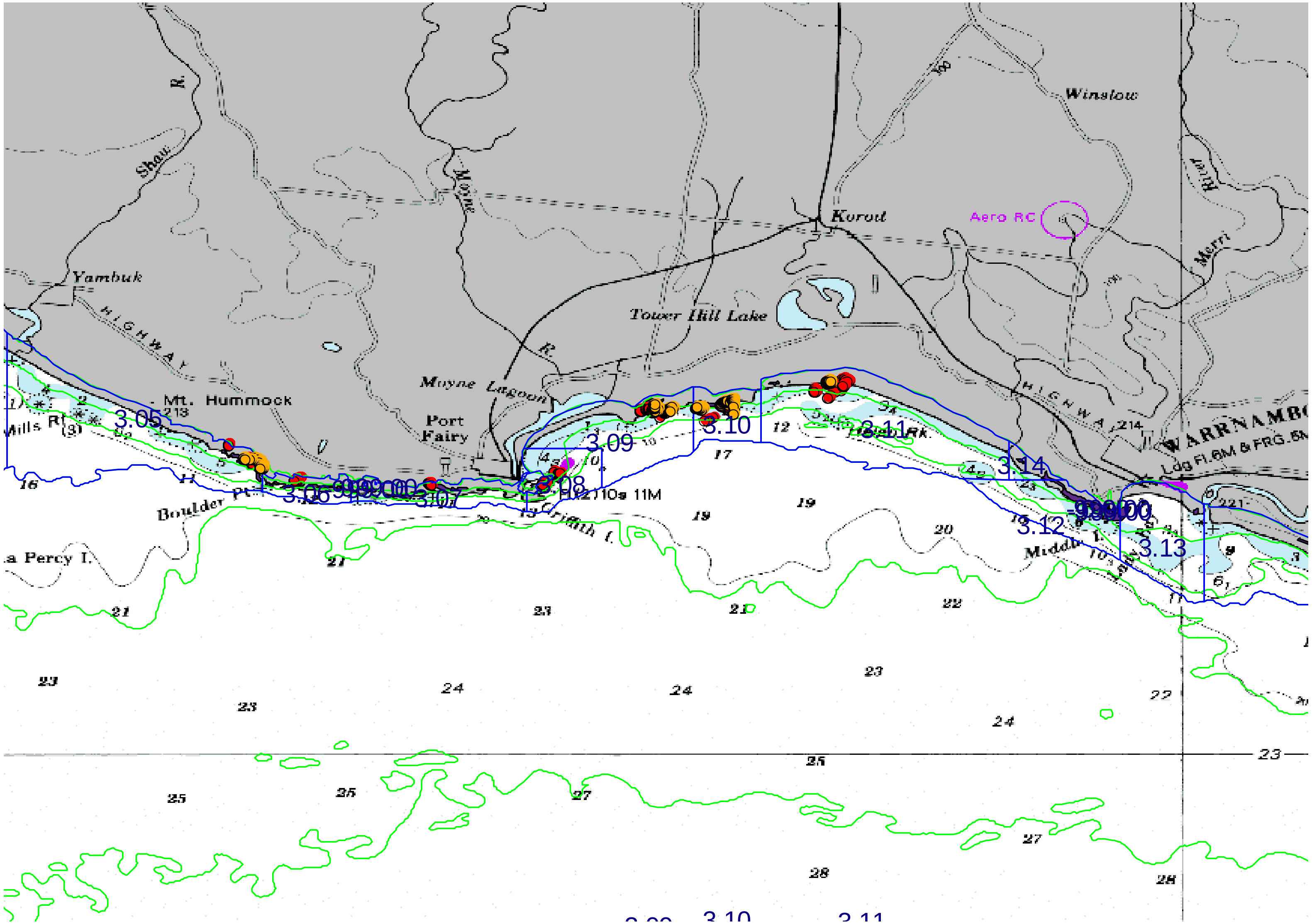
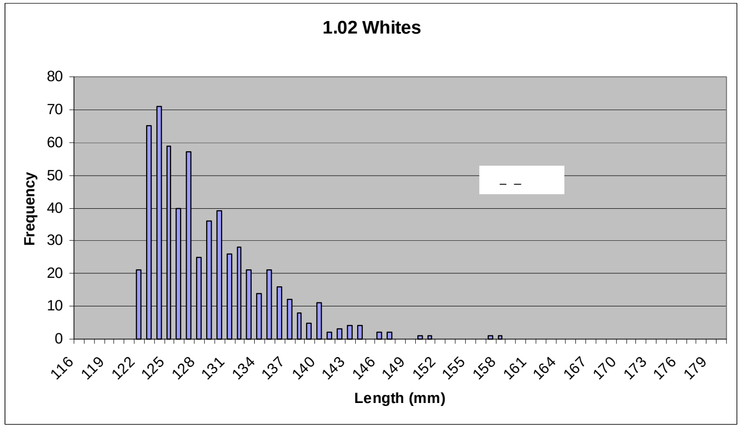
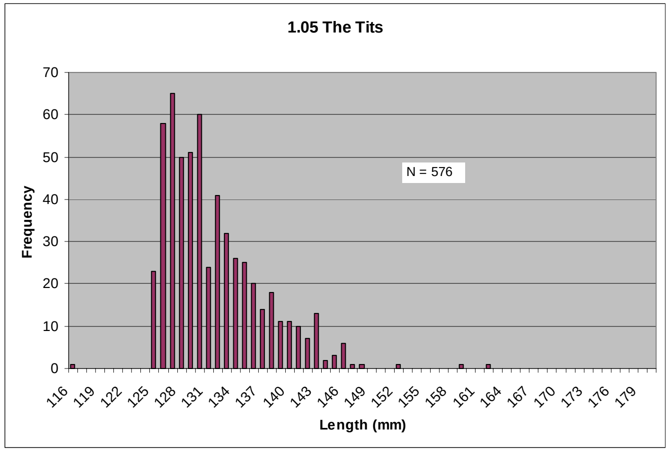
164
168
172
176
180

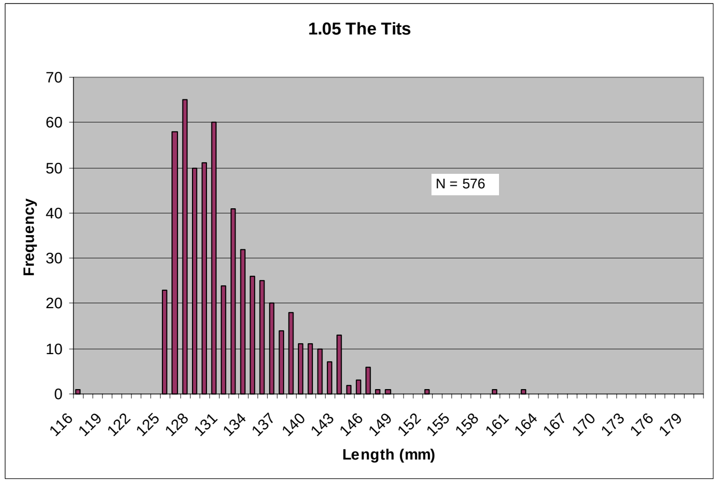

Shaw R.
Moyne R.
Yambuk
HIGHWAY
Mt. Hummock
Port Fairy
Moyne Lagoon
Tower Hill Lake
Koroit
Winslow
Aero RC
Merri River
Boulder Pt
Griffith I.
3.05
3.06
3.07
3.08
3.09
3.10
3.11
3.12
3.13
3.14



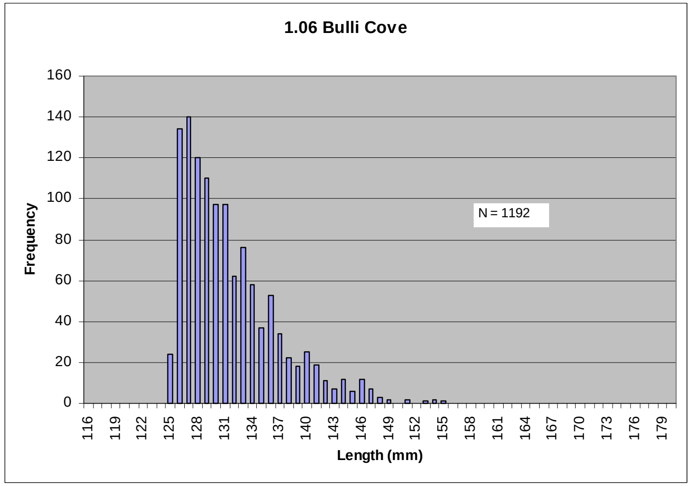
1.02 Whites
Frequency
Length (mm)



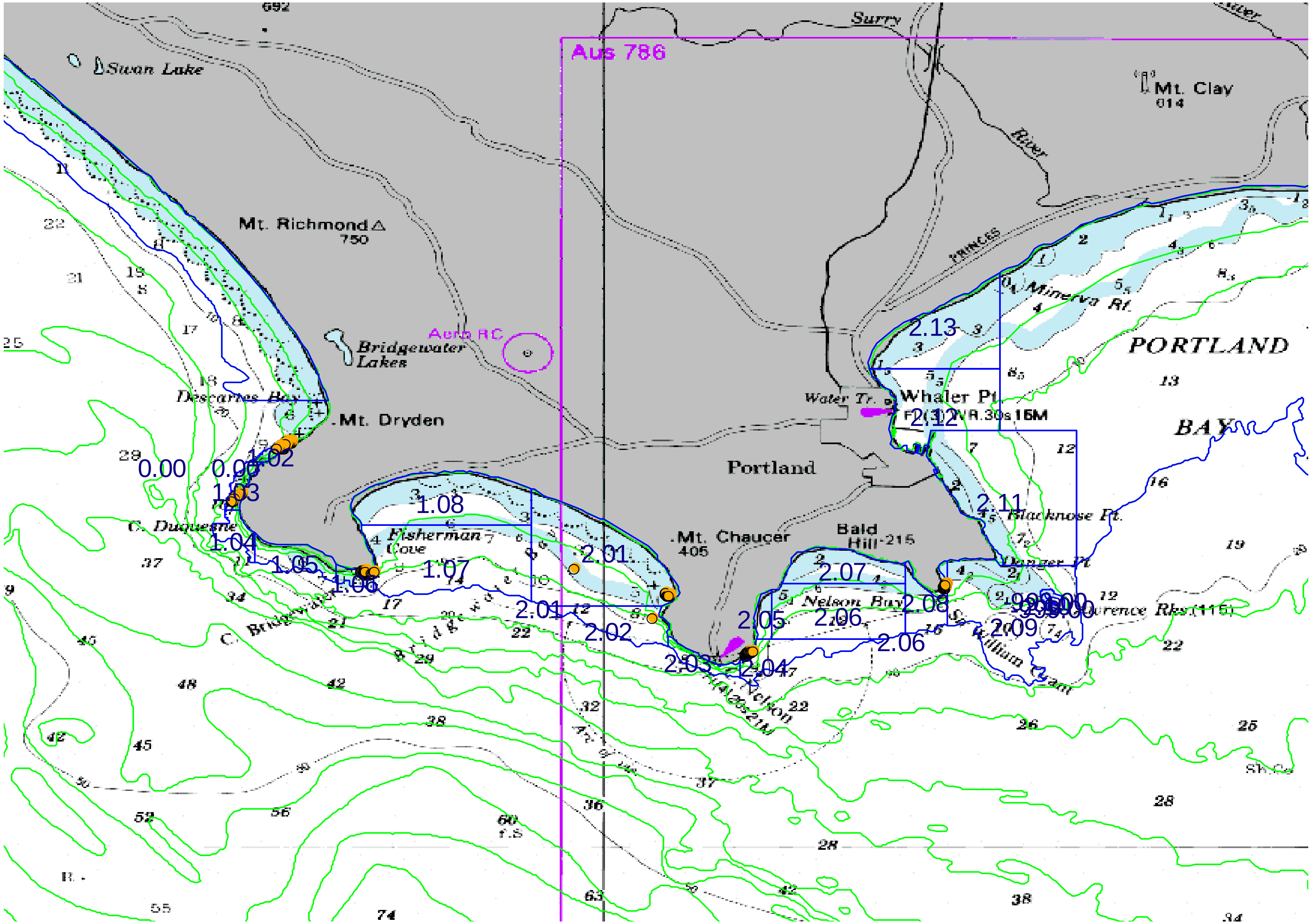
1.05 The Tits
N = 576
Frequency
Length (mm)



1.05 The Tits
N = 576
Frequency
Length (mm)



1.06 Bulli Cove
N = 1192
Frequency
Length (mm)


Aus 786
Swan Lake
Mt. Richmond
750
Bridgewater Lakes
Aero RC
Descartes Bay
Mt. Dryden
C. Duquesne
Fisherman Cove
C. Bridgewater
Portland
Mt. Chaucer
405
Bald Hill 215
Nelson Bay
Water Tr.
Whaler Pt.
Minerva Rf.
PORTLAND
BAY
Blacknose Pt.
Danger Pt.
Mt. Clay
614
Surry
River
PRINCES
0.00
0.06
1.02
1.03
1.04
1.05
1.06
1.07
1.08
2.01
2.02
2.03
2.04
2.05
2.06
2.07
2.08
2.09
2.11
2.12
2.13

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PIRVic Marine & Freshwater Systems

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Project Overview

- Investigate and recommend on web-based presentation of user selected statistical summaries of abalone fisheries data in graphical and tabulated form using maps as the primary selection tool.
- Design and build "map" based selection of data to populate graph and table templates for display on web pages.
- Use recommendations from initial investigation e.g. maps may be map pictures (tif, bmp) overlayed by grids, or with "hot spots" to select regions/fishing blocks)
- Use commercial catch sampling (length frequency) and commercial catch and fishing effort summary information in MySQL (data at the day and reef levelfor catch).
- Also select date range, data type, graph or table outputs to screen or pdf files.
- Given polygon information in the form of lists of boundary co-ordinates, write process to assign data to reef codes (statistical reporting blocks) used for commercial catch reporting.
- Automatically generate hardcopy statistical summary report in pdf format.

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Project Overview

Intended System Environment:
Web page delivery of data stored in MySQL. Currently building a data acquisition and storage system in MySQL and an industry information website (using ASP).

Profile of Intended Users:
Users will be members of the Victorian commercial abalone industry spanning a broad range of computer literacy levels that typify the general public rather than specialist users. However, industry members generally have a good knowledge of the geography of their fishing grounds.

Description of Current System, if applicable
Maps resident in ARCview as shapefiles and as separate lists of boundary coordinates. Simple program to assign sampling data to spatial catch reporting codes (~150 reef codes).
Data storage and reporting using MSAccess (Hardcopy pdfs have low quality format graphical tools for summarising statistics).

Comments
Alternative contact:Bruce , Modeler at above address.
Flexibility: A reasonable degree of flexibility exists in how the project objectives are to be achieved.
Extension: An additional task if time and resources permits is to develop code that automates uploading of raw catch and effort data files (an output from DPI's Fisheries Information and Licensing System) into MySQL, then summarise/process the data into appropriate tables.

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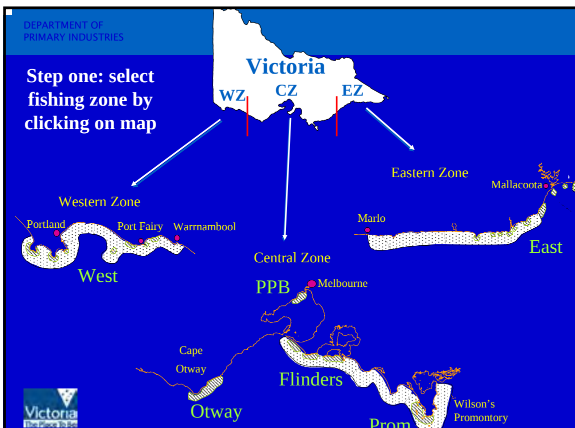
Step one: select fishing zone by clicking on map



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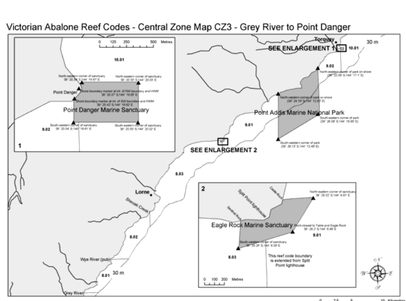
Step two: select reef code by clicking on map



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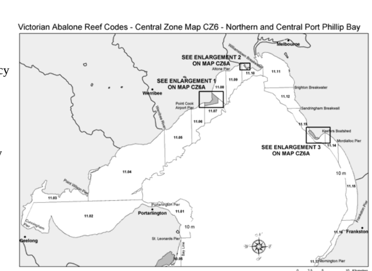
Step three: select template by clicking on button

- Commercial length frequency
- Catch
- Boundary details
- Population length frequency

Reset



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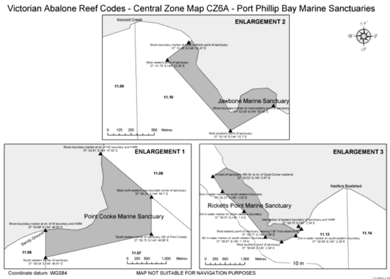
Step four: select sub-ordinate reef code if necessary



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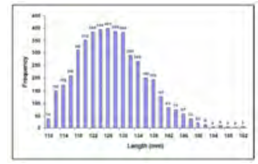
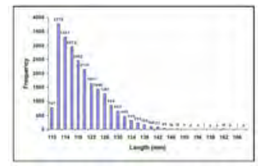
Commercial l-f template



1980



2000

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Diversweb main page

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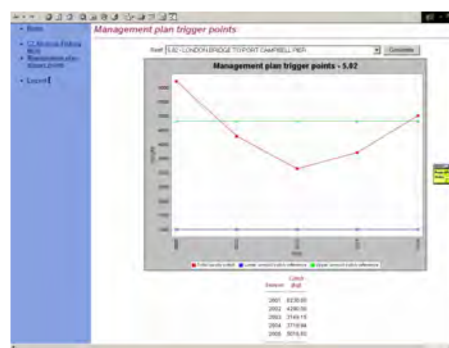
Diversweb trigger point graph



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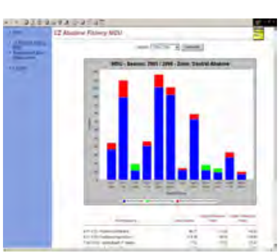
Diversweb CZ MOU graph



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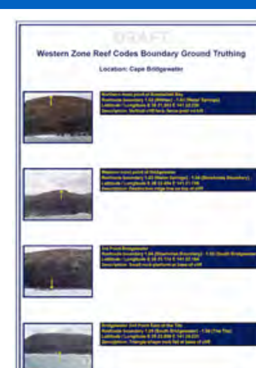
Photos of WZ reefcode boundaries



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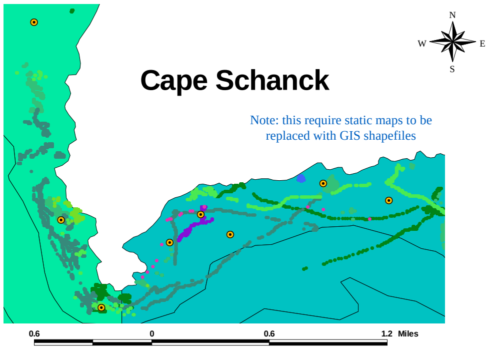
Extension: Tracking effort patterns



Orange dots = FIAS sites

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Measuring shell length

- 2006 = Electronic (measuring board
- 1996 = Manual (vernier calipers)

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Electronic shellfish measurer & data loggers

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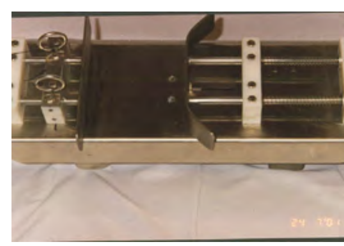
TTS measuring board components



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TTS measuring board components

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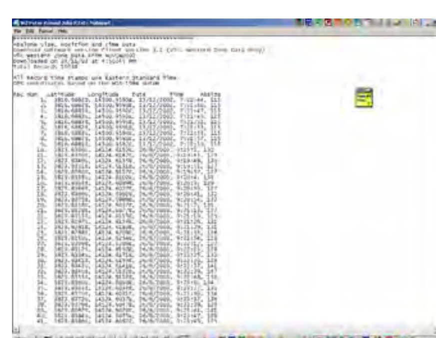
Downloaded data from TTS measuring board



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Output from TTS Measuring Board

TTS Systems Data Capture

Abalone catch report

Total records = 165

Downloaded on 23 Jul 2001 x 3:08:37

Latitude S	Longitude E	Time	Date	Size (mm)
3815.7549	14510.8691	13:43:27	23-Jul-01	140
3815.7549	14510.8691	13:43:49	23-Jul-01	121
3815.7549	14510.8691	13:43:54	23-Jul-01	132
3815.7549	14510.8691	13:43:59	23-Jul-01	123
3815.7549	14510.8691	13:44:03	23-Jul-01	118
3815.7549	14510.8691	13:44:07	23-Jul-01	118
3815.7549	14510.8691	13:44:11	23-Jul-01	126
3815.7549	14510.8691	13:44:17	23-Jul-01	152
3815.7549	14510.8691	13:44:24	23-Jul-01	116

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Scielex shellfish measuring board

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Measuring board components

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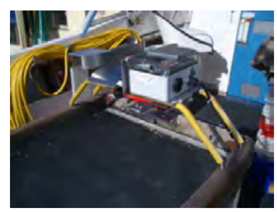
Boat mounting arrangements



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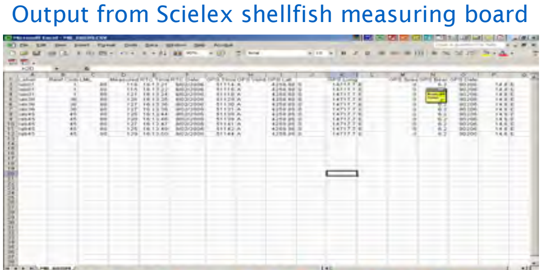
Output from Scielex shellfish measuring board



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Current

Processed manually

Future

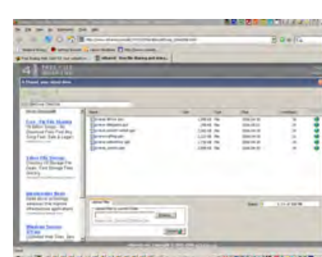
Association rep. downloads logged data to computer, logs onto website using password and uploads by selecting file from browser.

Data is filtered and reef codes assigned to ea. Obs.

Log (+error) file created

Feed back rpt to user

Administrator can over-ride



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Current & planned applications?

- Current:
  - Post pdf files of reports for downloading
  - Expand range of data types available for viewing
  - Export processed CandE data automatically ea day to up date "Divers Web" templates.
- Future:
  - Use the system as an on-line tool to conduct reef scale workshops – viewing information and recording assessments

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