ASSESSMENT OF THE SUSTAINABILITY OF VICTORIAN ABALONE RESOURCES

by

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CERTIFICATE OF AUTHORSHIP / ORIGINALITY

I certify that this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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'Treat the Earth well; it was not given to you by your parents, it was loaned to you by your children. We do not inherit the Earth from our ancestors, we borrow it from our children'

Ancient North American proverb.

For Tristan and Ashley: thanks for the loan, I hope this modest contribution pays off some of the interest.

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Dr David Smith, Director of MAFRI, is thanked for providing the encouragement and support necessary for me to complete this thesis whilst in full-time employment. I also thank Dr Rob Day (University of Melbourne), Associate Professor Peter Hanna (Deakin University) and Dr Scoresby Shepherd for their support as referees for my candidature, and for many helpful discussions on abalone biology and ecology during the past decade.

Additional acknowledgements are contained in the papers and reports incorporated in the body of this thesis. Contributions from co-authors of these publications are fully described below.

Finally, I'm indebted to my wife Susan and sons, Tristan and Ashley, for their forbearance and unrelenting support whilst I was pre-occupied with writing this dissertation.

Sources of the Works

The works included in this thesis were completed during the past decade in the execution of my duties as the senior scientist leading the Abalone Assessment Sub-program at MAFRI. MAFRI is a Victorian state government research institution operating under the jurisdiction of Fisheries Victoria, a Division of the Department of Natural Resources and Environment. The principal role of MAFRI is to provide research, consultancy and educational services required for the sustainable management of aquatic resources and their environment. All the works included in this thesis have been published by either Fisheries Victoria or peer reviewed scientific journals.

Collaboration

As with most research of this nature, the works resulted from my collaboration with members of multi-discipline teams operating under my direction. Although I initiated the projects on which these works are based, and oversaw the conduct and direction of the majority of these, there was substantial intellectual and technical input by colleagues. The joint authorship of the various works and the roles of collaborators as described below accurately represent this input. All collaborators have attested that my claims are *bona fide*.

Scientific papers

Dixon, C.D., **H.K. Gorfine,** R.A. Officer R.A. & M. Sporcic. 1998. Dispersal of tagged blacklip abalone, *Haliotis rubra*: implications for stock assessment. *Journal of Shellfish Research* 17(3): 881–887.

> This paper resulted from the FRDC project 95/165 for which I was Principal Investigator. My main roles in this paper were the experimental design and revision of initial and final drafts. Cameron Dixon was the main architect for the work and did most of the analysis, under the guidance of Miriana Sporcic, and the writing under my supervision. Rick Officer contributed substantially to the experimental design and collection of field data and assisted with editing the manuscript.

Gorfine, H.K. 2001. Post harvest weight loss has important implications for abalone quota management. *Journal of Shellfish Research* 20(2): 795–802.

> I was the main architect for this work through all its phases and wrote the entire manuscript. Technical assistance was provided by David Forbes, Cameron Dixon and Sonia Talman.

Gorfine, H.K. & C.D. Dixon. 2001. Diver behaviour and its influence on assessments of a quota managed abalone fishery. *Journal of Shellfish Research* 20(2): 787–794.

> I was the main architect for this work through all its phases and wrote the entire manuscript. Cameron Dixon assisted with the survey design, supervised the data collection, processed the data, and assisted with analyses, compilation of tables and production figures.

Gorfine, H.K., D.A. Forbes & A.S. Gason. 1998. A comparison of two underwater census methods for estimating the abundance of the commercially important blacklip abalone, *Haliotis rubra*. *Fishery Bulletin* 96: 438–450.

I performed the majority of this work apart from the field components. David Forbes assisted with the design and collected most of the data. Anne Gason provided statistical advice, performed the Monte Carlo simulations and helped revise the manuscript for publication.

Gorfine, H.K., B.L. Taylor B.L. & T.I. Walker. 2001. Triggers and targets: What are we aiming for with abalone fisheries models in Australia? *Journal of Shellfish Research* 20(2): 803–811.

I compiled and wrote this paper, illustrating key points by drawing on a range of analyses principally conducted by colleagues. Bruce Taylor was responsible for the development and application of fisheries models and Terry Walker played a major role in the design of model-based analyses.

Hart, A.M., **H.K. Gorfine** & M.P. Callan. 1997. Abundance estimation of blacklip abalone (*Haliotis rubra*) I. An analysis of diver-survey methods used for large-scale monitoring. *Fisheries Research* 29: 159–169.

Hart, A.M. & **H.K. Gorfine**. 1997. Abundance estimation of blacklip abalone (*Haliotis rubra*) II. A comparative evaluation of catch-effort, change-in-ratio, mark-recapture and diver-survey methods. *Fisheries Research* 29: 171–183.

Both these papers were written by Anthony Hart under my supervision to publish the results of FRDC project 93/100 for which I was the Principal Investigator. Much of my contribution was in conceiving the project and producing initial experimental designs that Anthony adapted. Anthony was largely responsible for the data collection and analysis phases of the project. I contributed to the editing of the final drafts of the manuscripts. Michael Callan was responsible for overseeing all technical aspects of the project and assisted with data processing and some of the analyses.

Officer, R.A., C.D. Dixon & **H.K. Gorfine**. 2001a. Movement and re-aggregation of the blacklip abalone *Haliotis rubra* Leach, after fishing. *Journal of Shellfish Research* 20(2): 771–779.

This paper resulted from the FRDC project 95/165 for which I was Principal Investigator. My main roles in this paper were initiating the project, advising about the experimental design, assisting with interpretation of results and revising initial drafts. I also participated in some of the fieldwork. Rick Officer was the main architect for the work and did most of the analysis and writing under my supervision. Cameron Dixon contributed substantially to the experimental design and collection of field data.

Officer, R.A., M. Haddon & **H.K. Gorfine**. 2001. Distance-based abundance estimation for abalone. *Journal of Shellfish Research* 20(2): 781–786.

This paper is an extension of the work done during the FRDC project 95/165 for which I was Principal Investigator. I played a significant role in conceptualising the application of distance based sampling methods to abalone abundance estimation. Cameron Dixon and I performed the field surveys to collect the main data used for the simulations in this paper. Rick Officer was the major architect of the work, identifying appropriate analytical techniques, writing the manuscript, and performing the computer simulations. Malcolm Haddon's role included providing expert advice and assistance with the computer simulations and in drafting and revising the manuscript.

Troynikov, V.S. & **H.K. Gorfine**. 1998. Alternative approach for establishing legal minimum lengths for abalone based on stochastic growth models for length increment data. *Journal of Shellfish Research* 17(3): 827–831.

My contribution to this paper included conceiving the application of the model to available data and writing most of the manuscript; however, the development and application of the mathematical formulae were done entirely by Vlad Troynikov. I was largely responsible for the interpretation of the results for the assessment of abalone fisheries.

Project reports

Gorfine, H.K. (comp.). 2001. Assessment of the Victorian abalone fishery against guidelines for the ecologically sustainable management of fisheries, April 2001 (revised March 2002). Unpublished submission from Fisheries Victoria to Environment Australia.

I compiled this report to address the guidelines established by Environment Australia for the assessment of the ecological sustainability of Australian fisheries under the *EPBC Act 1999* (Cwlth). The report was composed using information from MAFRI fishery assessment reports, the Abalone Management Plan and the SCFA Abalone Case Study. Although the report was not formally published it was made publicly available on the Department of Natural Resources and Environment and the Environment Australia Internet sites.

Gorfine, H.K. & D. Dixon (eds.). 2000. *Greenlip Abalone—1999.* Compiled by the Abalone Stock Assessment Group. Fisheries Victoria Assessment Report No. 26. Marine and Freshwater Resources Institute: Queenscliff, Victoria, Australia.

I completed almost all of the analyses and writing for this report. The field work was conducted by specialist contractors and Cameron Dixon assisted me with the survey design and produced most of the figures and tables.

Gorfine, H.K., B.L. Taylor & D.C. Smith (eds.). 2002. *Abalone—2001.* Compiled by the Abalone Fishery Assessment Group. Fisheries Victoria Assessment Report No. 43. Marine and Freshwater Resources Institute: Queenscliff, Victoria, Australia.

I wrote most of this report, Bruce Taylor conducted the fishery modelling and wrote the Appendix and David Smith did most of the editing prior to publication. The work is a compilation of contributions by a range of MAFRI Abalone Sub-program staff and Abalone Fishery Assessment Group participants.

Gorfine, H.K., R. Tailby, F.Gant, M. Donaldson & I.Bruce. 2002. *Estimation of illegal catches of Australian abalone: Development of desk-based survey methods.* FRDC Project 2000/112 Final Report. Marine and Freshwater Resources Institute: Queenscliff, Victoria, Australia.

This was a final report to the Fisheries Research and Development Corporation (FRDC) that I compiled as Principal Investigator for the project. Because of their expertise in criminological investigations, MAFRI sub-contracted the Australian Institute of Criminology (AIC) to conduct the study under my supervision. Much of the text was taken verbatim from a confidential Australian Institute of Criminology (AIC) report to the Marine and Freshwater Resources Institute. Rebecca Tailby and Frances Gant were the authors of the confidential AIC report. The AIC report made a number of recommendations to which Murray Donaldson and Iain Bruce, senior fisheries investigators with Fisheries Victoria responded. Their responses were appended to the FRDC report. A more general descriptive paper by Rebecca Tailby and Frances Gant that was published in the AIC Trends and Issues series was also appended to the FRDC report. Because dissemination of the entire contents of the AIC report has the potential to compromise the integrity of fisheries enforcement it will not be made public. It was my task to consult with relevant fisheries managers, intelligence and enforcement officers and members of the National Fisheries Compliance Committee to identify those details that should not be revealed and to compile the publicly available report in the format prescribed by the FRDC.

Thesis outline

This thesis provides an assessment of the sustainability of Victorian abalone resources by linking a sequence of chapters based on published works (Fig. 1).

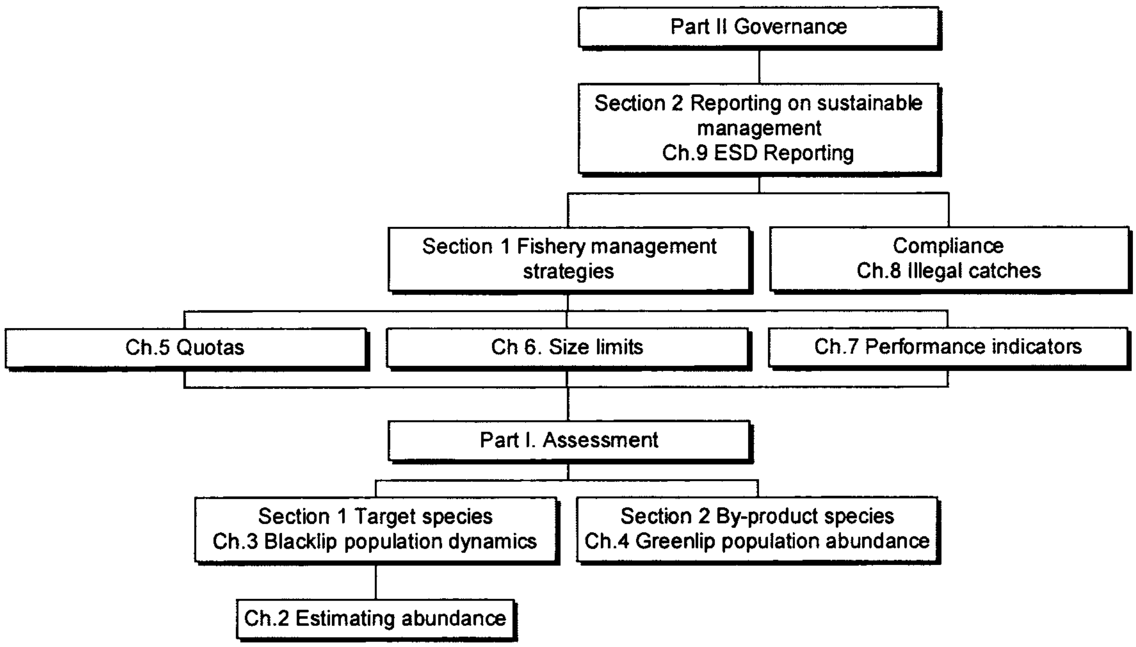

Figure 1. Diagram depicting hierarchy of linkages among the respective thesis chapters.

In Part I, Section 1, I considered the assessment of abalone fishery resources including methods for the conduct of fishery independent abundance surveys (Chapter 2). Chapter 3 describes how abundance data and fishery dependent catch data are incorporated into a model of blacklip population dynamics to estimate current biomass and predict the likely biomass outcomes under alternative levels of catch. For greenlip abalone a more empirical approach is used to make a snapshot stock assessment (Section 2, Chapter 4). In Part II important aspects of Governance, including the application of fishery management strategies (Section 1) were examined and how the management of the fishery is formally linked to assessments (Chapter 7). The two principal strategies examined were quotas (Chapter 5) and size limits (Chapter 6). Illegal fishing compromises the effectiveness of quota and size limit strategies and this topic is dealt with briefly in Chapter 8. In Chapter 9 I described and reflected on a range of approaches to demonstrating and reporting on sustainability and provided an example of a report compiled to satisfy the requirements of federal biodiversity conservation legislation for approval to export native marine species.

Abstract

Many of the world's abalone fisheries have collapsed and in the past 25 years global abalone production has almost halved. Australia now produces 55% of the world's wild abalone and its abalone fisheries are close to, or above, their limits for sustainable yield. Although recruitment over-fishing has generally been singled out as the principal cause of collapse, other factors related to changes in environmental patterns and ecosystem dynamics are also implicated.

It is in this context that the central question of this thesis about the sustainability of Victorian abalone populations is posed. The answer to this question would be obvious with the hindsight that follows a collapse, but for a predominantly healthy fishery this is a different proposition. This thesis presents one of the few comprehensive frameworks for abalone resources assessment and sustainable management worldwide. The key elements in the overall governance of the fishery are explored through a compilation of formally published papers and publicly available assessment documents. Topics for these works range from fishery independent abundance surveys, through fishery assessment modelling, biological performance indicators and management strategies to reporting outcomes for ecological sustainability objectives under state and federal legislation. This is done in a mostly quantitative framework that incorporates explicit linkages between assessment and management decision-making processes.

Our assessments indicate that the Victorian blacklip resource has been largely sustainable during the past 40 years. The management history of the fishery suggests that this owes much to prudent introduction of a broad range of input and output controls at the behest of industry. However, recent instances of localised depletion, a large but unquantified illegal catch and model predictions of declining mature biomass suggest that there is no room for complacency. In contrast to blacklip, greenlip abalone resources are in need of restorative action and the future existence of a commercial greenlip fishery in Victoria is problematic. It is vitally important that we continue to refine our management, attempt to understand its limitations, address the difficult ecological issues and avail ourselves of emerging technologies that enable greater efficiency and precision in the scale of assessment and management.

Finally, having an effective assessment and management framework is insufficient on its own to demonstrate the sustainability of Victorian abalone resources. To properly satisfy legislation for resource sustainability there is a need to document and report the outcomes against specific assessment criteria audited by an independent body on a regular basis. Continued approval to export Victorian abalone overseas is contingent on meeting this requirement.

Research synopsis

Research into Victorian abalone resources commenced during the late 1960s with the involvement of Scoresby Shepherd, an abalone biologist from South Australia, followed by the appointment of Konrad Beinssen as Victoria's first abalone fisheries biologist. Konrad initiated investigations that focussed on reproductive biology and parameters such as natural mortality and growth. He also investigated the fishing power of commercial abalone divers, commenced fine-scale mapping of abalone-producing reefs and attempted to model the fishery. Changes in Government fisheries research priorities led to the cessation of this research during the mid to late 1970s, although industry reporting of catch and effort continued.

Rob Day, a senior lecturer at the University of Melbourne, was the only researcher consistently studying Victorian abalone during the late 1970s to early 1980s. During the mid 1980s, state government sponsored research into Victorian abalone recommenced with Paul McShane successfully obtaining a grant from the Fishing Industry Research Trust Account to determine the stock-recruitment relationship for blacklip abalone. This led to a highly productive period of study of the fisheries ecology of Victorian abalone, during which Paul completed much of the work initiated by Konrad and extended this with investigations of early life history, recruitment dynamics, population structure and abundance.

Since 1992 I have been engaged in assessing the sustainability of Victorian abalone resources under contemporary management regimes. This thesis collates and integrates a range of publications that address assessment methodology, several underpinning biological processes, and the application of selected methods to assess the Victorian abalone stocks. Consideration is given to the management implications of the results of these studies that include insights into operational aspects of the fishery, particularly the role of fishing practices.

The papers by Gorfine et al. (1998a) and Hart et al. (1997) report the results of investigations that compare the efficacy of several underwater survey methods and describe the application of preferred approaches in the conduct of fishery independent monitoring of commercially important abalone populations. This work involved intensive field-based experimental trials and removal of a pre-determined quantity of abalone by commercial abalone divers from about 15 hectares of reef during experimental fish-downs. A range of criteria was used to evaluate the relative superiority of one method over the others. Primarily, sensitivity to the impact of controlled fishing was used to discriminate between alternative methods, and secondarily, logistical considerations such as cost and ease of application. We found that transect based surveys provided a relatively accurate and cost-effective means of estimating abalone abundance. Time-based surveys were more precise but lacked accuracy and tended to underestimate the fishing impact. Methods based on Tag-Release-Recapture provided acceptable results but were labour intensive, and Change In Ratio techniques failed to satisfy the critical assumption that there was no change in the abundance of the unfished sub-legal sized component of the population. In Hart and Gorfine (1997) the assessment of fishery independent survey methods was extended to a comparison with fishery dependent methods commonly used to assess fin-fisheries. This work demonstrated that the use of fine-scale catch rate data as an index of abundance was unreliable in detecting changes due to fishing because of the spatial patchiness of abalone populations. The failure of conventionally reported catch per unit effort to respond to abalone population decline is well known.

One of the difficulties that confronts those attempting to estimate abalone abundance underwater is that a proportion of the abalone in each population cannot be observed because it resides in cryptic habitat within crevices and under large boulders. The amount of cryptic space is a function of the physiography of each reef complex that tends to vary with the geology of the substrate and its response to weathering from exposure to wave energy. Observations during comparisons of survey methods suggested that fishing stimulated emergence of abalone from cryptic habitat and that abalone moved in response to disturbance caused by both the survey activity and the fishing. We hypothesised that this was because smaller-sized abalone emerged from cryptic spaces to occupy sites on the reef that were formerly occupied by harvested abalone. We further postulated that the effects of emergence of abalone from cryptic space on abundance estimates would be exacerbated if abalone re-aggregated to maintain their patchy distribution. The need to test these hypotheses led to a further study on movement and re-aggregation of abalone in response to fishing.

In Gorfine et al. (1998b) we report the results of the study into movement and re-aggregation. Although there have been a number of studies of abalone movement this was the first attempt to investigate post-fishing re-aggregation. The study involved extensive in-situ tagging, measuring and detailed plotting of the positions of abalone within experimental plots before and after experimental fishing at two locations that differed physiographically.

One study location contained reef of high rugosity that was extensively dissected by crevices, whereas the other had reef of low relief with minimal cryptic space. Although direct observation and measurement of emergence from cryptic habitat remained elusive, because tagging the cryptic component was not possible, we were able draw some inferences about the amount of emergence. This was achieved by comparing the expected with the observed differences in absolute abundance between pre- and post-fishing surveys after accounting for the numbers of abalone immigrating estimated from movements of tagged abalone into the experimental plots after fishing. At the highly rugose location substantially more abalone remained in the experimental plots after fishing than could be accounted for by immigration alone.

Contrary to expectation, it was larger rather than smaller-sized abalone that tended to emerge. In the location with limited cryptic space immigration appeared to be the dominant post-fishing recovery process, but interpretation of the data was confounded by a tendency for abalone to disperse after tagging. A clearer picture became evident when the tagged abalone (about 20% of the study populations) were excluded from the analysis.

In both instances there was a tendency for abalone to re-aggregate and partly restore post-fishing abundances to pre-fishing levels. This result has important implications for both the interpretation of time series of population abundance indices and for the management of abalone fisheries. Re-aggregation, particularly where emergence from cryptic space of legal or close to legal size abalone is a factor, will result in inter-annual estimates of relative abundance that may be insensitive to underlying downward trends in absolute abundance, in other words the abundance estimates are hyperstable. Hyperstability in abundance indices will present a more optimistic prognosis for the fishery than is warranted. Re-aggregation also means that unlike non-aggregating species, abalone will tend to maintain their vulnerability to capture, or catchability, as abundance declines. For many species catchability decreases with declining abundance to provide greater protection for the residual stock. We concluded that this tendency for catchability to remain high might explain why abalone stocks are prone to sudden collapse.

The tendency for tagged abalone to disperse probably reflects a predator escape response. This behaviour has important implications for tagging studies that are commonly used to estimate population growth and mortality parameters that are important for fisheries modelling. Indeed, the estimation of growth and mortality were secondary objectives of the movement and re-aggregation study. The paper by Dixon et al (1998) estimates the numbers of abalone likely to have dispersed from the experimental plots at the location with low rugosity and discusses the effects of this dispersion on mortality estimates. Loss of tagged abalone through dispersion could not be estimated for the highly rugose location because dispersal of abalone into cryptic spaces within the experimental plots could not be observed. Once again this work highlighted the difficulties presented by habitats with cryptic components. Growth was also estimated for both locations and showed substantial differences in the relative proportions of abalone at each location that were likely to attain the legal minimum length (LML) for capture. The growth analysis applied was the same as that described by Troynikov and Gorfine (1998).

The paper by Troynikov and Gorfine (1998) demonstrates a novel alternative to the conventional application of deterministic growth equations to length increment data. In this study a stochastic analysis was adopted using a modified Gompertz equation for length increment data. We estimated the percentiles of maximum shell length expected for each of three Victorian abalone populations. The percentiles of maximum length showed that the proportions of abalone likely to be excluded from the fishery by the current LMLs varies considerably among locations. In other words the effectiveness of current LMLs to protect stock from over-fishing is variable. In some instances there is a loss of yield to the fishery because the majority of abalone in some populations will not reach shell lengths that are sufficiently large enough for them to become part of the stock. In other instances the LMLs are sufficiently low that all abalone are likely to enter the stock at some stage in their lives.

The fishery assessment report edited by Gorfine et al. (2002b) combines the time series of fishery independent relative abundance, catch history and the some of the results for the above studies into a quantitative assessment of stock status. This facilitated by development of to apply a length-based model adapted specifically for abalone fisheries. The model inputs catch data and engages estimates of growth and mortality parameters, using Bayesian prior probability distributions, to produce estimates of biomass depletion that are fitted to trends in the fishery independent abundance index. Future relative biomass is projected under current and alternative catch quotas using the Markov Chain Monte Carlo simulation procedure to assess the sustainability of the abalone resource within a risk-based framework.

Although we acquired several years of recruitment data through suction sampling of tiny, recently settled, post-larval abalone from reef surfaces, the data showed that recruitment was episodic and a more comprehensive sampling design was required. This sampling was abandoned because of the prohibitive costs of implementing a large scale post-larval sampling program and the very high and variable mortalities expected for abalone during the immediate post-settlement phase of their life history. Consequently, recruitment parameters in the model are estimated internally using the Beverton-Holt equation. The fishery assessment report includes the model specifications and equations, although these may be modified in the future as model development is an on-going and evolving process.

Current outputs from the fishery model show that relative biomass has mostly declined since catch quotas were introduced during 1988. Future projections show that declines in biomass can be expected in four out of the six regions modelled during the next 15 years if total catches remain unchanged. As a consequence of these results, co-managers recommendations of 5% quota reductions in the Western and Central Zones of the fishery and a modest 1% increase in the Eastern Zone have been implemented by Fisheries Victoria for 2002–03 to prevent further declines and promote confidence in the assessment process.

Gorfine and Dixon (2000b) present an assessment of the Victorian greenlip fishery. No previous assessments have been made for this species, although some data on growth and reproduction were collected during the early 1970s. Our conclusions were that the greenlip abalone catch history and current abundances were consistent with a collapsed stock that has failed to recover despite low fishing intensities during the past 20 years. Indeed, analysis of fine-scale spatial variance in densities revealed that individuals and small clusters of 2–3 abalone are spaced on average about five metres apart. Spacings of in excess of two metres have been shown to exponentially reduce fertilisation rates during experiments conducted on South Australian greenlip populations (Babcock and Keesing 1999). Greenlip abalone catches in Victoria reduced from about five percent of the landed catch during 1978 to less than one percent during 1998. Unlike blacklip abalone, mature greenlip abalone do not occupy cryptic spaces and are consequently more vulnerable to over-fishing. Victoria's central coast represents the eastern-most boundary for the geographic distribution of greenlip abalone, further adding to this vulnerability. Because there is no time series of independent abundance estimates for this species and reported landings are sporadic, we did not attempt to model this fishery. However, using blacklip exploitation rates as a guide we estimated that a total allowable catch of no more than 20 tonnes, with provisos, should be established if the greenlip fishery is to continue. The recently released Victorian Abalone Fishery Management Plan has recommended a separate TAC of zero for this species until stocks recover. Our advice, that active intervention in the form of a stock restoration program will be required if greenlip abalone populations are to return to their former productivity, is currently under consideration.

Several issues arise from the application of models to assess the Victorian abalone fishery and provide advice for management decision-makers. Some of these relate to model inputs and include the factors affecting the quality and assumptions about the available data, and others relate to the interpretation of model outputs in managing the fishery. The studies of abundance indices and their responses to fishing have been examined and their limitations identified in the papers referred to earlier. Gorfine and Dixon (2001) and Gorfine (2001b) give consideration to some of the limitations in using catch and effort information by examining the fishing behaviour of divers and the relationship between reported daily catch per unit effort (CPUE) and instantaneous catch rates. CPUE has been steadily increasing during recent years in the three management-zones of the Victorian abalone fishery. However, when the data were examined on a more localised scale it became clear that the increasing CPUE mostly resulted from changes other than increases in abalone abundance. These included reporting effort as time underwater when it was previously reported as time at sea, a shift in fishing effort away from less productive towards more productive areas of the fishing grounds, and an increase in diver efficiency as contract divers progressively replaced licence holders in the water. Indeed as part of the most recent assessment, examination of CPUE also revealed that in most instances where trends were substantially increasing, there were concomitant decreases in catch and effort (Gorfine et al. 2002b). These papers also consider the effects of contemporary management on fishing practices and highlight the issues of managing on a scale that is an order of magnitude larger than the scale at which the fishery is prosecuted.

Gorfine and Dixon (2001) present the results from what is possibly the first ever program on onboard observation of catch and effort for an abalone fishery. Analysis of the data shows that instantaneous catch rates are both many times higher and much more variable than daily reported catch per unit effort. However, the two forms of catch rate data can be reconciled when allowances are made for the over-estimation of daily effort by the divers and the post harvest weight loss estimated by Gorfine (2001b) that occurs prior to the official weigh-in and reporting to Fisheries Victoria. Results from this investigation also show that 80% of all abalone harvesting occurred in depths shallower than 13 metres despite the targeted blacklip abalone occurring as deep as 30 metres. This reflects the safety consciousness of the current generation of abalone divers who seek to avoid excessive hyperbaric exposure and means that much of the fishing is concentrated relatively close to shore.

Much of the apparent sustainability of the contemporary fishery seems to have resulted from the maintenance of traditional patterns in diver behaviour rather than bureaucratic management control. Changes in diver demographics and a shift away from owner-operator fishing licences has created the potential for a loss of stewardship among the catching sector of the Victorian abalone industry unless a new management paradigm is adopted. The paper by Gorfine et al. (2001) critically examines the quantitative performance measures used to manage abalone fisheries in other Australian States. Suggestions are made about the selection of appropriate reference points and how these can be linked to quantitative assessments of the Victorian fishery and used to make management decisions that mitigate against unsustainable abalone harvests.

The major threat to future sustainability of Victorian abalone resources is perceived to be the prevalence of abalone poaching. Today, poaching is generally regarded as a form of theft. Gorfine et al. (2002a) report the findings of one of the first-ever evaluations of the utility of enforcement agency data holdings for quantifying illegal catches across Australia. This work has lead to a suite of recommendations for improving existing compliance and intelligence databases and has paved the way for future research into new data collection strategies that may provide statistically defensible estimates of illegal catches.

The effective linkage of fishery assessment and management requires a suitable framework for reporting. A reporting framework is required not only to ensure that there is linkage between the two processes, but also that the linkage is transparent and amenable to audit. Legislation to facilitate sustainable fisheries management and public accountability at all levels of government in Australia now mandates that reporting occurs according to specified guidelines and is evaluated against bench-marking criteria. The report by Gorfine (2001a), *Assessment of the Victorian Abalone Fishery against Guidelines for the Ecologically Sustainable Management of Fisheries*, provides an example of how the reporting requirements under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* (Cwlth) may be addressed (Environmant Australia (2002a). This report is necessarily focused on the ecological impacts of the Victorian abalone fishery. All-important socio-economic factors do not come directly within the purview of the *EPBC Act 1999* (Cwlth).

The collection of publications, hitherto described, documents a comprehensive and unified approach to the provision of scientific advice for the sustainable management of the Victorian abalone fishery. Some of this work is groundbreaking in so far as it has not been previously attempted or because the results challenge conventional perceptions and in some instances are counter-intuitive. It is reasonable to claim that the work overall makes an original contribution towards large-scale abalone resource assessment worldwide. Despite this, many questions remain unanswered, issues unresolved, there is scope for improvement and fertile ground for future research. Many of the major challenges in abalone assessment that remain will require advances in available and affordable technology, increased research funding, and changes in the way that our abalone fisheries are managed.

It is appropriate that this thesis provides critical and candid evaluation of the efficacy of current and proposed assessment and management strategies in the quest to ensure a perpetual cycle of continuous improvement.

Chapter 1 Introduction

Abalone fisheries have demonstrated a propensity towards abrupt stock collapse the world over (see Part VII in Shepherd et al. 1992). During the past 25 years wild abalone production has fallen staggeringly from at least 18 000 tonnes in 1975 to slightly more than 10 000 tonnes in 1999 (Gordon 2000). Australia remains as one of only several countries that still possess productive abalone fisheries. The central question posed in this thesis is whether Victorian abalone resources are sustainable in the medium to longer term within the context of our current knowledge of abalone population biology, the monitoring and assessment strategies adopted and the contemporary management regime. This chapter documents background information about the biology and life history of abalone generally, provides a global perspective on abalone fisheries, describes the biogeography of blacklip and greenlip abalone in Australia, and outlines the recreational, indigenous and commercial sectors and management history of the Victorian abalone fishery. The concept of sustainability is introduced and its application is described for fisheries generally, and the Victorian abalone fishery specifically. A working definition is provided that has national agreement among fisheries agencies across Australian jurisdictions. Application of this definition to the Victorian abalone fishery is described within the global context of historical exploitation and sustainability of abalone fisheries.

A rationale is provided for the ensuing chapters that deal specifically with the information requirements and processes used to assess whether Victorian abalone resources are sustainable under contemporary management arrangements. This rationale stems from state and federal legislation that requires fisheries management agencies to demonstrate, via an appropriate reporting framework, the ecological sustainability of the fisheries they manage. These requirements for reporting on sustainability are described in detail.

Systematics

Abalone are marine snails or gastropods belonging to the Haliotidae, a family of the recently erected order Vetigastropoda within the new sub-class Orthogastropoda (Ponder 2002). Note that most texts place the Haliotidae in the now redundant systematics of sub-class Prosobranchia, order Archaeogastropoda. In this new systematic revision the subclasses Opisthobranchia and Pulmonata have been combined into the new order Heterobranchia (Ponder 2002). Lindberg (1992) describes the poor representation of abalone in the fossil record, that he ascribes to the susceptibility of shells towards disintegration (see also Shepherd and Breen 1992), and expresses concern about the paucity of knowledge about the evolution and phylogeny of the genus *Haliotis*. Almost a decade later, Geiger wrote a PhD dissertation (Geiger 1999) that included a review of fossil abalone and made comparisons with extant species. In his review, Geiger (1999) notes that 35 fossil species have been described, although their status as separate species is unconfirmed. Geiger (1999, p. 83) also states that 'A critical and comprehensive revision of fossil abalone has not been attempted and is not feasible because of the limited material'.

Abalone are now classified according to the following taxonomic hierarchy (Ponder 2002):

Kingdom	Animalia		
Phylum	Mollusca		
Class	Gastropoda	Cuvier,	1798
Subclass	Orthogastropoda		
Order	Vetigastropoda		
Super family	Pleurotomarioidea	Swainson,	1815
Family	Haliotidae	Rafinesque,	1815
Genus	Haliotis		

Unlike the hermaphroditic orthogastropods in the order Heterobranchia, vetigastropods have separate sexes (Hiscock 1975). An anteriorly oriented aperture to the mantle cavity also distinguishes the Vetigastropoda. The more primitive members of this order, such as haliotids, release their gametes into the water column for external fertilisation and feed herbivorously. The most recent of contemporary studies of the systematics of the Haliotidae has identified 56 described species and 10 sub-species of the genus *Haliotis* worldwide (Geiger 1999), although Lindberg (1992) lists 65 species and Hahn (1989c) mentions that there are over 100 species. Shell morphology is the principal taxonomic characteristic used for identification of both fossil and extant abalone, although molecular and ultrastructure analyses have played an important role in contemporary studies. Diagnostic features include the row of excurrent tremata along the left-hand margin of the shell, as well as paired bipectinate ctenidia and a well-developed (hypertrophied) foot muscle girdled by a characteristic epipodium (Lindberg 1992).

'Abalone' is the common name adopted for members of the genus *Haliotis* in the United States. It derives from the American-Spanish word abulón that in turn originated from aulon, a word in the language of Native Americans from Monterey Bay, California (Merriam-Webster 2000). Creators of the board game of the same name, but pronounced ab'e loan as opposed to ab'e lon i, coined the term from *ab*, the latin prefix for never, and alone to mean 'never alone'. The aggregating behaviour of abalone makes this a particularly apt definition.

The genus name *Haliotis* means sea ear and refers to the ear-like shape of the shell. Many of the common names for abalone in various countries have this meaning eg. the South African 'perlemoen' for *H. midae* comes from the Dutch word paarlemoen and the term 'ormer' from *H. tuberculata* comes from the French oreille de mer (Hahn 1989c). The inelegant Australian term 'mutton fish', originally used for *H. laevigata* (Harrison 1969), reflects the difficulty experienced with mastication when abalone meat is inexpertly prepared and over-cooked.

The dextral helical spiral of abalone shells strongly exhibits the torsion caused by anti-clockwise rotation of the visceropallium during development (Hiscock 1975). As a consequence of this rotation in abalone, paired internal organs such as the ctenidia are asymmetrical, with the left-hand side member of each organ pair larger than the member on the right-hand side of the body (Lindberg 1992). However, unlike many gastropods the shell is not strikingly coiled (Geiger & Poppe 2000).

Functional anatomy

Abalone shells have a low flat morphology with a large aperture. This provides a streamlined profile that reduces drag from wave energy and currents (Barnes 1987, Tissot 1992) and permits the habitation of narrow crevices in the reef substrate. As mentioned previously, the outer left margin of an abalone shell is perforated with a series of holes called tremata, more commonly referred to as respiratory pores. Patency of the tremata is maintained by protruding pallial tentacles (Hiscock 1975). The first two or so antero-lateral tremata allow the ingress of water into the mantle cavity to oxygenate the ctenidia, and the tremata posterior to these provide exits for the exhalant current to facilitate the discharge of renal waste and expulsion of gametes (Barnes 1987, Hiscock 1975). The sculpting of the outer layer of the shell or periostracum and the tremata varies among species. Substantial intra-specific variation may also be exhibited (Geiger 1999).

In some species the shell is highly crenulated and the tremata elevated, in others the shell is smooth and the tremata are flush with the rest of the shell surface. The two most abundant abalone species in Victoria, *Haliotis rubra rubra* Leach 1814 (blacklip) and *Haliotis laevigata* Donovan 1808 (greenlip) differ in this regard. *H. rubra* shells display an array of irregular ridges radiating away from the spire. Faint growth lines traverse the ridges and the tremata are distinctly raised. In contrast, *H. laevigata* shells are smooth and their relatively smaller diameter tremata are flush. It is plausible that these differences relate to habitat preferences, with blacklip shells adapted to create localised micro-turbulence within the boundary layer of water above the shell surface so that water exchange is increased (Tissot 1992). *H. laevigata* are generally found in locations where currents prevail and the need for increased water exchange is likely to be reduced.

The powerful muscular foot enables abalone to resist the shearing forces from strong water movements that characterise their habitats (Naylor & McShane 1997a). Indeed, large abalone are capable of resisting forces up to one-half an imperial ton (Hyman 1967).

Abalone feed by scraping their tongue-like radula covered with rows of chitinous teeth across the surfaces of substrates and macroalgae. As the abalone grow and their buccal cavity enlarges they progress from feeding on epilithic diatoms, to turfing algae and finally to macroalgae. Although many abalone species are grazers, others appear to predominantly feed on fragments of drift algae (Andrew & Underwood 1992, Ault & DeMartini 1987, Tegner & Dayton 2000).

Biogeography

Abalone are found throughout many tropical, sub-tropical and warm temperate regions in both northern and southern hemispheres (Geiger 1999). Lindberg (1992) notes that haliotids were globally distributed from the Miocene onwards with the Pacific Rim possessing a rich fossil record. Fewer species are distributed in cool temperate waters

(Geiger & Poppe 2000). There is a tendency for shell size to be inversely related to water temperature with the largest species found in temperate regions and tropical species to be generally smaller in size (Lindberg 1992). This correlation between shell size and temperature applies within as well as among species and is the reason that most of the world's current and formerly productive abalone fisheries are located in cool temperate regions.

As well as *H. rubra* and *H. laevigata*, other smaller and less common species found in Victoria include *H. scalaris emmae* Leach 1814 and *H. coccoradiata* Reeve 1846. *H. scalaris* is characterised by a prominent spiral ridge that runs midway between the row of tremata, and the spire of the shell. It is distributed from the South Australian border as far eastwards as Waratah Bay. *H. coccoradiata*, often mistaken for juvenile *H. rubra*, is restricted to the Mallacoota region in eastern Victoria. Roe's abalone, *H. roei* Gray 1827, is reported as occurring in western Victoria, but has not been observed during MAFRI research or monitoring.

Haliotis laevigata Donovan, 1808
Point Lonsdale Bight, Central Victoria, 159 mm.
Coll. H. Gorfine

Haliotis coccoradiata Reeve, 1846
Long Reef, Collaroy, NSW. Australian Museum C.104260. Coll. J. Kerslake
Reproduced with kind permission from Des Beechey.

Haliotis rubra rubra Leach, 1814
Thunder Cave, Western Victoria, 158 mm.
Coll. A. MacDonald

Haliotis scalaris emmae Reeve, 1846
Port Fairy, Western Victoria, 87 mm.
Coll. P. Shea

Plate I. Shells of abalone species found in Victoria.

Blacklip abalone

Victoria's blacklip abalone resource forms part of a larger distribution that extends from northern NSW southwards through the islands of Bass Strait to southern Tasmania, and westwards along the Victorian and South Australian coasts to Western Australia. Consistent with the relationship between larger size and cooler water temperature, blacklip abalone from southern Tasmania attain much larger shell lengths than those from NSW. Sizes of Victorian abalone are intermediary between these extremes.

Although blacklip abalone are found throughout Victoria, there are some sections of coast where this species has historically been uncommon or absent. Obviously, the large tract of mostly sandy substrate along the Ninety Mile Beach in Gippsland is one example where abalone would be expected to be absent. Another region where this species is generally in low abundance, except for a few relatively small reef complexes, is the region from Point Lonsdale to Lorne. This section of coast faces predominantly southeast and tends to be somewhat protected from the large southwesterly swells that prevail in western and central Bass Strait. However, the algal vegetation and habitat physiography are ostensibly similar to regions of the coast where abalone are abundant.

There is also evidence that the contemporary fishing grounds for blacklip abalone cover a much smaller area than they did prior to the introduction of quotas during 1988. This spatial contraction appears to have had more to do with catching efficiency than with any early stock depletion.

Greenlip abalone

Greenlip abalone are restricted to waters from Wilsons Promontory to the west and have different habitat requirements from blacklip abalone. Populations of greenlip abalone can be found at Wilsons Promontory, Waratah Bay, Inverloch, Cat Bay, Flinders, Nepean Bay, Queenscliff Bight, Torquay to Apollo Bay and Boulder Point near Port Fairy to Dutton Way in Portland Bay (McShane et al. 1986a, Gorfine & Dixon 2000b). To some extent the occurrence of this species complements the distribution of blacklip populations along the coast, with greenlip being found in more sheltered locations.

Life history

Abalone are dioecious broadcast spawners with each female producing up to 2 million eggs annually (McShane et al. 1986b). Fecundity of sexually mature abalone increases with increasing length and may vary substantially (McShane et al. 1986b, Nash et al. 1994). However, reproductive maturity is a function of age not length (McShane 1990). Fertilisation gives rise to lecithotrophic larvae that pass through trochophore and veliger phases whilst suspended in the water column over about 4–11 days (Fig. 2). Although able to survive without exogenous nutrient sources (Seki & Kan-no 1977), abalone larvae can absorb organic compounds directly from the surrounding water (Manahan & Jaeckle 1992). Veligers possess cilia allowing a feeble swimming capacity that cannot overcome the influence of surge and currents, but does enable settling larvae to reject unsuitable substrates by rising back into the water column (Hahn 1989). The lack of more widespread larval dispersal appears to suggest that the planktonic abalone larvae are not pelagic, but rather remain concentrated in eddies of current or entrained beneath the kelp canopy that typically covers their habitat (McShane et al. 1988). However, a drift-tube study by (Tegner & Butler 1985), a study by McShane et al. (1988) and another by Prince et al. (1987) have provided additional evidence in support of localised dispersal of planktonic abalone larvae.

Settlement

Juvenile blacklip abalone settle almost exclusively on pink crustose coralline algae (CCA) such as *Lithothamnium* (McShane & Smith 1988) and *Sporolithon* spp. (Daume et al. 1999b). Chemical attractants in the CCA and mucus slime trails remaining after abalone grazing activity have been advanced as possible settlement cues (see McShane 1992). Recent studies in New Zealand showed that pre-grazing by juvenile *H. iris* conspecifics improved the settlement-inducing activity of biofilms (Roberts 2001). On the basis of studies of cultured abalone, Hahn (1989) inferred that mucus was the most likely settlement inducer in the wild because this would attract the settling larvae to suitable habitat supportive of growth. He suggested that mucus secreted during grazing contains bacteria that may be used as a food source by post-larval settlers. This is supported by a more recent review of post-larval feeding and growth (Kawamura et al. 1998). Roberts (2001) points out that chemical cues in the mucus, in combination with other factors, provides equally valid but untested explanations for settlement induction. Recent evidence indicates that the growth forms of the CCA, rather than its taxa, are the important determinants of settlement (Shepherd & Daume 1996). It has been suggested that some forms of CCA possess micro-crypts within which the abalone can shelter from wave action (Naylor & McShane 1997a); however, it is also postulated that smooth CCA crusts promote stronger pedal adhesion (Shepherd & Daume 1996).

Settlements of blacklip abalone are asynchronous between populations and episodic showing high variability in densities both spatially and temporally (McShane & Smith, 1991). Both post-larval survivorship and growth are positively correlated with settlement density under hatchery conditions (Daume 1999a). During the initial phases of post-settled life, the juvenile abalone tend to occupy cryptic habitat emerging at night to feed on epilithic diatoms and later turfing algae as the buccal cavity and radula increase in size (Kawamura et al. 1998, Takami et al. 2000).

Maturation

Abalone attain sexual maturity in Victoria between 4 and 6 years of age (McShane 1990) and probably have a maximum life expectancy of 10–15 years. This accords with the recovery of tagged California red abalone after 16 years at liberty (Taniguchi & Haaker 1996). Recent MAFRI observations indicate that onset of first maturity in Port Phillip Bay occurs at a shell length of about 65 mm. However, in some of the faster growing populations in the Eastern Zone most abalone at the legal minimum length of 120 mm were found to be immature.

Size at first maturity varies substantially among locations throughout Victoria and reflects the high degree of heterogeneity in growth. Once the abalone mature, reproductive output becomes a function of shell size. Morphometric measurements indicate that slower growing mature abalone often have deeper shells per unit length (Gorfine unpublished data). It is plausible that this allows the accommodation of a larger gonad than do the longer flatter shells of faster growing, less mature individuals.

Habitat

There are distinct differences in habitat preference between blacklip and greenlip abalone in Victoria. Blacklip abalone generally prefer substrates of igneous origin that offer fissures, gutters and overhangs for protection. Blacklip abalone habitat is generally dominated by kelps, in particular the crayweed *Phyllospora comosa,* and characterised by high wave energies and surge (McShane & Smith 1991). Adult greenlip abalone tend to have a more emergent existence than blacklip abalone and are typically found exposed on low relief sedimentary reef adjacent to seagrass beds dominated by *Amphibolus antarctica*. Greenlip habitats are typically subject to higher currents, but lower wave energies than blacklip habitats.

Feeding

Australian temperate abalone species tend to prefer red algae in their diet, although they do feed on kelps and some types of green algae (Day & Fleming 1992, Foale & Day 1992). Although kelps represent most of the algal biomass in abalone habitats, there is evidence that in Australia their relatively higher levels of phenolic compounds (Shepherd & Steinberg 1992) and tougher thallus (McShane et al. 1994) make them less palatable than other algal groups. Although Shepherd and Steinberg (1992) could not separate the effects of phenolic content and toughness, they cited studies of overseas species that showed kelps to be highly palatability to abalone. From this they deduced that algal toughness was unlikely to be a limiting factor in abalone feeding. However, unlike their study, my colleagues and I were able to show that the toughness of agar gel discs of varying strength was negatively correlated with consumption rate and we concluded that toughness was a valid explanation of food preference (McShane et al. 1994).

Shepherd and Steinberg (1992) considered storage polysaccharides and digestibility in their discussion of potential explanations for the apparent differences in food algal preferences they observed; however, they did not consider protein content. In another study in which I was a collaborator we identified the essential amino acid profile (relative to lysine) required to meet the dietary requirements of blacklip abalone (King et al. 1996). Much previous research on dietary requirements of shellfish, including abalone, had focussed on fatty acids and polysaccharides, rather than amino acids.

Our results were remarkably consistent with the relative amino acid composition that Allen and Kilgour (1975) determined for California red abalone. Recent studies by Shipton and Britz (2001) showed a significant correlation between dietary lysine and both growth and protein efficiency in *H. midae*, indicating that lysine might be the primary limiting amino acid in the diets tested. Lysine was one of the essential amino acids that we concluded was limiting in blacklip abalone diets. However, we found that arginine and leucine were more limiting than lysine, whereas Shipton and Britz (2001) found leucine negatively correlated with growth rate, suggesting some variation in amino acid requirements among species. Algal protein content has been shown to be an important determinant of growth rates for a range of abalone species (Boarder & Shpigel 2001). A major difference between brown and red algae is the relatively higher digestible nitrogen content in red algae, (Fleming 1995). Fleming (1995) showed that the preference blacklip abalone exhibit for red algae is related to the higher digestible nitrogen content for these algae.

In blacklip abalone habitats, the red algae form an understorey of foliose, crustose and turfing forms, whereas in greenlip habitat many red algae occur as epiphytes on the stems of seagrasses (personal observation). However, in both instances water movements in these environments tend to ensure a ready supply of red algal drift. It makes sense that abalone display a preference for species among the available algae that promote the fastest growth and development.

The spatial distribution of abalone is characteristically patchy with aggregations often clustered in and around gutters, crevices, scour holes and the bases of rocky pinnacles and bomboras. Two hypotheses for this aggregating behaviour are that it occurs in locations where drift algae is more readily available, and that it occurs seasonally to maximise fertilisation success and larval dispersal during spawning periods.

Some species of abalone, including blacklip abalone, are opportunistic feeders and tend not to forage for food (at least when they are observed during daylight hours), instead relying on drift algal fragments (Tegner & Dayton 2000). Drift algae are more likely to be concentrated in gutters and crevices that offer some protection from the high wave energies that detach and pulverise these algae (Shepherd 1986a).

Evidence from New Zealand suggests that abalone growth occurs independently of the density of attached algae and casts doubt on the notion that reductions in abalone density in slow growing areas will promote faster growth (McShane 1995). One corollary to this observation is that intraspecific competition for food does not disadvantage abalone in high-density aggregations. As an illustration of the benefits of aggregative behaviour, on one occasion I observed several smaller abalone feeding on an algal fragment that was clamped to the reef beneath the foot of a large blacklip abalone.

The existence of density dependence effects on the growth of wild populations of blacklip abalone is equivocal and the subject of on-going research in Victoria. Nash et al. (1994) found that abalone tend to re-aggregate at 'hot-spots' after numbers have been initially reduced by harvesting and concluded that this behaviour was food related.

However, there is also evidence that aggregating behaviour is strongest during spawning periods, including studies in southern Australia by Shepherd (1986b) and Prince (1989), studies in British Columbia by Sloan and Breen (1988). These studies are reinforced by anecdotal reports from Victorian abalone divers that they have observed unusually high densities on elevated parts of reefs during spawning. Indeed I have witnessed increased blacklip abalone activity in less concealed locations and greatly reduced pedal adhesion to the substratum during the lead up to spawning. Normally abalone are difficult to prise off rocks following disturbance, but on this occasion they could be readily removed by hand without an abalone iron. Sloan and Breen (1988) report similar observations for pinto abalone, *H. kamtschatkana*, in British Columbia.

Emergence

The preference for cryptic habitat by juveniles, as well as by many adult blacklip abalone, makes accurate enumeration of absolute densities almost impossible, except in those locations of low relief or where reef complexes are comprised of boulders that can be easily overturned (Officer et al. 2001). The tendency to inhabit cryptic spaces varies among species with *H. kamtschatkana* (British Columbia) exhibiting a weak preference and *H. rufescens* (California) a much stronger preference (Sloan & Breen 1988). Ault and DeMartini (1987) observed that the preference of *H. rufescens* for cryptic habitat resulted in juveniles and adults occupying distinctly different microhabitats in northern California and proposed that movement from juvenile to adult habitat must occur as the abalone grow. Although *H. laevigata* juveniles have a similar preference for cryptic habitat as do blacklip, greenlip adults tend to remain unconcealed. It is likely that occupancy of cryptic habitat provides protection against predation and against high wave energies (Shepherd & Breen 1992) at the expense of optimum food availability. Although this may be offset by nocturnal foraging when predators, such as morwong, are less active and sea conditions are relatively calmer.

Emergence from cryptic habitat is a feature of abalone populations that is not well understood. Abalone emerge from cryptic habitat over a range of sizes (Gorfine et al.

1998b) this may relate to the onset of maturity, but the need to seek improved food access, escape from predators and displacement by competitors are other possibilities. One hypothesis is that larger abalone aggregating along the entrances to crevices are in more favourable positions for feeding and consequent growth, and inhibit the emergence of more cryptic individuals. Observations suggest that when larger unconcealed abalone are harvested from their homesites, other individuals migrate to occupy the vacated locations on the reef that are identifiable by 'scars' i.e. ovoid-shaped areas of rock devoid of epibiota (Hart et al. 1997). It is possible that at least in some instances these immigrants have emerged from concealed crevice space. Our observations suggest that replacement of harvested abalone via emergence is likely to occur from larger rather than smaller abalone (Officer et al. 2001b). Indeed during our studies larger abalone have been observed to push smaller individuals off homesite scars (C. Dixon 1999, personal communication, March). The emergence of smaller abalone from crevice space is likely to be a trade-off between access to better food and increased risk of predation. If a smaller abalone succeeds in gaining improved food access upon emergence then the risk of predation may be offset by more rapid growth. Recently emerged abalone can sometimes be distinguished from those emerging earlier by an absence of epibiota on their shells, as well as by being smaller than the scars they occupy. However, Gorfine et al. (1998) found that the lack of epibiota on the shells, often referred to as 'whiteback abalone', was not a reliable indicator of recent emergence in the locations they studied.

An associated hypothesis is that the growth rates of recently emerged abalone increase commensurate with improved access to food. Obviously the extent to which this may apply to a particular abalone population will vary with the amount of cryptic habitat. Abalone divers report that some, but not all, reefs often appear as though they have not been fished when the divers return several months after fishing. Emergence from cryptic habitat is one plausible explanation for some reefs appearing to be unaffected by fishing, and abalone divers' classification of reefs as 'recovery' and 'non-recovery' probably relates to differences in the amount of cryptic habitat.

Growth

Variability in growth rates between abalone populations is characteristically high over relatively small spatial scales of 10s to 100s of metres due to the effects of complex topography and water movement on associated food availability (Nash et al. 1994). In addition, age cohorts tend to coalesce with increasing size as growth rates slow, so that variation in length-at-age between individuals is high within a population at a particular site. This makes the delineation of cohorts impossible among emergent abalone in the absence of a validated method for determining the age of Victorian blacklip abalone (de Jong 1990, McShane & Smith 1992). In contrast, studies of Tasmanian blacklip abalone show that one annual growth ring is laid down in the shell each year and that by counting the these growth rings estimates of age for individual abalone can be made (Officer 1999). Growth validation studies of Victorian blacklip abalone by Day et al. (2001) indicate that although estimation of the average age of a population may be possible, with current methods the reliable estimation of individual ages remains intractable.

The asymmetry and large variation in growth rates between individual abalone indicate that deterministic estimates of growth parameters are unreliable descriptors of growth. Furthermore, whilst the asymptotic von Bertalanffy growth equation can be used to adequately describe the growth of mature abalone the sigmoid Gompertz equation best describes both juvenile and adult growth (Troynikov et al. 1998). The Schnute equation provides even greater flexibility in the estimation of growth parameters and has been used to describe the growth of blacklip abalone in NSW (Worthington et al. 1998). Quantiles of growth rate distributions provide a more reliable and informative means for describing rates of growth and for comparing growth between populations (Troynikov 1998, Troynikov & Gorfine 1998). Troynikov et al. (1998) found that juvenile growth varies more with season than initial size but that growth increments are more dependent on length than season for larger blacklip abalone.

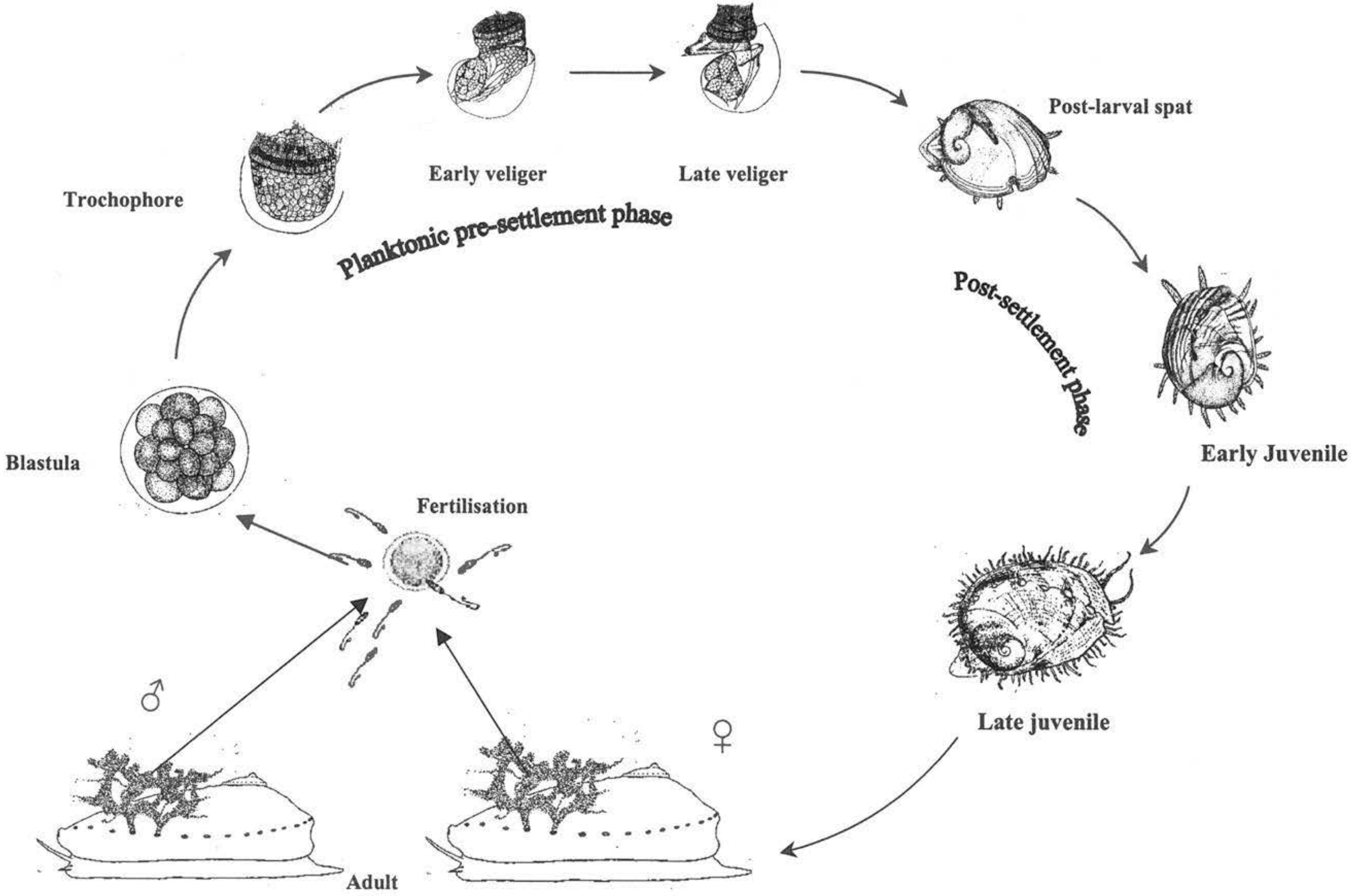

Figure 2. Abalone life cycle

Mortality

Predators

Apart from humans, predators of blacklip abalone include shell-boring invertebrates, sea-stars, crabs, rock lobsters, octopus, urchins, rays, heterodontid sharks, wrasses and leatherjackets (Shepherd & Breen 1992). Banded morwong, captured for the live fish market from the waters around Mallacoota, regurgitate large quantities of small abalone shells (~ 10–20 mm) whilst in holding tanks (Gorfine unpublished observations).

Density-dependence

During the first six months post-settlement, natural mortality in blacklip abalone has been shown to be density dependent and high; i.e. > 90% (McShane 1991). Potential sources of mortality for post-larvae included dislodgment from the substratum and predation. Studies on the role of CCA in protecting abalone from dislodgment have given rise to conflicting hypotheses. Naylor & McShane (1997a) considered that non-geniculate forms of CCA provided shelter from strong water movement, whereas Shepherd and Daume (1996) concluded that the smooth forms of CCA provided greater pedal adhesion. Naylor and McShane (1997b) conducted *in vitro* experiments that showed predation by infaunal polychaetes associated with CCA tended to counter the benefits of refugium afforded by non-geniculate CCA. They inferred from this and other studies that the preference of post-larval settlers for CCA may not necessarily promote the growth and survival of these recruits.

More recent work by Naylor and McShane (2001) provided evidence of higher mortality rates among post-larval settlers that were exposed to strong wave action than among those in more sheltered locations. They also found that survival decreased by 50% when in the presence of conspecific adults, an obsersation that they attributed to pedal smothering by the adults. However, post-settled survival rates in their study were unaffected by the presence of grazing sea urchins and predatory sea stars.

Mortality rates in older abalone are slower and Beinssen and Powell (1979) estimated the natural mortality of blacklip abalone, that were sufficiently large to be tagged, at $M = 0.2$. In modelling the Western Zone fishery, Sanders and Beinssen (1996) assumed that natural mortality was length dependent.

The effect of density on mortality rates of larger juveniles and adults is less clear. Recent research on greenlip abalone in South Australia tentatively indicates the possibility that mortality rates are independent of density (C. Dixon 2002, personal communication, 10 March). Whilst population recruitment is highly variable, the merging of multiple age cohorts into single size classes of pre-recruits ensures that stock recruitment at a regional level remains relatively stable (McShane 1992a, Nash et al. 1994). More recent studies by myself and colleagues at Point Cook in Port Phillip Bay provided an estimate of M = 0.38, that accounts for loss through dispersal and tag-induced mortality. However, environmental and habitat characteristics at this location are mostly atypical of Victorian abalone resources.

Disease

Apart from catastrophic events such as severe storms, pollution events, and habitat destruction, disease provides the greatest potential for mass mortality. This has been amply demonstrated in the black abalone populations of California, in both the Channel Islands (Haaker et al. 1992, Lafferty & Kuris 1993, VanBlaricom et al. 1993) and the mainland (Altstatt 1996). In this instance infection with a newly described species of intracellular bacterium from the *Rickettsia* group, provisionally named 'Candidatus *Xenohaliotis californiensis*' (Moore et al. 2001) led to a condition known as Withering Syndrome (WS) in which the foot of the abalone becomes atrophied (Altstatt 1996). Presence of this condition was obvious to commercial abalone divers who unwittingly selected against apparently healthy black abalone that may have been resistant because the fishery remained open (CDFG 2001). The net result was that black abalone populations declined to the extent that *H. cracherodii* was recently designated by the National Marine Fisheries Service as a candidate species under the U.S. Federal *Endangered Species Act* (CDFG 2000b, CDFG 2001). Although red abalone appear to be refractory to WS, clinical signs of the disease and subsequent mortality has been observed in aquaculture facilities and causes greater morbidity and mortality at elevated water temperatures (Moore et al. 2001). Another disease confined to land-based aquaculture facilities in California (Leighton 1998) is caused by infestations of the sabellid polychaete *Terebrasabella heterouncinata* (Finely et al. 2001) that disrupts shell growth with consequent increased mortality rates (Leighton 1998, Ruck & Cook 1998). This polychaete is endemic to wild abalone in South Africa (Ruck & Cook 1998) and was inadvertently introduced in imported shipments of *H. midae* used for research during the late 1980s (Finley et al. 2001). This exotic introduction, together with the identification of a non-pathogenic *Rickettsia* in South African abalone, has led to speculation that the *Rickettsia* bacterium affecting California black abalone was also introduced from South Africa (Handlinger 2000).

In Australia the disease of most concern is caused the protozoan *Perkinsus olseni* that is widely distributed among molluscs throughout Australia, except in Tasmania (Goggin & Lester 1995). Like WS if affects the foot, but in this infection pustular lesions are formed. Infection has been detected on a number of occasions during recent years in South Australian abalone (Lewis *et al.* 1986). These outbreaks have been restricted to the Port Lincoln area and around the coast of the Yorke Peninsula, where in some locations it almost eliminated greenlip abalone stocks (Shepherd & Branden 1990). During a 1995 outbreak, dark streaks of infected tissue were not detected until shipments of canned abalone were inspected in Japan. Usually, the lesions are visible on the external surfaces of the foot, but on this occasion only internal lesions occurred allowing the infected abalone to escape detection in Australia. *Perkinsus* infection is believed to be temperature dependent with encapsulation of the protozoan occurring at 15°C and excystment and consequent mortality at 20°C. *Perkinsus* infection has also been observed seasonally during warmer months in abalone from reefs north of Sydney (N. Andrew 1996, personal communication, July). Shepherd *et al.* (1999) suggest that cooler sea temperatures associated with La Niña may explain a recession in the occurrence of *Perkinsus* during 1998–99. Recently there has been a considerable outbreak of *Perkinsus* in the north-central and central coasts of New South Wales, causing substantial declines of up to 95% in abundance. This disease episode has led to a ban on taking abalone from waters between Port Stephens and Jervis Bay for five years (NSW Fisheries 2002). Fortunately the southern region of NSW, where most of the fishery is based, has remained unaffected at this stage (D. Worthington 2002, personal communication, February).

There have been occurrences of foot lesions in some Victorian abalone from Port Phillip Bay during 1990, but pathology tests ruled out infection by *Perkinsus* (Phillips 1990). The incidence of these lesions was of limited duration and not widespread. Although pathological changes were evident during microscopic examination of the tissues, the cause was indeterminate.

Toxic algae

Paralytic Shellfish Poison (PSP), a toxin produced by dinoflagellates, thought to have been introduced into Australia in ships' ballast water, was identified in low to moderate concentrations in the foot and gut tissues of a limited number of abalone sampled from Lorne in western Victoria during mid-July 1992. This finding was of significant public interest because if ingested in sufficient concentration, PSP can cause morbidity and mortality in humans. The contamination was discovered soon after cysts of the PSP-producing dinoflagellate *Gymnodinium catenatum* were detected in the water column and sediments (Todd 2001).

There are a number of documented occurrences of PSP-affected abalone from other abalone-producing countries including Spain, New Zealand, and more recently, South Africa. In South Africa, PSP contamination was first noticed in farmed abalone and further investigation revealed the presence of the toxin in wild populations (Pitcher et al. 2001). The occurrence of toxin was associated with *Alexandrium* blooms, although no causal relationship could be established. During 1994 Japan placed a ban on abalone imports from Spain when samples from a 50-tonne shipment of *H. tuberculata* were found to have unacceptably high levels of PSP toxin (Sutton 1994). *H. tuberculata* appears to have a high capacity to accumulate these PSP toxins (Bravo *et al.* 1995, 1999). PSP toxins had previously been detected in *H. tuberculata* from northwest Spain during 1991 (Martinéz *et al.* 1993). The PSP toxins were found in all tissues of the Spanish abalone but were particularly high in the foot (Lin *et al.* 1995). This is in contrast to New Zealand and Victoria where the highest concentrations were found in the gut.

In Hahn (1989a) a brief section is devoted to toxicity of abalone guts. Hahn (1989a, p. 193) states that poisoning from the consumption of abalone guts has been a frequent occurrence in Japan since it was first reported about 100 years ago in 1899. Outbreaks of poisoning occur seasonally during spring, with the timing varying geographically and the level of toxicity varying among species. In tests of laboratory rats the most serious cases caused limb paralysis and death within one hour of ingestion. Hahn (1989a) names pyrophenophorbide, a photodynamic compound found in abalone liver, as the toxic agent. Although this account bears similarity to the aetiology of PSP, no explanation is provided about how pyrophenophorbide accumulates in abalone tissues.

The South African studies point towards PSP having significance beyond human health, having found that it causes some mortality among cultured stocks and abnormalities in larval development that might affect recruitment processes in the wild. One of the earlier South African studies in the 1980s associated *H. midae* becoming involuntarily detached from the substrate and washing ashore with a preceding bloom of the dinoflagellate *Gymnodinium nagasakiense* (Shepherd & Breen 1992).

The most probable mechanism for PSP contamination in abalone is ingestion, during grazing, of resting cysts and vegetative cells that have precipitated from blooms (Shumway 1995). Apart from human health risks, a major concern with such occurrences is that the commercial consequences are more serious if detection is made by the overseas trading partner rather than by the supplier (Hickey 1994). In New Zealand there is a ban on the export of abalone gut. It is important that surveillance for known contaminants in Australian abalone be undertaken on a routine basis by abalone producers and distributors to protect public health and allay the concerns of overseas importers.

Exotic species

Although strict quarantine regulations in Australia governing the importation of animal and plant products make the entry of new pests and pathogens unlikely, vectors such as trans-oceanic shipping have inadvertently provided entry for exotic species into Australian waters (Jones 1991). The northern Pacific sea-star, *Asterias amurensis*, is an exotic species that may pose a threat to abalone. *A. amurensis* is believed to have been initially transported to Tasmania during the early 1990s in the ballast water of Japanese ships that carry woodchips back to Japan after discharging some of that ballast in port. Several specimens of *A. amurensis* were first identified in Port Phillip Bay during 1995–96. Whether these specimens arrived in Victoria via Tasmania or directly from Japan is unclear; however, Port Phillip Bay has major ports in Melbourne and Geelong that service a substantial amount of international shipping. Numbers in Port Phillip Bay had increased to an estimated 33 million in June 1999 and have further increased with successful spawning during the summer of 1999–2000 (G. Parry 2000, personal communication, April). *A. amurensis* is known to feed on juvenile abalone in its native Japan, yet it is unclear whether this seastar presents a risk to Australian abalone populations. At this stage it appears that *A. amurensis* prefers more sheltered areas than abalone and consequently has not had any obvious impact on Tasmanian or Victorian abalone stocks. The native sea star *Coscinasterias muricata*, abundant in many sheltered locations in Victoria, is the only known local predator of *A. amurensis* that has been identified to date. However, it is unclear what effect, if any, *C. muricata* may have on the spread of *A. amurensis*.

Discovery of the Japanese kelp, *Undaria pinnatifida*, at Point Wilson in Port Phillip Bay during 1996 (Campbell & Burridge 1998) highlights the need for control of exotic species. Campbell and Burridge (1998) expressed concern that the vigorous growth of *U. pinnatifida* may out-compete or displace dominant native macroalgae. Indeed, *U. pinnatifida* has been colonising reefs off Tasmania's east coast for more than a decade (Sanderson & Barrett 1989) and appears to compete with the native kelp *Ecklonia radiata* (G. Parry 2001, personal communication, April). However, *U. pinnatifida* is a natural part of the diet of abalone species in its native Japan and might not affect the feeding and nutrition of blacklip abalone unless it reduces the diversity of native algal species, such as some of the smaller foliose red algae (Sanderson & Barrett 1989).

Eradication of these pest species is likely to be problematic if not impossible and if left unchecked is likely to spread to suitable habitat on other reefs along the Victorian coast.

Interactions with other native invertebrates

Urchins and rock lobsters

Urchin spine canopy has been found to have a protective role in providing shelter for juvenile abalone in some parts of the world but not in others. This type of relationship has been documented for the red sea urchin *Strongylocentrotus franciscanus* with the red abalone *Haliotis rufescens* in California (Rogers-Bennett & Pearse 1998, Tegner & Dayton 2000), urchin *Parenchinus angulosa* with the perlemoen *H. midae* in South Africa (Day & Branch 2000a) and for *Anthocidaris crasspina* with *H. discus discus* in Japan (Kojima 1995). These observations suggest such relationships are highly species-specific which seems unusual given the apparent physical nature of the relationship. However, there is no evidence to suggest that small juvenile abalone prefer one sympatric urchin species rather than another. The apparent species-specificity may simply reflect the prevalence of only one urchin species in each region studied to date. No such relationship has been documented in Australia (where sympatry occurs among some urchin species) and McShane (1991) even speculated that adult urchins may inadvertently ingest recently settled abalone (McShane 1991), although there is no evidence to support his hypothesis.

The apparent absence of this commensal relationship in Australia may indicate either a lack of intensive investigation or that there are plenty of alternative locations in which juvenile abalone can shelter. In contrast to juvenile abalone, the interaction between adult abalone and urchins is one of competition with both invertebrates feeding on similar macroalgal assemblages (Andrew & Underwood 1992). Although abalone prefer to feed on drift algae (Andrew & Underwood 1992) and seem to have little impact on attached vegetation (Tegner & Dayton 2000), urchins may exert substantial influence on macroalgal vegetation cover and compostion (Andrew & Underwood 1992, Tegner & Dayton 2000). Changes in macroalgal assemblages that are brought about by urchin grazing can render habitats unsuitable for abalone (Andrew & Underwood 1992). However, grazing behaviour varies among urchin species, as does feeding behaviour among abalone species, and Day and Branch (2000b) point out that *P. angulosa* is a drift feeder not a grazer.

In abalone-producing regions of the North Pacific sea otters are major predators of urchins (and abalone) with consequent effects on abalone productivity (Tegner & Dayton 2000), whereas in the Southern Hemisphere rock lobsters may occupy this role.

Although recent research has demonstrated substantial size-specific predatory regulation of urchins by the lobster *Jasus llandii* (Mayfield & Branch 2000, Tarr et al. 1996), in Australia and New Zealand there is insufficient evidence to support the hypothesis that rock lobster predation controls urchin abundance (Tegner & Dayton). However, rock lobsters have been heavily exploited in Australia and New Zealand for over a century. In south eastern Australia, urchin barrens devoid of foliose algae are associated with the occurrence of the black sea urchin *Centrostephanus rodgersii* (Andrew 1994, Andrew & Underwood 1992). Uki (1984) documented a similar occurrence in Japan of what he called 'sea desert' caused by grazing activity of the urchin *Strongylocentrotus nudus* and resulting in poor abalone harvests. Barrens habitat is present along much of the east coast of New South Wales (Andrew & O'Neill 2000), where the eastern rock lobster (*Jasus verrauxi*) has been heavily exploited since 1873 (Kailola, et al. 1993). Less extensive barrens are also found in eastern Victoria near Mallacoota, the Flinders Group of islands in the eastern entrance of Bass Strait and northern Tasmania. In these regions the abundance of the southern rock lobster (*J. edwardsii*) species is low, reflecting the limited supply of larvae originating from parental stocks in western Bass Strait (D. Hobday 2002, personal communication, March).

The geographic range of *C. rodgersii* and the associated barrens habitat appears to be restricted to the region influenced by the warm East Australian Current that passes down the eastern seaboard from NSW to northern Tasmania. In central and western Victoria where the dominant urchin species is the white urchin *Heliocidaris erythrogramma* and southern rock lobsters are highly abundant there is generally no barrens habitat (personal observation). However, *H. erythrogramma* has been observed to cause barrens on Victorian reefs in rare instances (R. Day 2002, personal communication, 21 March). Gardner et al. (2002) cite recent studies in Tasmania indicating that larger legal-sized *J. edwardsii* in Tasmania have a substantial predatory impact on *H. erythrogramma* and postulate that over fishing southern rock lobster populations may precipitate the formation of urchin barrens. However, in northern Port Phillip Bay there are no southern rock lobsters and both *H. erythrogramma* and *H. rubra* are abundant. Rays and other potential urchin predators are present in substantial numbers (personal observation) and might be expected to provide some control over urchin and abalone abundance. Whether the rarity of barrens in central and western Victoria is due to the absence of *Centrostephanus rodgersii*, or predatory control of *H. erythrogramma* by southern rock lobsters or some combination of these or other factors is unknown but worthy of further consideration. An alternative explanation for the absence of barrens where *H. erythrogramma* in abundant is that like *P. angulosa* in South Africa, this species is a drift algal feeder. As a drift feeder there may be less direct competition with *H. rubra*. This would also explain why we have observed *H. erythrogramma* and *H. rubra* co-occurring in high densities (Gorfine unpublished data).

Although in reviewing abalone mortality, Shepherd and Breen (1992) identified rock lobsters as abalone predators, they were only able to cite one study. The importance of abalone in the diets of Australian rock lobsters is unknown, although most Australian recreational divers who hunt southern rock lobster will attest to the efficacy of using freshly shucked abalone to lure the lobsters from their crevices to facilitate capture (personal observation). If either *J. edwardsii* or *J. llandi* are significant predators of *H. rubra* this will add further complexity to the interaction patterns discussed.

Sea stars

The native 11-arm seastar *Coscinasterias muricata* is a large asteroid, attaining a maximum radius of about 250 mm, that is common throughout the abalone-producing states of Australia (Marine Research Group of Victoria 1984). Although it is a predator of abalone, the primary prey of *C. muricata* are bivalves such as the blue mussel *Mytilus edulis* and abalone are seldom eaten when mussels are abundant (Day et al. 1995). *C. muricata* is abundant in many sheltered locations in Victoria, such as Port Phillip Bay, where both mussels and abalone are plentiful. However, it is also found in a variety of more exposed locations along the coast and reports from Victorian commercial abalone divers in the Western and Eastern Zones of the fishery suggest that numbers of this seastar have increased substantially in some of these locations during the past decade. During the past two years' annual abalone surveys, numbers of *C. muricata* in transects have been counted. In many instances where this seastar is in relatively high abundance, abalone abundance is low and vice-versa. However, for the majority of locations surveyed *C. muricata* was absent (Gorfine unpublished data).

It is likely that where bivalves are absent or in low abundance, blacklip abalone becomes the primary prey species (Day et al. 1995). Blacklip and greenlip abalone possess relatively well developed escape responses to attacks by predators like *C. muricata* (Day et al. 1995, Parsons & MacMillan 1979) and I have observed several blacklip abalone rapidly crawling over rocks to flee when one member of their aggregation was attacked. However, the relatively low oxygen carrying capacity of the copper-based haemocyanin pigment in abalone blood (Hiscock 1975) is likely to limit the duration over which these escape movements can be sustained.

C. muricata was reported in large numbers at The Skerries, in the Eastern Zone of the Victorian fishery, prior to a blacklip population collapse at this formerly productive reef complex (Gorfine & Dixon 2000a). Although it is unclear as to the direct cause of the collapse, and other factors such as illegal fishing were implicated, predation by *C. muricata* may have contributed to recruitment failure.

World abalone fisheries

The muscular foot is the main edible part of an abalone (Plate II), although the gut may also be consumed or used as a basis for dipping sauces, the recipes for which are often closely guarded secrets (Hahn 1989). The shells may also be used for jewellery, artwork, buttons and utensils. These applications are the basis for historical and contemporary fisheries and many are linked to strong cultural traditions (Geiger & Poppe 2000).

Evidence from middens indicates that abalone were first used for food and trade by aboriginal peoples in northern America and Australasia many thousands of years ago (Cuttris 1998, Davis et al. 1992, Haaker et al. 1986, Johnston 1991, Schiel 1992). Fisheries have existed for many centuries in China, Japan and Korea and Taiwan (Nie 1992, Sloan & Breen 1988, Hahn 1989a), with the first documentation of Japanese ama abalone divers in about 30 A.D. (Hahn 1989a). Artisanal fisheries began in the western countries from about the mid 1850s (Sloan & Breen 1988), often commencing with Chinese immigrants harvesting from the intertidal zone or hooking abalone from boats, and later involving Japanese hard hat divers until the outbreak of second world war (Guzmán del Próo 1992, Parker et al. 1992, Prince & Shepherd 1992). Most of this early production was exported as shell for jewellery (Parker et al. 1992) or as dried meat (Parker et al. 1992, Prince & Shepherd 1992). An 1882 report on Australian fisheries mentions that although abalone were abundant in Tasmania and fetched 9 pence per pound, they were too difficult to collect to justify fishing, except when the weather was unfavourable for pursuing more sought after species such as sharks (Tenison-Woods 1882). The availability of SCUBA and hookah diving equipment during the mid 1950s and early 1960s signalled the start of modern commercial abalone fisheries (Davis et al. 1992, Farlinger & Campbell 1992, Prince & Shepherd 1992), although the use of compressed air is prohibited in some countries such as New Zealand (Schiel 1992).

During the 20th century, commercial abalone fisheries have existed in Australia, Britain (Channel Islands), Canada (British Columbia), China (including Taiwan), Japan, Korea, France (Brittany), Mexico (Baja California), New Zealand, Oman, South Africa, Thailand (occasional fishery) and USA (California and Alaska) (Hahn 1989c, Sawatpeera 1998, Shepherd et al. 1992). Some of these countries with wild abalone populations, such as China (Nie 1992), Japan (Kojima 1995), Taiwan (Chen 1989) and

Thailand (Upatham et al. 1998), are now reliant on cultured abalone production. In the cases of Japan and Korea aquaculture production is directed at re-seeding natural populations rather than land-based or caged grow-out. Notably, Chile (Godoy & Jerez 1998, Godoy et al. 1992) and Iceland (Nielsson 1994), where no wild *Haliotis* populations exist, have imported Californian red abalone (*H. rufescens*) for aquaculture production. Because of its higher potential profitability, Iceland has also imported *H. discus hannai* from Japan (Nielsson 1994).

There are many similarities among the world's abalone fisheries, including those that remain viable and those that have collapsed. These similarities include biological characteristics among species that should not surprise given their generic relationship. However, one of these characteristics is the high variability and plasticity both within and among species that manifests as marked responses to environmental change. This variability conspires against attempts to generalise and predict. Similarities do not end with biology and extend to the behaviour of fishers in all groups including licensed, unlicensed, recreational and indigenous. This should indicate to astute fisheries scientists that many of the problems that have precipitated the collapse of abalone fisheries might also affect those that remain viable. One salient point is the relative differences in pressures on the respective fisheries in terms of anthropogenic disturbance of habitat and intensity of exploitation. It is no great revelation that the last remaining viable fisheries have mostly escaped some of the pressures that two decades ago were just starting to adversely affect those that have since collapsed. Countries such as Australia and New Zealand have much lower human population densities relative to the lengths of their coastlines and less associated pollution, habitat degradation and ecosystem disturbance. Increased human population growth will doubtlessly challenge the future sustainability of these fisheries.

Plate II. Live blacklip abalone (*Haliotis rubra*) - ventral view.

Brief histories of some of the world's commercial abalone fisheries are provided below:

Northeastern Pacific

The California fishery started during the 1850s, and modern commercial hard hat diving gear was introduced in about 1940. The five of the seven available species that were targetted included *H. fulgens* (green), *H.corrugata* (pink), *H. sorenseni* (white) (formally protected since 2001), *H. rufescens* (red) *and H. cracheroidii* (black). From 1952-68 the commercial fishery produced more than 1800 tonnes annually, with a peak catch of slightly less than 2500 tonnes for 1957. By 1992 commercial annual landings had reduced to about 236 tonnes from serial depletion among species (Davis 1993, Davis et al. 1992, Haaker et al 1994) and in 1997 the commercial fishery was closed (California Department of Fish and Game 2000). At the time of closure the fishery was producing an annual catch of about 350 tonnes (Gordon 2000). A substantial recreational (snorkel only) fishery exists and continues to remain open north of San Francisco (Karpov et al. 1998) with an estimated annual catch 730000 abalone in 2001 (McHugh 2002).

Further north in Washington State there is a modest recreational fishery for *H. kamtschatkana*, but no commercial fishery. From a creel census survey conducted in 1983–84 the recreational catch was estimated to be about 12 tonnes (Farlinger & Campbell 1992).

In British Columbia and Alaska the pinto abalone, *H. kamtschatkana*, was the only species available (Farlinger & Campbell 1992). The Alaskan commercial fishery recorded a peak landed catch of 168 tonnes in 1981 that subsequently declined to 34 tonnes in 1988–89 despite the provision of guideline harvest ranges. During some years more than 40 vessels participated in this small fishery (Farlinger & Campbell 1992). The British Columbian fishery commenced in 1914, but total landings remained mostly below 20 tonnes, with several exceptional peaks, until the 1970s. Catches peaked at 433 tonnes in 1978, when there were 78 divers in the fishery (Sloan & Breen 1988). An annual catch quota of 227 tonnes was introduced during the following year. Despite successive reductions in quota, annual catches fell short of the amounts set until 1988, when the quota was 47 tonnes and the reported catch was 46 tonnes (Franger & Campbell 1992).

The earliest Mexican abalone fishery commenced in about 1860, although catches were not reported until 1923 (Guzmán del Próo). Guzmán del Próo 1992 reports that by 1950 catches peaked at 6000 tonnes live weight equivalent. However, Ramade-Villanueva et al. (1998) and Ponce-Díaz et al. (1998) provide conflicting figures that showed peak catches of 4000 tonnes of meat in 1965 and almost 3000 tonnes of meat in 1969 (i.e. 12000 and 9000 tonnes live weight equivalent) respectively for the central zone of the Baja California Peninsula. Unlike the U.S., there is no recreational fishery in Mexico (Ramade-Villaneuva et al. 1998). However, there is a relatively undocumented subsistence fishery, particularly for the more accessible intertidal black abalone *H. cracheroidii* (B. Tissot 2002, personal communication, 16 October) that may account for some of the discrepancies among catch statistics. In 1970 the fishery began to decline rapidly and although quotas were introduced in 1973, catches fell to a low of 400–500 tonnes in 1984-85 (Guzmán del Próo 1992, Ramade-Villanueva et al. 1998). Following this decline the fishery recovered to the extent that catches rose to almost 1000 tonnes in the early 1990s. However, during the mid-1990s further declines occurred associated with El Niño related warm water events to reduce catches to about 500 tonnes (Ramade-Villaneuva et al. 1998, Shepherd et al. 1998). In stark contrast to trends in the stock status of the fishery, the number of people dependent on it increased by 40% from 1991–98 (Ponce-Díaz et al. 1998). Ninety seven percent of the total landings are comprised of the two main species, *H. fulgens* and *H.corrugata*, the remainder being made up of *H. rufescens and H. cracheroidii* (Ramade-Villaneuva et al. 1998). Although an important component of the catch until its populations collapsed in 1976, *H. sorenseni* has been formally protected from fishing since 1995 (Shepherd et al. 1998).

Northwestern Pacific

The centuries-old Japanese fishery first experienced the effects of over-fishing in the heavily populated regions in the southern and central parts of the country (Cuthbertson 1978). Abalone culture commenced in the 1930s in a bid to regenerate natural stock productivity. The fishery is based on five species, *H. discus hannai* (Ezoawabi), *H. gigantea* (Madaka), *H. sieboldi* (Megi), *H. discus* (Kuro) and *H. diversicolor supertexta* (Tokobushi) (Beinssen 1982) and in 1973 produced 7473 tonnes whole weight most of which was consumed domestically (Inoue 1976). By 1979 production had stabilised at 5000 tonnes (Uki 1984) and remained unchanged during the next decade, then between

1989 and 1999 'wild' production fell to 2100 tonnes (Gordon 2000). During the same decade farmed production increased from 200 to 300 tonnes per annum (Gordon 2000).

The Korean wild fishery (about 500 tonnes in 1989) is dependent on traditional women skin divers, as was the traditional ama diver fishery in Japan. Contemporary Korean production of *H. discus hannai, H. gigantea*, *H. sieboldi*, and *H. discus* is similar to Japan in that the emphasis is on re-seeding the natural resource with hatchery-reared juveniles (Yoo 1989). Yoo (1989) suggested that increased pollution and coastal reclamation was expected to cause decline in wild production.

Production in mainland China has involved two species, *H. discus hannai* and *H. diversicolor* used both as food and in Chinese traditional medicine as 'Shi_Jue-Ming' which is believed to be beneficial for eyesight and liver (Nie 1992). Wild production peaked at about 100 tonnes in the 1950s, but had decreased to 60 tonnes by the early 1990s due to over harvesting (Nie 1992). In 1999 China had 300 abalone farms that produced 3500 tonnes (Gordon 2000).

Most of the Taiwanese production that occurred during the mid 1970s came from fishing (Chen 1989). Chen (1989) states that aquaculture production of *H. diversicolor supertexta* was initiated because of increased demand and escalating prices, but makes no mention about the status of the wild fishery. Taiwan is now the second largest producer of cultured abalone in the world, having undergone rapid expansion during the decade 1989–99 to increase production six-fold to 3000 tonnes (Gordon 2000, Gordon & Cook 2001).

Northeastern Atlantic

A small mostly recreational fishery for the ormer, *H. tuberculata*, exists in the British Channel Islands and Brittany in France. However, harvesting abalone on the Island of Guernsey, the only location where SCUBA was allowed, was prohibited during 1973 because of a fall from a peak annual catch of slightly more than 40 tonnes during 1967 to about 5 tonnes for the year preceding the closure (Clavier 1992).

Northwestern Indian Ocean

The Omani fishery for *H. mariae* (common name sufailah) on the Dhofari coast (Shepherd et al. 1995) commenced in the 1950s and peaked at about 200 tonnes live weight in 1980. About 350 divers, limited to only a face mask and prising tool, participated in the fishery at this time (Johnson et al. 1992). In 1991 the catch had decreased to 91 tonnes and concern about continuing decline saw the introduction of a 2-month fishing season and a 90 mm size limit (Shepherd et al. 1995).

Southern Africa

The South African fishery commenced in 1949 and is based on one species, *H. midae* (common name perlemoen). Peak landings of 2800 tonnes occurred in 1965, then declined markedly as the accumulated stock was depleted. Consequently a quota of 386 was introduced in 1968 but was unable to be harvested. In 1970 a quota of 227 tonnes meat weight was harvested, but on-going concern led to a further reduction to 660 tonnes live weight, equivalent to about 163 tonnes of meat, in 1983 (Tarr 1992). Following a period of relative stability throughout the 1980s to the mid-1990s, a substantial rise in illegal fishing resulted in a drastic reduction in the 1996 TAC from 615 to 550 tonnes whole weight. Among the seven fishing zones for abalone, a 90% cut in TAC for the zone adjacent to the township of Hawston, where illegal activity was most prevalent, accounted for the majority of the 65 tonne reduction (Hauck & Sweijd 1999). The continuing impact of illegal catches on abalone abundance throughout the latter 1990s and into this millennium has perpetuated the need for quota reductions to the extent that the TAC now stands at 432 tonnes whole weight per annum (Tarr & MacKenzie 2002).

Australasia

New Zealand has a commercial fishery based on paua, *H. iris*, that commenced during the mid-1940s, when only the shell was marketed and the meat was discarded (Schiel 1992). Total catches peaked at almost 2000 tonnes in 1981 (Schiel 1992) and total landings, under quota management, are now about 1200 tonnes (Breen et al. 2001). Recent assessments indicate that some regions of the fishery are sustainable (Breen et al 2001) whilst others are not (Andrew et al. 2000, Breen et al. 2000).

Although abalone are found in all Australian states and the Northern Territory, commercial fisheries exist only at latitudes greater than 30°S. All five southern states have viable limited-entry commercial fisheries managed by Individual Transferable Quotas (ITQs) and Legal Minimum Lengths (LMLs). All commenced in the early to mid 1960s and have undergone a developmental period of rapidly increasing catch, followed by a declining phase as the virgin biomass was removed and each fishery became more reliant on annual recruitment to its stock (Harrison 1969). Three out of the 11 endemic *Haliotis* species described from temperate Australian waters (see Geiger 1999) are harvested commercially. These species are *H. laevigata* (greenlip), *H. roei* (Roe's abalone) and *H. rubra* (blacklip).

Western Australia has the second smallest catch (345 tonnes in 2001) and is based mostly on *H. laevigata* and smaller quantities of *H. roei* and *H. conicopora*, alternately classified as *H. rubra conicopora* (a *H. rubra* conspecific commonly referred to as brownlip). During the development of the fishery catches peaked at 326 tonnes in 1972/73 (Demersal Mollusc Research Group 1982) and quotas were introduced in 1985–86. Two non-commercial species, *H. elegans* and *H. semiplacata* appear to be confined to southwestern Australia.

The commercial catch of about 867 tonnes in South Australia is based almost equally on *H. laevigata* and *H. rubra*, although attempts are being made to start a small fishery for *H. roei*. In 1968/69 total catches reached a maximum of 1609 tonnes (Demersal Mollusc Research Group 1982) and decreased until zonal quotas were introduced in 1985 and 1990 to arrest this decline (Prince & Shepherd 1992). There have been some concerns expressed during the last couple of years that intense effort in nearshore regions has depleted stocks (Shepherd et al. 2001), but recent observations suggest that at least some of the areas thought to be depleted are improving (K. Rodda 2002, personal communication, February). Non-commercial species in South Australia include *H. cyclobates* and *H. scalaris scalaris*.

Tasmania has the largest commercial wild abalone fishery in the world with current annual quotas totalling 2800 tonnes, comprising 95% *H. rubra* and 5% *H. laevigata*. Development of this fishery was much later than in the other states and catches did not peak until 1984 when they reached 4500 tonnes (Prince & Shepherd 1992, p. 413). General concerns that this catch level was unsustainable lead to a quota of 3806 tones being introduced during the following year. By 1989 the quota had been reduced in steps to 2076 tonnes. Because of stock improvement in the remote weather-prone southwest of the island, quotas were increased to 2520 tonnes in 1999. Rather than stimulate increased fishing effort in the southwest as intended, this increase led to an intensification of effort on the more accessible eastern seaboard. Concerns about sustainability saw the blacklip fishery sub-divided into East, West and Northern zones in 2000. Total quotas were increased in both 2000 and 2001. However, further concerns about the sustainability of stocks in the East Zone led to a 25% reduction in the quota for this zone at the start of 2002 (Hammond 2002). The total TAC for Tasmania is now 2537 tonnes and size limits have been increased in various areas due to overwhelming concern about stocks among the catching sector. In contrast quota owners were apparently reluctant to have their quotas reduced and many wanted an increase in the West Zone to compensate for the east Zone decrease. It is likely that further reductions of the East Zone quota will be required in 2003 to enable stocks to stabilise (C. Mundy 2002, personal communication, 4 April).

Almost all of the Victorian catch is comprised of *H. rubra* with only small quantities *of H. laevigata* harvested infrequently. *H. cyclobates* is recorded from Tasmania and Victoria. Other non-commercial species reported for Tasmania, Victorian and New South Wales include *H. scalaris emmae* and *H. coccoradiata*.

New South Wales has the nation's smallest abalone fishery (305 tonnes in 2001) and is based entirely on *H. rubra*. Throughout the 1960s and 70s there was a non-interventionist management policy that allowed the fishery to develop relatively unfettered (Prince & Shepherd 1992). After peaking at 1362 tonnes in 1971/72 (Demersal Mollusc Research Group 1982) the fishery declined with substantial reductions in daily landings (Prince & Shepherd 1992). Typical daily landings in this fishery were almost an order of magnitude lower compared with Tasmania.

Recently there have been indications of improvement in the abundance of blacklip abalone populations in New South Wales consistent with recruitment of a substantial cohort. This improvement has been reflected in reported landings in the southern region of the fishery that have trebled or quadrupled in some instances during the past couple of years (D. Worthington & J. Smythe 2001, personal communication, August). The most recent assessment for the fishery concluded that further increases in biomass were likely in the near future, even if current quotas were moderately increased (Worthington et al. 2001). However, this conclusion is tempered by some members of the NSW industry asserting that the improved landings partly resulted from the entry of young enthusiastic and efficient contract divers into the fishery (M. Bateson 2002, personal communication, 11 April), and that landings have recently reached a plateau or declined slightly (C. Dixon 2002, personal communication, 12 April).

H. brazieri is a non-commercial species unique to the region between central New South Wales and Southern Queensland. In general the non-commercial species are characterised by small size, low abundance or both. However, the non-endemic tropical species *H. asinina,* or ass's ear abalone, found on the southern section of the Great Barrier Reef off the Queensland coast, is used as a commercial aquaculture species in southeast Asian countries such as Thailand (common name Cholburi). This species has not been used commercially in Australia, but has high potential as an aquaculture species because of its predictable spawning pattern, very high meat to shell weight ratio and potentially rapid rate of growth (Jackson et al. 2001, McNamara & Johnson 1995).

Australia is the only country that has increased production of wild abalone during the past decade (Gordon & Cook 2001). World abalone production has declined in all other countries during the same period, although aquaculture production in mainland China and Taiwan has substantially reduced the deficit in the supply-demand equation.

The Victorian fishery

The blacklip abalone, *Haliotis rubra*, is Victoria's main commercial abalone species and the less abundant greenlip abalone, *H. laevigata*, is the only other harvested abalone species in the state. Although greenlip abalone was a target species during the first decade of the fishery, in more recent times most greenlip catches have been incidental to relatively larger blacklip catches and it is now considered more appropriate to categorise greenlip as a by-product species.

Victoria produces about 14% of the world's reported wild abalone harvest (Gordon 2000), and is Australia's second largest abalone-producing state. With a landed value of around A$63 million in 2000/2001 it is the most valuable among the state-managed fisheries in Victoria (Fisheries Victoria 2002).

Main features

Catch (2001–02)	1449 tonnes (whole weight)	
Catch composition (2001–02)	99.9% blacklip abalone	
	0.1% greenlip abalone	
Value (2000/2001)	A$63 million	
Fishery Access Licences	Eastern Zone	23 licences
	Central Zone	34 licences
	Western Zone	14 licences

Commercial sector

Contemporary Victorian abalone divers mostly operate from high-speed trailerable planing hull vessels (5–10 m overall length) powered by outboard motors (usually twin motors with combined power of 230–450 HP). The vessels are launched by truck, four wheel drive or tractor, sometimes across the beach. This allows access to a large range of productive reefs from relatively few ports. Productive reefs, with the exception of those in Port Phillip Bay, are generally swell prone and much of the harvesting occurs close to the wave break zone in conditions of surge and turbulence.

The divers wear 7 mm or 9 mm thick neoprene wetsuits for protection from exposure and the associated buoyancy is compensated by lead shot vests rather than weightbelts. Compressed air is supplied to the diver's demand valve by about 100 metres of umbilical hose connected to a hookah compressor mounted on the stern quarter of the vessel, or to a bank of high-pressure cylinders. Several divers breathe enriched air (nitrox) mixes to increase allowable bottom times and some wear a bail-out bottle as an alternative air source in the event of air supply failure.

Abalone are prised from the rocky substrate by a flat bladed purpose-built ‘abalone iron’ and placed in an open-mouthed nylon mesh catch bag. As the catch bag fills with abalone the diver uses a small parachute or lift bag, inflated with compressed air to compensate for the weight of the abalone, to assist in its transport. Some divers choose to accompany their full catch bag to the surface, whereas others prefer to fully inflate the parachute to allow the bag to ascend freely and rely on the deckhand for retrieval at the surface.

The catch bag is periodically hauled aboard the boat by the deckhand using a davit and winch mounted on the gunwale. The deckhand also tends the compressor or bottle bank, keeps watch, sorts the catch to check that the abalone are of legal size, removes large epibiota from the surface of their shells and packs them into fish bins. When abalone are harvested for live export the catch is irrigated with seawater, either from a spray system driven by a pump mounted on the hookah compressor or by periodic manual inundation. The catch is often kept undercover, especially if there is the possibility of rain.

Most abalone harvesting is conducted by drifting rather than anchoring, with the deckhand moving the vessel as necessary. This enables the diver to cover more reef area, to operate in tidal currents and to minimise the need to ascend to the surface. However, it increases the workload of the deckhand. On-board observations showed that 80% of all harvesting occurred shallower than 13 m with an average depth of 9 m and a range from 1 m to 27 m (Gorfine & Dixon 2001). Some divers now use dive computers to track their depths and bottom times and calculate their decompression obligations and many use oxygen as either an in-water or surface decompression gas.

Recreational sector

Recreational harvesting accounts for only a small proportion of the abalone harvested from Victorian waters annually, but there are a number of specific issues related to recreational diving for abalone worthy of consideration. Recreational pressure on abalone populations is usually greatest in locations readily accessible from major urban population centres. This is the case in Western Australia where ease of access to stocks of *H. roei* within the Perth metropolitan area has made it necessary for the Western Australian Department of Fisheries to restrict recreational harvesting of this species to limited hours during specific days of the year.

In Victoria, most of the recreational pressure appears to occur adjacent to the Greater Melbourne Metropolitan region on reefs in Port Phillip Bay and bordering the Mornington and Bellarine peninsulas. There is also concentrated recreational diving activity in the Cape Otway region (Millar 1996). The recreational harvest may be disproportionately high in these regions compared with other more remote and less accessible locations.

Multi-cultural diversification in Victoria over the past decade has increased consumer preference for seafood such as abalone, particularly from people of Asian origin. Coupled with the substantial increases in the participation rates in snorkelling and SCUBA diving activities since the early 1980s, it is inevitable that recreational pressure on Victorian abalone will continue to increase.

During 1998–99 a six-month ban was placed on the recreational capture of all abalone in Victorian waters. The ban was imposed during the lead up to a change in fisheries regulations that now requires recreational divers to cut the abalone in half through to the shell upon removal from the water (to reduce its market value), in addition to observing pre-existing possession limits, LMLs and seasonal closures (greenlip abalone only). These new regulations also prohibited the harvesting of abalone outside daylight hours and from the intertidal zone that has its offshore boundary defined as the 2-m isobath. The requirement to cut the foot has proved most unpopular since its introduction and this has recently led to formal discussions to establish whether there is a strong enough case for the regulation to be rescinded.

Indigenous sector

Victoria's indigenous Koori community is divided into separate groups, with each group having inherited responsibility for using and conserving the natural resources within a specific geographic region. Ten of these regions are bounded by coast, giving their respective clans traditional access rights and customary responsibility for marine resources (Victorian Fisheries 1996). The boundaries of these contemporary community groups do not necessarily coincide with traditional tribal or clan boundaries, although they roughly accord with the aboriginal language groups identified among coastal Koories (Clark 1990, 1996, 2001). In excess of 2500 archaeological sites of past Koori activity, mostly less than 6000 years old, have been identified along the Victorian coast. Many of these sites are middens containing the shells of molluscs, including abalone (Cuttris 1998, LCC 1993).

The Gunditjmara people (comprising several clans) inhabited the coast and hinterland in the Western Zone of the fishery, bounded by the South Australian border in the west and the Hopkins River in the east. Today, responsibility for this region is divided between the Kerrup Jmara Elders Corporation (Kerrup Jmara is the name of the clan which owned the land around Lake Condah), who oversee the coast west of Codrington, and the Framlingham Aboriginal Trust who look after the coast eastwards from Codrington (ATSIC 2000). The Framlingham territory extends into the Otway region of the Central Zone of the fishery where coastal land ownership was distributed among the Kirrae Whurrong, Katanubut and Wathaurong clans. The following is an edited version of the text of a letter from Herbie (Graeme) Harradine, Cultural Officer, Framlingham Aboriginal Trust:

Framlingham Aboriginal Trust is the authorised Aboriginal organisation under the Aboriginal and Torres Strait Islander Heritage Protection Act 1984, and includes the coast from Codrington in the west to Lorne in the east; this area includes the near shore zone from Codrington to approximately Cape Otway and includes Deen Maar Island (Lady Julia Percy Island).

Abalone (Tyaleek) are part of Aboriginal culture as are all natural things. Tyaleek were and remain an important food source for Aboriginal people, but more importantly are a basis for family and clan activity such as social and formal gatherings on the coast to harvest and feast. The shell of tyaleek also has significance in religious ceremonies and was traded with inland clans. This trade was an integral part of Aboriginal society could be considered justifiably as the first commercial abalone harvesting in Australia. 'Within the Levy Point Coastal Reserve near Warrnambool is a location known as Tarerer, this was a place of ceremony and meeting of numerous people from different clans and tribes, anecdotal reports are that up to 2000 people met at this place for ceremonies. It was the responsibility of the host clan the Tarerer-gundidj to provide food and water, people from outside of the host clan were not allowed to hunt and gather while in attendance (L. Harradine 13/10/2000)'. In southwest Victoria it is almost inevitable that where there are onshore or near shore reefs or suitable substrate that the adjacent shore will have middens containing abalone shell. On Deen Maar Island (Lady Julia Percy I.) that is approximately 10kms offshore there is ample evidence of Aboriginal use that predates white occupation.

Abalone are still taken today by the Framlingham community on a regular basis. However, aboriginal Australians are now restricted by recreational practices under current fisheries regulations. Aboriginals point out that legislation and economics have effectively excluded them from participating in an important social, spiritual and economic activity. It is illegal for them to practise their culture by a person having more *than 10 abalone in possession at any one time. For example, in general only 1 or 2 people in a family or clan are capable of taking abalone for use by that group of people and 10 abalone per fisher is an inadequate quantity. These take limits were set without any real negotiation or consultation with the Aboriginal community.*

The current commercial arrangements for licensing has effectively removed Aboriginal people from any opportunity to obtain economic return from what was once an important social and economic activity. The impact of restricted access for Aboriginals is exacerbated because areas of accessible reef that were once rich in abalone are now denuded through impacts of localised over fishing and coastal development. Alienation of reefs for proposed Marine Parks and aquaculture zones will further restrict Aboriginal access in the future.

The Moogji Aboriginal Council East Gippsland Incorporated provides a similar account of customary use of abalone in their region within the Eastern Zone of the fishery (personal observation 2001, interpretive trail, January). Here, Cape Conran was an important meeting place being near the traditional border of the land of the Gunnai (Kurnai) people (comprising five clans living between Andersons Inlet and Bemm River) and the Bidawal or Maap people whose territory stretched from Bemm River to Greencape in NSW. Like the western Victorian clans, the Gunnai hosted ceremonies among neighbouring clans including the Bidawal and the Monaro people, whose traditional lands lie inland to the north. The abundance of food, availability of ochres for ceremonies and picturesque setting made Cape Conran an ideal location for meetings. The Gunnai name for abalone is *Walkan* which they collected, along with periwinkles, by unaided breath-hold diving around the partially exposed rocks at the East Cape. The mudstone rocks of the East Cape are dissected by channels that provide ready access from the shore into water several metres deep. My personal experience is that blacklip abalone remain abundant at this location and can still be easily harvested by breath-hold diving close to shore in moderate swells. Evidence of traditional collection and consumption of abalone and other shellfish at the East Cape of Cape Conran is provided by the numerous 3000-year old middens scattered among the rocks on the shoreline.

Abalone was also an important source of seafood for indigenous peoples in coastal regions now covered by the Central Zone of the fishery, including the Wathaurong people whose territory stretches from Cape Otway to Port Phillip and the Bunurong people who are traditional owners the lands of the Mornington Peninsula and Westernport region through to Andersons Inlet.

Aquaculture sector

Although not strictly part of the fishery, the aquaculture sector has potential to affect the wild fishery through removals to collect broodstock, outplanting and escape of hatchery-reared animals into the wild, discharge of parasites and pathogens in effluent, and impact on market demand and supply. It may also provide larval and juvenile abalone reared from local broodstock for re-seeding to restore depleted populations.

Abalone is the fastest growing aquaculture sector in Victoria with a tenfold increase in hatchery production between 1999/2000 and 2000/01 based on an industry comprising 11 businesses employing 33 permanent and 7 casual staff in 2000/01. The fiscal year 2000/01 saw the first grow-out production of 5 tonnes of 'cocktail' sized abalone sold commercially for a value of A$232,000 (Fisheries Victoria 2002). In 2001/02 production more than doubled to 13 tonnes (Fisheries Victoria 2002) and feedback from overseas buyers suggests that cultured abalone compete favourably against wild caught abalone in the marketplace (A. Ziolkowski 2002, personal communication, November).

Management history

The Victorian commercial abalone fishery began during 1962–63 and divers were only required to hold a non-specific A$6 fishing licence. During the following four decades, progressive implementation of various management measures occurred in response to the development and performance of the fishery (Table 1). Most of the early participants in the fishery were young, without previous fishing experience and attracted by the lifestyle offered by abalone diving (Victorian Fisheries & Wildlife Division 1975). The number of divers participating in the fishery reached a maximum of about 300 during 1965 and then decreased to 162 by 1968. Increasing from a harvest of 376 tonnes, live weight, of abalone during 1965/66, production peaked a reported 3384 tonnes during 1967/68. The increase in production occurred as many part-time divers left the fishery and those remaining began to rely on abalone diving as their main source of income. This is reflected in a seven-fold increase in annual fishing effort over the same period from an average of about 23 hours per diver to 168 hours per diver. Correspondence to the Government fisheries managers from the Mallacoota Fishermen's Association in 1967 expressed concern about the sustainability of escalating effort and requested that a range of management measures, such as licence limitation and size limits, be introduced (Kurz 1967).

A A$200 Abalone Fishing Licence was introduced as part of the *Fisheries Act 1968* (Vic). This became effective during May 1970 and reduced the number of divers to 108. As a limited entry fishery with non-transferable licences the number of licensed divers declined to 90 by 1982 through attrition of licence holders. After 1967/68, production declined steadily and although Sanders and Beinssen (1972) reported the catch as stable at about 2000 tonnes per annum as a result of licence limitation, catches continued to decline, despite some annual fluctuations upward, reaching lows of 1143 tonnes in 1977/78 and 1275 tonnes in 1983/84.

Although catch rates declined by about 13% during the 10 years between 1968 and 1978, the reduction in annual harvest can be explained partly by reduced fishing effort resulting from diver attrition, but mostly by the drop in beach prices during 1977/78 (Stanistreet 1978). However, decreases in production between 1978 and 1983 occurred concurrently with annual fishing effort increasing to an average of 305 hours per diver in 1982/83 (almost double the average effort per diver of 1967/68) and the lowest recorded average catch rate of 47 kilograms per hour.

During 1968 the Victorian abalone fishery was divided into two management zones (Eastern and Western Zones), and during 1970 a third management zone (Central Zone) was added. Each licence holder was restricted to fishing in one specific zone so that by late 1970 there were 34, 56 and 18 licensed divers in the Eastern, Central and Western Zones, respectively.

Legal minimum lengths (LMLs) were also introduced into the fishery during 1968. For blacklip abalone these LMLs were 10 cm for Port Phillip Bay, 11 cm for all other areas between Lakes Entrance and Lorne; and 12 cm elsewhere. A single LML of 13 cm was set for greenlip abalone in all areas.

During 1984 the *Fisheries (Abalone Licences) Act 1984* (Vic) was introduced to permit licence transferability on a two for one basis to encourage new, generally younger divers into the fishery without causing an unsustainable increase in catch. Licence fees were then based on the average price per kilogram paid to divers for the preceding year's catch. However, the entry of highly motivated divers, who had each paid A$100,000–160,000 to purchase two consolidated licences and a A$10,000 licence transfer fee, led to a substantial increase in production to 1900 tonnes during 1987/88. A three-fold increase in the beach price, from an average of A$4.59 per kilogram live weight in 1983/84 to A$15.00 in 1987/88, provided an additional incentive to increase fishing effort. By this time some divers were landing about 40 tonnes of abalone annually.

A Total Allowable Catch (TAC) for the abalone fishery was introduced in 1988, under the *Fisheries (Abalone) Act 1987* (Vic), to control the catch. Zone boundaries were re-defined to 148° E (between Central and Eastern Zones), and 142° 31' E (between Western and Central Zones). Separate TACs of 460, 700 and 280 tonnes were set for the Eastern, Central and Western Zones, respectively. These TACs were equitably distributed by allocating a quota of 20 tonnes per annum to each licensed abalone diver (each Central Zone licence holder was allocated 20.58 tonnes). Also, licences became transferable on a one for one basis. Each diver's quota allocation effectively became an individual transferable quota (ITQ). The total TAC of 1440 tonnes, comprising 1420 units, was set to limit the catch to about 70% of the production in the early 1970s.

Since the introduction of licence transferability, and licence consolidation on a two for one basis, the number of licence holders has been 23, 34 and 14 in the Eastern, Central and Western Zones respectively. Similarly divers' individual transferable quotas (ITQs) have not changed since their introduction. With the exception of TACs, several of the current management strategies emanated from a Fisheries Management Workshop held during May 1973 (Kurth et al. 1973).

Apart from licence limitation and zonation, TACs and LMLs are the main strategies for managing Victoria's abalone fishery. Current catch quotas were initially set on the basis of early assessments and observed stable levels of catch. Prior to fishery modelling, Victoria's approach was to adopt a management strategy that attempted to assess changes in abundance at a number of fixed sites in each management zone under current TACs. Recently, the introduction of a stock-reduction model in a risk assessment framework has greatly improved the ability to monitor and predict changes in the stock status of the Victorian fishery. Fishery managers now use model outputs to assess the consequences of a variety of alternative management strategies.

Table 1. History of management strategies adopted for the commercial abalone fishery in Victoria (✡ major milestones).

1962	Fishery commenced, only non-specific \$6 fishing licence required.
1968✡	Abalone licence limitation and \$200 fee introduced.
	Fishery divided into Eastern and Western Zones.
	LMLs introduced for blacklip abalone (100 mm Port Philip Bay, 110 mm Lorne to Lakes Entrance, 120 mm elsewhere) and greenlip abalone (130 mm).
	Recreational daily bag and possession limit of 10 abalone per person introduced.
1970	Central Zone introduced such that the three zones were divided by longitudes 142° 31' East and 148° East.
1968–71	Merit system used for replacing retiring older divers with younger operators.
1983	Mechanism for full transferability of licences explored.
	Intention to legislate for transfer of licences, issue of licences by tender and revised fee structure announced.
1984✡	Two for one licence transferability introduced under new regulations.
	Transfer fee set at \$10000.
	Annual licence fee set at \$2620 and licence fee formula established for linking future licence fees to beach price for abalone, i.e. (beach price/\$3.20) x \$5000.
	Annual licence fees raised gradually, starting at 50% and increasing by 10% per annum.
1986	Annual abalone licence fee increased to \$4990.
1987	Abalone licence fee increased to \$10120 (including VicFish levy), which was the maximum allowable under the *Fisheries Act 1968* (Vic).
1988✡	TACs introduced (460 t for Eastern Zone, 700 t for Central Zone, 280 t for Western Zone).
	Abalone Quota Management System (AQMS) introduced.
1991	LML reduced from 120 mm to 100 mm in Gabo Harbour.
1994	Abalone Management Plan underpinned by co-management initiative.
	Temporary LML of 100 mm for divers under special permit to facilitate stock depletion experiment.
1995	LML increased from 100 mm to 110 mm for Gabo Harbour which becomes part of Airport Area to be administered under a single permit. Airport Area catch limit, at the 110 mm LML, increased from 4000 kg to 4500 kg per diver.
	Abalone processor licences introduced with \$20000 annual fee.
	Introduction of bin sealing & tagging scheme with new notification procedures.
	Abalone national audit trail initiated.
	New *Fisheries Act 1995* (Vic) with nominated divers for FALs introduced.
1996	Proposal to administer Airport Area reefs by regulation rather than renewable permit.
1999	Recreational fishing permit introduced. Harvesting restricted to daylight hours and depths > 2 m. Requirement to cut abalone foot upon landing.
2001	Eastern Zone industry members voluntarily increased size limits on heavily exploited reefs.
2002	Western Zone industry members voluntarily increased size limits on all exploited reefs.
	Victorian Abalone Fishery Management Plan implemented.
	TACs adusted in all zones for the first time since quotas were introduced.

The concept of sustainability

Proclivity among contemporary environmental commentators to quote adages such as 'We do not inherit the earth from our ancestors, we borrow it from our children' reflects changes over the past two decades in community attitudes towards anthropogenic exploitation of natural resources.

Implicit in the notion of borrowing something is that the item borrowed will be returned to its owner in the same, or better, condition than when it was received by the borrower. This analogy is particularly apt to sustainable use of natural resources. This is not purely altruistic considering that the persistence of our genes depends on the availability of habitable environments for our descendants (see Levin 1999, p. 148). Warren (1998) asserts that kin selection principles will cause the present generation of humans to forego some contemporary comfort to achieve a suitable or improved future environment for their offspring. However, in a commentary on marine fisheries Mace (1997, p.7) states 'The social costs of the degradation of ecosystems and the environment have yet to be paid for by future generations'. Consequently, sustainable management mandates a precautionary approach to exploitation of natural resources.

In this context the emphasis should be on managing exploitation rather than managing natural resources directly. This is not merely semantics when we consider that management is about modification of human behaviour so that undesirable activities are discouraged and desirable behaviours are promoted. This distinction is important because Western democracies are characterised by freedom of choice, civil liberty and public ownership of natural resources. These factors collectively constrain our capacity to manage solely for ecosystem sustainability. Indeed, the assertion that 'common property begets common poverty' gains some credence from examples of centralised government-based management strategies. Such strategies often attempt to please everyone whilst satisfying no one and fail to engender support because of a perceived lack of benefit at the level of the individual or the small group (see Levin 1999, pp.35–8). On the other hand, bestowing proprietorship of natural resources on individuals or small groups creates incentives for sustainable management only amongst those who are direct beneficiaries and effectively disenfranchises the remainder of the community.

To those who subscribe to Hardin's original thesis of Tragedy of the Commons (Hardin 1968), that '...unregulated access to common resources leads to unchecked exploitation and environmental degradation', Aswani (1998) asserts that there should be a distinction between common tenure and open access. He argues that a contemporary definition of common resource access means that resources are not open to everyone and that common, or corporate, systems of resource management can provide effective fisheries regulation. Mace (1997) suggests that any system that is not open access will confer some form of property right to resource users. Kurien (1995) puts the case for community-level collectivism in the management of common property resources and provides examples of villages initiating the establishment of artificial reefs to conserve artisanal coastal fisheries resources in India.

In 1972 the United Nations (UN) conference on Human Environment held in Stockholm effectively propelled discussion about sustainable development onto the international stage. However, it was not until a decade later that the 1982 UN Convention on the Law of the Sea (UNCLOS) provided the first major international instrument to connect marine resource protection with exploitation (UN 1982). Free and open access to all users gave way to 'A new world order in fisheries' that saw responsibility for Economic Exclusion Zones (EEZ) that extended 200 miles to seaward, encompassing 80–90% of global fish stocks, come under the jurisdiction of coastal States (FAO 1995a). In 1987 the World Commission on Environment and Development released a report entitled *Our Common Future* that highlighted poverty and deprivation as major causes of environmental degradation (WCED 1987). The report emphasised the need to broaden the concept of ESD to include promotion of social and cultural development and well-being as essential elements for sustainability (Hundloe 2001). In this context 'development' refers to socio-economic enhancement rather than more restricted definitions of economic growth. Other fora that promulgated the concept of ESD in relation to marine resources included the International Conference on Responsible Fishing and the UN Conference on Environment and Development (UNCED), both held during mid-1992.

During 1995 the FAO International Code of Conduct for Responsible Fisheries (FAO 1995b) was released. This code promotes fisheries management that places resource conservation objectives above all others. Specific objectives included avoiding excess fleet capacity; fostering economic viability; including the needs of subsistence fishers and small-scale operators; conserving ecosystem and habitat diversity; protecting endangered species; facilitating recovery or restoration of depleted stocks; assessing and redressing adverse impacts on the environment; and ensuring highly selective and environmentally safe fishing equipment and techniques (FAO 1995b).

Most people will have some concept of what is meant by sustainability, but interpretations among individuals may vary substantially. Obviously, it could be expected that polarisation would occur depending on whether an individual possesses a conservation or an exploitation-oriented perspective. To avoid confusion when conducting a reasoned discussion on sustainability we require a working definition. During 1988 the Fisheries and Agriculture Organization (FAO 1995b) Council defined sustainable development as '...the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development conserves land, water, plant genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable...'.

In Australia, a less anthropocentric definition, which is currently recognised by all levels of Government, was introduced during 1992 as part of the National Strategy for Ecologically Sustainable Development, NSESD (Commonwealth of Australia 1992). This definition was adopted from a 1990 Commonwealth discussion paper on ESD that was more broadly based than is indicated by the wording of the definition (Commonwealth of Australia 1991). In this instance sustainability is defined as,

'...using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased...'.

Implicit in this definition is the notion that if ecological processes are maintained then desirable human benefits will follow. This contrasts with the idea that basic human needs must be satisfied before communities can be expected to consider the health of the ecosystems in which they exist. In a relatively prosperous nation like Australia the NSESD definition seems appropriate; however, it may be unrealistic if applied in a global context. It should be also be recognised that despite national agreement about a definition there is still considerable scope for variation in how broadly it is applied.

For some contemporary organisations, such as Environment Australia, the focus is on the natural ecosystems of which the exploited species are a part. Environment Australia defines 'Ecologically sustainable' as '… use of natural resources within their capacity to sustain natural processes while maintaining the life-support systems of nature and ensuring that the benefit of the use to the present generation does not diminish the potential to meet the needs and aspirations of future generations…' (Environment Australia 2000). Although similar to the FAO definition, in practice there is greater emphasis on conserving ecosystems and the word 'Development' is excluded.

For fisheries management agencies, the emphasis has traditionally been on development, and the application of sustainability policy has frequently been restricted to attempts at maximising sustainable yield for individual species, even when multiple species are harvested from the same ecosystem. The Standing Committee on Fisheries and Aquaculture (SCFA), an assembly of chief administrators of state, territory and federal Australian fisheries agencies, has adopted a more expansive view that explicitly accommodates the social, economic and ecological dimensions (Chesson et al. 2000). In the parlance of corporate managers, this is often referred to as the triple bottom line.

Ward (2000, p. 436) suggests that 'Sustainability is as much about economic, social and cultural aspects of human existence as it is about ecology or population dynamics, and it may be achieved at different levels depending on stakeholder values and aspirations…'.

Much has been written during the past decade about how we may sustainably exploit fisheries resources. However, in practice there appears to be more failures than successes, both historical and contemporary, in achieving this goal (Buckworth 1998, Mace 1997, Stephenson & Lane 1995, Walters 1998, see also WWF 1998). For example, despite a Common Fisheries Policy (CFP) among the Member States of the European Union (EU), under-resourced attempts to manage complex multi-species, multi-gear fisheries as single units of stock, whilst satisfying a myriad of inter-cultural demands, conspires against sustainability (Laurec & Armstrong 1997, WWF 1998). Caddy (1995) argues that resource scientists are not to blame for this dysfunction in fisheries management. Mace (1997) and Morgan (1997) largely concur suggesting that poor institutional arrangements and policy failures have been more limiting than scientific assessments and management. Walters (1998) is less charitable suggesting that scientific advice provided to managers about stock sizes and potential production has often been incorrect.

Most of the world's fisheries, including those within Australia's jurisdiction, are regarded as either fully or over exploited (Garcia & Newton 1997). Perry et al. (1999) note that most of the developing or under-developed fisheries resources are invertebrates and that a 46% increase in invertebrate catches between 1984 and 1995 resulted from an increase in overall production and a shift away from declining vertebrate fisheries. In Victoria, invertebrates comprise almost two thirds of commercial landings and 90% of the landed value (Fisheries Victoria 2002). In the quest for additional fish resources, global emphasis on the development of aquaculture as a viable alternative to ailing wildstock fisheries has not provided the anticipated ecological sustainability panacea because of associated problems of environmental degradation and ecosystem impact (Mace 1997, WWF/IUCN 1998).

Concerns about our capacity to manage Australian abalone resources sustainably are well-grounded due to the previously noted litany of abalone stock decline and collapse beyond our shores and recent accounts of localised depletion within Australia (Shepherd & Baker 1998, Shepherd et al. 2001). However, the causes of these problems are multiple and complex and often vary spatially within and among species (see Parker et al 1992). This multi-plexity mitigates against generalising among species and makes failures difficult to predict. Indeed, characteristic ecological differences between blacklip and greenlip abalone in Victoria extend to differences in their vulnerability to over-fishing. Although the greater vulnerability of greenlip abalone has resulted in widespread stock collapse in Victoria, this has not become manifest in other greenlip-producing States despite intensive exploitation.

Although Australia is one of the few bastions of viable wild-stocks of abalone that remains in the world, contributing 55% of the global wild production, its two largest abalone fisheries have recently experienced their first reductions in catch quotas since the late 1980s. Although recent improvement in the New South Wales resource demonstrates that blacklip abalone stock decline is not necessarily a one way trip, this does not provide grounds for complacency. It would be imprudent to assume that apparent sustainability during the past four decades provides sufficient evidence that current management strategies will ensure the future persistence of viable abalone resources in Australia.

Part I. Assessment of abalone resources

This part has separate sections for blacklip and greenlip abalone, consistent with federal environment protection and biodiversity conservation legislation that requires the sustainability of fish catches to be considered on a species by species basis. Section 1 focuses on blacklip abalone and describes the need for estimating the abundance of this species, the preferred methods used and the reasons for their selection (Chapter 2). Critical evaluation is made of the strengths and weaknesses of each method within the context of the design of broad-scale monitoring programs aimed at establishing time series of abundance. Aspects of population dynamics associated with movement of blacklip abalone are described and the effects of these processes on the Victorian fishery are considered (Chapter 3). The preceding elements are then incorporated into an assessment of the current and future status of Victorian blacklip abalone populations that draws substantially on the outputs of a length-based model of the fishery (Chapter 3).

Section 2 provides an assessment of the current status of greenlip abalone resources based on a review of previously acquired data and a single survey of populations along the Victorian coast (Chapter 4). Because of the 'one-off' nature of the survey the assessment methods differ from those applied for blacklip abalone in Section 1.

Section 1. Target species – blacklip abalone (Haliotis rubra)

Chapter 2 Estimating abundance

Overview

Transect sampling has been the most widely used technique throughout the world for conducting underwater visual census of abalone and despite its limitations has been useful in establishing fishery independent time-series of abundance. The main limitations relate to the patchy and clumped distribution of abalone that leads to bias in abundance estimates based on low to medium levels of replication. The need for high numbers of replicates, difficulty in accurately delineating the boundaries of the sampling area and the frequently hostile sea conditions in abalone habitat have given rise to a well-founded perception that alternative methodologies may be required.

We evaluated a range of fishery independent and dependent alternatives in several studies aimed at finding the most efficacious method for detecting the impact of removals by fishing. We found that fishery independent timed-collections are efficient and provide estimates with high precision, yet are inaccurate in predicting the effects of abalone removals. Commercial catch rates recorded at high spatial resolution under controlled fishing conditions were prone to hyperstability and could not be relied on for detecting reductions in abundance. Transects, distance-based estimates and mark recapture collectively all provided accurate results but presented a range of logistical difficulties, including those described above. Mark recapture was time demanding and consequently costly. Distance-based measurement was shown in simulations to have a high probability of estimating absolute abundance. However, this method requires high levels of replication (250–300 samples per site) and presents technical difficulties in locating individual abalone at random.

We have applied a modification of conventional strip or belt transects to annually survey Victorian abalone populations at up to 165 fixed sites in the commercial fishing grounds during the past 10 years. This has provided relative abundance and length-frequency data with adequate precision to be used as the primary information to assess the status of the blacklip abalone resource.

Background

Assessment of the impact of harvesting on targeted fish populations requires quantitative measures of abundance that detect the effects of removals of observed catches (Richards and Schnute 1998). Fishery independent methods have generally been preferred for estimating abalone abundance because of actual or perceived limitations in the utility of fishery dependent data for this purpose. For instance, although catch-per-unit-effort (CPUE) as reported by fishers is commonly used as an index of abundance for assessments of many fisheries, CPUE is generally regarded to be unreliable as an indicator of abundance. This applies not only to abalone (Breen 1992, Dichmont et al. 2000, Sloan & Breen 1988 and Tarr 1992), even under rigorous data collection regimes associated with highly controlled fishing (Hart & Gorfine 1997), but many other species (Harley et al. 2001, Walters 1998). Walters (1998) points out that a major failing in stock assessments has been the lack or inadequacy of fishery independent indices of abundance. He suggests that for most fisheries the costs of acquiring these data are prohibitive and that for this reason quota-based management policies should be abandoned in favour of exploitation-based strategies. With its high value of production, abalone may be one of the few exceptions to this assertion.

For high value fisheries such as abalone, illegal catches are often substantial but unquantified and unaccounted among catch and effort statistics. Fishery independent surveys involve direct observation of those abalone remaining on reefs after fishing and consequently provide an integrated signal from all sources of fishing mortality.

There has been much dialogue and research directed at establishing a 'best' method for estimating abalone abundance. Propensity to aggregate into clusters that form a patchy spatial distribution pattern and juvenile preference for inhabiting cryptic spaces within the reef substratum are two important reasons why the solution to this quest is not simple. In a terrestrial environment, mapping of distribution patterns of organisms at a variety of scales is relatively more tractable. It is evident from objective comparisons of alternatives that different approaches may be required for the same species in different geographic regions and for different categories of population abundance.

A variety of methods have been applied to estimate abalone abundance, although transect methods are most frequently reported in the literature. Transects or other area based measures have been used for temporal monitoring of abundance in Australia (Gorfine et al. 1998), British Columbia (Farlinger & Campbell 1992, Sloan & Breen 1998), California (Davis et al. 1996, Haaker 1994, Karpov et al. 1998), Mexico (Guzmán del Próo 1992, Prince & Guzmán del Próo 1993, Shepherd et al. 1998), New Zealand (Sainsbury 1982) and South Africa (Dichmont et al. 2000, Tarr 1992). Timed search methods have been the main alternative and their use has precipitated debate about the best methods. Timed searches were introduced in Victoria during 1990 and New Zealand during 1992 (McShane 1994). This method has also been used in South Australia (Shepherd & Partington 1995, Shepherd et al. 1999) and more recently in California (California Department of Fish and Game 2000). In New Zealand timed searches gave way to visual estimates of patch size and a modification of this method is currently in use today (Andrew et al. 2000).

Estimating the relative frequency of different patch size categories has the advantage of reducing hyerstability that affects more conventional estimates of relative density.

Hyperstability in abundance estimates results from serial depletion of aggregations by fishing, post-fishing re-aggregation, and emergence from cryptic habitat. Patch size estimation is likely to be insensitive to emergence and may not be responsive to re-aggregation. In New Zealand, where the technique has been used, research by Andrew et al. (2000) indicates that *H. iris* does not re-aggregate in response to fishing mortality. One limitation of the technique as it was initially applied in New Zealand was that the assumption that the same area per unit time was swept for each sample was unlikely to be true. Sonar equipment that measures distance and direction underwater has recently appeared in the recreational diving marketplace and may overcome this limitation.

Also, changes in the aggregation pattern may occur that are unrelated to removals by divers. In the introduction (Chapter 1), mention was made of the escape response of abalone when confronted by a predator such as the seastar *Coscinasterias muricata*. Although it is not known whether abalone that have evaded predatory attacks return to their original homesities, an in vitro study of the less mobile blue mussel *Mytilus edulis* showed increased aggregation occurred when mussels were exposed to a predatory stimulus (Côté & Jelnikar 1999).

Habitat disturbance can also affect abundance estimates by causing changes in abalone distribution patterns. Recently one of our research divers revisited a tag release site in eastern Victoria after several months to check on the condition of several hundred tagged blacklip abalone. The site is marked by a weighted float suspended about 1.5 m above the reef. He observed that the float line and surrounding reef area was engulfed by at least half a metre of sand and that the tagged abalone had retreated to a more elevated part of the reef complex (J. Rudge 2002, personal communication, March). This is not the first occasion these kinds of observations have been made during our survey work in Victoria. During previous years abalone have occasionally been seen concentrated on vertical surfaces immediately above the sand line adjacent to gutters where decomposing sessile invertebrates and macroalgae remain buried (D. Forbes 1998, personal communication, April). In one instance abalone were found to be more clumped than usual and commercial abalone divers reported experiencing difficulty with locating aggregations, but obtaining better than average catches when they did find them. Ault and DeMartini (1987) report similar observations of *H. rufescens* departing sites along the sand edge of reefs when threatened by smothering sand in California. Andrew and O'Neill (2000) also report that during surveys of urchin barrens habitat in southern New South Wales they observed sand burial of a reef between visits several months apart. If these events were widespread and frequent they could be expected to compromise the utility of abalone survey data for estimating the impact of fishing mortality.

Because of difficulties with precise delineation of sampling boundaries and areas swept for most techniques, plot-less sampling has recently been considered as a possible alternative. This led to our investigation of distance estimation methods. These methods rely on lineal measurements of distance between nearest neighbours and from randomly selected points to nearest individuals. Distance estimation can potentially provide accurate estimates of abundance unaffected by boundary effects of areal and time based measures. Rather than measuring the average number of abalone per unit area, this method measures the average unit area per individual abalone, and effectively integrates densities of individuals within aggregations with the density of aggregations. Essentially, the geometric mean of nearest neighbour distances (when measured as distance from a randomly chosen abalone to its nearest neighbour) and distances from random points to nearest abalone, provides a compound value as an unbiased estimator of density. Indeed, our results indicate that estimates of absolute rather than relative abundance are possible with this technique (Officer et al. 2001b). However, replication levels and associated costs are much higher than with area and time based methods. There is also an element of concern about how well the distance estimation performs for highly clumped populations because current procedures do not incorporate the variation in density within clumps in the analysis (K. Byth 2002, personal communication, April).

Distance estimation methods do not eliminate variation due to observation error because an observer's ability to identify nearest abalone will vary and this will be affected by visibility and swell, as are all underwater survey techniques. We found that a minimum of 250 replicates were necessary for what was a relatively small population in low rugosity reef complex. Transect sampling at current replication levels, using the protocols developed by us for broad-scale monitoring, provided estimates with coefficients of variation of about 25%. Coefficients of variation of this magnitude are considered to provide sufficient statistical power to detect effect sizes small enough to be useful for abalone population monitoring (Dichmont et al. 2000)

In 1996 we trialed and evaluated a range of methods that we thought were suitable for broad-scale monitoring of blacklip abalone populations. Much of the stimulus for this work came from perceptions that the effects of variation among observers tended to be high and that sensitivity of abundance estimates to real declines in abundance was low. Based on this study and further work we have concluded that there is no best technique that is suited to all situations.

Survey design is as important in estimating abalone abundance as is the survey technique selected. Despite statistical limitations most techniques in current use are applied in a fixed site (repeated measures on sites over time) design to reduce replication levels and associated costs. Fixed site designs are not an option for distance estimation techniques.

There are marked differences in the nature of abalone habitats throughout southern Australia that warrant different approaches to abundance surveys. In NSW, abalone are mostly confined to medium to large gutters in mostly sedimentary and metamorphic rock. These gutters have discernible boundaries that facilitate recognition during subsequent fixed site surveys. NSW surveys are based on about 400 gutters that are re-visited annually (D. Worthington 1999, personal communication, 23 July). In Victoria, the geology and associated weathering is more diverse and abalone are generally more abundant. Dense stands of *Phyllospora comosa* increase the difficulty in recognising sites based on topographic features.

Although there are clear preferences for gutters and vertical surfaces in Victoria (as illustrated in Plate III), abalone are found over most of the reef and the gutters are frequently ill-defined. Victorian surveys are based on samples from six transects selected at random from twelve equally spaced radii at each of 156 fixed sites that are visited annually. In Tasmania, large bomboras make transect sampling problematic as do the heavy laminae of *Durvillaea potatorum* that obscure the abalone and impede divers swimming close to the reef surface (R. Officer 1999, personal communication, 22 July). In South Australia and Western Australia the mostly sedimentary reefs are less complex, abalone are less obscured by kelp and research divers less impeded by dense and heavy laminae (personal observation). This enhances the reliability of visual census and provides greater opportunity for using photographic and videographic survey techniques (K. Friedman 2001, personal communication, 26 October).

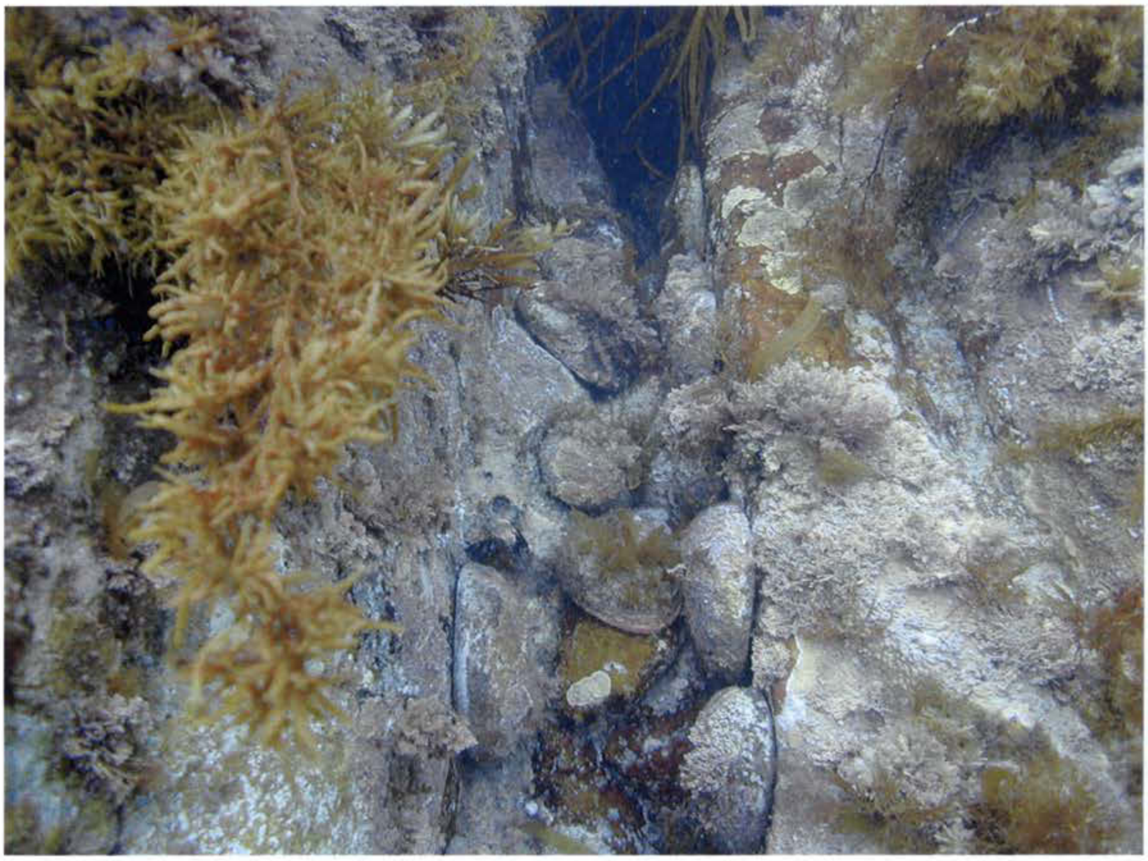

Plate III. Blacklip abalone (*Haliotis rubra*) typically aggregated in a narrow gutter.
Reproduced with kind permission from the Tasmanian Aquaculture and Fisheries Institute. Photo: D. Tarbath

The Victorian design suffers from pseudo-replication (Hurlbert 1984, see also Stewart-Oaten et al. 1986) in the sense that the transects within a site are not strictly independent of each other within each annual survey. This is a necessary compromise to ensure the efficiency and safety of research divers conducting surveys. However, the random selection of transects within each site should ensure some spatial independence within surveys and temporal independence among surveys. Because the prime objective is to establish a time series of abundance, the need for temporal independence is of greater importance than ensuring spatial independence.

One limitation that affects both Victorian and New South Wales surveys is that fixed site designs effectively preclude the progressive addition of new sites unless they can be effectively standardised with the old sites by some independent method. This is dealt with in Victoria by applying generalised linear models for standardisation of the abundance data. The SAS® GENMOD procedure (SAS Institute 1997) is used so that when an additional site is introduced into the survey its data are standardised to the mean abundance for that year. Consequently, only the future trend and not the initial value in abundance at the new site affects the results.

Concerns about research divers' effects on variation in estimates have recently re-surfaced due to a necessity to introduce new diving teams into our monitoring in Victoria. However, several investigations including comparisons of repeated counts by individual divers and repeated transects among divers have shown the techniques give reproducible results and that variation among divers within a particular team is relatively small (Gorfine unpublished data). We are currently investigating the effects of modifications in survey technique; specifically the effect of changing from collections to non-destructive counts of the abalone within transects. We are also rigorously investigating differences between survey teams to ensure that the data can be properly standardised if necessary.

Despite the introduction of independent survey techniques in several Australian states during the late 1980s to early 1990s, there were no explicit links to quota setting until attempts were made to model abalone fisheries during the mid to late 1990s. The first application of a model that combined the use of both fishery dependent and independent information occurred in NSW (Worthington 1997). Victoria followed suit with a similar model several years later and the NSW model was concurrently adapted for assessments of the New Zealand paua fishery (Breen et al. 2000). Recently a prototype fishery assessment model, based on the NSW and Victorian assessment models and refined at MAFRI, has been introduced in Tasmania and South Australia. However, unlike NSW and Victoria, both these states have yet to establish broad-scale fishery independent abalone surveys. Capturing the dynamics of abalone populations in fishery assessment models to determine current and future stock status is the subject of the following chapter.

Papers

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Hart, A.M., **H.K. Gorfine** & Callan. M.P. 1997. Abundance estimation of blacklip abalone (*Haliotis rubra*) I. An analysis of diver-survey methods used for large-scale monitoring. *Fisheries Research* 29: 159–169.

Hart, A.M., & **H.K. Gorfine**. 1997. Abundance estimation of blacklip abalone (*Haliotis rubra*) II. A comparative evaluation of catch-effort, change-in-ratio, mark-recapture and diver-survey methods. *Fisheries Research* 29: 171–183.

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Hart, A.M., & **H.K. Gorfine**. 1997. Abundance estimation of blacklip abalone (*Haliotis rubra*) II. A comparative evaluation of catch-effort, change-in-ratio, mark-recapture and diver-survey methods. *Fisheries Research* 29: 171-183.

Officer, R.A., M. Haddon & **H.K. Gorfine**. 2001. Distance-based abundance estimation for abalone. *Journal of Shellfish Research*. 20(3): 781-786.

Chapter 3 Blacklip population dynamics

Overview

Fishery assessments require a framework to ensure that monitoring data are synthesised and analysed in an advisory process explicitly linked to protocols for criterion-based management decisions. Fishery modelling can provide much of this framework to utilise available data, in a way that is consistent with established concepts and the known biology of abalone, to produce estimates of the impact that alternative management strategies may have on the current and future status of the resource. We have progressed from the direct use of fishery independent and dependent statistics in semi-quantitative assessments of stock status to the development and application of a length-based production model. This model delivers outputs that can be considered against a set of performance indicators specified in the Abalone Management Plan to enable a risk-based assessment of contemporary and alternative catch quotas and size limits.

Background

Fisheries models provide biologically sensible frameworks of population dynamics that facilitate optimum use of available data to make objective assessments about resource status. Breen (1992) reviewed the application of a range of stock assessment models that had been applied to abalone fisheries. He identified the poor correspondence between catch-per-unit-effort and stock size and our limited understanding of the relationship between present stock size and future recruitment as major constraints on modelling.

The previous chapter dealt with selecting appropriate methods for estimating the abundance of abalone populations. Although abundance indices can be used exclusively in adaptive management regimes to track relative stock status (Dichmont et al. 2000), they provide no capacity to predict yields from a fishery under alternative management strategies. This is a major limitation for quota managed fisheries. Well-constructed models can overcome this limitation; however, many of the tenets that apply to large-scale vertebrate fisheries do not necessarily apply to abalone. Consequently, it has only been in recent years that modelling has been employed in abalone fisheries assessments and mostly in the quota-managed fisheries of the Southern Hemisphere.

Not surprisingly, inability to reliably estimate the ages of abalone (McShane & Smith 1992) has led to adoption of length-based models that are remarkably similar among different countries and jurisdictions. There are some unique characteristics of abalone population dynamics that affect the assumptions and parameterisation of these abalone fisheries models. This chapter includes investigations into movement and fine-scale spatial patterns and how these may affect assessments. Movement and re-aggregation processes tend to have similar, but more localised effects, to schooling fishes, in terms of creating hyperstability in abundance estimates and rendering abalone more vulnerable to over-fishing by maintaining catchability as population numbers decrease.

In this chapter the fishery assessment report edited by Gorfine et al. (2002) documents the outcomes from the most recent modelling of blacklip abalone population responses to fishing. The length-based model used as the primary assessment tool for the Victorian fishery is fitted to time series of fishery independent abundance and length-frequency. The model does not attempt to reconstruct the actual biomass history or past productivity of the stock, but instead extrapolates the biomass of the stock into the past under current circumstances to discover its potential yield at different proportions of current catch levels. In this context the pre-fished biomass is essentially the biomass to which the current population would theoretically rebuild if fishing mortality was zero. Reasons for this approach include recognition that the area of abalone habitat is likely to have decreased during the early development of the fishery as other organisms replaced abalone that were removed, absence of suitable data for model fitting prior to the 1990s, and absence of a density dependent productivity function in the model.

The model used is still at an early stage of development, although it appears to fit to fishery independent length-frequency data quite well in many instances. However, the closeness of the fits simply means that the growth function incorporated in the model is appropriate for the assumed level of natural mortality. This does not necessarily imply that the model outputs are an accurate reflection of reality.

This model can be applied at any spatial scale, limited only by the availability of spatially representative data for fitting and parameterisation. Insufficient data has inevitably led to the application of the model at scales larger than those preferred for an organism, such as abalone, with a relatively small metapopulation size. Nonetheless model outputs have been incorporated into assessments of the fishery.

The most recent 2001 fishery assessment has indicated that total catch levels are too high to maintain current biomass levels with 70% confidence in four out of six modelling regions. At a zonal scale, the maximum constant yields that were predicted for base case scenarios were 94% in the Western Zone, 90% in the Central Zone and 104% in the Eastern Zone. The use of modelling as a tool to assess the status of the target species and explicit linkages between model outputs and fishery performance indicators are key elements required to satisfy the legal obligations for ESD reporting that is the subject of Chapter 9.

The conceptual framework for modelling is valid in terms of what is known about the life history of blacklip abalone populations. However, there are some components of the abalone life cycle that require elucidation. In particular, there is the issue of density dependence and how this affects growth, mortality and reproduction. The nature of the density dependent relationship has implications about the suitability of using a Beverton-Holt recruitment function in the model. Several authors suggest that abalone population growth is governed by depensatory dependence which means that population growth slows at low densities (Rose et al 2001). Proponents of this hypothesis argue that Allee's effect manifests as reduced fertilisation rates consequent to harvesting from aggregations because abalone rely on aggregations to increase spawner density for fertilisation success (Babcock and Keesing 1999, Hobday et al. 2001, Shepherd et al. 2001).

However, it also seems reasonable to postulate that there must be some limit to the carrying capacity of a particular habitat and that eventually competition for space and food will give rise to compensatory processes where population growth asymptotes at high densities consistent with the Beverton-Holt function (see McShane 1995). Indeed without compensation, harvesting would rapidly become unsustainable as the density of the spawning population was reduced (Rose et al. 2001). In a study of a highly dense settlement of post-larval *H. rubra*, McShane (1991) showed that mortality was density dependent. Similarly, Connell (1985) concluded that mortality between juvenile and adult stages for a range of intertidal invertebrates was independent of initial density when recruitment was low, but became density dependent at high recruitment levels. This suggests that depensation may affect the supply of post-larvae at low spawner densities, but at high spawner densities a compensatory relationship occurs after settlement. One way of reconciling these observations is to propose some form of logistic relation where there is an optimum, below which depensation occurs and above which a compensatory process exists. Hilborn and Walters (1992, p.262) point out that this can be achieved by including an exponential parameter that has a value larger than 1.0 within the spawning stock variable of the Beverton-Holt relation. However, stock recruitment data are required to estimate this parameter and the difficulty of effectively sampling smaller size classes of abalone because of their preference for cryptic habitat (described in Chapter 2) will make its estimation implausible.

One of the issues often overlooked in discussions about stock-recruitment relationships is the definition of recruitment. Booth and Brosnan (1995) point out that unlike settlement, the definition of recruitment in the study of marine populations is arbitrary, often depending on the perspective of a particular researcher. To an ecologist it will generally be interpreted as entry of post-larval organisms into a population, but to a fisheries scientist the usual definition is entry to the stock. This makes comparisons among studies difficult and may lead to confusion. McShane (1995) discusses the effects of selecting different stages in abalone life history to measure recruitment. He states that the use of juveniles instead of post-larval settlers as indicators of recruitment can obscure or exaggerate stock-recruitment relationships.

The current version of the length-based model used to assess the status of the resource appears to function effectively, but there is a need to test how well the model reflects reality. As mentioned in the previous chapter, similar length-based models have been used to provide assessments of the fisheries in NSW (Worthington et al. 1999) and New Zealand (Breen et al. 2000). Further simulation work to examine the effects of applying the model at different spatial scales is possible with existing data. However, because of a lack of historical data required for fitting the model there are limitations to conducting retrospective analyses that attempt to predict the present or recent history from the past. Retrospective analyses are only possible if CPUE is used as an index of abundance for model fitting. Use of CPUE will require some novel means for standardisation because attempts to standardise these data have so far proved unsuccessful. One further aspect requiring resolution is the effect that spatial dynamics associated with clumped distribution patterns may have on fishery independent abundance estimates. Changes in the relative abundance index that are unrelated to fishing mortality, or hyperstability towards fishing related declines in abundance may produce inaccurate model outputs (Richards & Schnute 1998).

One of the most important aspects of assessing a fishery is the incorporation of statistical uncertainty (Caddy 1997). Uncertainty is a measure of the variability in population parameters and in responses of the population to fishing. Specifying the uncertainty in estimates facilitates a risk-based approach to management decision-making. An acceptable level of risk is subjectively determined by fisheries co-managers and specified as a component of many performance indicators (see Chapter 7). The addition of a normal random variate to the recruitment function incorporates stochasticity into the model and expresses the uncertainty in population parameters.

Uncertainty in the responses of abalone populations to fishing mortality is accommodated in the modelling by generating stochastic outputs from Markov Chain Monte Carlo (MCMC) simulations. The value for a performance measure at an assumed level of risk is simply the equivalent percentile value of the probability distribution of outputs from the MCMC simulations. This is preferable to the less conservative alternative of relying on single point values derived from maximum likelihood estimates, where risk will be close to 50% for normally distributed outputs (National Research Council 1998). Despite the need for a precautionary approach to fisheries management, and abalone in particular, there is reluctance among some stakeholders and senior government bureaucrats to embrace this approach. This becomes apparent when they express their dissatisfaction with the provision of a statistical range as a response rather than a unique deterministic value.

In addition to model outputs, assessment of the Victorian blacklip abalone fishery covers a broad range of information, both current and historic, that provides managers with an holistic perspective of the contemporary status of the resource. A description of the fishery performance indicators used by managers to translate the assessment outcomes into management decisions is provided in Chapter 7.

Papers and report

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Section 2. By-product species – greenlip abalone (H. laevigata)

Chapter 4 Greenlip population abundance

Overview

Victorian greenlip abalone resources have only supplied a small proportion of reported landings throughout the history of the fishery. This reflects the relatively small and fragmented distribution of available habitat. Consequently very little research and no formal assessment of this species had been done in Victoria prior to our study in 1998. For the last decade greenlip catches have generally been taken in association with relatively large catches of blacklip, hence its designation as a by-product species.

Recent catch statistics for the fishery were consistent with low productivity and indicated the possibility of collapse. In 1997 we commenced field surveys of areas known to have supported commercially harvestable populations of greenlip abalone. We utilised data from research conducted about 25 years earlier on key population parameters in conjunction with our survey results to perform a 'snapshot' assessment of the resource status.

We concluded that the current status of greenlip stocks was mainly consistent with over-harvesting during the 1960-70s and subsequent failure to recover despite low levels of catch during recent years. The resource is no longer capable of supporting more than a very modest fishery of questionable sustainability. Consequently a separate catch quota set to zero has been recommended for this species and we believe that some form of restorative intervention will be required for this fishery to resume in the future.

Background

Greenlip is important as a target species in the abalone fisheries of South Australia (42% of TACs) and Western Australia (58% of TACs), but much less so in Tasmania (5% of TACs). In contrast, Victorian catches have always been quite small and are now almost negligible (~0.3%). During the decade since quotas were introduced in Victoria the majority of daily catches for which greenlip abalone were reported also contained substantially larger amounts of blacklip abalone. Consequently, greenlip is now considered to be a by-product species. The low total value of Victorian greenlip catches has resulted in limited allocation of research funds for its assessment. However, recent implementation of the Commonwealth *EPBC Act 1999* (Cwlth) compels the Victorian Government to become involved in formal assessments of the status of greenlip abalone resources separately from blacklip (Environment Australia 2002a). If greenlip abalone are to be exported from Victoria in the future, then the state government must instigate separate management arrangements directed at attempting to restore greenlip populations.

It should be no revelation that because of its relative commercial importance, extensive research into the population biology of greenlip abalone has been undertaken in South Australia during the past three decades. This research has revealed the many differences in behavioural ecology and habitat preference compared with blacklip that were described in Chapter 1. In contrast, current research and monitoring of greenlip abalone in Victoria is quite limited and this chapter presents one of relatively few studies undertaken in this state. Unlike blacklip abalone populations, the baseline information about Victorian greenlip abalone is also limited so temporal comparisons are mostly speculative. However, some data on length-frequency, growth, morphometry and reproduction were collected during the late sixties to early seventies and the early to mid eighties. A comprehensive survey underpinning the assessment report by Gorfine and Dixon (2000b) in this chapter was completed during 1997-98 and provides an important element for comprehensively reporting on the sustainability of Victorian abalone resources.

Because of the lack of temporal series of fishery independent abundance and length-frequency data, the paucity of spatially explicit growth data and the absence of estimates of natural mortality, methods used for greenlip assessment differed from those described in Chapters 2 and 3. However, the limited number of populations throughout Victoria meant that more intensive survey methods were feasible for this species. To some extent this meant that a snapshot survey for greenlip abalone was more informative than if the same survey methodology was applied to blacklip populations.

The Abalone Management Plan (Fisheries Victoria 2002) mandates that biennial surveys of greenlip abalone resources are undertaken in the future and that a TAC of zero should prevail until the resource has recovered to an extent deemed sufficient to sustainably support a viable fishery. At best, stock recovery will lead to only a modest fishery for this species because of the limited and fragmented areas of suitable habitat. At this stage recovery of Victorian greenlip populations seems unlikely without intervention in the form of a re-seeding or stock restoration program.

Report

Gorfine, H.K. & D. Dixon (eds.). 2000. Greenlip Abalone—1999. Compiled by the Abalone Stock Assessment Group. Fisheries Victoria Assessment Report No. 26. Marine and Freshwater Resources Institute: Queenscliff, Victoria, Australia.

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Part II. Governance

Part I of this thesis addressed aspects of abalone resource assessment that underpin management decisions directed at ensuring ecologically sustainable fishing practices. Part II extends this work with publications that consider the governance of the Victorian abalone fishery in terms of its fishery management strategies and the ESD reporting requirements for the fishery management system as a whole.

Section one examines the relationship between management strategies and observed fishing and post-harvesting practices (Chapters 5 and 6) and critically evaluates some of the options for measuring the performance of fishery management strategies (Chapter 7). Section two integrates the assessment sections in Part I with Section 1 of Part II and information on poaching (Chapter 8) into an ESD reporting framework using guidelines and benchmarks specified by Environment Australia (Chapter 9).

Section 1. Fishery Management Strategies

Fisheries assessments provide managers with quantitative information about the likely consequences of alternative harvest strategies.

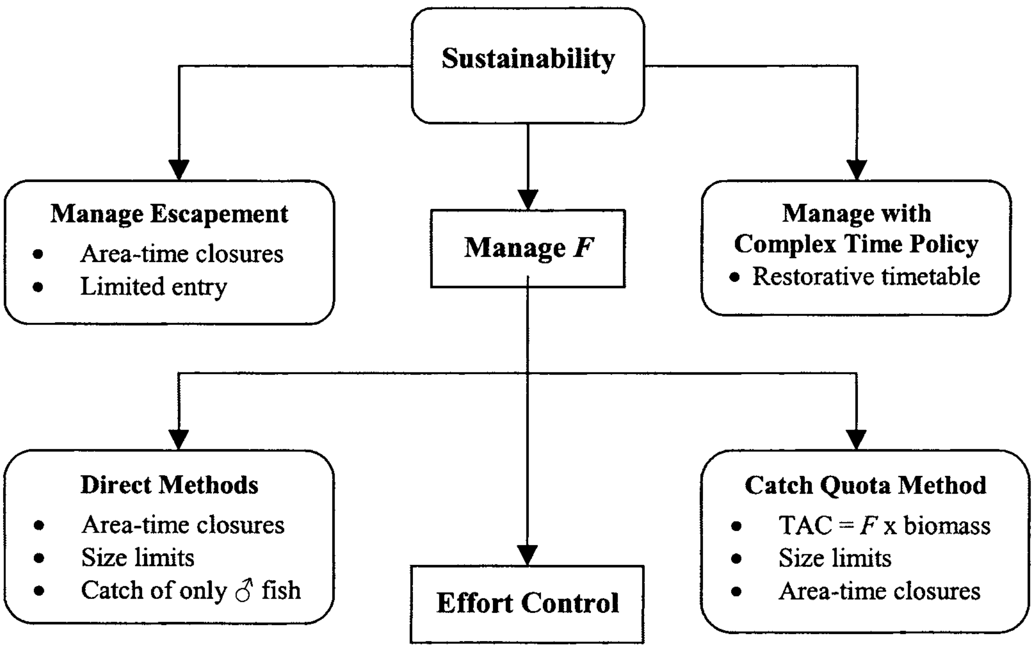

Figure 3. Possible management strategies to achieve sustainability (after National Research Council 1998).

As described in the introduction in Chapter 1, management of the Victorian abalone fishery is primarily based around a catch quota strategy supplemented by size limits (Fig. 3). There are no direct controls on effort, although limited entry and zonal allocation of fishery access licences provides an upper limit. Seasonal and areal closures have not been used in this fishery.

Chapter 5 Quotas

Overview

Catch quotas have become a frequently used management tool; however, their effectiveness is governed by several factors including fishing behaviour patterns and the incentives that drive these behaviours. Quotas based on individual transferable access entitlements provide the strongest incentives for resource stewardship among fishers.

However, for logistical reasons quotas are generally applied over broad spatial scales that may be inappropriate for sedentary invertebrates, like abalone, primarily because of their mostly limited larval dispersal. The apparent sustainability of the Victorian blacklip abalone resource is not necessarily due in entirety to the formalised management arrangements of the fishery. It is important to come to some understanding about the informal arrangements in attempting to assess the sustainability of this resource under contemporary management. This objective was addressed by undertaking a study involving on-board observation of the daily fishing activities of several commercial abalone divers in different parts of the fishery.

Results from the study clearly showed that divers were adept at maximising their returns per unit effort and achieving their daily catch expectations. Divers' high catch rate thresholds, or stopping 'rules', that prompted relocation to alternative reefs and provided a pattern of rotational harvest among reefs mitigated any tendency to overharvest. Formal management arrangements should avoid strategies that may lead to reductions in diver expectations and acceptable catch rate thresholds.

Background

Although quota based management strategies are common among vertebrate fisheries they have only found favour with fisheries agencies responsible for abalone management in the Southern Hemisphere. In the Northern Hemisphere most of the management regimes for commercial abalone divers are based on input controls, although daily bag limits are applied to recreational divers. Notable exceptions are the commercial abalone fisheries of British Columbia and Alaska (Farlinger & Campbell 1992). However, as those responsible for developing strategies to recover the collapsed fishery in California consider quota management as a possible tool (CDFG 2000a) it is critical that they are cognisant of its limitations and do not see it as a panacea.

Morgan (1997) quotes OECD statistics that show catch quotas that were not assigned as Individual Transferable Quotas (ITQs) failed to prevent the decline or collapse of 16 out of 22 fisheries. Most prominent among these were herring stocks in British Columbia, Iceland and Europe. Eleven of the 16 fisheries were subject to limited entry. Reasons given for this failure in Total Allowable Catches (TACs) to sustain fisheries centred around competition to land the largest share of the TAC, excess fishing capacity, shortened fishing seasons and consequent reductions in profitability. Mace (1997) also asserts that TACs and limited entry have mostly failed to promote biologically and economically sustainable fisheries, attributing much of the problem to over-capacity.

In contrast 23 out of 31 fisheries managed by ITQs were apparently sustainable and showed improved economic performance (Morgan 1997). As described in Chapter 1, the Victorian abalone fishery has been subject to ITQ management since 1988. In instances where ITQs fail to prevent fisheries declines Morgan (1997) suggests that it is usually a consequence of:

- enforcement difficulties,
- inadequate data and scientific advice,
- departure from agreed protocols for TAC setting (ITQs often set too high),
- and constant catch quotas being insufficiently conservative during cyclical periods of naturally low recruitment.

He also identifies lack of structure in TACs to accommodate large differentials among classes of fish as a problem. An example of this for Victorian abalone is those occasions when market demand results in a higher price for smaller abalone and effort becomes concentrated in Port Phillip Bay where a lower size limit prevails. Among these possibilities he suggests that poor institutional arrangements that separate government and industry functions are most responsible and that industry support for management arrangements is critical for success. Mace (1997) identifies poor data quality from mis-reporting, non-reporting and careless reporting of effort and CPUE by fishers as a major impediment that results from fishers' mistrust about the data being used to their disadvantage. She suggests that electronic tracking and recording systems should be used to overcome this limitation.

Morgan (1997) asserts that one of the main strengths of ITQs is the strength of the property rights that they confer and the incentives for improved utilisation leading to resource sustainability. Victorian divers have recently developed an on-board measuring machine with an integrated GPS that logs the lengths of abalone in the catch, as well as the date, time and position of the vessel as the deckhand progressively checks the catch and packs it into bins throughout the course of a day's fishing. Early trials have proved successful and it is now being implanted as a pilot program. This example provides evidence to support Morgan's claim about the benefits of ITQs and it partially satisfies Mace's call for electronic acquisition of fishery dependent data.

Perry (1999) emphasises the importance of the small spatial scales over which sedentary marine invertebrate populations' function and the need to take this into account when establishing management and assessment strategies. Historical patterns in diver behaviour, limited Government resources and convenience have conspired to ensure that most abalone fisheries management is prosecuted at scales that are one or more orders of magnitude too large to be consistent with contemporary theories about abalone population dynamics. At the crux of this issue is the limited dispersal of abalone larvae, despite a relatively long planktonic phase (Prince et al. 1987, 1988; McShane et al. 1988). Victoria's abalone fishery is no exception to the problem of large-scale management and this is consequently reflected in the scale of assessments.

However, there is evidence that by informally creating a regime of finer-scale spatial management, conventional harvesting patterns of Victorian abalone divers have tended to compensate for the coarse scale over which quotas are applied (Gorfine & Dixon 2001). These behaviours are not purely acts of altruism, they are manifestation of abalone divers' endeavour to maximise the profitability of their fishing operations under an ITQ management regime. Despite Morgan's claims about ITQs, on their own they do not account for, nor guarantee the persistence of these behaviours.

Aswani (1998) suggests that optimal foraging theory provides a cogent evolutionary explanation for exploitation strategies favourable to sustainability among the CMT practices of Pacific Islanders. Optimal foraging for patchily distributed food, refers to the trade-off that must occur if the proportion of time spent looking for a patch of food relative to the time spent consuming food in a patch is to optimise the energy returned for the energy expended. Time spent consuming food in a patch must be sufficient to offset the search time during which no food was consumed. It postulates that when the optimum point is attained an organism will depart from one food patch to search for another (Begon et al. 1990, pp. 329–334).

To some extent this is analogous to our observations of abalone diver behaviour, where divers try to maximise their daily catches and do not persist with fishing stocks at low catch rates. However, rather than a single point optimum or threshold, there is a range of catch rates within which divers may cease to fish and relocate to another part of a reef complex or to a different location. Obviously the reward of locating dense patches of abalone depends on each diver's knowledge about where these patches are likely to occur. Inexperienced divers, without benefit from the knowledge of an experienced deckhand, are likely to have to spend more time in each patch to justify the longer times they inevitably spend searching to discover dense aggregations of abalone.

If serial depletion leads to the search for highly productive reefs becoming increasingly difficult, it is likely that the threshold for relocation will decrease. Indeed we have sometimes observed divers returning to regions of reef fished earlier in the day after their subsequent searches have not been rewarded with the success anticipated. This shift in baseline tends to belie the espoused sustainability of rotational harvesting practices in the absence of other controlling factors.

The persistence of diver behaviours that minimise the impact of fishing on abalone populations is dependent on the maintenance of incentives that foster resource stewardship in a climate of changing diver demographics and industry structure. Indeed factors such as increased vigilance in regard to occupational health and safety and high vessel fuel costs militate against profit maximisation and may decrease stewardship incentives. The paper by Gorfine and Dixon (2001) on diver behaviour, how it affects patterns in catch and effort and what this implies for assessment of resource sustainability helps illustrate the issue of stewardship. However, Walters (1998) challenges the notion that fishers have fundamental rights to freedom of movement and choice of fishing location. The need to formalise management arrangements to foster sustainable fishing patterns is discussed in Chapter 10.

In their desire for profitability, abalone divers are no different to other fishers. In his opening address to an international conference in Lisbon during 1998 titled 'Resolving the Global Fisheries Crisis', J. Gummer (former UK Secretary of State for the Environment and the then Chair of the Marine Stewardship Council) quoted the following passage from Henry Fielding 's writings in 1756, '...while a fisherman can break through the strongest meshes of an Act of Parliament, we may be assured that he will learn so to contrive his own meshes, that the smallest fry will not be able to swim through them' (WWF 1998, p.4). Although 'quota busting' is uncommon among Victorian abalone divers, vertical integration with processors has lead to legitimate exploitation of regulations that allow catches to be drained for an extended period prior to being reported for official decrementing from individual quota allocations. My study on post-harvest weight loss demonstrates that the potential for gains is substantial and compromises the intent of quota management (Gorfine 2001b).

Apart from weight loss, stringent regulations and auditing via an Abalone Quota Management System (AQMS) and State-wide Quality Inspection Program (SQIP) limit the potential for the commercial sector to harvest abalone above their entitlements. However, outside the commercial sector there is a significant and thriving illegal sector that operates at a variety of levels of scale and sophistication. The high beach price of abalone ensures that there are some members of the community who are not dissuaded by prospects of substantial fines and periods of incarceration. This topic is explored in more detail in Chapter 8.

A process for setting quotas is described in the Abalone Management Plan and involves selecting the best choice TAC that will avoid further biomass depletion in the short-term and allow the biomass to attain 110% of that required to produce the maximum sustainable yield (MSY) in the longer-term. Changes in quota may be made to progress towards these performance targets or to respond to the activation of performance triggers, as discussed in Chapter 7. Morgan (1997) suggests that TACs should ideally be set at the biomass that provides maximum economic yield (MEY) and fishery profit. This strategy is generally more conservative than setting quotas at MSY and should maximise the market price of licences (Morgan 1997). To some extent the 10% safety margin means that the economic performance target for the Victorian abalone fishery should correspond closely with MEY. However, the accurate estimation of B_{MSY} is currently problematic (see Chapter 7). Another related issue is whether to set a variable or constant TAC. Morgan (1997) claims that because long-term cumulative catches under a variable TAC are generally less than if a constant catch quota prevailed, variable quotas are more conservative.

In a discussion of ecosystem fisheries management from an economic perspective, Arnason (2000) points out that instances may arise under ITQ management where the quota share price becomes negative in which case it is in the quota holder's interest to restore value rather than continue to harvest. If the optimum TAC becomes negative, due to collapse, then stock enhancement (funded by the quota holders) becomes the logical consequence.

It is generally agreed that effective resource management depends on the active engagement of fishers in the decision-making process (Mace 1997, Morgan 1997). This co-management, discussed in Chapter 10, is seen as critical if dissent is to be overcome should the need arise to decrease catch quotas (Morgan 1997).

Notwithstanding the results of studies in this chapter that highlight some its deficiencies, quota management at least limits the total amount of abalone resources that can be harvested in any year and there is little doubt that this has made a significant contribution toward the sustainability of the Victorian fishery.

Papers

Gorfine, H.K. 2001. Post harvest weight loss has important implications for abalone quota management. *Journal of Shellfish Research*. 20(3): 795–802.

Gorfine, H.K. & C.D. Dixon. 2001. Diver behaviour and its influence on assessments of a quota managed abalone fishery. *Journal of Shellfish Research*. 20(3): 787–794.

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Gorfine, H.K. & C.D. Dixon. 2001. Diver behaviour and its influence on assessments of a quota managed abalone fishery. *Journal of Shellfish Research*. 20(3): 787-794.

Chapter 6 Size limits

Overview

Size limits in the form of legal minimum lengths (LMLs) are ubiquitous among the world's abalone fisheries. However, when used as the primary instrument for management they have failed to prevent the collapse of stocks in the Northern Pacific. Explanations for this are various, but are not necessarily because the LML was too small. Other factors such as highly variable and episodic recruitment associated with large-scale climatic processes such as El Niño appear to have played a role. Nonetheless, size limits can provide at least some theoretical level of protection from recruitment over-fishing and should be included in management strategies. It is therefore necessary to have some means of determining the appropriate level.

Appropriate size limits will vary among locations on a small spatial scale because of the highly heterogenous growth exhibited by abalone that gives rise to substantial spatial variation in the proportion of mature abalone for a particular size-category. Yield per recruit modelling is often employed, but it assumes annual recruitment and is often applied using deterministic growth parameters that do not accurately reflect the underlying distribution of the data from which they were estimated. A more conservative approach is to select size limits that protect a large proportion of the population for a minium of two yeas after the onset of reproductive maturity.

We developed and applied a method for incorporating heterogeneity in growth data into an analysis of how much protection was likely to be provided by varying size limits. This approach also has particular value in identifying those slow growing population that remain inaccessible to the fishery at the current LMLs. Lowering the size limit at these locations can take the pressure off faster growing populations that have a greater exposure to fishing before they mature.

Background

In the previous chapter I suggested that quotas applied over broad areas are insufficient to provide insurance against over fishing. As input controls Legal Minimum Lengths have the potential to protect abalone populations against recruitment over-fishing if set at appropriate sizes. It is simpler to ensure compliance with LMLs and they are easier to apply at high spatial resolution than quotas. LMLs can be based on optimising yield-per-recruit (YPR) or more conservatively eggs-per-recruit (EPR) from appropriate models. Because abalone mature with age rather than size, LMLs can be selected to allow for a potential level of egg production before recruitment to the stock.

However, YPR and EPR models have data requirements and assumptions that, as with the fishery model described in Chapter 3, may be difficult to satisfy for abalone (Nash 1992). One source of difficulty is estimating natural mortality given the limitations of tag-release-recapture methods of abalone. This problem was the subject of the paper on dispersal patterns of tagged abalone (Dixon et al. 1998) that I've included in Chapter 3. To some extent these limitations have been overcome in Tasmania by adopting a 'rule of thumb' that requires each abalone to have a predicted two seasons of spawning prior to becoming available for capture. Growth from tagging and size at 50% mature from samples collected during the spawning season. In most instances these models are deterministic and no attempt has been made to capture the heterogeneity in growth that characterises abalone.

Our work on applying a stochastic model of growth to produce quantiles of the predicted maximum lengths clearly demonstrated the varied levels of protection offered by current LMLs (Troynikov & Gorfine 1998). In some instances almost all abalone in the population would become available to the fishery if they were not subject to natural mortality in the interim. Whether or not this would compromise sustainability would depend on the rate of growth and exploitation rate. Clearly, fast growing populations subject to high rates of fishing mortality would be expected to be less sustainable. However, there was insufficient information from this modelling alone to make judgements about whether current LMLs were too low in these instances.

In contrast, for some populations relatively few individuals were predicted to grow sufficiently large to enter the stock, thus effectively excluding these populations from the fishery. Given that limited larval dispersal means that the importance of these so-called 'stunted' populations as sources of recruitment for adjacent populations is likely to be low, reducing LMLs may be an appropriate way to relieve the fishing pressure from more heavily exploited fast-growth populations. Periodic fish-downs of stunted populations, as practised for the blacklip abalone resource in the Southern Zone in South Australia (Mayfield et al. 2001, Shepherd et al. 1999), is one option for achieving this goal. An alternative is to allocate a portion of existing catch entitlements to fish a specified area at a reduced LML at a time of each individual diver's choosing, with prior notification required to facilitate compliance. This strategy has been used with apparent success in the Airport Area of the Eastern Zone of the Victorian fishery for more than two decades.

It is important that the term 'stunted' is used judiciously because there is a need to differentiate between those populations whose growth potential is insufficient to recruit to the stock at current LMLs, and those that will enter the stock but take longer than most because of slower growth rates. It is also important to avoid incorrectly attributing the apparent lack of large abalone to stunting when knife-edge selectivity is the cause. If growth data are unavailable then the localised catch history is vital to interpretations of observed size structure.

As with quotas, LMLs alone are unlikely to be sufficient to sustain an abalone fishery. Size limits applied to the Californian fishery were assessed to be adequate, yet the fishery collapsed (Tegner et al. 1989). An explanation advanced for this observation is that recruitment is episodic and occurs too infrequently to enable protection of spawning individuals for several seasons' prior to their entry to the stock to deliver much benefit (Hobday et al. 2001). It is unclear whether environmental conditions that are adverse to spawning success occur with sufficient frequency to create similar problems for Victorian abalone populations; however, a precautionary approach would assume this to be the case.

In Victoria, LMLs provide an effective supplement to quota management strategies and can be more easily applied at finer spatial scales. As described in Gorfine et al. (2002) in Chapter 3, work is currently underway to determine optimal LMLs at the scale of reef complexes. Comprehensive studies of size at maturity and growth have been implemented along the Victorian coast. It is hoped that by ensuring LMLs optimise recruitment, the risk of serial depletion at the reef-scale will be averted.

Paper

Troynikov, V.S. & **H.K. Gorfine**. 1998. Alternative approach for establishing legal minimum lengths for abalone based on stochastic growth models for length increment data. *Journal of Shellfish Research*. 17(3): 827–831.

Troynikov, V.S. & **H.K. Gorfine**. 1998. Alternative approach for establishing legal minimum lengths for abalone based on stochastic growth models for length increment data. *Journal of Shellfish Research*. 17(3): 827-831.

Chapter 7 Performance indicators

Overview

The application of measurable performance indicators in the form of trigger and target reference points associated with biological thresholds for sustainability and fishery production targets has received much attention among fisheries assessors and managers during the past decade. More recent attention as focussed on the emerging invertebrate fisheries, particularly in developing countries, that in part reflect a tendency to shift effort towards species of lower trophic levels as those at higher levels become fully utilised or depleted.

The introduction of performance indicators for abalone fisheries is relatively recent and confined to the tri-nations of Australia, New Zealand and South Africa. Within Australia a range of quantitative and semi-quantitative performance indicators have been specified in various fishery management plans, but some were of questionable utility. Victorian was the last of the abalone-producing states to establish a formal management plan for its fishery and had the benefit of interstate experiences on which to base decisions about the types of indicators to adopt. Comparisons were made among the various types of indicators that were compatible with the kinds of information available, including outputs from fishery model developed for fishery assessment. Previous management strategies played a strong determining role for the indicators proposed initially, that were further refined to ensure consistency with assessment processes.

Background

Performance indicators can be defined as those attributes that can be measured to gauge the present or predicted future status of a fishery and its dependent elements. They provide a vital quantitative link between assessment and management processes.

One recently developed model for incorporating performance indicators into a fishery management plan is to specify a series of operational objectives for a suite of management goals, with each objective having a single performance indicator. For each performance indicator, a reference point based on known values that are likely to achieve the operational objective is identified (Chesson et al. 2000). These reference point values may represent desirable targets to be achieved within a specified time period, or threshold values established to minimise the risk of being outside the range of maximum or minimum biologically allowable limits (MBALs) for sustainability (see Garcia & Staples 2000). Ideally these values should have an accompanying level of risk that reflects the probability of achieving or triggering the reference point. The choice of risk levels is a managerial decision that will vary among performance indicators depending on the consequences if a target is not achieved or if a trigger is activated. There is a trade-off between the level of risk adopted and the conservatism of the reference point (Caddy 1998). The less conservative reference points would generally be expected to have high confidence probabilities (i.e. low risk levels). In addition to risk levels, time frames should be specified for the achievement of target reference points.

In the event of trigger activation, one or more prescribed management responses will be initiated to ensure timely action to prevent the fishery from becoming unsustainable. Although performance indicators may change in response to new knowledge and ideas gathered as part of a process of continual improvement in fishery governance, it is important that the performance indicators and their reference points are agreed among stakeholders prior to their implementation. The temptation to dispute or ignore performance indicators under adverse circumstances is too great to not have prior consensus agreement.

The development of performance indicators for the Victorian abalone fishery is relatively recent. The drafting of a management plan for the fishery in response to a new *Fisheries Act 1995* (Vic) that replaced the *Fisheries Act 1968* (Vic) provided the basic stimulus, whilst the coincidental implementation of the Commonwealth *EPBC Act 1999* (Cwlth) and a surge of national interest in researching fisheries sustainability issues strengthened this incentive.

Performance indicators relevant to the biological assessment of the fishery can be broadly separated into those concerned with sustaining abalone populations and those concerned with sustaining those structures and functions of the ecosystem that depend on abalone populations remaining within their natural range of variability.

Estimating the impacts of abalone removals on abalone populations is relatively straight forward despite the infancy of the fishery modelling used make these estimates. However, for Victorian subtidal rocky habitats the impacts of abalone removals on the remainder of the ecosystem are less clear and at present cannot be reliably estimated because of a lack of knowledge about critical inter-specific relationships that underpin ecosystem structure and function. Doubtless, this will provide fertile ground for future ecological research if adequate funding is available.

The paper by Gorfine et al (2001) in this chapter critically examines a range of possible performance indicators that may have application for the Victorian abalone fishery. This work formed the basis for some of the performance indicators adopted in the Abalone Management Plan that were used as evidence of sustainable management strategies in the submission prepared for Environment Australia (Chapter 9). However, there have been a number of refinements in response to the relationship between these indicators and the outcomes from more recent fishery assessment modelling and from progress with ideas about how best to define and measure ecosystem impacts within the constraints imposed by current knowledge. The targets and triggers in the Abalone Management Plan are:

<u>Ecological Target</u>

- mature biomass [or egg numbers] at level estimated for 2000 (B_{2000}) with 70% confidence (30% risk).

<u>Ecological Triggers</u>

- mature biomass [or egg numbers] at 90% of the value estimated for 2000 with 80% confidence (20% risk) [lower limit]
- annual catch for one or more reef codes at either extreme of the range [upper and lower limit] during 1988-2000
- ecosystem health indices at 90% of average value of previous 3 years (lower limit)

<u>Economic Targets</u>

- maximum constant yield consistent with the stock at 110% of the mature biomass (or egg numbers) at MSY (B_{MSY}) estimated with 70% confidence
- maximum fishery profit

<u>Economic Trigger</u>

- fishery profit at 70% of average for previous 3 years (lower limit)

Compliance Target

- optimal compliance (when marginal cost equals marginal monetary benefit)

The ecological target has been established to ensure that in the absence of definitive knowledge about how much pre-fished biomass should be conserved, the relative biomass of abalone should at least be maintained at current levels. The economic target of maximum sustainable yield (MSY) is often seen as a more appropriate performance indicator, with many contemporary fisheries management regimes in the northern hemisphere treating the biomass at MSY (B_{MSY}) as a MBAL or limit reference point rather than a target (Caddy 1998). However, MSY is not always defined in the same way and in New Zealand, for instance, it has been defined as the maximum constant catch that can be taken sustainably at all probable future levels of biomass (Annala et al. 1998). A recent review by Francis (1999, p. 4) defines MSY as the maximum long-term catch that can be achieved for a given fish stock and a given harvest strategy, by applying one of the harvesting rules that make up the strategy. He suggests that the harvesting strategy should include the time frame for achieving an MSY objective and the frequency and size of changes in TAC that are acceptable in moving towards the objective. Francis (1999) emphasises that there is no one MSY for the stock, owing to its dependency of the harvesting strategy. The Victorian Abalone Management Plan does not specify a harvesting strategy in this way, although there is a defined TAC setting process.

Classically, MSY is the yield that can be achieved when a stock is at its most productive level. This implies compensatory density dependence so that as the pre-fished biomass is reduced a fish population will experience increased rates of growth (but see McShane & Naylor 1995) and recruitment resulting in improved yield up to some maximum beyond which yield will progressively decline. Based on the known biology of abalone discussed in Chapter 1, it is reasonable to expect departures from this theory. One of the main problems with B_{MSY} lies with its proper estimation (see Hilborn & Walters 1992). If, as my colleagues and I suspect, the current abalone biomass in Victoria is less than B_{MSY}, then substantial reductions in catch will be necessary to restore stocks to 110%B_{MSY}. Reductions in catch of this magnitude are unlikely to be acceptable to the majority of industry stakeholders and will create economic hardship for some participants. However, there is also the possibility that B_{MSY} lies below current levels and those reductions in catches are not warranted. Under these circumstances potential yield will be foregone and undue loss of profitability will occur.

The selection of a contemporary reference biomass for the ecological target as an alternative to the conventional use of pre-fished biomass (B_0) is discussed in detail in Gorfine et al. (2001). There is published precedent for this approach (Overholtz et al. 1993, cited in Quinn & Deriso 1999). In New Zealand, where use of performance indicators for fisheries management is arguably more advanced than in Australia, alternatives to B_0 are also being considered (Paul Breen 2001, personal communication, October). Reasons for this shift in strategy relate to the large uncertainties in estimates of B_0 and not knowing what proportion of B_0 should be conserved to sustain the fishery. An alternative to using either pre-fished or contemporary biomass as a baseline in reference points is that of Sigler and Fujioka (1993), cited in Quinn and Deriso (1999), who used the minimum observed spawning biomass (of sablefish) in a time series as a threshold level. However, almost all the biomass depletion curves estimated from the Victorian abalone fishery model indicate that current biomass levels are the lowest in the history of the fishery, which would lead to the selection of B_{2000} in any case.

The economic target of maximum fishery profit is subordinate to the ecological target, but is also intended to ensure consideration of market conditions before deciding whether to increase catch quotas.

The trigger reference points cover loss of current biomass, spatial shifts in catch patterns and loss of profitability. Both loss of biomass and loss of profitability may indicate that catch levels are too high at the zonal scale. Because catching patterns have been relatively stable since quotas were introduced, any substantial change in these patterns should be regarded with suspicion and more thoroughly investigated. It is anticipated that catch patterns will be more sensitive to serial depletion and will provide a more spatially explicit assessment of stock status than estimates of relative biomass made at zonal or regional scales.

Non-compliance with regulations, particularly among unlicensed divers, is a major concern more fully explored in Chapter 8. However, there are no agreed benchmarks for measuring compliance rates in the Victorian abalone fishery and there are currently no methods for standardising enforcement effort. Because accurate quantification of the substantial illegal catch is improbable, indices of compliance per unit enforcement effort are required before the compliance target can be properly implemented. Although the estimation of enforcement costs is relatively straightforward, it will be difficult to place a value on the benefits from enforcement. These benefits can be split into two components, the market value of intercepted catches, and the market value of catches foregone by the illegal sector due to deterrence. When illegal catches are intercepted these have less value, in a resource sustainability context, than those that are deterred. Abalone that remain in the water as a consequence of effective enforcement have long-term non-monetary value from contributing to resource sustainability and direct monetary value from being available to the licensed sector. Victorian regulations allow seized abalone to only be sold domestically, and the proceeds must be transferred to consolidated revue. Changes to these regulations could increase the value of seized catches by allowing them to be sold for export and by using the proceeds to reduce the marginal costs of enforcement.

Although abalone fishery management should be consistent with higher order biodiversity and ecosystem sustainability management policies, the implementation of strategies to achieve the goals of these policies is beyond its scope. The Victorian abalone fishery is one of several that share the same rocky subtidal ecosystem and no single fishery assessment program has the resources to deal with the over-arching need for 'whole of ecosystem' monitoring. Instead we have focussed on those species known or believed to interact with abalone and whose abundance can be measured with reasonable precision. These species will, at least in the short term, be used as the main indicators of ecosystem health. However, it is recognised that there is a need to refine such indices and that this can only be achieved through an improved understanding of the complex interrelationships among species affected by abalone removals.

Equally important as performance indicators are the prescribed management responses if triggers are activated. The Abalone Management Plan specifies three levels of response ranging from a 'watching brief', to intensive further investigation and immediate intervention to reduce catch quotas and/or increase size limits. However, the Plan provides little guidance about which level of management response to select under varying circumstances of multiple trigger activation. Caddy (1998) recommends a 'traffic light' approach where the sequential activation of increasing numbers of triggers (analogous to red lights) progressively increases the level of management intervention.

Shepherd et al. (2001) suggests a modification of Caddy's approach that uses a combination of triggers as a 'troublespot thermostat'. Specifically they recommend using catch patterns, fishery independent patch size and density estimates and $F_{40\text{-}50\%}$, with fishery closure and stock restoration being the ultimate response if all these triggers are progressively activated. Adopting a similar approach could enhance the Victorian management strategy. This would militate against any tendency for co-managers to deviate from the precautionary principle and select a 'soft option'.

It may be argued by some that the abalone industry should not have to bear the burden of decreased catch quotas and associated reduced incomes if over-fishing is not the principle cause of declines in abalone biomass. However, the FAO Code of Conduct for Responsible Fisheries (FAO 1995b) states, 'If a natural phenomenon has a significant adverse impact on the status of living aquatic resources, States should adopt conservation and management measures on an emergency basis to ensure that fishing activity does not exacerbate such adverse impact. States should also adopt such measures on an emergency basis where fishing activity presents a serious threat to the sustainability of such resources. Measures taken on an emergency basis should be temporary and should be based on the best scientific evidence available'.

Paper

Gorfine, H.K., B.L. Taylor B.L. & T.I. Walker. 2001. Triggers and targets: What are we aiming for with abalone fisheries models in Australia? *Journal of Shellfish Research* 20(3): 803–811.

Gorfine, H.K., & B.L. Taylor B.L. & T.I. Walker. 2001. Triggers and targets: What are we aiming for with abalone fisheries models in Australia? *Journal of Shellfish Research* 20(3): 803-811.

Section 2. Reporting on Sustainable Management

Chapter 8 Illegal catches

Overview

Illegal catches are prevalent throughout many of the world's abalone fisheries. However, the problem is particularly severe in the Southern Hemisphere where relatively healthy fisheries still prevail. Sustainable management of the licensed sector is greatly compromised by illegal harvesting that 'at best' represents lost revenue to the community and 'at worst' threatens the viability of these fisheries.

We've attempted to quantify illegal catches in Australia using available data sources. Disappointingly, we found that the databases we were able to access were not designed to produce quantitative statistics, despite the thousands of records they contained, and no reliable estimate could be made. However, we were able to produce a range of recommendations that should improve the capacity for estimating illegal catches in the future and Victorian fisheries crime investigators are developing a process for implementing many of these recommendations. Our study also recommended some future research directions, including the possibility of obtaining information directly from offenders via a structured interview process.

Background

The high commercial value and accessibility of abalone have made these organisms the target of illegal fishing throughout the world. Gordon (2000) states that illegal harvesting is by far the largest and most important reason for the 30% decline in global abalone fisheries production during the past decade (Gordon & Cook 2001). Illegal activity involving abalone has been documented for Australia (Prince & Shepherd 1992), British Columbia (Sloan & Breen 1988), Brittany (Clavier 1992), California (Daniels & Floren 1998), Japan (Beinssen 1982), Mexico (Ponce-Díaz et al. 1998), New Zealand (Schiel 1992) and South Africa (Sweijd et al. 1998). In some instances rough estimates are equivalent to 50% or more of legal catches and are mostly considered to be increasing. However, these are only guesstimates and none have been quantified with any precision. A projected shortfall in global abalone supply of 5000 tonnes for 2004 (Gordon & Cook 2001) will ensure a continuing strong demand for illegally harvested abalone. With the demise of most other abalone fisheries, Australia and New Zealand are vulnerable targets for increases in abalone related crime.

Abalone theft (poaching) is an attractive proposition for both organised crime that transcends national boundaries (Neales 1997a,b) and small-scale domestic criminals (Daniels & Floren 1998). McHugh (2002) suggests that in the Californian sport fishery for abalone, which occurs north of the entrance to San Francisco Bay, breaches of abalone regulations are the most common among fisheries offences. He cites California Department of Fish and Game statistics that illegal abalone catches amounted to 250,000 or 34% more than the legal count of 730 000 abalone estimated to have been taken by recreational divers in 2001.

An escalation of abalone theft in South Africa during recent years has severely depleted the perlemoen (abalone) resource and compromised the viability of the wild fishery (Hauck & Sweijd 1999, Hauck 2000, Van Zilla 2000). The number of illegally taken abalone seized each year has risen almost eight-fold since 1999 to an estimated 800,000 for 2002 (Tarr & MacKenzie 2002). Tarr and MacKenzie (2002) suggest that this may extrapolate to an illegal catch of about eight million abalone per annum, which would be equivalent to about four times the legal commercial catch. However, the situation in countries such as South Africa and Mexico is more complex than in others because of the presence of informal and subsistence sectors motivated by systemic poverty, high rates of unemployment and low living standards (Hauck & Sweijd 1999, Dedina & Young 1995). In South Africa, subsistence fishers are permitted to sell their legal recreational catches on the domestic market, although invariably the abalone that they sell for relatively small profit eventually find their way into the export market via unscrupulous profiteers associated with Asian crime syndicates. In Mexico, there are numerous small coastal fishing communities scattered along the Baja Peninsula that include abalone amongst a variety of marine species that they exploit as their sole means of generating income. Over-exploitation of fish resources is commonplace and there is scant adherence to regulations. Abalone *piratas*, comprising both semi-permanent local residents and entrepreneurial outsiders, who organise gangs of young men from surrounding economically-depressed districts, remove up to several thousands of dollars worth of abalone each outing with apparent impunity (Dedina & Young 1995).

In both countries, illegal abalone harvesting is considered a lucrative low-risk activity that provides financial returns far in excess of the meagre wages obtained from the limited legitimate employment opportunities that are available. The low risk of apprehension is attributed to alleged corruption among Government officials and the failure of their respective fisheries agencies to either recognise or act upon this dereliction of duty. Another feature in common between the two countries is the fear of retribution that exists among law abiding local residents if they attempt to interfere with illegal abalone operations (Hauck & Sweijd 1999, Dedina & Young 1995).

Conflict between equitable access for customary use and contemporary regulations that restrict resource allocation to those who can afford to purchase entitlements provides yet another facet to this complex situation. In South Africa, restricted commercial access is associated with the racial oppression and political injustices of recent decades and inculcates the de-legitimisation of regulations (Hauck & Sweijd 1999). Traditionally, indigenous groups of Baja California were semi-nomadic, following the seasons according to food availability and shelter from the elements. During winter they would travel down to the coast where they could gather mussels and abalone along the shore. Today, these native communities are often confronted by economic impediments to obtaining permits that would allow them to legally make use of their natural resources (Wilken-Robertson 1997). This is an issue that is not unique to South Africa and Mexico, although it is probably manifest in more breaches of abalone regulations in these countries than elsewhere. As discussed in Chapter 1, Australian Aboriginal people maintain that fisheries regulations, and denudation of accessible nearshore reefs since the introduction of these regulations revoked their customary tenure, denies them access to abalone resources for traditional social and economic activities. This results in limited illegal sales of abalone as 'bush-tucker' at community markets, more as a protest against perceived injustice than as an enterprise for financial gain (personal observation).

In Australia, commercial viability of stocks persists despite the prevalence of illegal catches. However, illegal abalone activities are seen as the biggest threat to the future sustainability of Australian abalone fisheries (Hemming 1994). Recent anecdotal information suggests an increasing involvement of more hardcore criminal elements seeking to diversify their activities. These groups are likely to be attracted by the high rewards relative to penalties for abalone theft when compared with crimes such as those involving narcotics or robbery.

Abalone theft is not a recent development in Victoria, having existed alongside the legitimate fishery throughout its 40-year history. A letter dated 21 September 1967 from the Mallacoota Fishermen's Association to the Commercial Fisheries Advisory Board of the Victorian Fisheries and Wildlife Department mentions that there were many unlicensed operators and consequently not all the catch was declared (Kurz 1967). Recently, a recidivist offender acquired his 85th conviction in a career spanning about 30 years as an illegal abalone diver based in Victoria, but also operating in Tasmania and South Australia (Traffic Oceania 2000). A 3.5 year term of imprisonment and penalties totalling almost A$156,000 were handed down in this instance (B. McCarthy 2002, personal communication, 21 February; Adams 2002).

However, much of the early illegal activity seems to have related to licensed divers declaring only part of their landings in order to minimise their apparent taxation obligations (Prince & Shepherd 1992). In recent times there have been a number of targetted enforcement operations that have netted substantial quantities of illegal abalone. Operation Churchill was one activity of this sort that uncovered an illegal factory conversion behind the facade of a residential dwelling. In this operation 31 004 abalone with a commercial value of A$300 000 were seized. The court imposed a pecuniary penalty order of almost one million Australian dollars and ordered the forfeiture of two houses under Victoria's *Confiscation Act 1997* (Hemming 2001).

There are numerous similar accounts of abalone offenders and successful enforcement operations. Consequently, it would be reasonable to assume that the summary statistics on abalone crime included substantial quantities of abalone, but they do not.

The report by Gorfine et al. (2002) appended to this chapter is a summary of the findings of a project that investigated the quantification of illegal abalone catches using available intelligence and compliance data. In an attempt to obtain objective information about the size of illegal catches I successfully obtained funds to conduct a desktop study to quantify the amounts of abalone documented in prosecution and intelligence holdings of state and federal enforcement agencies with jurisdiction over fisheries and fisheries products. This was the first time anyone had attempted a national project to quantify fisheries crime among unlicensed fishers in Australia.

Our investigation concluded that no valid estimates were possible due to the nature of the information recorded and the construction of the databases in which this information was stored. If quantitative estimates are to be made in the future then current practices for recording, storing and retrieving information need to be modified and new methods of data acquisition explored.

Although improvements to existing fisheries compliance data systems and development of new field methods may provide definitive estimates of contemporary illegal catches in the future, this cannot satisfy the need for historical estimates. In the paper by Gorfine at al. (2002) in Chapter 7 we pointed out that a critical element in applying production modelling to assess the fishery is the input of an accurate history of the total catch. It is the trend in this catch history that drives the productivity or recruitment function in the model rather than any absolute value. As described in the 2001 Fishery Assessment report in Chapter 3, to date the unaccounted catch has mostly been treated as a fixed proportion of the reported commercial catch. Because there is no trend, the notional proportion selected does not affect the biomass trajectories predicted by the modelling. Applying a trend would affect these predictions and for this reason there is a strong need to find ways of estimating such trends.

The only prospect for quantitative estimation of historical trends seems to be interviews with licensed and unlicensed divers who fished for abalone during the past four decades. This would be a substantial undertaking inevitably biased towards younger participants as many of the early divers are now deceased. There is some possibility of fitting data from interviews to socio-economic indicators such as market value and unemployment rates. However, the efficacy of using these and other similar factors is unknown, as is the use of an interview strategy.

At present the most definitive conclusion we can make is that the unaccounted catch levels selected thus far can be accommodated in the modelling to produce plausible prognoses for the resource. In part, the application of fishery independent data for model fitting incorporates the effects of the illegal catches. Nonetheless, inability to quantify illegal catch history persists as a deficiency in our assessments that increases the risk to sustainability.

Report

Gorfine, H.K., R. Tailby, F.Gant, M. Donaldson, M., & I.Bruce. 2002. Estimation of illegal catches of Australian abalone: Development of desk-based methods. FRDC Project 2000/112 Final Report. Marine and Freshwater Resources Institute: Queenscliff, Victoria, Australia.

Gorfine, H.K., R. Tailby, F.Gant, M. Donaldson, M., & I.Bruce. 2002. Estimation of illegal catches of Australian abalone: Development of desk-based methods. FRDC Project 2000/112 Final Report. Marine and Freshwater Resources Institute: Queenscliff, Victoria, Australia.

Chapter 9 Satisfying legislative requirements for ESD

Overview

A number of different frameworks are available for reporting on ecological sustainable development for fisheries. These can be subdivided into those focussed on process and those that are outcome-centred. The independently audited process-based approaches such as environmental management systems (EMS) and ISO 14001 are useful for a fishing industry to demonstrate its environmental credentials to the public and consumers; however, it is mostly outcome-oriented reporting that is required to satisfy state and federal legislation.

The federal legislation reflects a focus on ecological sustainability in contrast to the broad orientation of the reporting frameworks developed by the Standing Committee on Fisheries and Aquaculture (SCFA). Ironically, Marine Stewardship Council certification, upon which the Environment Australia's ESD assessment criteria are based, will not satisfy the legislation on its own accord.

I compiled a report, based on current and proposed assessment and management arrangements, as a submission to Environment Australia (EA) for assessment of the Victorian abalone fishery under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth). The wildlife trade provisions of this legislation provide a framework for to ensure that any harvesting of marine species destined for export is managed for ecological sustainability. Although yet to be ratified by the federal Minister for Environment, the assessment by Environment Australia has now been completed and approval of the application to export Victorian abalone recommended.

In this chapter the different approaches to ESD reporting and assessment are compared and contrasted, and aspects of the submission to EA are discussed. Specific issues arising from the public consultation phase of the submission are evaluated and the draft final recommendations from EA, upon which the export approval will be conditional, are described.

Background

Both state and federal legislation govern sustainable use of abalone resources and protection of their supporting ecosystems in Victoria. At state level, the *Victorian*

Fisheries 1995 (VIC) contains specific provisions for the inclusion of ecological sustainability components in fisheries management plans. Specifically:

PART 3 — MANAGEMENT PLANS
28. *Management plans*
(6) A management plan must—
(*f*) specify performance indicators, targets and monitoring methods;
(*e*) as far as is known, identify critical components of the ecosystem relevant to the plan and current or potential threats to those components and existing or proposed preventative measures;

At federal level, new Commonwealth wildlife trade laws that meet Australia's obligations under the Convention on International trade in Endangered Species (CITES) have recently been enacted. The *Wildlife Protection (Regulation of Exports and Imports) Act 1982* (Cwlth) was repealed by the *Environment Protection and Biodiversity Conservation Amendment (Wildlife Protection) Bill 2001* (Cwlth) that incorporates enhanced wildlife protection provisions into the *Environment Protection and Biodiversity Conservation (EPBC) Act1999* (Cwlth). Implemented on 16 July 2000 and effective from January 2002, the *EPBC Act 1999* (Cwlth) provides,

(i) a definition of sustainable use (EA 2002a)

Part 23—Division 2—Section 528

Ecologically sustainable use of natural resources means use of the natural resources within their capacity to sustain natural processes while maintaining the life-support systems of nature and ensuring that the benefit of the use to the present generation does not diminish the potential to meet the needs and aspirations of future generations;

and,

(ii) some principles for sustainable development,

Part 1—Section 3A

The following principles are principles of ecologically sustainable development:

a) *Decision-making processes should effectively integrate both long-term and short-term economic, social and equitable considerations;*

b) *Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for post-poning measures to prevent environmental degradation;*

c) *The principle of inter-generational equity – that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations;*

d) *The conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making;*

e) *Improved valuation, pricing and incentive mechanisms should be promoted.*

The spectrum of approaches to demonstrating the satisfaction of these legal requirements ranges from process to outcome focussed reporting frameworks (Fig. 4). Emphases range from conservation of the natural environment to sustainable management of natural resources. Typical of the process-based approach is the development of an Environmental Management System (EMS) based on the International Standards Organisation ISO 14001 standard (Standards Australia, and Standards New Zealand 1996). ISO 14001 is concerned with the quality of the environmental management process (Chesson et al. 2000), predicated on a belief that if the process is functioning correctly then the desired outcomes from the process will follow as a matter of course. The Joint Accreditation System of Australia and New Zealand (JAS-ANZ 2002) accredits independent auditors who can be engaged to assess an EMS against this standard.

The FRDC-funded SeaQual 'Green Chooser' project, conducted by Seafood Services Australia, to develop a model Environmental Management System (EMS) for the Australian fishing industry is an example of a process-based strategy for industry to voluntarily establish their credentials in environmentally responsible and ecologically sustainable use of natural resources (FRDC 2002a). Motivation for fishing industry bodies to develop EMS is increasing because of the need to address changes in natural resource policy and management paradigms, satisfy public pressure for assurance that the environment is protected from adverse impacts of fishing, and to comply with new environmental legislation (Rosenberg 2001).

An alternative to ISO 14001 that can be pursued by both industry and government is Marine Stewardship Council (MSC) certification (MSC 2002). The MSC focuses on outcomes as well as the process for their delivery. MSC is a non-profit, non-government organisation (NGO), based in London that provides an infrastructure for assessing fisheries against its three broad principles for ecological sustainability. The first principle deals with sustainability of the target species, the second with ecosystem impacts and the third with the management infrastructure. MSC does not evaluate and assess fisheries directly, instead it accredits expert organisations to do this under its purview (D. Leadbitter 2001, personal communication, 13 December). Applicants for MSC certification, who can be any fisheries stakeholders, contract an accredited assessor who assembles a panel of experts (usually three persons) to conduct the assessment. This is done at the applicant's expense and the accredited assessor produces a report that includes a judgement on whether the assessment results in non-certification, certification subject to specific conditions or unconditional certification (rare). For each assessment the accredited assessor establishes case-specific evaluation criteria under the three MSC Principles. Certification is for a period of 5 years, during which time the accredited assessors will audit the fishery without forewarning. One of the benefits of certification for a fishery is that it allows its industry to use the MSC logo to identify their products as environmentally responsible. This satisfies the demands of retailers who seek to establish their environmental credentials with those customers with preferences for environmentally sound products.

The MSC philosophy is not one of environmental perfection among fisheries, but rather the encouragement of improvement in environmental impact through the adoption of 'best practice' (D. Leadbitter 2001, personal communication, 13 December). The certification process can assist individual fisheries to clarify where they need to improve their performance. This can be done via an initial, confidential pre-assessment before application for a full assessment. The main advantage of MSC certification compared with ISO 14001 is that it was developed specifically as a standard for fisheries (Chesson et al. 2000).

The increased requirement for fisheries co-managers to report to multiple agencies about the sustainable use of the marine resources under their stewardship has led to the need for a streamlined generic nationally-acceptable reporting framework. It was with the objective of developing such a framework that the Standing Committee on Fisheries and Aquaculture (SCFA) initiated an FRDC-funded project (FRDC 2002b). The project arose when it became apparent that existing instruments for sustainability reporting were not sufficiently broad to meet the full range of jurisdictional responsibilities and community expectations of fisheries management agencies. The urgency to develop a broad reporting framework stemmed from a growing awareness that existing instruments, such as MSC certification, would not necessarily satisfy the requirements of Environment Australia under the *EPBC Act 1999* (Cwlth). This is despite the EA guidelines drawing heavily on those of the MSC. With its outcome focus, the SCFA ESD Reporting Framework is designed to be a complement rather than an alternative to an EMS (Chesson et al. 2000).

The SCFA/FRDC ESD Reporting project used a series of fisheries case studies from across Australia to test its reporting framework (Chesson et al. 2000). The Victorian abalone fishery was chosen as the subject of one of the case studies, for which I was the nominated Case Study Manager. The SCFA-ESD Reporting Framework comprises a dendrogram of fishery components and sub-components with each sub-component having a single specific operational objective and associated performance indicator (as described in Chapter 7). This approach was useful for integrating quantitative performance measures with management objectives. However, it became clear through discussions with EA representatives during the case studies that the SCFA framework would not obviate the need to produce a specific report against the EA Guidelines when making an application for an exemption to allow export of marine organisms under the *EPBC Act 1999* (Cwlth). Unlike the EA Guidelines, the scope of the SCFA framework is much broader and embraces many socio-economic aspects of fisheries not covered by EA's jurisdiction. However, the SCFA ESD Reporting Framework provided a useful and effective template for gathering together the required information in an appropriate from. It was in this context that I compiled the submission to Environment Australia appended to this chapter.

In contrast with ISO 14001 and MSC certification that are voluntary, EA's requirements under the Commonwealth *EPBC Act 1999* (Cwlth) are mandatory for continued export of fisheries products (EA 2002a). In addition, EA is less concerned with process and is strongly outcome driven, although some concessions are likely to be made where outcomes are difficult to measure and processes are well established and conventionally accepted.

Each of the approaches for assessment and reporting discussed so far focus on sustainable management. In contrast, the State of Environment (SOE) reporting, developed by the Australian and New Zealand Environment Conservation Council (ANZECC), is seemingly predicated on the idea that departures from a pristine natural environment are undesirable and consequently that fishing mortality should be minimised rather than optimised (Chesson et al. 2000).

One of the other features of the EA and MSC assessment processes, that sets them apart from ISO 14001 (see Greenpeace 2002), is the requirement for public consultation. Following the public consultation phase of the EA application for the Victorian abalone fishery during late 2000, feedback based on the submissions received by EA was provided to Fisheries Victoria. Several issues with assessment and management arose from these public submissions. Assessment concerns focussed on impacts of the fishery on the genetic integrity of populations, a belief that fertilisation is a rate limiting step in stock-recruitment and that spawner density should be a performance indicator with a trigger reference point set at a minimum density.

Genetic studies have shown that abalone populations conform to an isolation by distance model exhibiting significant heterogeneity between some populations over short distances in seeming contradiction to relatively high overall levels of gene flow throughout the geographic range for each of the three commercially exploited species (Hancock 2000). This pattern is consistent with the apparently localised dispersal of abalone larvae, occasionally punctuated by more widespread dispersal under favourable environmental conditions. Brown (1991) estimated a neighbourhood size for blacklip abalone of about 500 km. On the basis of this information it seems reasonable to conclude that abalone removals, localised translocation of mature adults and re-seeding with hatchery-reared abalone from locally collected broodstock are unlikely to compromise the genetic diversity of Victorian blacklip abalone populations. It also seems reasonable to surmise that the possible benefits of restorative actions will likely outweigh the risks that these initiatives pose to the genetic integrity of abalone populations.

One submission to EA cited the findings of Babcock and Keesing (1999) in making a case for establishing a reference point based on minimum density. Babcock and Keesing (1999) showed that for greenlip abalone, average nearest neighbour distances of 2 m corresponded to fertilisation success rates of less than 50% and that, based on studies by Shepherd and Brown (1993) and by Shepherd and Partington (1995), this may represent a critical threshold for recruitment failure. When the nearest neighbour distance increased to 16 m the fertilisation rate was about 3%. Direct conversion of these distances gives equivalent densities of 0.318 and 0.005 abalone m^{-2} respectively.

Although well-intended, and possibly sensible for some non-aggregating species, there are some fundamental flaws with the overly simplistic inference from the studies cited, that a single density value can be identified as an MBAL and used to establish an appropriate performance indicator. To convert the nearest neighbour distances to density assumes a uniform spatial distribution within greenlip abalone aggregations and does not consider the pattern among aggregations.

If fertilisation is a rate limiting step and density of mature abalone is to be used as a surrogate, then the measure used should be a function of the densities within aggregations and the total number of aggregations, not a biased estimate of density. Certainly, the geometric mean of nearest neighbour distances (when measured as distance from a randomly chosen abalone to its nearest neighbour) and distances from random points to nearest abalone, provides an integrated value that may be an absolute estimator of density. This was described as an alternative method for abundance estimation in the paper by Officer et al. 2001 in Chapter 2. However, the work cited in the public comments did not consider the bias that occurs when nearest neighbour distances are directly converted to density without allowing for the patchy distribution of aggregations. Average transect densities of mature Victorian blacklip abalone rarely exceed 0.3 m^{-2} which, given the apparent sustainability of much of the Victorian blacklip resource, casts doubt on the general applicability of the results of Babcock and Keesing (1999).

Strength of concern about this issue relates to the recent association made between low density and the endangered status of white abalone (*H. sorenseni*) in California (Davis et al. 1998). Although plausible, connections made by Hobday et al. (2001) between the low density and widespread population collapse of Californian white abalone and the results of Babcock and Keesing (1999) for greenlip abalone fertilisation success in South Australia are speculative. Furthermore, the extension of this hypothesis to species such as blacklip abalone is tenuous. As McShane (1995) points out, there is evidence of large interspecific differences in abalone recruitment.

The circumstances that led to the listing of white abalone on 29 May 2001 as the first endangered invertebrate in the U.S. implicate a range of causes, from among which Hobday et al. (2001) identify over-fishing as the most likely. Examination of the catch history for this species reveals that despite relatively high fecundity, most exploited populations of white abalone failed to sustain fishing for more than one or two seasons (Hobday et al. 2000). In other words, persistence of the fishery relied on serial depletion among geographically distinct populations. Given the extreme depth of the habitat for this species (20–65 metres), hyperbaric exposure limits for compressed air divers meant that they could apply far less effort than for shallower species. The degree of clumping for this species is not described and whether the limited bottom time (time from start of descent to commencement of ascent) for diving led to fishing behaviours that removed greater proportions of aggregations than would occur in shallower depths is unclear.

Although over-fishing may have been the prime causative agent for the demise of white abalone populations, there is no clear explanation about why this species was so much less resilient to fishing mortality than other commercially exploited species. One clue may be that white abalone habitat comprises open low relief boulder habitat surrounded by sand (Hobday et al. 2001). This suggests that unlike Victorian blacklip abalone populations, but in common with many greenlip populations in Victoria, cryptic habitat in which white abalone can seek refuge from large predators is limited or non-existent. Another possible explanation may lie with the effect of the extreme depth of habitat on its life history. However, depth is unlikely to be the only factor because there are a number of small warm water species found in depths up to several hundred metres (Lindberg 1992).

One additional factor that may have been critical is food availability. The effects of El Niño events in depressing macroalgal productivity along the Californian coast are well-documented (Haaker et al. 1998, Tegner et al. 2000). Shepherd et al. (1998) described the same effects at the island of Natividad off the coast of Baja California. Interference with upwelling of cold nutrient rich water results in elevated water temperatures and reduced algal productivity. Because of their deeper range with associated lower light penetration, white abalone are likely to be more affected by poor algal productivity and availability than shallower species. The reduction in availability and quality of food algae is believed to lower fecundity levels in abalone (Shepherd et al 1998, Uki & Kikuchi 1982) and this may provide a better hypothesis for recruitment failure among white abalone populations. Indeed, Hobday et al. (2001, p. 509) recognise this as a contributing factor, but it was apparently ignored by those wanting to extrapolate this study to blacklip abalone populations.

As described in Chapter 1, evidence of an Allee effect for blacklip abalone is equivocal and if it occurs may not be as critical for stock recruitment as some authors have claimed. Tendency for populations to collapse at low adult densities may also be explained by settlement failure due to reduced levels of conspecific grazing. If this were true then settlement rather than fertilisation would be rate-limiting. More important for future stock recruitment may be density independent effects of unfavourable environmental conditions on population recruitment.

Additionally, the suggestion to adopt a deterministic point estimate of minimum critical density as a reference point discounts the use of transect densities, as temporal trends in relative abundance, to fit the biomass estimates from the modelling of the fishery, as described by Gorfine et al. (2002) in Chapter 3. It also fails to accommodate spatial and interspecific variation in critical density that should be expected among abalone populations. This could be overcome by specifying a percentile of the probability distributions of densities at a metapopulation scale. However, I do not believe that this would necessarily achieve a better outcome than fitting to a time series of transect-derived densities in a stochastic model.

The main area of weakness in reporting on the ecological sustainability of the Victorian abalone fishery relates to the second of the EA Principles that deals with impacts on the ecosystem (Environment Australia 2000). It must be recognised that knowledge about the role of abalone in the functioning of temperate subtidal rocky marine ecosystems is limited and mostly related to impacts of other organisms on abalone rather than to downstream effects of abalone removals. The current abalone population monitoring described by Gorfine et al. (2002) in Chapter 3 includes as much monitoring of non-target species as is feasible for a single-species fishery assessment program.

Ecosystem effects of commercial fish removals involve more than abalone, with southern rock lobster (*Jasus edwardsii*), periwinkles (*Turbo undulatus*), urchins (*Centrostephanus rodgersi* and *Heliocidaris erythrogramma*), wrasses (*Notolabrus tetricus, N. fucicola*) and morwong (*Cheilodactylus spectabilis, C. fiscus*) also targetted in the same habitat. Separate specialist ecosystem monitoring is required to properly deal with assessing the collective impact of these removals on other species.

The scale of the challenge to establish credible indices that measure the impacts of fisheries on their ecosystems should not be underestimated (see Pitcher & Pauly 1998). In a review of this topic, Rice (2000) evaluates a range of metrics including diversity indices, ordination methods, aggregate indicators and model-based techniques. Rice (2000, p. 687) cautions that none can be used without reservation and that the final interpretation may be biased by researchers' preconceptions, especially if more than one approach is used. He concludes that most metrics are relatively easy to apply, although it is very hard to maintain rigour in their application and objectivity in interpreting the results. Andrew and O'Neill (2000) refer to the problem of scale in developing useful models of community dynamics that accommodate the impacts of fisheries. They point out that attempts to model the population dynamics of individual species are already challenged by a paucity of data. This was borne out by the discussion of abalone population dynamics in Chapter 3.

Despite the practical limitations of implementation, the Victorian Government has a comprehensive policy on biodiversity conservation outlined in a strategy document (DNRE 1997). This strategy includes an outcome focussed reporting framework on the performance of biodiversity conservation programs for all natural resources within Victoria. Victorian fisheries management policies are effectively subsumed by this biodiversity conservation policy.

Notwithstanding the need for ecosystem impact assessments, EA has indicated that in the shorter term their requirements will be mostly satisfied by compliance with the first principle, which deals with sustainability of the target species and by-catch issues (G. Anderson 2001, personal communication, 15 August). This is predicated on the idea that if Principle 1 is satisfied then in many instances the objectives under Principle 2 are likely to be met.

Although EA's final assessment of the Victorian abalone fishery has yet to be formalised, a series of recommendations have been provided to Fisheries Victoria, upon which the export approval will be conditional. These are:

- Fisheries Victoria should inform Environment Australia of any future changes to the management regime of the Victorian Abalone Fishery.
- Fisheries Victoria to consult with other fishery agencies on the development and implementation of appropriate biological parameters and reference points for abalone harvesting, and pursue with other agencies a national process for developing, adopting and reviewing these indicators, along with periodic review of respective abalone stock assessment processes.
- Report on the performance of the fishery against the fishery's objectives, performance indicators and reference points as part of the annual Fishery Assessment Report process.
- Fisheries Victoria take actions to improve reliability of illegal abalone catch estimates and establish and implement measures to achieve the reduction targets set out in Victorian Abalone Fishery Compliance Strategy.
- Abalone Fishery Committee should give priority to defining the target biomass to produce the ecologically sustainable yield from the fishery within 3 years and review this estimate within the context of the annual stock assessment process.
- Reliable growth data across the various regions of the fishery should be obtained as a high priority to ensure the effectiveness of existing management controls and continued sustainability of abalone stocks.
- Fisheries Victoria to investigate and establish, over the next 3 years, appropriate decision rules, relevant to regional-scale management, to prevent the potential localised depletion of abalone stocks.
- Fisheries Victoria should within 12 months assess the extent of take and level of recreational abalone fishing, with an emphasis on greenlip abalone impacts, and implement additional management measures where necessary.
- A full risk assessment on the ecological implications, including disease and genetic impacts, of artificial stock enhancement of abalone in Victorian reefs should be completed before any reseeding program is undertaken.
- Fisheries Victoria review within 3 years the effectiveness of beach weighing measures currently being implemented, including any implications for the stock assessment process.
- The Abalone Fishery Committee gives priority to the development of decision rules based on an identified list of indicator species to provide the basis for monitoring and responding to ecosystem changes.

Report

Gorfine, H.K. (Comp.). 2001. Assessment of the Victorian abalone fishery against guidelines for the ecologically sustainable management of fisheries, April 2001 (revised March 2002). Unpublished submission from Fisheries Victoria to Environment Australia.

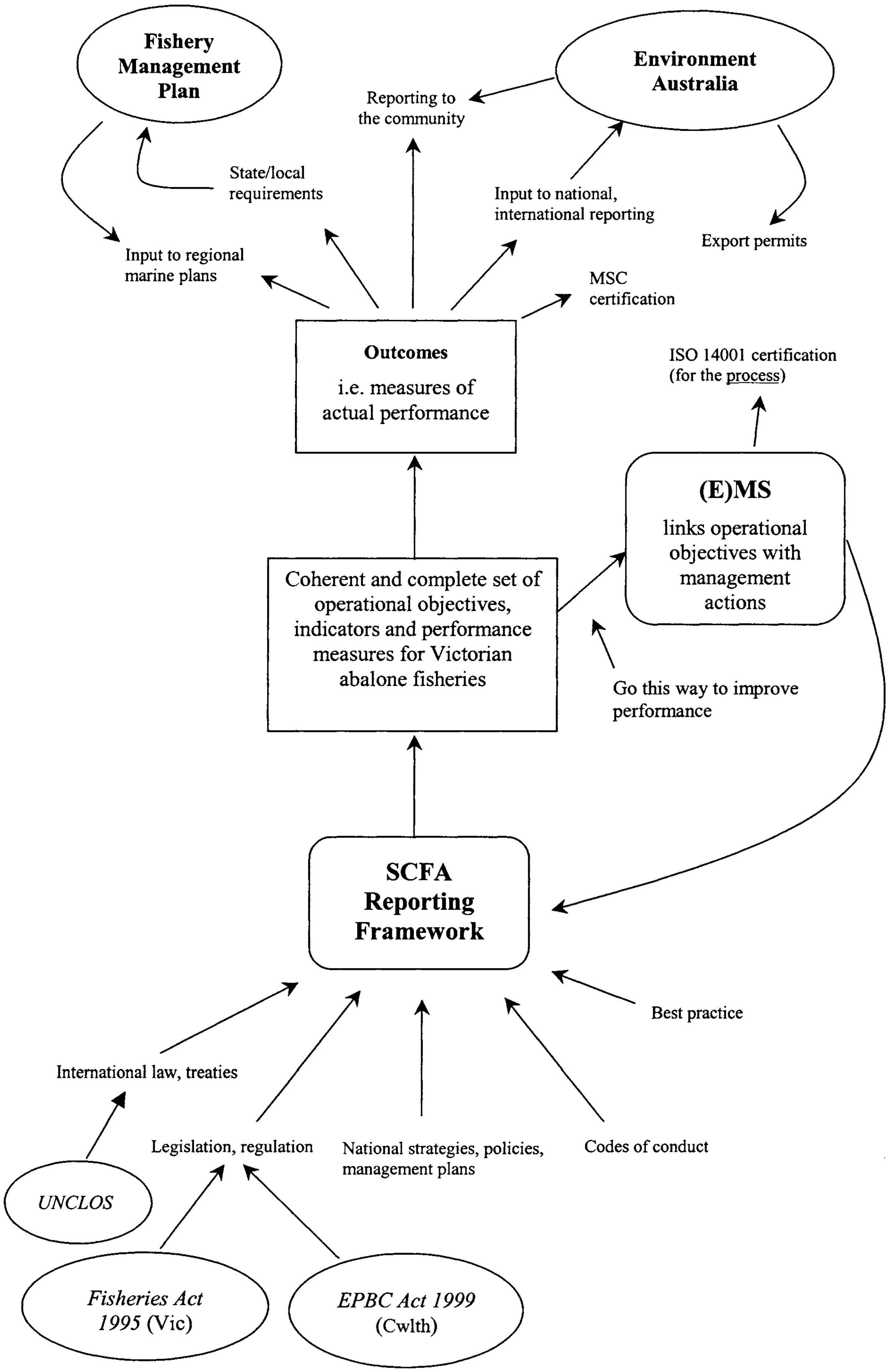

Figure 4. Relationship between ESD reporting and governance elements for the Victorian abalone fishery (adapted from Chesson et al. 2000).

Submission to Environment Australia:

Assessment of the Victorian Abalone Fishery against Guidelines for the Ecologically Sustainable Management of Fisheries

April 2001 (updated March 2002)

Compiled by Harry Gorfine

Overview

Preamble

This report addresses the criteria contained in guidelines developed by Environment Australia (EA) for reporting on the ecological sustainable development (ESD) of fisheries under the jurisdiction of the Wildlife Protection (Regulation of exports and imports) Act (1982). This reporting requirement is a consequence of recent amendments to Schedule 4 of this act that have de-listed a range of marine species, including abalone, from exemption provisions for export certification. It is intended that this report will serve as an important step towards EA certification for the export of Victorian abalone.

The Victorian abalone fishery is operated under a management regime that is described-in detail in the Victorian Abalone Fishery Management Plan. This report is necessarily consistent with the operational objectives of the Fishery Management Plan that in-turn complies with provisions of the Victorian Fisheries Act (1995). The Victorian Fisheries Act, under PART 3 — MANAGEMENT PLANS, section 28. *Management plans*, clause (6) states that,
A management plan must—
(*e*) as far as is known, identify critical components of the ecosystem relevant to the plan and current or potential threats to those components and existing or proposed preventative measures; and
(*f*) specify performance indicators, targets and monitoring methods;
Subclause (f) accords with Principle 1 of the EA guidelines and similarly subclause (e) accords with Principle 2.

The objectives of the Fishery Management Plan were developed in accordance with the Victorian Fisheries Act (1995), Environment Australia guidelines and the ESD framework proposed by the Standing Committee on Fisheries and Aquaculture. The objectives form an integrated package with those concerned with ensuring sustainability of the abalone resource and associated ecosystem having paramount importance. With this in mind the objectives to be pursued will be as follows:
Ecological objectives:

* Productive capacity of stocks sustained into the future at low levels of risk.
* Ecosystem health (including genetic integrity of abalone) not jeopardised by abalone fishery practices.
* Management responsive to changes in ecosystem health.

Economic objectives:

* Opportunities for commercial production fully utilised.
* Commercial production economically efficient.
* Commercial production directly enhanced through appropriate activities (including aquaculture, ranching, enhancement, and access to stunted stocks).

Social objectives:

* Equitable assignment of productive capacity between commercial, recreational, indigenous, and non-exploitative uses.
* Recognition of past access by indigenous Australians.

* Appropriate community return where there is commercial use of publicly owned abalone stocks and habitats.

Governance objectives:

* Management which is cost-effective and transparent.
* Recovery of the attributable costs of management, including research and compliance.
* Stakeholders and government fisheries administration sharing responsibility and involvement in management.
* Compliance targets for licensed sectors of the fishery achieved and monitored.
* Illegal activities prevented and targets for reduction of theft monitored and achieved.

Performance indicators are quantities to be measured in order to track the status of the fishery relevant to the objectives.
Target reference points represent the status that management wishes to achieve, while trigger reference points indicate that the status may be unacceptable to the extent that immediate remedial action is required.
The following suite of performance indicators and reference points, associated with the above fishery objectives, will be applied. Reference points were not applicable for many of the objectives, either for reasons of utility or practicality. In these cases only the performance indicator is provided.

Fishery Dimension	*Criteria to be Measured*	*Management Objective*	*Performance Indicator*	*Target Reference Point*	*Trigger Reference Point*
Ecological	sustainability of abalone stocks	productive capacity sustained into the future with low level of risk	mature biomass and/or egg numbers annual catch	mature biomass (or egg numbers) at level estimated for 2000 (B_{2000}) with 70% confidence (30% risk)	mature biomass (or egg numbers) at 90% of value estimated for 2000 with 80% confidence (20% risk) [lower limit] annual catch for one or more reef codes at either extreme of the range since 1988 (upper and lower limit) during 1988-2000
	ecosystem health	ecosystem health not jeopardised by abalone fishery practices	indices of ecosystem health	not applicable	ecosystem health indices at 90% of average value of previous 3 years (lower limit)
	ecosystem health	management adequately responsive to changes in ecosystem health	monitoring of entities, functions of entities, and stakeholder satisfaction	not applicable	not applicable

Fishery Dimension	*Criteria to be Measured*	*Management Objective*	*Performance Indicator*	*Target Reference Point*	*Trigger Reference Point*
Economic	production	opportunities for commercial production fully utilised	commercial yield (i.e. annual catch)	maximum constant yield consistent with the stock at 110% of the mature biomass (or egg numbers) at MSY (Bmsy) estimated with 70% confidence.	not required because the TAC setting process ensures close adherence to the target, without need for a trigger reference point
	economic efficiency	commercial production to be economically efficient	fishery profit	maximum fishery profit	fishery profit at 70% of average for previous 3 years (lower limit)
	catching efficiency	commercial production to be economically efficient	commercial catch per unit effort (CPUE)	not applicable	not applicable
	production	productive capacity directly enhanced/ maintained through appropriate activities (inc. aquaculture, ranching, and enhancement)	yields from wild fishery, aquaculture, ranching, and enhancement	not applicable	not applicable
Social	assignment of productive capacity	equitable access to productive capacity between commercial, recreational, indigenous, and non-exploitative uses	yield ratios (commercial: recreational: cultural: non-exploitative) where non-exploitative yield is the yield foregone.	not applicable	not applicable

Fishery Dimension	*Criteria to be Measured*	*Management Objective*	*Performance Indicator*	*Target Reference Point*	*Trigger Reference Point*
Social (Cont)	indigenous usage	recognition of past access by indigenous Australians	indigenous access	not applicable	not applicable
	community return	community return where there is commercial use of publicly owned abalone stocks and habitats	community return	to be defined by government policy	not applicable
	management costs	cost-effective management	total management costs	to be defined by government policy	not applicable
Governance	cost recovery	recovery of attributable management costs	attributable cost recovery	to be defined by government policy	not applicable
	co-management	stakeholders and government sharing responsibility and involvement in management	existence of co-management entities, functions of entities, and stakeholder satisfaction	not applicable	not applicable
	non-compliance (licensed sectors)	compliance targets for licensed sectors achieved and monitored	compliance indices	compliance targets achieved	not applicable
	illegal activity (non-licensed sectors)	prevention of illegal activity targets for non-licensed sectors achieved and monitored	compliance indices, illegal catch and value, and cost of enforcement	optimal compliance (when marginal cost equals marginal monetary benefit)	not applicable

Explanatory Notes:

* Several reference points have an incorporated level of risk, reflecting mathematical uncertainty in the measurement of performance. The risk is in respect to the likelihood that the estimated outcome will not be realised. A value of 30 percent reflects a moderately low level of risk.
* The mature biomass (or egg numbers) primary trigger reference point uses the 1992 values against which to measure change. The normally preferred alternatives of measuring change against the zero-exploitation biomass (B_0) or the biomass at maximum sustainable yield (Bmsy) were not chosen, due to the practical difficulties of determining these with certainty at present. This trigger point is appropriate for zones or sub-zones for which there are sufficient data to assess biomass values.
* The annual catch trigger reference point uses the extremes of the range for the years since 1988 as the trigger values. Quota management was first introduced in 1988, with the TACs for each zone having remained constant to the present. The trigger seeks to safeguard against excessive exploitation levels and stock depletion at the reef code level of spatial aggregation, for which estimates of mature biomass are not presently available. The trigger caters for localised situations where it is not feasible to obtain data which is sufficiently refined spatially to permit mature biomass estimates.
* Indices of ecosystem health are to reflect the abundance of those organisms considered linked to fishery practices or to the well-being of the abalone stocks; such as food and habitat organisms (floating and encrusting algae), predators (sea urchins, sea stars, other gastropods, parrot fish, crabs, and lobster), and shelter species (kelp).
* Choosing maximum constant yield at 110 percent of mature biomass at MSY (Bmsy) as the economic production target reference point rather than MSY itself provides an additional safety margin in respect to ensuring the sustainability of stocks. It is also a proxy for maximum fishery profit, the other economic target point.
* Compliance indices will include but not be limited to number and hours of quality inspections, number and types of warnings and offences, number and types of legal briefs, number of defendants and convictions, and magnitude of penalties and fines. They are to be grouped according to whether the inspections are routine or special.

Information used to support the management of the fishery is collected, synthesised and analysed by the Abalone Fishery Assessment Group (AbaloneFAG) that engages fisheries managers, scientists and stakeholders in workshops to produce annual assessments of fishery status and corresponding management advice. The Marine and Freshwater Resources Institute (MAFRI), is a research agency within Fisheries Victoria and has responsibility for convening the AbaloneFAG and conducting the Abalone Assessment Sub-program. Results from annual assessments are published by MAFRI in a Fishery Assessment Report series.

To date information has been gathered primarily to assess the sustainability of abalone populations. Similar programs exist to assess the sustainability of southern rock lobster and southern wrasse whose geographic distributions coincide or overlap with those of abalone. Whilst the abalone assessment program extends to include species that are regarded as important determinants of the survival of abalone, the inclusion of species that are dependent on abalone is limited. Fishery assessments of sympatric species such as urchins and turban snails are not made routinely because of the relatively small quantities and low values of their fisheries. However, an independent ecosystem monitoring program has been conducted by the Parks, Flora and Fauna Division of the Victorian Department of Natural Resources (of which Fisheries Victoria is also a Division) during the past few years. This work has been primarily undertaken in support of the establishment of a system of Marine Protected Areas along the Victorian coast, but includes several locations where fishing is permitted. A comprehensive range of quantitative data gas been acquired through this work that with improved knowledge of the functional relationships within abalone ecosystems should allow more sophisticated analysis of impact of the abalone fishery on ecosystem performance.

The Fishery

Victorian abalone resources support an export fishery that had a landed value of about $70M during 2000/01. This makes it the most valuable of Victoria's state-managed fisheries.

The commercial fishery commenced in 1962 and during its relatively short history has been subject to fairly intensive management in the form of legal minimum lengths (LMLs), zonation of the fishery (Central, Eastern and Western), limited entry and quotas. As a consequence the fishery has been relatively stable and remunerative. The catching sector has developed effective fishing practices and equipment, and efficiently provides a good landed product.

Two species of abalone are caught, blacklip (*Haliotis rubra*) as the main targetted species, and greenlip (*H. laevigata*) mostly as a by-product species that comprises less than one percent of the total catch.

Since output management was introduced in 1988 there has been an annual total allowable catch (TAC) of 1,440 tonnes (blacklip and greenlip combined), allocated in respect to 1,420 quota units distributed amongst the 71 current holders of Abalone Fishery Access Licences (AFAL). The catch is processed by eighteen licensed processors, most of whom are concentrated in the Central Zone.

Biology

Blacklip abalone

Abalone are characteristically variable with respect to most of their life history parameters (see McShane and Smith 1991, Troynikov and Gorfine 1998). Like many other molluscs, scientific evidence suggests environmental conditions play a dominant role in the population dynamics of abalone. Consequently, patterns of variability in abalone mirror spatial and temporal variability in the environments where this mollusc is distributed. This variability is accommodated in the approach adopted for management and assessment of Victorian abalone resources.

Victorian blacklip abalone populations may be less vulnerable to population collapse than others because abalone that are not in relatively dense, accessible aggregations tend not to be fished (McShane 1996). Cryptic behaviour (tendency to inhabit narrow crevice spaces) exhibited by blacklip abalone and complex topography characterising Victorian reef systems combine to provide a buffer against over fishing that is not so readily apparent in many other abalone fisheries.

High fecundity ensures that abalone gametes are plentiful when environmental conditions are suitable, and also means that environment, rather than fishing mortality can be a major determinant of recruitment failures. However, abalone populations exhibit a propensity for serial depletion because of their limited larval distribution. Management regimes should take this into account by focussing on metapopulation-scale processes when setting input and output controls.

Greenlip abalone
Although many of the general biological characteristics are common between blacklip and greenlip abalone, greenlip are somewhat less cryptic as adults than are blacklip abalone, making greenlip more catchable and vulnerable to over fishing (Gorfine and Dixon 2000a). Greenlip also have different habitat requirements and their preferred habitats tend to be fragmentally distributed within Victoria. This results in relatively small and more isolated meta-populations than occurs with blacklip abalone, reducing the capacity for recovery of greenlip stocks via larval recruitment from adjacent populations. Greenlip tend to grow faster and attain a larger size than blacklip abalone and consequently their management requires larger legal minimum size limits (LMLs) to avoid recruitment over-fishing.

Assessment of the management regime against the stated criteria.

Documented, publicly available and transparent
The management regime is documented in the Victorian Abalone Fishery Management Plan to which this report is appended. The Managment Plan stems from extensive consultation via a Reference Group convened from among all stakeholders in the community. In contrast with past quota management arrangements, the Plan provides for separate management of blacklip and greenlip abalone stocks. The release of an earlier Draft Abalone Fishery Management Plan, including a previous version this report, for public consultation satisfies the need for public availability and transparency. The final Plan was not be published and implemented until public comments on the Draft were considered.

Annual Fishery Assessment reports for both blacklip and greenlip abalone are published by the Marine and Freshwater Resources Institute and distributed to all stakeholders to ensure that management advice is transparent and that the community is fully informed about the current and predicted future status of the resource (Gorfine and Forbes 1994 a, b, c & d, Gorfine and Walker 1997a & b, and Gorfine and Dixon 2000 a & b).

Developed through a consultative process providing opportunity to all interested and affected parties, including the general public

The Fishery Management Plan was developed through a consultative process involving a reference committee with broad stakeholder representation reporting to a ministerially appointed steering committee with an independent chair. The draft version of the Plan was released for public consultation and made available via the Department of Natural Resources and Environment's website.

Ensure that a range of expertise and community interests are involved in individual fishery management committees and during the stock assessment process.

The involvement of a range of expertise and community interests is documented in the Fishery Management Plan. There is broad stakeholder involvement in both the assessment and the management decision-making processes (see Appendix 1 for fishery assessment and management committees' composition). Conservation groups, in particular, are well represented amongst these interests, with the Victorian National Parks Association (VNPA) nominated as the peak conservation body. Consultation with peak bodies is a mandatory requirement of the Victorian Fisheries Act (1995).

Be strategic, containing objectives and performance criteria by which the effectiveness of the management arrangements is measured.

The Fishery Management Plan contains objectives, indicators and performance measures for measuring the effectiveness of the management arrangements for each component identified in these guidelines. The objectives and performance criteria are described in the Preamble. For some components, objectives, indicators and performance measures are established and data are available to demonstrate actual performance over time. For other components, objectives, indicators and performance measures are in various stages of development and/or the necessary data collection is being initiated.

Be capable of controlling the level of harvest in the fishery using input and/or output controls.

The management regime is capable of controlling the level of harvest with respect to each retained species using input and/or output controls as documented in the Fishery Management Plan and provided for under the Victorian Fisheries Act (1995) and its subordinate legislation.

Contain the means of enforcing critical aspects of the management arrangements.

The management regime has the means of enforcing critical aspects of the management arrangements as documented in the Fishery Management Plan and provided for by the Victorian Fisheries Act (1995).

Provide for the periodic review of the performance of the fishery management arrangements and the management strategies, objectives and criteria.

The Fishery Management Plan provides the basis for management of the fishery for a period of five years. Should there be a need for the Minister to amend the plan, notice of this intention will be published in the Government Gazette and there will be formal consultation with stakeholder groups. Notwithstanding this there is a process for continual review and improvement of assessment of the fishery via the AbaloneFAG.

Be capable of assessing, monitoring and avoiding, remedying or mitigating any adverse impacts on the wider marine ecosystem in which the target species lives and the fishery operates.

For the Victorian abalone fishery these capabilities are highly developed relative to many other major export fisheries. Details are provided elsewhere in this report and in the Fishery Management Plan.

Require compliance with relevant threat abatement plans, recovery plans, the *National Policy on Fisheries Bycatch*, and bycatch action strategies developed under that policy.

The management regime requires compliance with the above with respect to the recovery of greenlip abalone populations which are considered to be a by-product species. There is no by-catch for this fishery.

Assessment of the management regime against Principles 1 and 2.

PRINCIPLE 1.

A fishery must be conducted in a manner that does not lead to over-fishing, or for those stocks that are over-fished, the fishery must be conducted such that there is a high degree of probability the stock(s) will recover .

Objective 1. The fishery shall be conducted at catch levels that maintain ecologically viable stock levels at an agreed point or range, with acceptable levels of probability.

Information requirements
1.1.1 There is a reliable information collection system in place appropriate to the scale of the fishery. The level of data collection should be based upon an appropriate mix of fishery independent and dependent research and monitoring.

Both fishery dependent and fishery independent data are collected as part of the fishery assessment process administered by MAFRI. Comprehensive tagging studies are also implemented to estimate key population parameters required for fishery assessment.

Fishery Dependent
These data include daily commercial catch weight (kg) of blacklip and greenlip abalone and effort (min) for each operator at a scale of reef complexes, small bays and headlands. This reporting is a mandatory component of the Abalone Quota Management System administered by Fisheries Victoria. In addition MAFRI undertakes commercial catch sampling and the world's only on-board observer program for abalone. The commercial catch sampling provides the size structure and reproductive condition of the catch, and the on-board observation provides instantaneous catch rates, and insights into diver behaviour including their harvesting techniques and dive depth profiles. On-board observers also interview divers about their observations and perceptions regarding the ecosystem at each site dived. Initiatives are underway for introducing finer scale spatial reporting, and the counting and measuring of all abalone in the catch using digital technology.

Fishery Independent
One of the advantages of abalone compared with other fisheries is the opportunity to observe populations directly during underwater surveys.
Blacklip abalone
MAFRI conducts a comprehensive annual survey of blacklip abalone at 150 fixed locations distributed across the commercial abalone fishing grounds in Victoria. Relative abundance of abalone is estimated from transect counts (Fig. 1), timed collections, and nearest-neighbour distances for random samples within each location.

The timed collections also provide independent estimates of abalone shell length frequency for the surveyed populations.

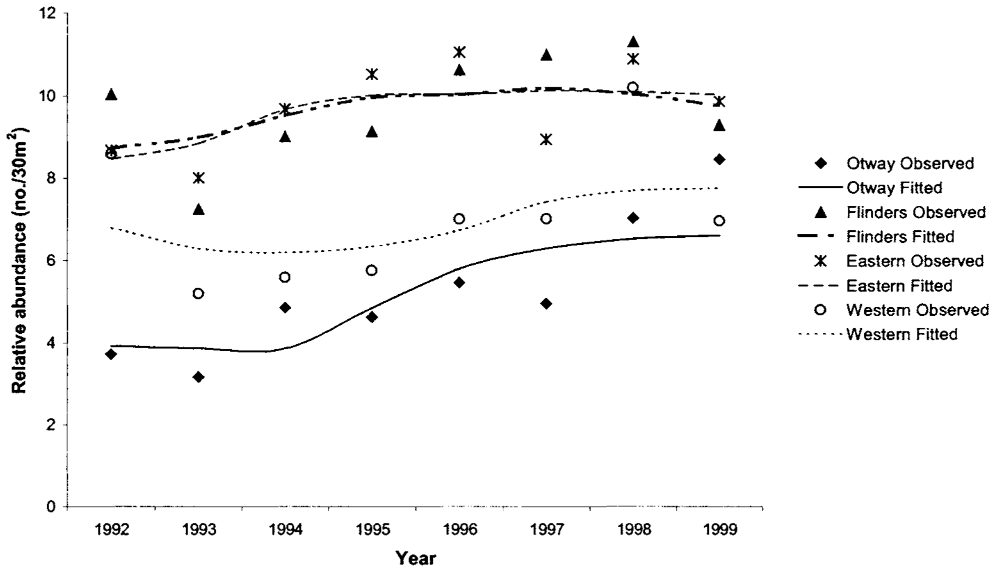

Figure 1. Inter-annual patterns of observations and standardised trends in relative abundance estimated from fishery independent underwater surveys.

Greenlip abalone

A comprehensive series of underwater surveys and a review of past data were undertaken to assess the status of greenlip abalone stocks during 1998. As far as possible, comparisons were made between contemporary and historic data to determine population changes and to formulate management advice (Gorfine and Dixon 2000a).

Tagging

Blacklip abalone

Tagging studies for growth, natural mortality and movement have been undertaken and are on-going. There is a substantial requirement for these data given the high spatial variability in these parameters for abalone. A proportion of this tagging involves abalone operators and tag returns provide incidental information about fishing patterns relative to tag release sites. Fig. 2 shows the predicted distributions of maximum length from two tagging studies fifteen years apart for a heavily exploited, fast growing, blacklip abalone population in the Eastern Zone. These results suggest

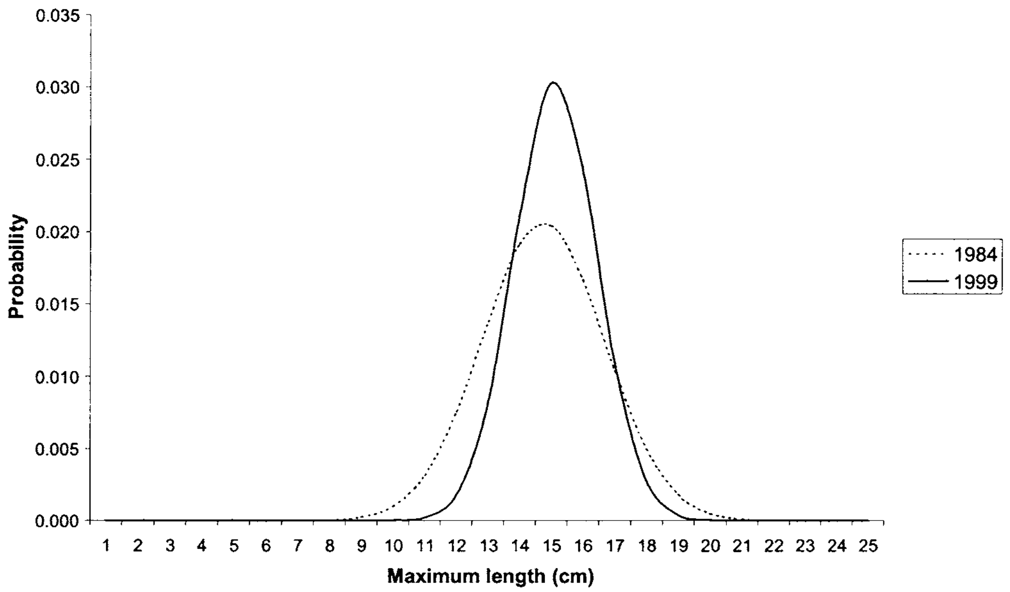

Figure 2. Distributions of predicted maximum length from tagging studies during 1984 and 1999 for the blacklip abalone population at Sandpatch Point in the Eastern Zone.

that fishing has produced very little change in the growth potential of this population and provides evidence that neither environmental and genetic factors have changed much despite 15 years of intensive fishing. Growth studies of wild abalone involving translocation experiments between fast and slow growing populations indicate that environmental factors are the predominant determinants of growth.

Greenlip abalone
Extensive tagging studies of growth and studies of reproduction were completed for Victorian greenlip abalone during the late 1960s and early 1970s. The original data were re-analysed by MAFRI as part of the greenlip abalone assessment during 1998.

Assessment

1.1.2 There is a robust assessment of the dynamics and status of the species/fishery and periodic review of the process and the data collected. Assessment should include a process to identify any reduction in biological diversity and /or reproductive capacity. Review should take place at regular intervals but at least every three years.

Blacklip abalone
Fishery modelling
A fishery assessment model has been developed for blacklip abalone that incorporates reported catch, catch rates (optional) and independently estimated abundance. The model needs to account for all mortality including landed (illegal, legal and recreational), discarding, high grading, and incidental mortality during fishing. The model is highly dependent on spatially variable growth, natural mortality and recruitment parameters. The recruitment parameters incorporate the reproductive capacity of the populations modelled and stochasticity is introduced into the recruitment function to reflect natural variation associated with environmental

fluctuations. The model is dynamic and can accommodate density dependence and depensatory effects.

Risk assessment

Assessments are made annually in accordance with requirements of the Victorian Abalone Fishery Management Plan for providing TAC advice to the Minister under the Fisheries Act 1995. A risk-based approach is adopted that incorporates the uncertainty in estimates of current and predicted stock status into the decision-making process. The risk framework provides for robust assessments of the consequences of alternative management strategies on the relative biomass of exploited abalone populations. In addition, the process is sufficiently flexible to allow managers to explore the effects of various assumptions about how the fishery operates in an iterative fashion. The fishery assessment process is holistic and although the current fishery model is a pivotal tool, it is only one of a range of informative mechanisms used to determine the status of the fishery. Annual assessments include a review of methodology and data requirements, and consideration of changes in abundance of species other than abalone.

Greenlip abalone

Although given sufficient data the current fishery model used for blacklip abalone could be applied to greenlip populations, in the absence of a fishery independent time series of abundance an estimate of absolute abundance was made from the 1998 surveys. These stratified random surveys were much more intensive than for blacklip, and densities of greenlip abalone were scaled to the digitised areas of their reef habitats contained in the MAFRI GIS. A combination of exploitation rates estimated for blacklip abalone and sensitivity analysis using the uncertainty in density estates was used to determine possible sustainable catches.

1.1.3 The distribution and spatial structure of the stock(s) has been established and factored into management responses.

Abalone reefs have been digitally mapped at high resolution and stored in MAFRI's GIS. Reporting areas and reefcodes exist as overlays in the GIS. Assessment modelling of the stocks within each fishery management zone is spatially disaggregated into key bioregions. These bioregions relate to areas with unique environmental characteristics reflected in population parameters, such as growth, that determine the relative productivity of the sub-stocks within those areas.

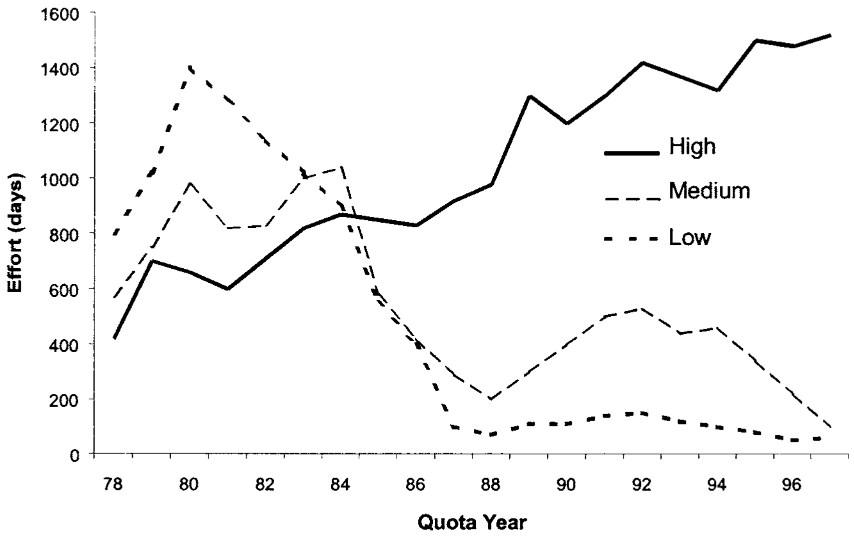

Figure 3. Temporal trends in the distribution of effort among reefs with high, medium and low catch rates

A performance indicator for blacklip abalone, based on changes in the inter-annual spatial pattern of catches for each region modelled, facilitates management responses to reductions in stock abundance on a high-resolution, localised scale (Victorian Abalone Fishery Management Plan). This performance indicator could also be applied to greenlip abalone stocks in the event that the commercial greenlip fishery is re-opened. In addition, there is provision in the assessment model to simulate shifts in fishing effort between modelling regions when estimating sustainable yields. Fig. 3 illustrates the spatial contraction of fishing effort away from low-medium productivity (catch rate) reefs that followed the introduction of catch quotas in 1988.

1.1.4 There are reliable estimates of all removals, including commercial (landings and discards), recreational and indigenous, from the fished stock. These estimates have been factored into stock assessments and target species catch levels.

Catch data exist for the commercial fishery since mid 1960s when fishery commenced in earnest (Fig. 4). The spatial and temporal resolution of the data varies from reporting blocks of 30' longitude to reefs (Table 1), and from monthly to daily respectively. The resolution and reliability has increased over time with commercial catch data continuing to be reported on a daily basis at the reef complex scale. Recently the reef-code system has been revised to provide higher spatial resolution.
An estimate of the recreational catch has been made by combining a survey of recreational dive industry activity in Victoria during the mid-1990s, with limited creel census data (Gorfine and Walker 1997a). A recreational catch of 30 tonnes was estimated of which only 2% were greenlip abalone. This estimate was based on a number of assumptions that could not be validated. Improved estimates of the recreational catch should be available once the National Indigenous and Recreational Fishing Survey has been completed (FRDC Project No. 1999–158).

A project to estimate quantities and source locations of illegally harvested abalone is also in progress with substantial data collated and currently being analysed (FRDC Project No. 2000 – 112).

Table 1. Cumulative catches during 1979-1998 for selected Reef Codes and/or Areas for each management zone.

Eastern Zone		Central Zone		Western Zone	
Reef Code	Catch (tonnes)	Area	Catch (tonnes)	Area /Reef Code	Catch (tonnes)
Sandpatch Point	1505	Mornington Peninsula	4827	Cape Nelson	1227
Aerodrome	1027	Cape Otway	2448	Cape Bridgewater	1039
Gabo Island	1015	Port Phillip Bay	2027	The Craggs	626
Big Rame Head*	744	Wilsons Promontory	1518	Killarney	554
Point Hicks	704			Passage-Lawrence Rocks	469
Island Point	699			Boulder Point-Port Fairy	453
Little Rame Head	629			Lady Julia Percy Island	433
				Lighthouse Reef	197

a) Blacklip (1966 – 1998)

b) Greenlip (1966 – 1998)

c) Greenlip (1966 – 1998)

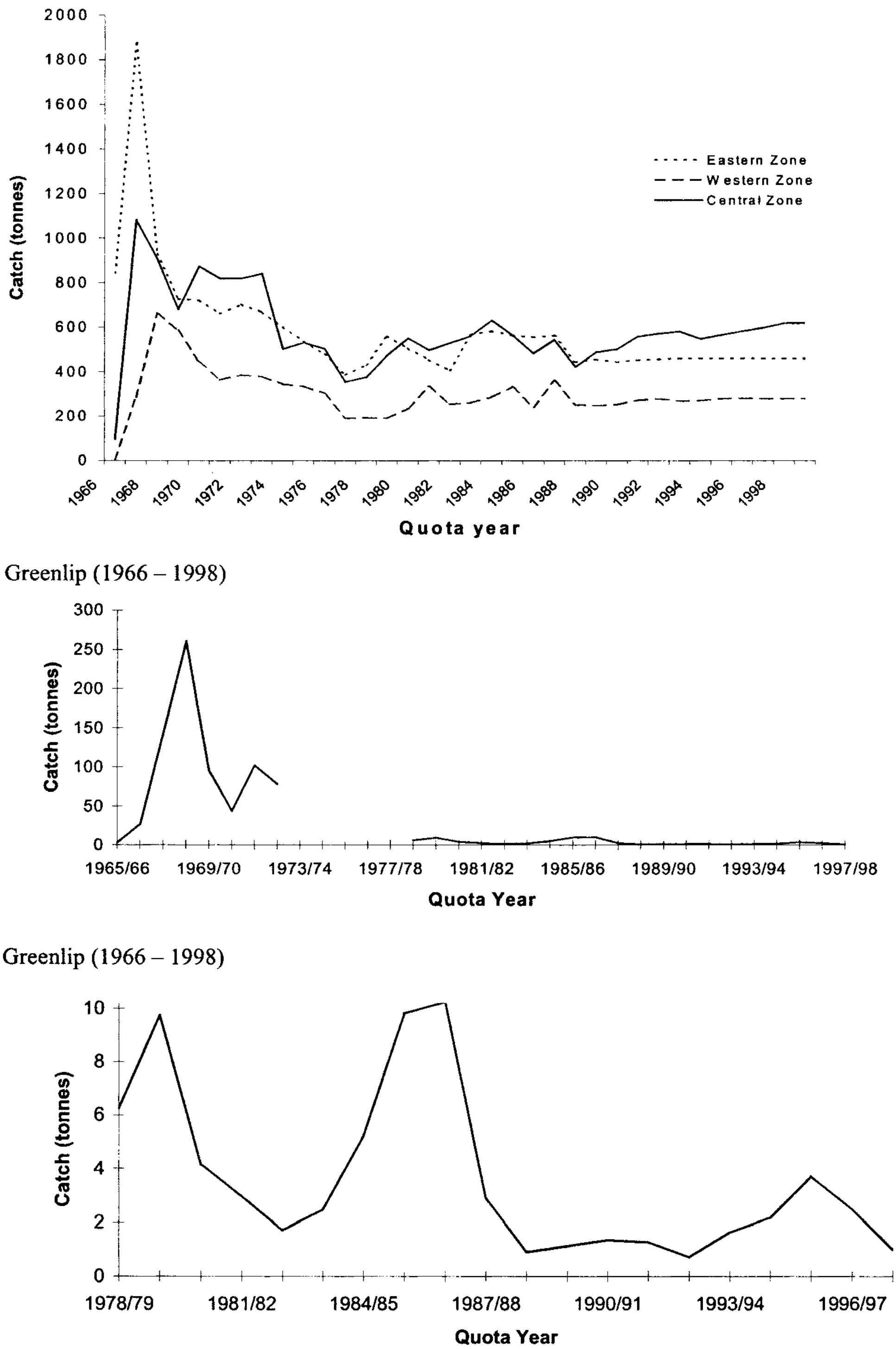

Figure 4. Catch history of Victorian blacklip and greenlip abalone for the three fishery management zones.

The catch data are the primary inputs to the fishery assessment model employed to estimate current and predict future stock status in terms of relative biomass. Another project (FRDC Project 1999–116) is being conducted by MAFRI to ensure that this assessment modelling represents 'best practice' for Australian abalone fisheries. Although illegal catches currently factored into the modelling are guesstimates, the trends in fishery independent estimates of abundance account for all extractions. Consequently, fitting the model to trends in fishery independent abundance ensures that 'signals' from illegal extractions are incorporated in model outputs.

1.1.5 There is a sound estimate of the potential productivity of the fished stock/s and the proportion that could be harvested.

Blacklip abalone

Model outputs are in the form of estimates of relative biomass for each year included in the model (e.g. Model Output = $B_{current}$ / B_{2000} and $B_{current}$ / $B_{initial}$). Once the model has been fitted and parameters estimated, the effects of alternative catch/management scenarios on future relative biomass can be predicated via simulation. This allows the selection of a management regime, such as a maximum constant yield, for which the predicted relative biomass remains stable (Fig. 5). These predictions take the form of a risk framework when the statistical distribution of model predictions is used to select a level of confidence probability that the actual value will not fall below the predicted value. In the Fishery Management Plan a confidence probability of 70% is specified (also expressed as 30% risk), or in other words the scenario selected is the one for which 70% of the predicted values are at or above the desired value. Adoption of a risk framework helps to ensure a precautionary approach to the assessment process. It is believed that the value specified represents a moderately low level of risk (Victorian Abalone Fishery Management Plan).

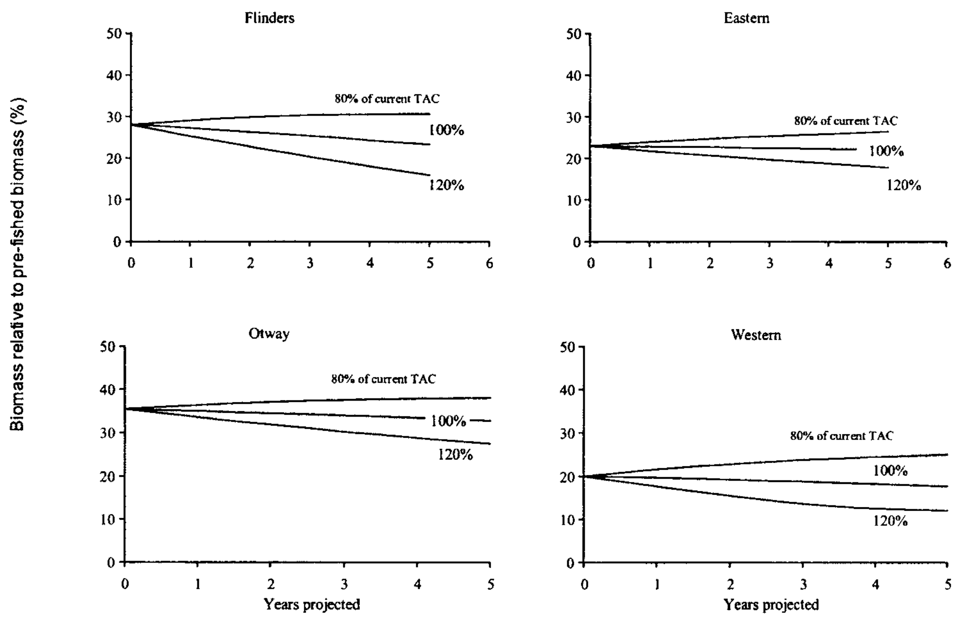

Figure 5. Biomass projections (30th percentile ie. 30% porbability that true values are below the curves) over the next five years for different proportions of the current zonal TACs in each region modelled.

Greenlip abalone
The estimate of potential catch for this species was based on the assumption that greenlip abalone can sustain the same exploitation rate as blacklip abalone. An absolute estimate of aggregate biomass for all the locations surveyed was used as the basis for this assessment of potential productivity. A precautionary estimate of the annual catch likely to be sustained was only 1–20 tonnes (Gorfine and Dixon 2000a). Current commercial catches, at about 1 tonne per annum, are close to the lower limit of this range. The estimated recreational catch of greenlip abalone is about half this amount (Gorfine and Walker 1997a).

Management responses

1.1.6 There are reference points (target and/or limit), that trigger management actions including a biological bottom line and/or a catch or effort upper limit beyond which the stock should not be taken.

Blacklip abalone
If the mature biomass (or egg numbers) falls below 90% of the value estimated for 2000 with 20% risk (lower limit) this will trigger a management response (Victorian Abalone Fishery Management Plan). The response should ensure that the stock is restored to an acceptable level within five years.

In recognition that biomass estimates are only practical for bioregions, an additional trigger has been established to accommodate small-scale problems that may precipitate serial depletion if left unresolved. If the annual catch for one or more reef codes is shown to be at either extreme of the range since 1988 (upper and lower limit) a management response will also be triggered (Victorian Abalone Fishery Management Plan).

The Fishery Management Plan specifies that the annual TAC be set at a level that will allow the current mature biomass to stabilise at 110% of the biomass required to support maximum constant yield. A confidence probability of 70% is specified for this performance indicator.

Greenlip abalone
The Fishery Management Plan recognises that this species was probably depleted by over-fishing two decades ago and, as indicated by the 1998 assessment, has not recovered. The estimated potential productivity is regarded as insufficient to sustain a commercial fishery for this species that can be regarded as having been a by-product species since the late 1970s. Consequently a separate greenlip TAC of zero is recommended in the Plan. For commercial fishing to resume, substantial increases in greenlip abalone abundance are required. No target is specified in the Plan, but a three to five-fold increase would not seem unreasonable as a minimum requirement for re-opening. It is likely that some form of intervention, such as enhancement using hatchery-reared offspring from local brood-stock, would be required for stock restoration. The Plan makes provisions for this activity, with constraints to safeguard existing wildstocks. There are several experimental abalone restoration projects in progress in Australia and overseas, but past results from these types of abalone research and development have not been encouraging. Even if enhancement becomes technically viable it may not be cost-effective from a commercial perspective.

1.1.7 There are management strategies in place capable of controlling the level of take.

Commercial fishing

Blacklip abalone

Quotas for the fishery are set annually by the Minister acting on advice of the Fisheries Co-management Council. This advice is based largely on assessments of the fishery completed by the Abalone Fishery Assessment Group at MAFRI. This Group involves stakeholder representatives from each relevant peak body. The assessments depend heavily on model outputs in the first instance, and secondly on verification of these outputs in terms of model assumptions, reliability of inputs and any external indicators of stock status.

In the event of a triggered response, the Minister's decision may follow several paths depending on the perceived severity of the change and urgency for a response. Whenever trigger reference points are reached the Minister will be notified. The Abalone Fishery Committee (AFC) will meet as a matter of urgency to determine its assessment and advice to the Minister. Its advice will be submitted through the Fisheries Co-Management Council, with a copy to Fisheries Victoria. Both these groups, as well as the Abalone Fishery Assessment Group (AbaloneFAG), include representatives from peak conservation bodies (see Appendix 1).

In deciding which course of action to recommend, AFC will consider the outcomes of the full range of fishery performance indicators as well as any other data it believes to be relevant.

On the basis of these considerations it will recommend one of the following courses of action to the Minister, together with a full explanation:

(i) No action be taken but that the situation be re-evaluated following observation of the behaviour of the resource for another fishing year or;

(ii) Immediate and intensive investigation be undertaken to clarify components of the performance of the resource or the stock assessment prior to further decisions and action or;

(iii) Action to be taken which adjusts the prevailing total allowable catch (TAC) and/or legal minimum length (LML) for the immediately following years, with the objective of restoring the mature biomass (or egg numbers) to above the trigger reference point within five years.

(iv) Other actions as appropriate to achieve recovery from the trigger value with the minimum delay as practicable but not exceeding five years.

Compliance with catch quotas and other restrictions is enforced by fisheries officers through routine surveillance, and inspection of both licensed and unlicensed operators, as well as through intelligence gathering and interception of illegal catches during targeted operations. Inspections and compliance monitoring are conducted in accordance with a Statewide Quality Inspection Program (SQIP) that specifies the minimum number of inspections required as part of annual Service Agreements between DNRE regions and Fisheries Victoria. Monitoring of the legal commercial catch to ensure compliance with quota allocations is accomplished via the Abalone Quota Management System administered by Fisheries Victoria's Special Investigations Group. Stringent reporting arrangements and a National Docketing System make it extremely difficult to 'launder' illegally caught abalone through licensed sectors of the Victorian industry. The effectiveness of enforcement activities against illegal operators has been demonstrated by successful targetted operations that netted large quantities of illegal abalone product. Substantial penalties imposed in recent years, including prison sentences and confiscation of assets, have shown that the Victorian judicial system is capable of effectively dealing with convicted abalone thieves.

It is anticipated that the project to develop methods to estimate quantities of illegally harvested abalone (FRDC Project No. 2000–112), referred to above, will provide additional strategies for auditing the effectives of compliance activities. Compliance will also be strengthened by a recent initiative of the Victoria Police Organised Crime Unit to conduct a strategic assessment of illegal abalone activities. This initiative rings substantial police intelligence resources to the issue. This initiative also has the potential for VicPol to apply equally substantial strategic investigative and prosecution resources, if the assessment concludes that increased policing of Victorian legislation, relevant to abalone fishing activities, is warranted.

Greenlip abalone

Currently, separate management arrangements for greenlip abalone only include a six-month seasonal closure during the spring-summer spawning period, and a larger LML of 130 mm that applies throughout the state. To date, greenlip abalone have been taken commercially as part of the same TAC applied to blacklip abalone. The Fishery Management Plan recommends separate arrangements be effected by an amendment to the Fisheries Act 1995.

Recreational fishing

Catch quotas are not applied to recreational fishing for abalone because the total harvest of 30 tonnes or less is relatively small compared with the commercial TAC. However, recreational management regulations include daily bag and possession limits for individuals, boats and vehicles. Separate possession limits and LMLs apply for recreational blacklip and greenlip abalone. The daily bag and possession limit is 10 abalone per person, of which no more than two can be greenlip during an open season that extends from April to October. Boat and vehicle limits are 50 abalone, of which only 10 may be greenlip. The recreational LMLs are identical to those that apply to the commercial fishery. Recreational management arrangements for greenlip abalone remain unchanged in the Fishery Management Plan because the relatively small recreational catch (about 600 kg) is believed to be sustainable and greenlip abalone are keenly sought by some recreational divers.

Recreational compliance is monitored as part of SQIP, however DNRE's regional fisheries management also has the resources of a number of specialist recreational fisheries officers who perform an educative as well as an enforcement role. Enforcement aimed at recreational users will continue to consist largely of routine overt patrols undertaken as part of the wider marine recreational fisheries enforcement effort. Service agreements will prescribe the quantity and characteristics of the patrols undertaken from the DNRE regional offices. Compliance levels of greater than 90 percent are to be sought from those taking abalone (Victorian Abalone Fishery Management Plan).

1.1.8 Fishing is conducted in a manner that does not threaten stocks of by-product species. (Guidelines 1.1.1 to 1.1.7 should be applied to by-product species to an appropriate level)

Greenlip abalone

Greenlip abalone has essentially been a by-product species since the late 1970s (Fig. 6). Reported catches of greenlip abalone during the entire history of abalone fishing in Victoria have never exceed 5% of the total catch and for the past decade have been less than 1%. The Fishery Management Plan recognises that this species was probably over-fished two decades ago and, as indicated by the 1998 assessment, has not recovered. The estimated potential productivity is regarded as insufficient to sustain a commercial fishery. Consequently a commercial TAC of zero is recommended in the Fishery Management Plan. However, recreational management arrangements will remain unchanged because the recreational catch is believed to be quite small and greenlip abalone are keenly sought by some recreational divers. For commercial fishing to resume a substantial, but unspecified, increase in stock abundance would be required.

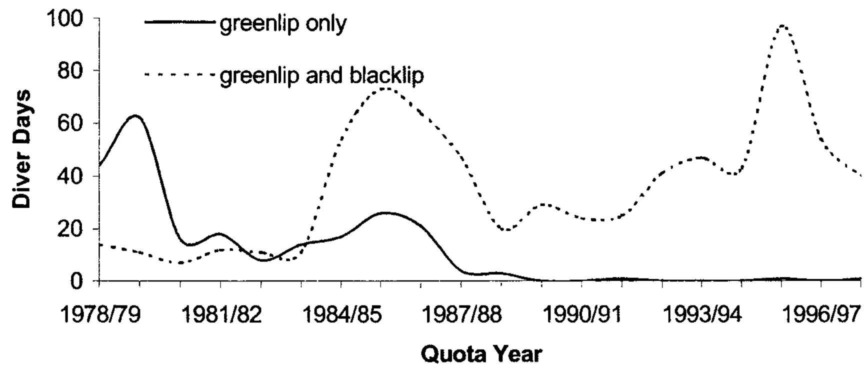

Figure 6. Comparison of diver-days of effort spent targeting greenlip abalone exclusively and targeting blacklip with greenlip as a by-product.

1.1.9 The management response, considering uncertainties in the assessment and precautionary management actions, has a high chance of achieving the objective.

Commercial fishery

Quotas were introduced during 1988 to limit the potential for substantial effort increases due to the replacement of older divers with new entrants to the fishery when transferability was introduced four years previously. The quotas represented about a 30% reduction in the average annual catch per diver and could reasonably have been expected to avert future declines in the medium term and stabilise the stocks. Recent model outputs show that the biomass has been relatively stable since 1988 (Fig. 7) and that both B_{1992}/B_{1988} and B_{2000}/B_{1988} are greater than 100%. This evidence suggests that quota adjustment should provide an effective management response for stabilising stocks in the event of a future decline in abundance

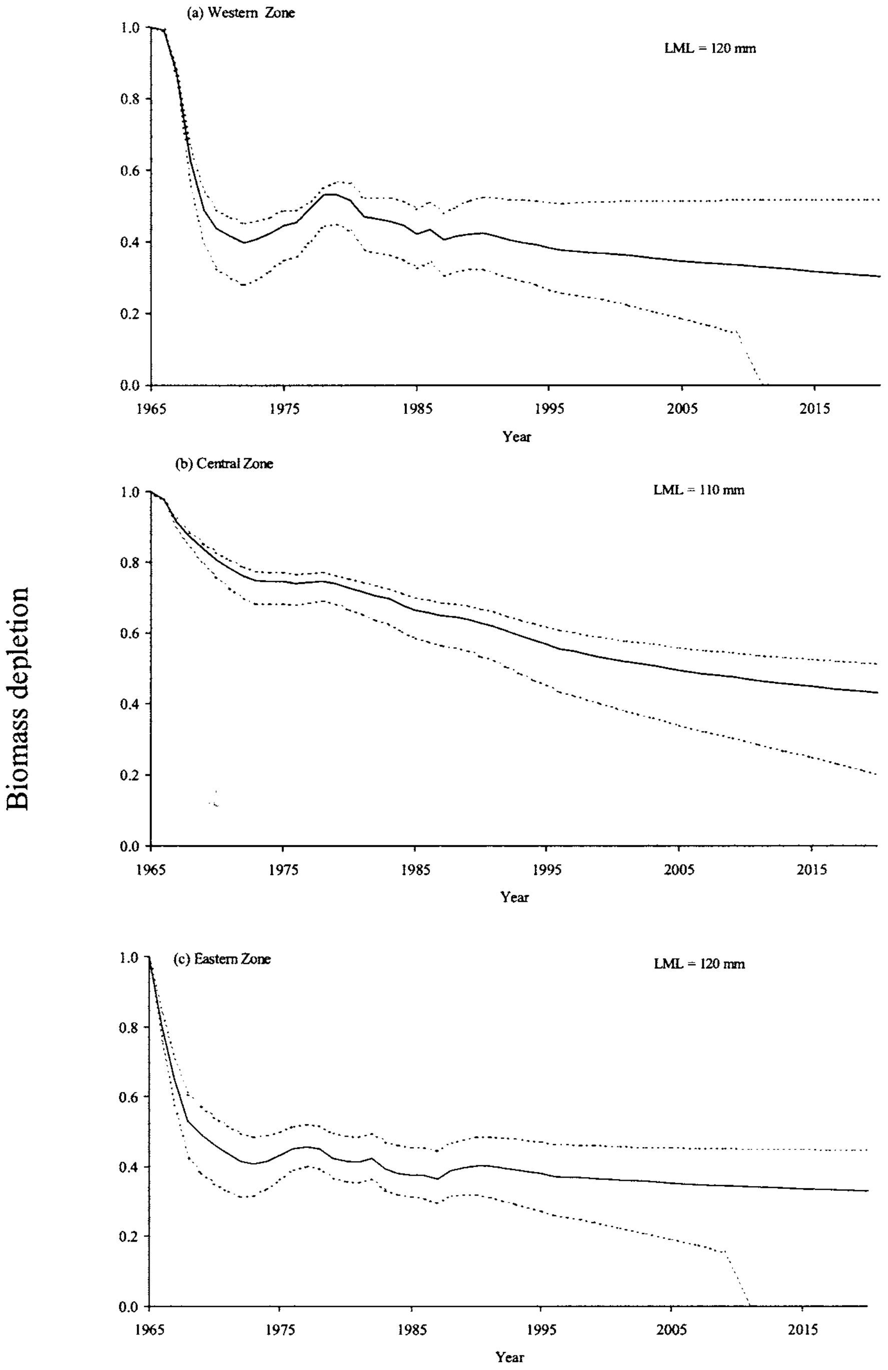

Figure 7. Biomass depletion (with 95% probability interval) for abalone larger than LML (projections with current TAC and assumed values of unaccounted catch) in the (a) Western Zone, (b) Central Zone, and (c) Eastern Zone.

Recreational fishery

Given the small quantities of recreational catch estimated, the current management strategy appears to be more than adequate for controlling the recreational harvest to ensure that it remains sustainable. Additional regulations, designed more as a deterrent to illegal activity than as direct input and output controls to conserve abalone resources, are applied to recreational divers. These include a requirement that all abalone must remain in the shell, with a cut in the foot, until reaching the place of consumption, and a prohibition on harvesting at night. The former requirement is aimed at decreasing the likelihood that abalone taken under recreational regulations will enter the export chain.

Objective 2. Where the fished stock(s) are below a defined reference point, the fishery will be managed to promote recovery to ecologically viable stock levels within nominated timeframes.

Management responses

1.2.1 A precautionary recovery strategy is in place specifying management actions, or staged management responses, which are linked to reference points. The recovery strategy should apply until the stock recovers, and should aim for recovery within a specific time period appropriate to the biology of the stock.

Target species – *blacklip abalone*

In the event that the relative biomass performance indicator for blacklip abalone decreases below the trigger reference point, there is a requirement for management intervention to ensure that the mature biomass (or egg numbers) is restored to a level greater than the reference point within five years. The management action could include an adjustment to the prevailing total allowable catch (TAC) and/or legal minimum length (LML) for the immediately following years, or other actions as appropriate to achieve recovery. The specified risk of 20 % probability that a decrease in biomass will fail to activate the trigger is regarded as precautionary.

By-product species – *greenlip abalone*

An assessment of greenlip abalone resources in Victoria concluded that the largest catch likely to be sustainable would be no more than 20 tonnes (Gorfine and Dixon 2000a). The Fishery Management Plan reflects this assessment in recommending that commercial catches be suspended for the life of the Plan or until follow-up surveys demonstrate substantial increases in stock abundance. These surveys are to be conducted biennially. The Fishery Management Plan also recognises that recovery without intervention is improbable for this species. Consequently, there is an additional recommendation that, where possible, reseeding in order to enhance the greenlip stocks is to be encouraged. This must be undertaken in full accord with the enhancement policy (discussed in the Fishery Management Plan) and should be accompanied by a program of monitoring growth and survival. Reporting of the results is to be through the fishery monitoring process involving the Abalone Fishery Committee.

1.2.2 If the stock is estimated as being at or below the biological and / or effort bottom line, management responses such as a zero targeted catch, temporary fishery closure or a 'whole of fishery' effort or quota reduction are implemented.

For greenlip abalone in Victoria the Abalone Fishery Management Plan proposes that legislation be changed to treat greenlip separately from blacklip in quota allocations and that because of the depleted status of stocks of this species that the TAC for greenlip abalone be set to zero. No change is proposed for recreational access because available evidence indicates that the impact of licensed recreational harvesting under current management arrangements (six-month seasonal closure and possession limit of two per person) is low.

PRINCIPLE 2.

Fishing operations should be managed to minimise their impact on the structure, productivity, function and biological diversity of the ecosystem.

Objective 1. The fishery is conducted in a manner that does not threaten bycatch species.

The Victorian abalone fishery is target-specific and has no bycatch.

Objective 2. The fishery is conducted in a manner that avoids mortality of, or injuries to, endangered, threatened or protected species and avoids or minimises impacts on threatened ecological communities.

The Victorian abalone fishery is target-specific and has no apparent direct effects on any threatened or protected species or threatened ecological communities and no known indirect effects.

Objective 3. The fishery is conducted, in a manner that minimises the impact of fishing operations on the ecosystem generally.

Information requirements

2.3.1 Information appropriate for the analysis in 2.3.2 is collated and/or collected covering the fisheries impact on the ecosystem and environment generally.

The Abalone Assessment Sub-program conducted by MAFRI undertakes annual surveys of abalone communities at 150 fixed locations across the breadth of the fishing grounds (Gorfine and Dixon 2000). In addition to these surveys, the Marine Strategy Unit of the Victorian Department of Natural Resources and Environment surveys species diversity and abundance at fixed sites within Marine Protected Areas (MPAs) as part of an Environmental Inventory Program (Ferns and Hough 2000). Although the former surveys are specifically directed towards the sustainability of abalone populations, the latter are more broadly focussed and concerned with entire ecosystem.

Assessment

2.3.2 Information is collected and a risk analysis, appropriate to the scale of the fishery and its potential impacts, is conducted into the susceptibility of each of the following ecosystem components to the fishery.

The Fishery Management Plan specifies that indices of ecosystem health be used as performance indicators of the impact of fishing on the ecosystem. Although abalone ecosystems are relatively well studied compared with the supporting ecosystems of many other fisheries, the formal use of ecosystem indices in the management of abalone fisheries is largely unprecedented.

1. Impacts on ecological communities

The main direct impact of the Victorian abalone fishery on ecological communities is the removal of 4–7 million abalone annually. No other organisms are removed and most competition between abalone and other organisms is for space. It is probable that the removal of large numbers of abalone is at least partially compensated by density dependent effects on growth and survivorship, however the scientific evidence to support this area of theory is scant and equivocal.

During annual fishery independent surveys, quantitative estimates of abundance of prevalent organisms other than abalone are undertaken. For vegetation these include cover abundance of major macroalgal divisions, kelp canopy and crustose coralline algae. Transect counts of urchins, sea stars, turban snails, and semi-quantitative estimates of other invertebrates are also made during these surveys. No counts of reef fishes are made, however fish counts are to be included in surveys of unfished MPAs.

One consequence of excessive stock depletion at a localised scale is the need for management intervention aimed at restoration. One restorative option is to translocate mature broodstock from nearby populations where abalone remain abundant. This raises an issue about potential impacts on genetic diversity within the depleted stock. Genetic effects from translocated and outplanted abalone reared in hatcheries have been reviewed by Benzie (1996) for South Australia and then extended to Victoria by Fleming (1997). The latter forms the basis for the policy on sea ranching that is included in the Victorian Abalone Fishery Management Plan.

Benzie (1996) concluded that any genetic shifts caused by additions of abalone from elsewhere would only be maintained whilst the additions continued and that permanent changes were improbable. In recommending a strategy for Victoria, Fleming (1997) considered the paradox between the large neighbourhood size of about 500 km coastline for blacklip abalone and the significant heterogeneity at a localised scale of several kilometres identified from the work of Brown (1991) and Brown and Murray (1992). The most likely explanation is that whilst gene flow is high over evolutionary time scales, inter-annual dispersal of larvae is localised to create a distance by isolation genetic structure for blacklip abalone populations. Consequently, the metapopulation scale referred to in the Fishery Management Plan represents a conservative approach to protecting the genetic integrity of Victorian abalone wildstocks.

Parallel concerns about the spread of disease from hatcheries are speculative. An endemic disease that thrives under hatchery conditions is likely to revert to low levels of infection in the unlikely event it is transferred back into the natural environment. Addition of abalone in accordance with the ranching policy appears to pose negligible risk to the ecosystem.

2. Impacts on food webs

Abalone are one of several dominant benthic herbivore groups in their communities. Others include sea urchins and turban snails. However, abalone tend to feed predominantly on drift algae rather than graze attached plants, reducing their direct competition with other grazing herbivores. Evidence of urchin barrens in Victoria is realtively uncommon and confined to Eastern Zone in habitats where

Centrostephanus rodgersii is the dominant urchin species. Barrens habitat is characterised by substantial changes in macroalagal assemblages towards compositions that are unfavourable to abalone (Andrew and Underwood 1992). *Heliocidaris erythrogramma* is the main urchin species west of Mallacoota and does not appear to have the same profound influence that *C. rodgersii* has on abalone communities.

Abalone are also prey for a range of reef fishes, particularly wrasses, morwong, rays and heterodontid sharks. Other significant predators include seastars, decapod crustaceans and shell-drilling gastropods (Shepherd and Breen 1992). Predator-prey interactions depend substantially on the relative size of the abalone to the predator. There is likely to be considerable functional redundancy because not all these groups are present within every abalone habitat. There is no known top chain predator in Victoria that depends solely on abalone for food and it is reasonable to surmise that the trophic effects of removing large numbers of abalone from the ecosystem are likely to be diffuse. More research is needed to examine the effects of reducing abalone populations on energy and nutrient flows within their ecosystems and the effects on organisms that may depend on the presence of abalone.

3. Impacts on the physical environment

Physical habitat

Abalone harvesting involves the direct removal of abalone from rocky reefs. This means there is no physical damage to the substrate that can be ascribed to the fishing activity. Abalone fishing operations take place from relatively small runabout boats (Gorfine and Dixon 2001). As with any small boating activity, there is some potential for anchor damage to the substrate and benthic organisms, however in temperate rocky reef systems this is negligible in terms of the ecosystem as a whole.

Water quality

There only obvious risk to water quality is pollution from spillage of fuel and oil from boats and hookah compressors. However, the limited number of commercial boats, and the volumes involved relative to the volume of seawater, mean that any impacts would be isolated and of limited consequence to the ecosystem.

Management responses

2.3.3 Management actions are in place to ensure significant damage to ecosystems does not arise from the impacts described in 2.3.1.

In the event that changes unfavourable to the maintenance of abalone ecosystems are detected during the fishery assessment process, the management response may follow several paths depending on the perceived severity of the change and urgency for a response. Whenever trigger reference points (in this case a 10% or greater change in ecosystem health indices, such as key species critical to the persistence of the ecosystem) are reached the Minister will be notified. The Abalone Fishery Committee (AFC) will meet as a matter of urgency to determine its assessment and advice to the Minister. Its advice will be submitted through the Fisheries Co-Management Council, with a copy to Fisheries Victoria.

In deciding which course of action to recommend, the AFC will consider the outcomes of the full range of fishery performance indicators as well as any other data it believes to be relevant.

On the basis of these considerations it will recommend one of the following courses of action to the Minister, together with a full explanation:

(i) No action be taken but that the situation be re-evaluated following observation of the behaviour of the ecosystem for another fishing year or;

(ii) Immediate and intensive investigation be undertaken to clarify components of the performance of the ecosystem prior to further decisions and action or;

(iii) Action to be taken which reduces the prevailing total allowable catch (TAC).

(iv) Other actions as appropriate to achieve recovery from the trigger value with the minimum delay as practicable but not exceeding five years.

2.3.4 There are decision rules that trigger further management responses when monitoring detects impacts on selected ecosystem indicators beyond a predetermined level, or where action is indicated by application of the precautionary approach.

The Fishery Management Plan requires that if ecosystem health indices (abundance indices for key species within major functional groups) decrease below 90% of their average value over the previous three years a management response will be triggered.

In applying this decision rule, recognition will be given to the dynamic nature of ecosystems that sees a flux of species over time. Stochastic processes of evolution, sometimes over relatively short time scales, give rise to different combinations of species that essentially perform a similar array of functions under similar environmental conditions (see Levin 1999). Where one species departs from the ecosystem, there is often another that can take over its functional role, often by increasing in abundance. This functional redundancy provides ecosystems with the resilience to persist through periods of environmental change. It also means that different combinations of species may be associated with abalone and that there is no one temperate rocky ecosystem for abalone, although there are some essential functional groups of organisms, on which abalone depend, that must be present. Mostly these are species of macroalgae and crustose coralline algae (CCA). There is no evidence of species whose persistence depends solely on the presence of abalone, although there is a range of predators and parasites that includes abalone in their diets.

When decreases are detected in the abundance of key species monitored during underwater surveys these will be considered during assessments of the fishery and communicated to fishery managers. The advice to fisheries managers will include an assessment of the extent to which decreases in these indices reduce the functional redundancy in the ecosystem. Changes in species diversity *per se* should not be grounds for management intervention unless there is clear evidence that fishing is the most probable cause.

If the Marine Strategy Unit surveys demonstrate ecosystem effects of concern that are attributable to removal of abalone then it is anticipated that this will be drawn to the attention of the relevant fishery managers.

2.3.5 The management response, considering uncertainties in the assessment and precautionary management actions, has a high chance of achieving the objective

The relationship between abalone and other ecosystem components is not well understood and likely to be complex. Utility of performance indicators (as specified) is consequently equivocal with regard to the objective. The performance measure for the indicator is robust in terms of ability to collect the necessary monitoring data, however, lack of knowledge means that a robust reference point for the indicator remains elusive. The recommendation of a trigger point set at 90% of the preceding 3-year average is conservative. Many organisms found in abalone dominated ecosystems exhibit substantial interannual fluctuations in abundance that are likely to driven by natural events. To ensure that the reference point is not inadvertently triggered, careful consideration must be given to the selection of each particular index of the ecosystem used in the indicator. However, there is little doubting that substantial loss of CCA or kelp overstorey will result in commensurate declines in abalone. It would also be reasonable to expect that overfishing of abalone will create space for other organisms, such as ascidians and sponges to colonise vacated abalone homesites. This may preclude restoration of abalone abundance despite favourable population recruitment events in the future.

The following example illustrates the complexity of interpreting ecosystem data from surveys of abalone habitats. Concerns have been expressed periodically by abalone divers over the past two decades about outbreaks of the native 11-arm seastar *Coscinasterias muricata* that appears to have become more prevalent and widespread along the Bass Strait coastline. This seastar is a known predator of abalone which have a relatively well developed escape response when in its presence. It is likely that the 11-arm seastar population responds to environmental cycles in similar fashion to the crown-of-thorns seastar on the Great Barrier Reef. Fig. 8 shows that in many instances where the 11-arm seastar is in relatively high abundance, abalone abundance is low and vice-versa. However, for the majority of locations surveyed 11-arm seastars were absent, yet abalone varied in abundance and consequently the correlation between the two species is weak. It is also worth considering that although the exotic sea star *Asterias amurensis* has not spread beyond the shelter of Port Phillip Bay to the more rugged Bass Strait reefs, *C. muricata* is the only known local predator of *A. amurensis.* This suggests that 11-arm seastars may have the potential to protect abalone populations if *A. amurensis* spreads to abalone reefs in sheltered areas outside Port Philip Bay.

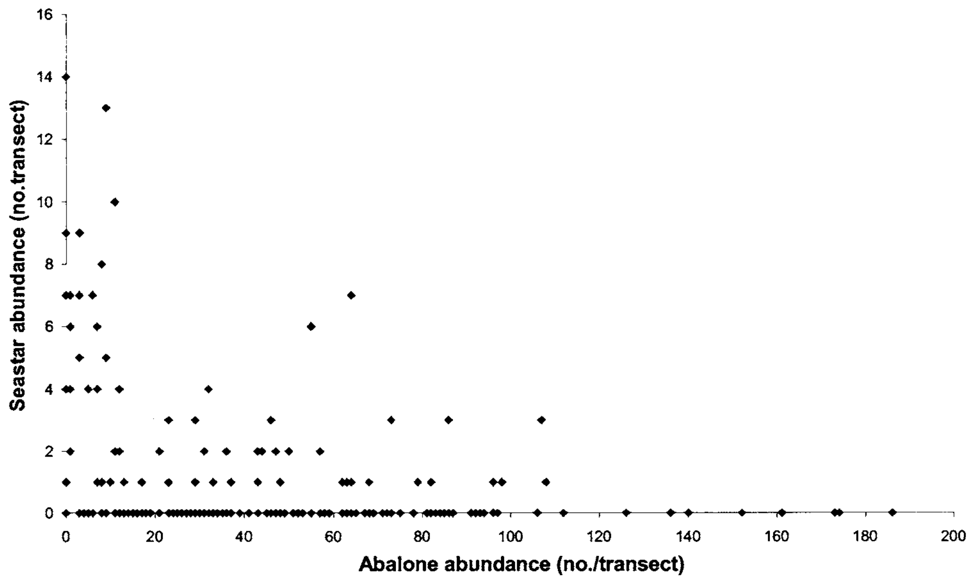

Figure 8. Abundance of abalone relative to 11-arm sea stars within transects surveyed in the Western Zone of Victoria.

Management responses for this performance indicator are unprecedented for abalone fisheries, although experimental manipulations of sea urchins and abalone have been trialed in NSW. Most of the focus overseas has been on responding to declines in abalone abundance, rather than other species in the ecosystem. Management responses in these instances have invariably included fishery closure and attempted restoration, often by outplanting hatchery-reared abalone with limited success. Because abalone share their habitat with other exploited species, including southern rock lobster, urchin, turbo (periwinkle), wrasses and morwong, trade-offs may be necessary. There is a need for recognition that the exploitation of any one these species will affect both the abundance of the others and the influence of those other species on the ecosystem. Such recognition may come in the form of integrated fisheries management plans in the future.

DEFINITIONS

The following defines how certain terms will be interpreted in application of the guidelines.

Associated and/or dependent species - species associated with or dependent upon harvested species, for example species which are predator or prey of the harvested species.

Biological diversity, biodiversity - the variability among living organisms from all sources (including marine and other aquatic ecosystems and the ecological complexes of which they are part). Includes 1) diversity within species and between species; and 2) diversity of ecosystems.

Bycatch - species that are discarded from the catch or retained for scientific purposes, and that part of the "catch" that is not landed but is killed as a result of interaction with fishing gear. This includes discards of commercially valuable species.

By-product - species that are retained because they are commercially valuable but are not the main target species.

Ecologically related species - species which, while not associated with or dependent upon a harvested species, nevertheless are affected by the fishing operation.

Ecologically sustainable - use of natural resources within their capacity to sustain natural processes while maintaining the life-support systems of nature and ensuring that the benefit of the use to the present generation does not diminish the potential to meet the needs and aspirations of future generations.

Ecologically viable stock - ecological viable stock has a general rather than a specific meaning. It refers to the maintenance of the exploited population at high levels of abundance designed to maintain productivity, provide margins of safety for error and uncertainty and maintain yields over the long term in a way that conserves the stocks role and function in the ecosystem.

Ecosystem - the biotic (living) community and its abiotic (non-living) environment.

Function - relationships between components of the ecosystem, without which individuals could not survive and/or reproduce. eg protection for juveniles provided by marine plants; trophic relationships.

Management regime - In this document, refers to the policies, plans, action plans, strategic research plans, and all documentation that relates to the operations and management of the fishery.

Overfishing - can be defined in two ways that can act independently or concurrently: 1) "recruitment overfishing", where fishing activities are causing a reduction in recruitment in succeeding years and cause the mortality of too many fish in total, too many pre-productive fish, or too many fish that have only spawned a few times. The end result is that the stock can no longer replenish itself adequately. 2) "growth overfishing": where fishing activities lead to a reduction in the size of the individuals of a species, as a consequence of which few specimens grow to the size for optimum yield.

Precautionary approach - used to implement the precautionary principle. In the application of the precautionary principle, public and private decisions should be guided by: 1) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and 2) an assessment of the risk-weighted consequences of the various options.

Precautionary principle - the lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment where there are threats of serious or irreversible environmental damage.

Precautionary recovery strategy - Management and operational strategy, designed to increase numbers within the stock, that incorporates the precautionary approach and includes mechanisms to avoid or mitigate adverse ecosystem effects.

Productivity - when applied to fish stocks the term productivity gives an indication of the birth, growth and death rates of a stock.

Reference point - an indicator level of fishing (or stock size) to be used as a benchmark for assessment or decision making.

Stock - In the strict sense, a distinct, reproductively isolated population. In practice, a group of individuals of a species in a defined spatial range which is regarded as having a relatively low rate of exchange with others of the species.

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Appendix 1 Victorian Abalone Management Advisory Committees

Abalone Fishery Committee (AFC)

Purpose

The AFC provides a process for bringing together stakeholder representatives and others with appropriate expertise, for the purpose of advising on the status of the fishery, and in particular to recommend 'best choice' values for the total allowable catch (TAC) and legal minimum length (LML) for each management zone. The AFC provides its advice on these matters to the Minister, through the Fisheries Co-management Council. The advice is provided annually or more frequently, as the Minister may request. The AFC also provides advice on planning of enforcement, research and other matters, including the provision of advice on annual plans and associated cost recovery.

Membership

* Independent Chairperson
* Member nominated by NRE Secretary (the abalone resource manager)
* Western Zone AFAL licence holder
* Central Zone AFAL licence holder
* Eastern Zone AFAL licence holder
* Abalone Processor
* Conservation member

Functions

1. Evaluate reports submitted by DNRE staff and industry members on the status of the fishery.
2. Prepare a Status of the Fishery Report for submission to the Minister
3. Prepare a recommendation on the 'best choice' combinations of TAC and LML for each zone of the fishery for submission to the Minister
4. Provide advice on other matters referred to it by the Fisheries Co-management Council.

AbaloneFAG

Purpose

The AbaloneFAG provides a process for bringing together scientists with a range of skills, resource users and resource managers, for the purpose of advising on methodology, synthesis of information, interpreting outputs, and for giving technical and scientific advice for use in managing the abalone fishery.

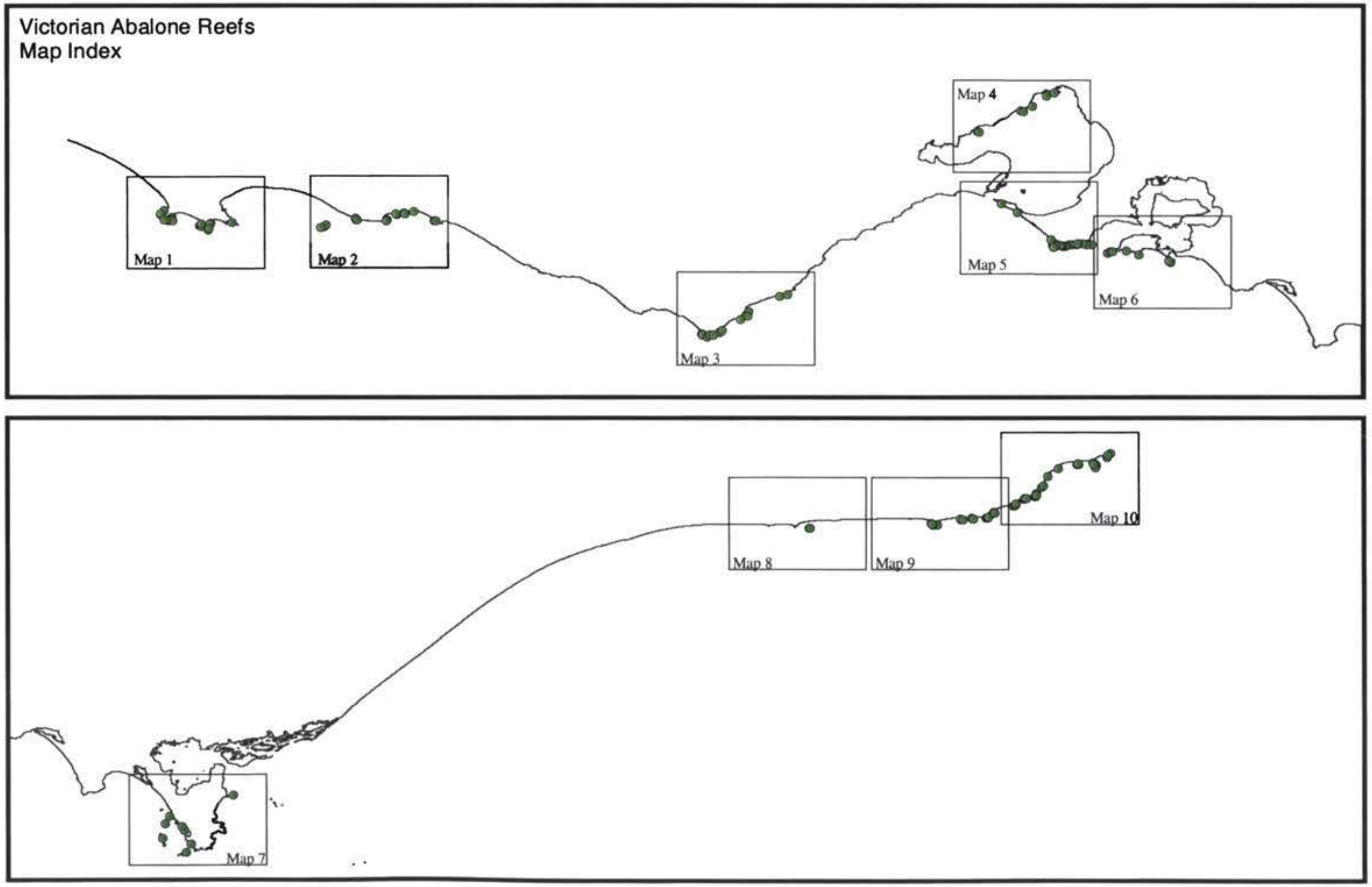
Participants

* MAFRI scientists directly involved in abalone research and assessment.
* Scientists with special expertise in abalone biology and fishery stock assessment.
* Fisheries Victoria
* Abalone Fisheries Committee
* Industry
* Victorian recreational fishing peak body (VRFish)
* Conservation peak body (Victorian National Parks Association), and
* DNRE coastal regions.

Functions

1. Improve scientific input into stock assessment of Victoria's abalone fishery.
2. Interpret assessment outputs for utilisation in the management of the fishery.
3. Encourage direct stakeholder participation in the stock assessment processes.
4. Provide a forum for planning future abalone stock assessment and other research needs and priorities.
5. Prepare annual Abalone Fishery Assessment Reports and associated scientific advice.

Abalone resource assessment: fishery independent survey sites, reef and catch-effort reporting blocks



Legend for Victorian Abalone Site Maps

$ Locations

s Abalone Sample Sites

Abalone Area Boundaries

30m Depth Contour

Road Network

Substrate Types

Reef

Sediment

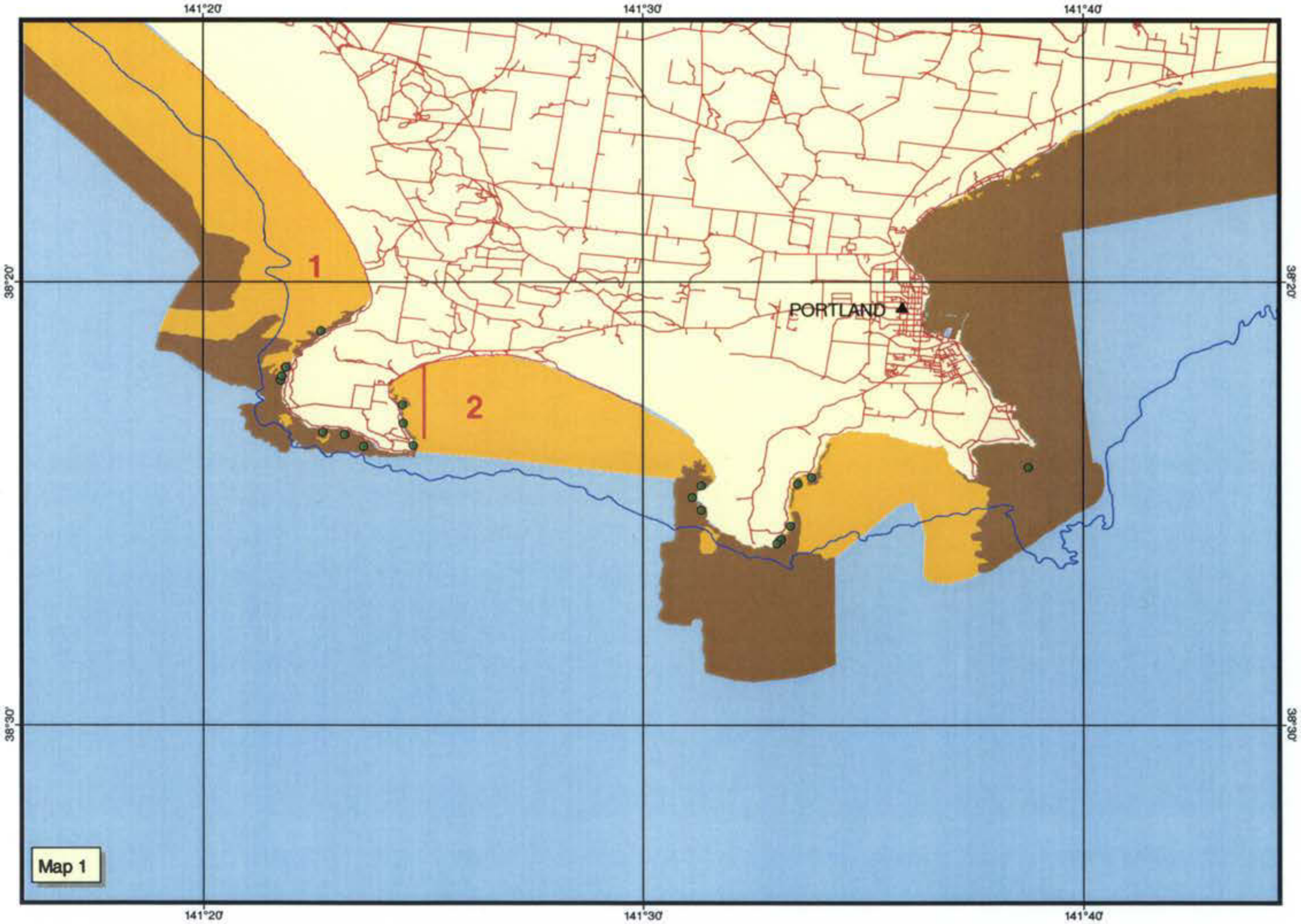
Undefined

5 0 5 10 15 Kilometres

N W E S

MARINE & FRESHWATER RESOURCES INSTITUTE

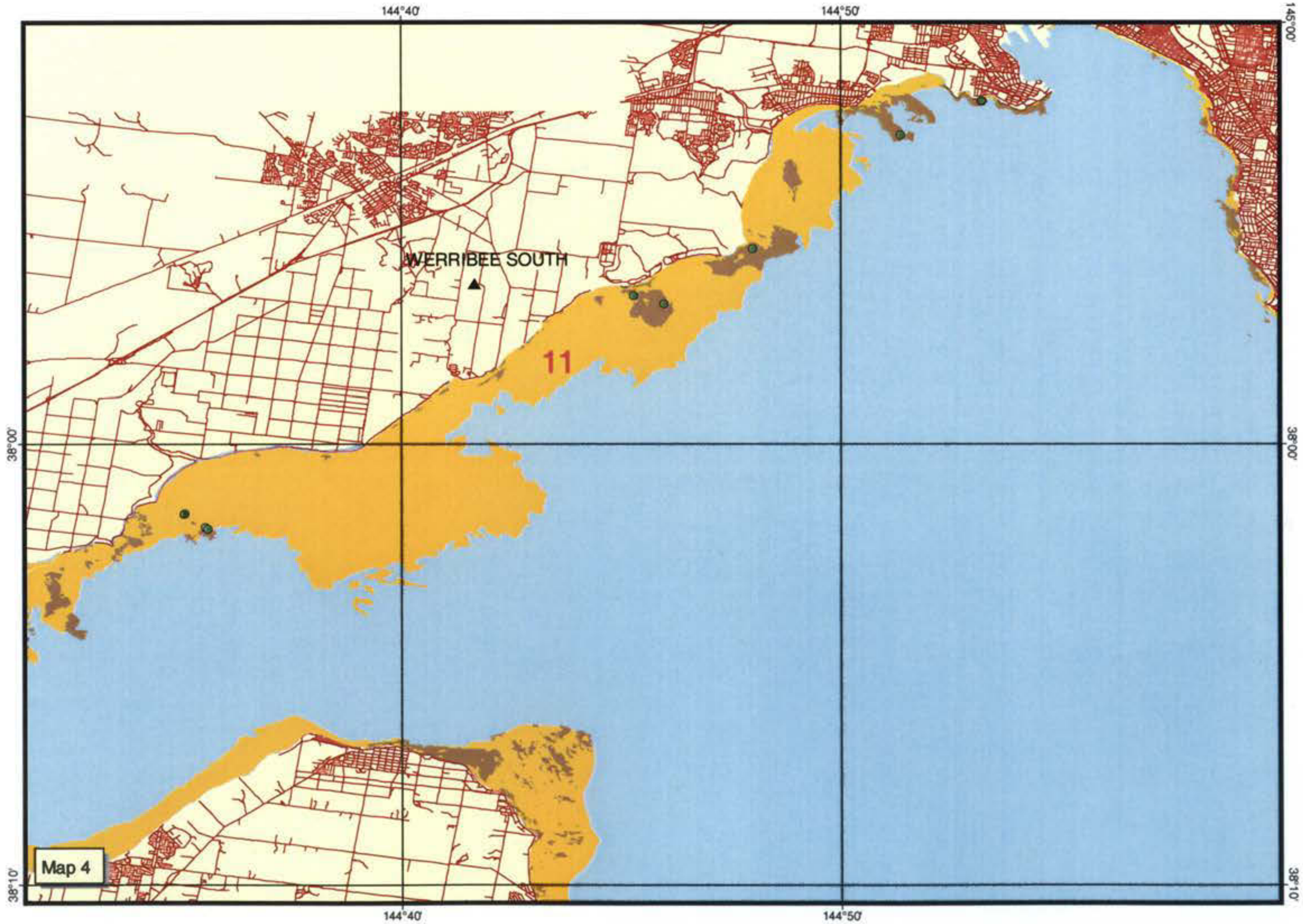
Maps 1 to 10 are all at a scale of 1:200,000
Maps are in Transverse Mercator Projection.
Horizontal Datum is AGD66



141°20'
141°30'
141°40'
38°20'
38°30'
1
2
PORTLAND
Map 1

142°00'
142°10'
142°20'
38°20'
38°30'
2
3
PORT FAIRY
WARRNAM
Map 2


143°30'
143°40'
143°50'
38°40'
38°50'
APOLLO BAY
8
6
7
Map 3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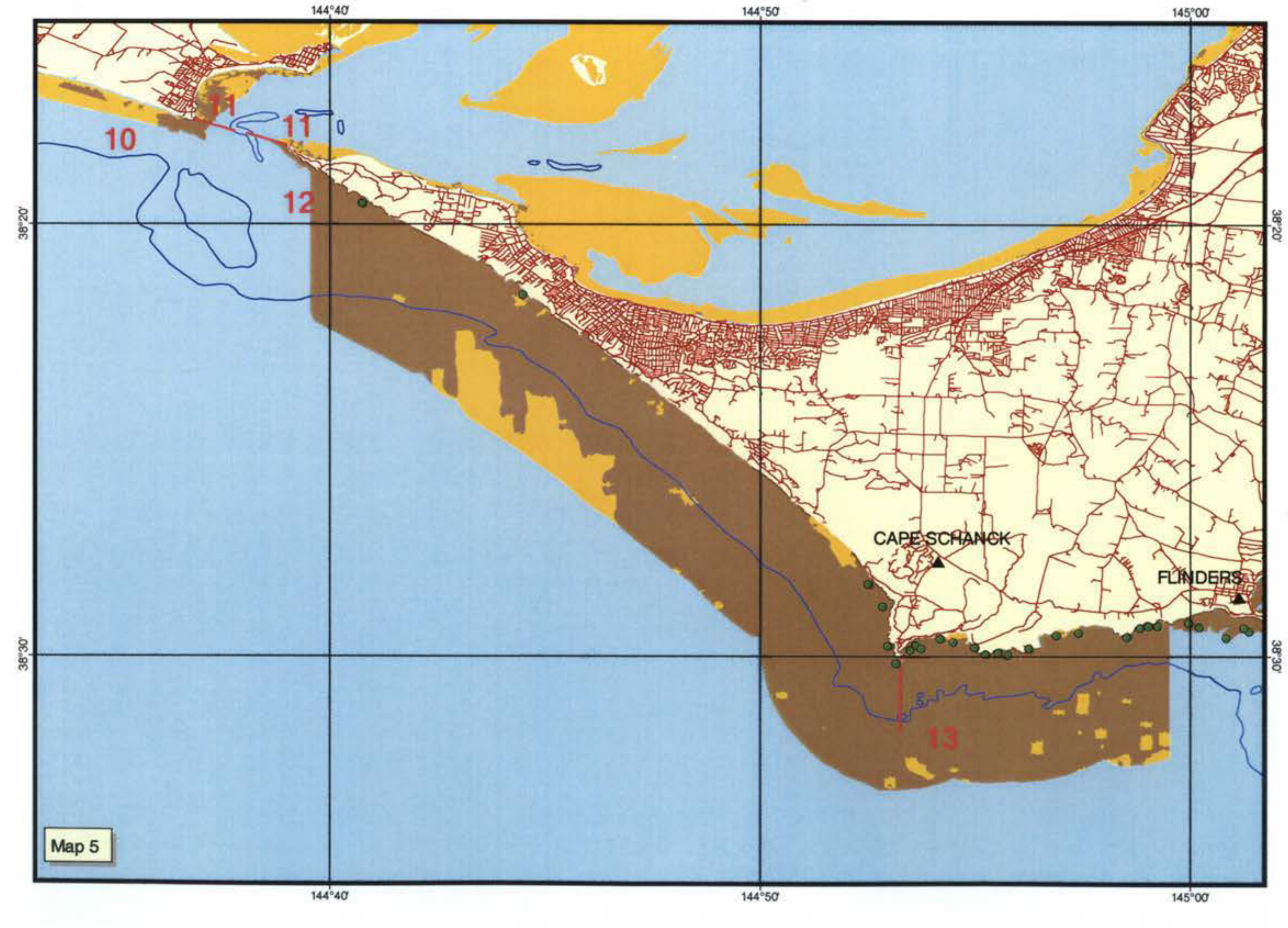
144°50'
145°00'
38°00'
38°10'
WERRIBEE SOUTH
11
Map 4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38°20'
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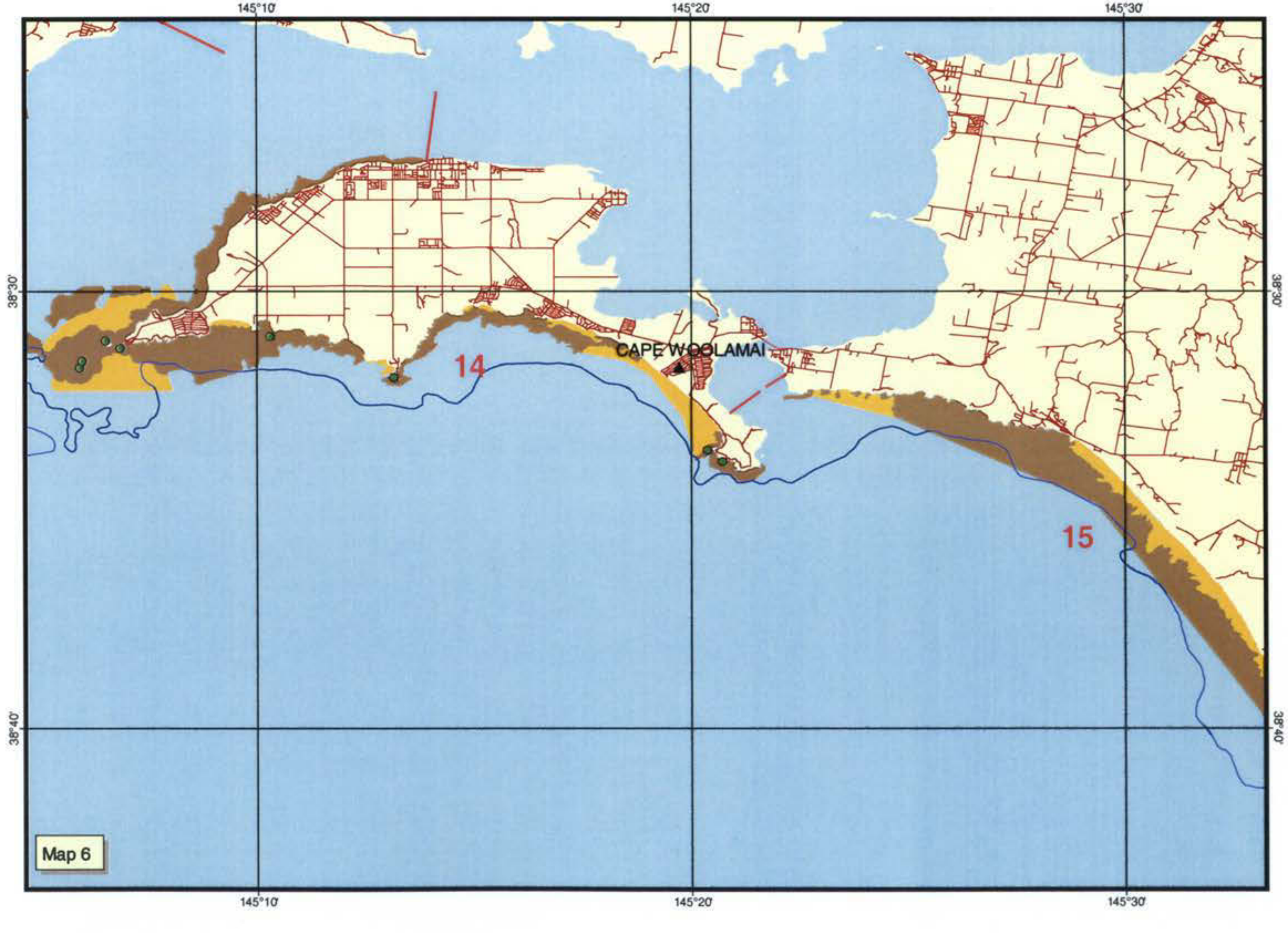
10
11
11
12
13
CAPE SCHANCK
FLINDERS
Map 5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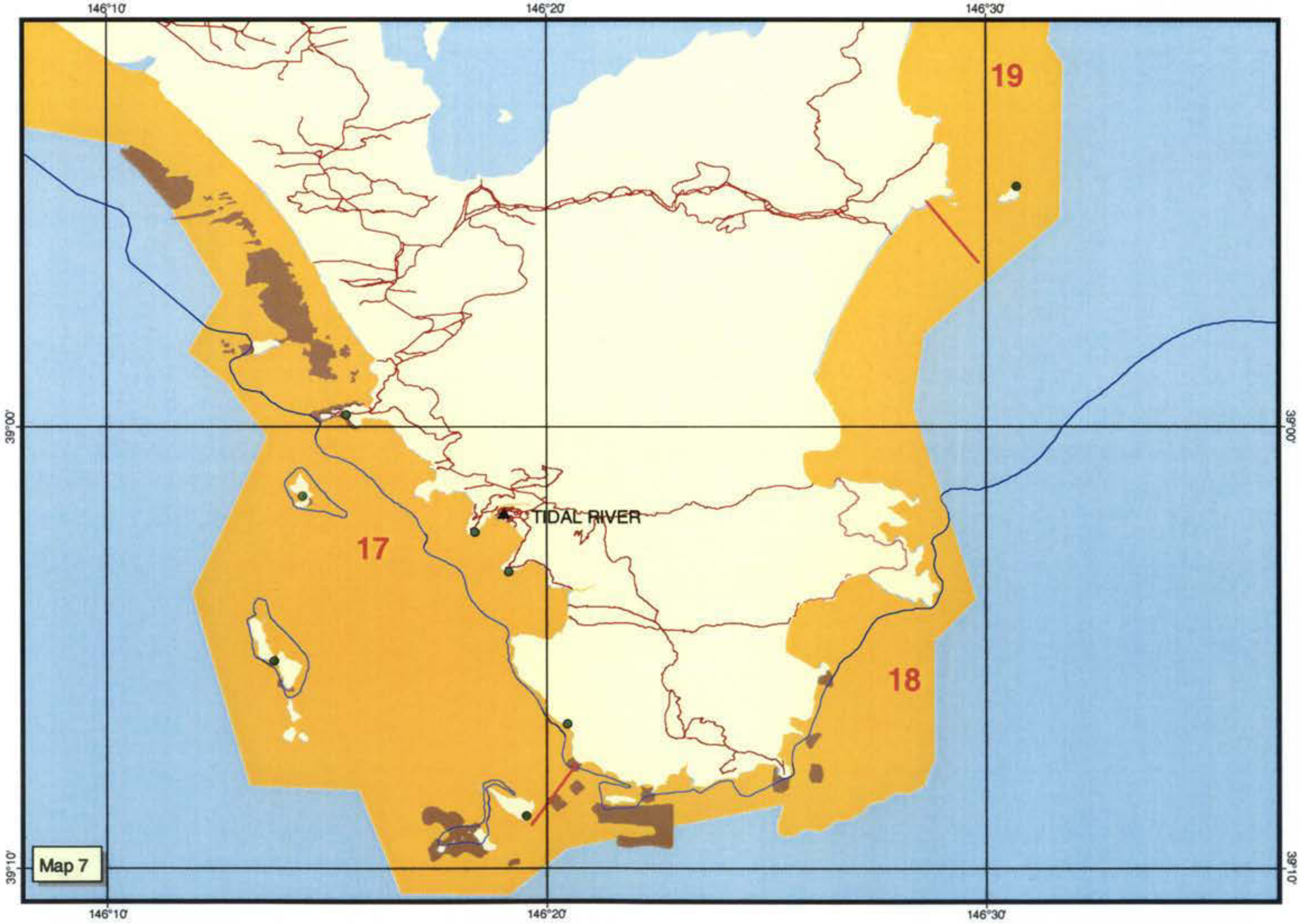
38°40'
CAPE WOOLAMAI
14
15
Map 6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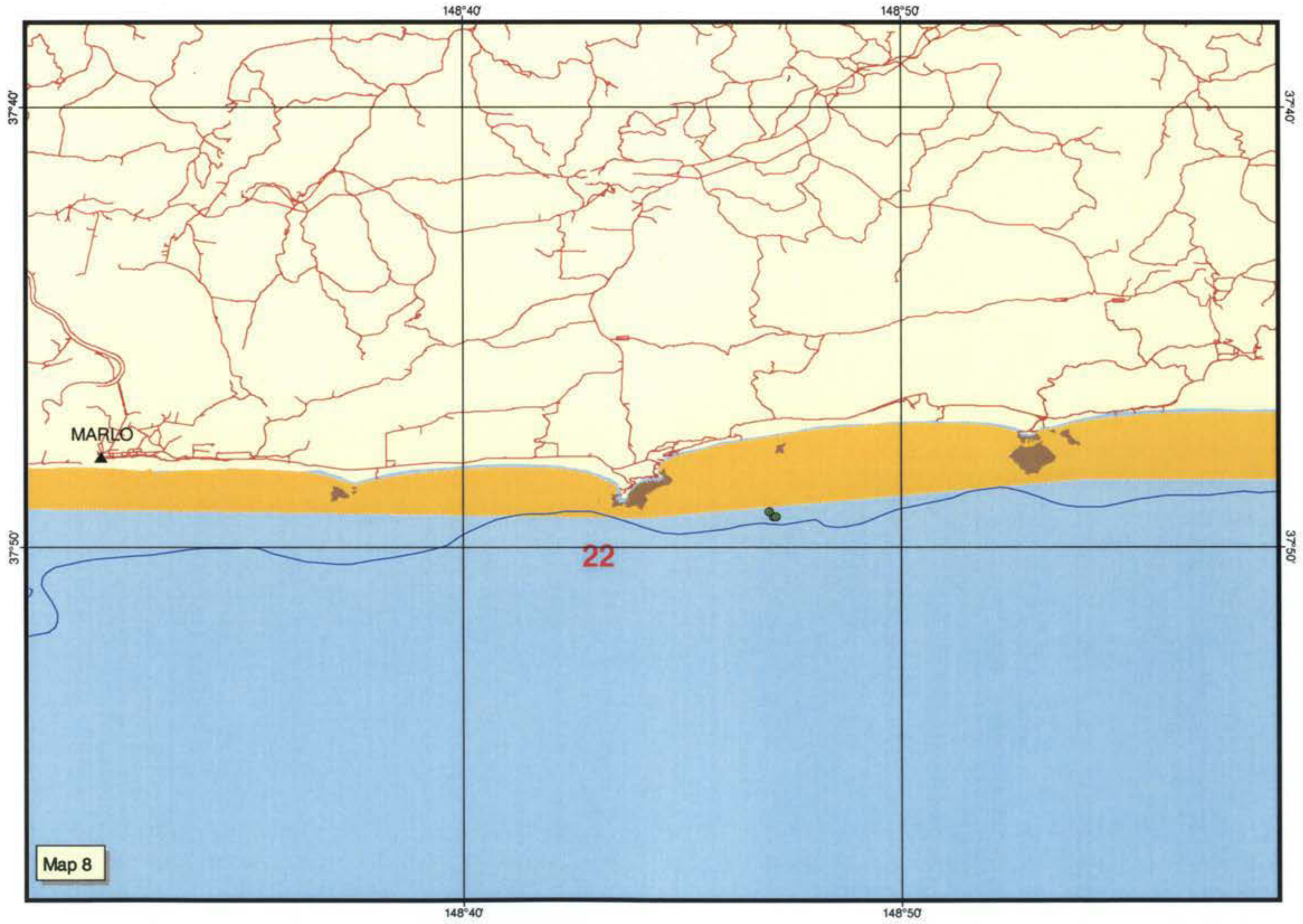
146°20'
146°30'
39°00'
39°10'
19
17
18
TIDAL RIVER
Map 7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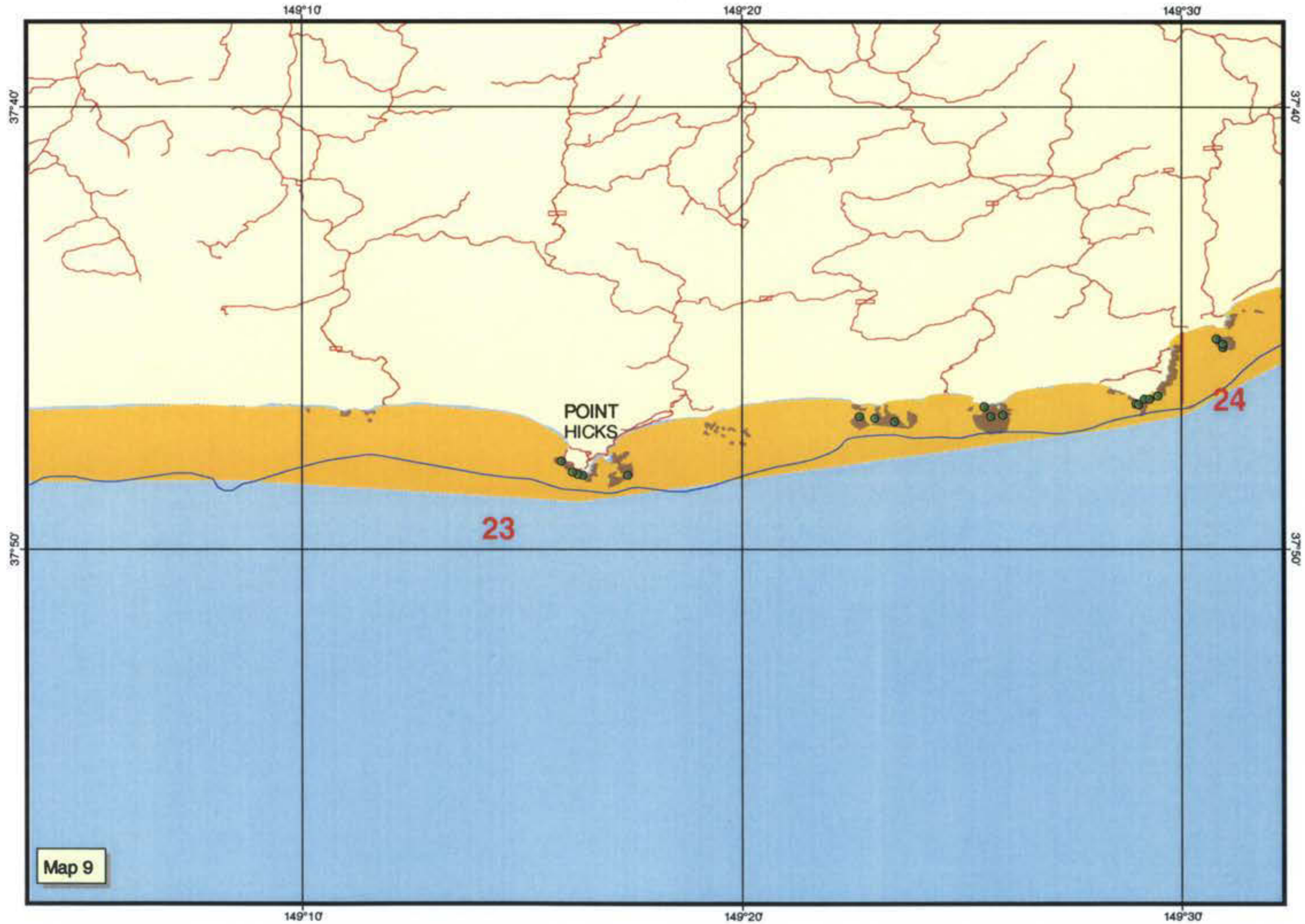
148°50'
37°40'
37°50'
MARLO
22
Map 8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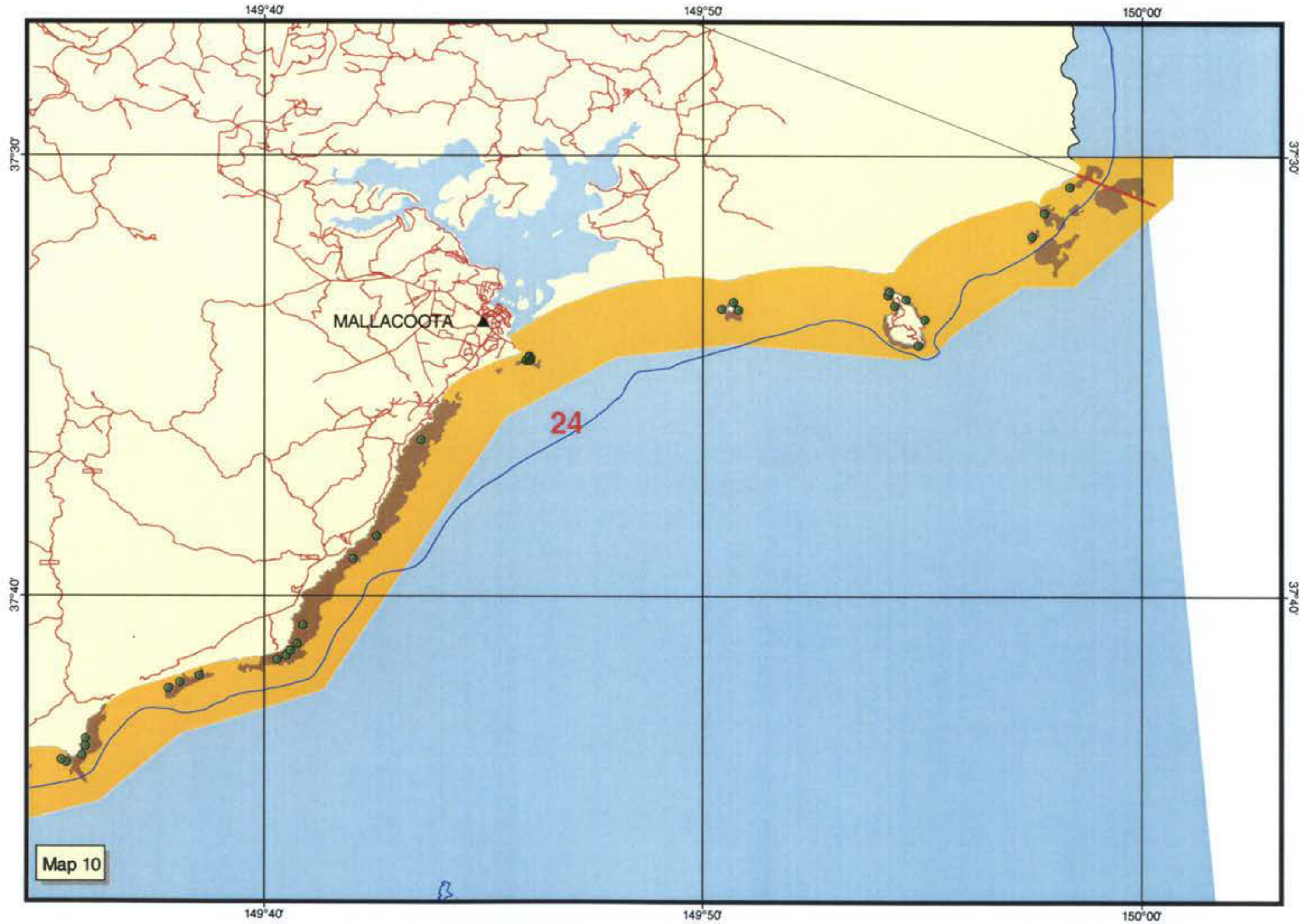
149°20'
149°30'
37°40'
37°50'
POINT
HICKS
23
24
Map 9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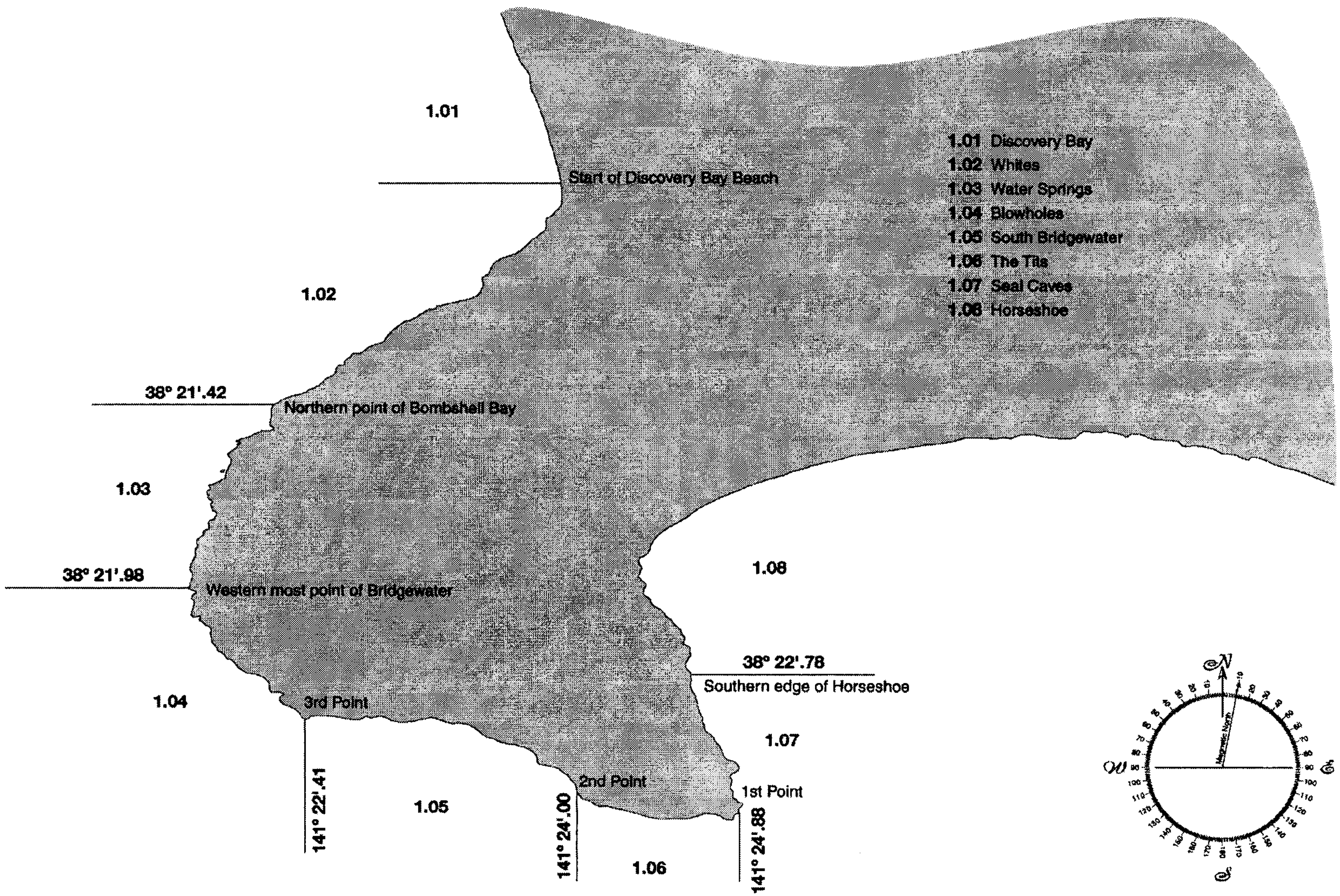
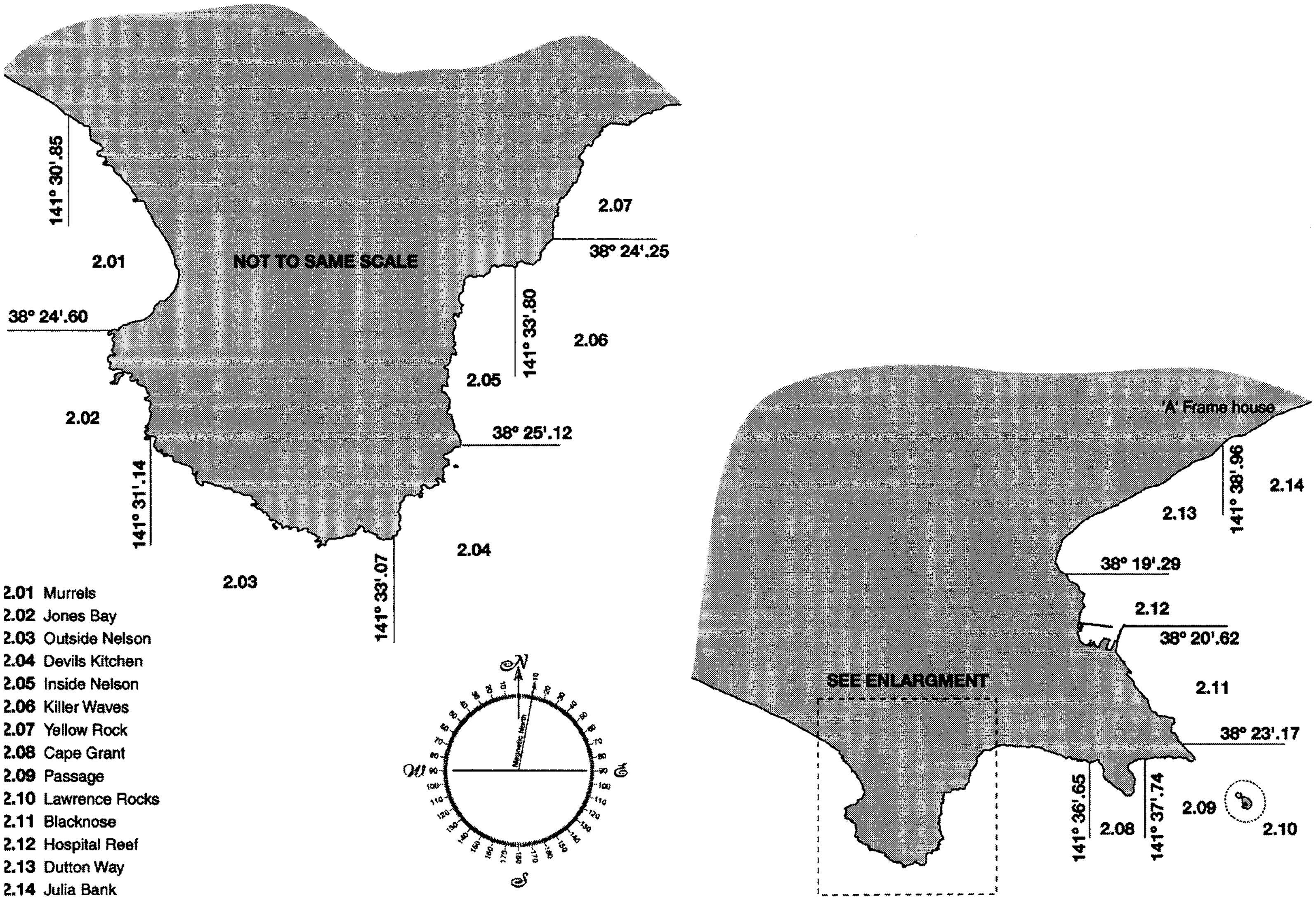
MALLACOOTA
24
Map 10

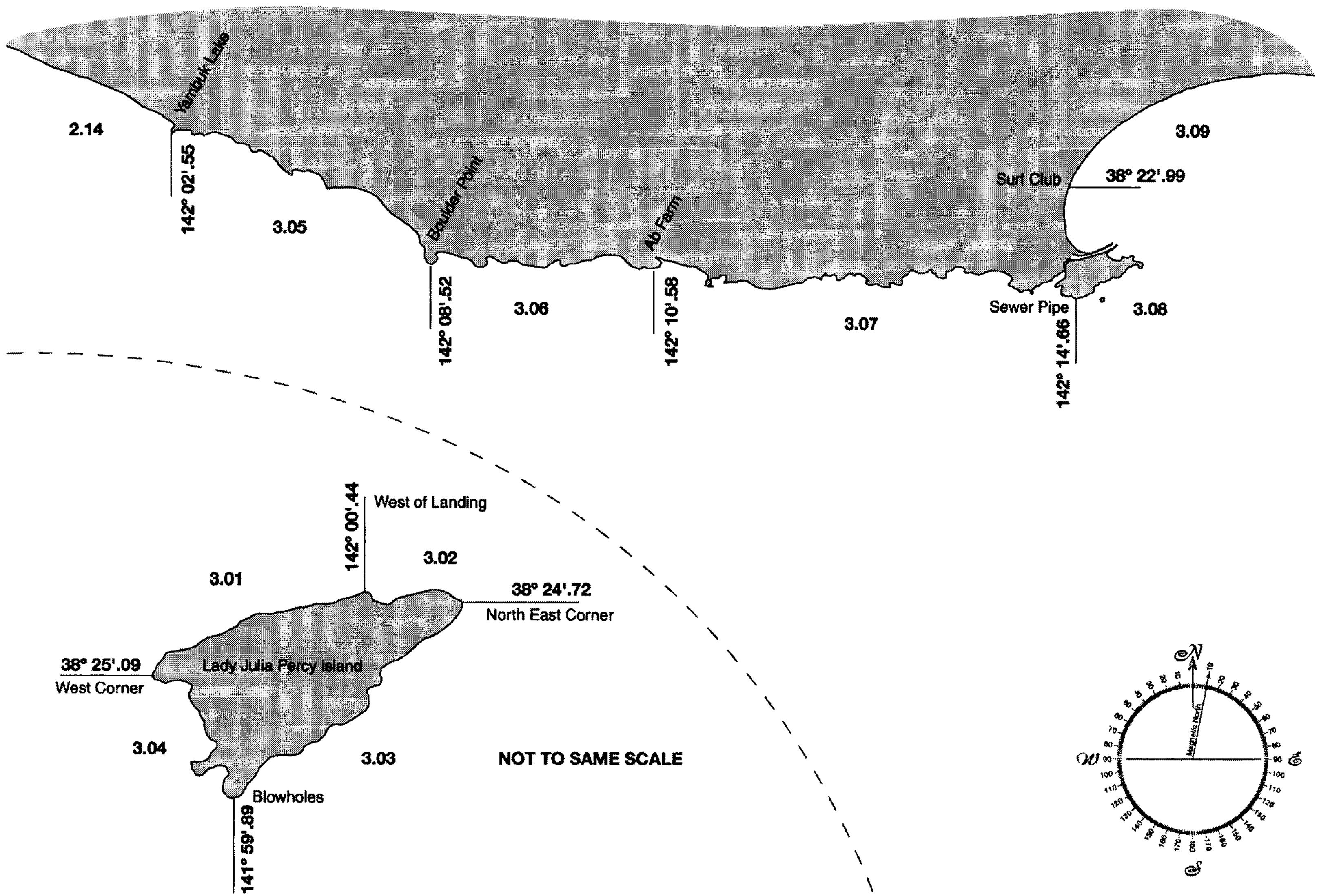


Victorian Abalone Reef Codes: Western zone, MapWZ1. (Cape Bridgewater)

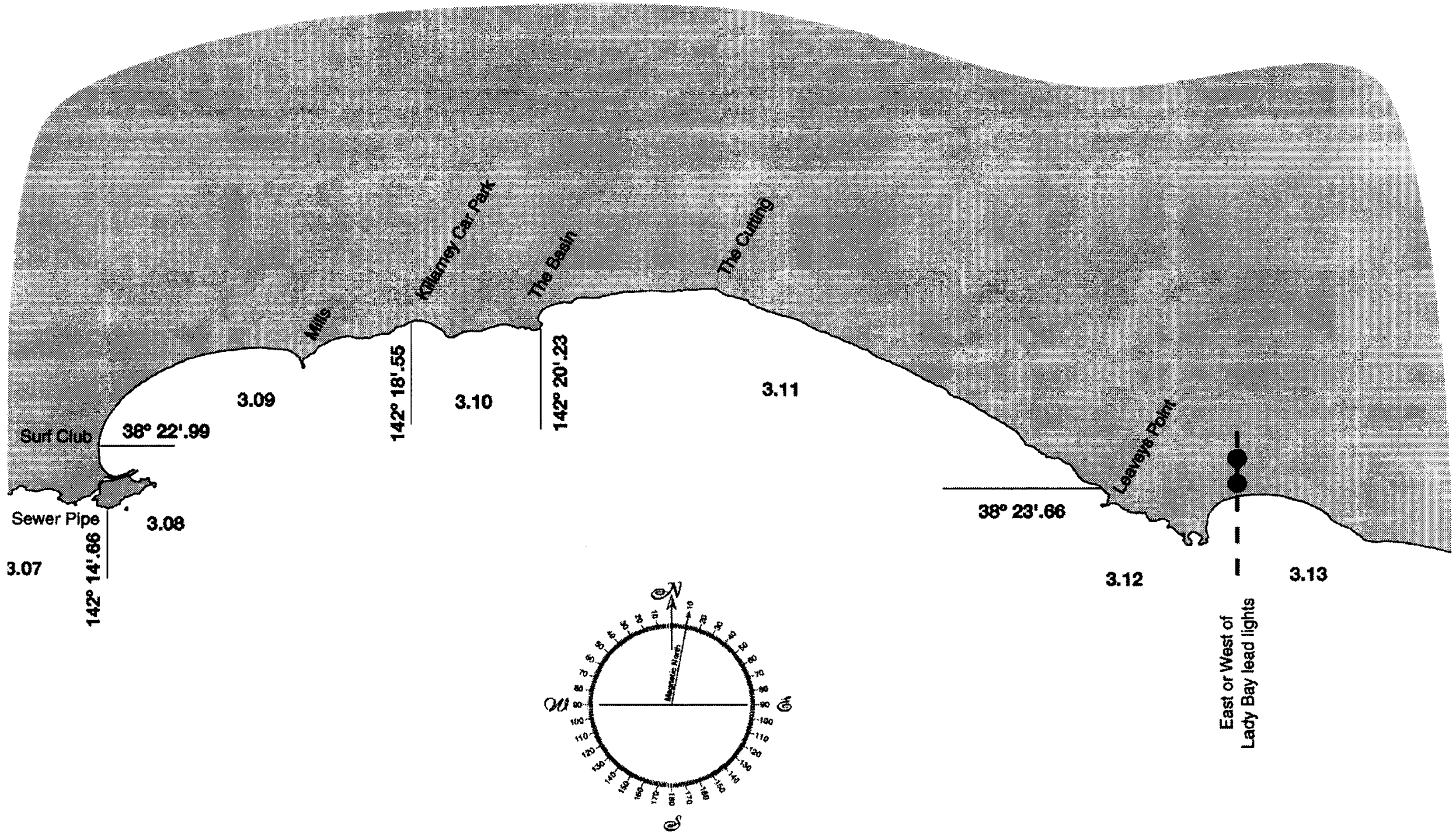


2.01 Murrels
2.02 Jones Bay
2.03 Outside Nelson
2.04 Devils Kitchen
2.05 Inside Nelson
2.06 Killer Waves
2.07 Yellow Rock
2.08 Cape Grant
2.09 Passage
2.10 Lawrence Rocks
2.11 Blacknose
2.12 Hospital Reef
2.13 Dutton Way
2.14 Julia Bank

Victorian Abalone Reef Codes: Western zone, MapWZ2. (Cape Nelson to Portland)

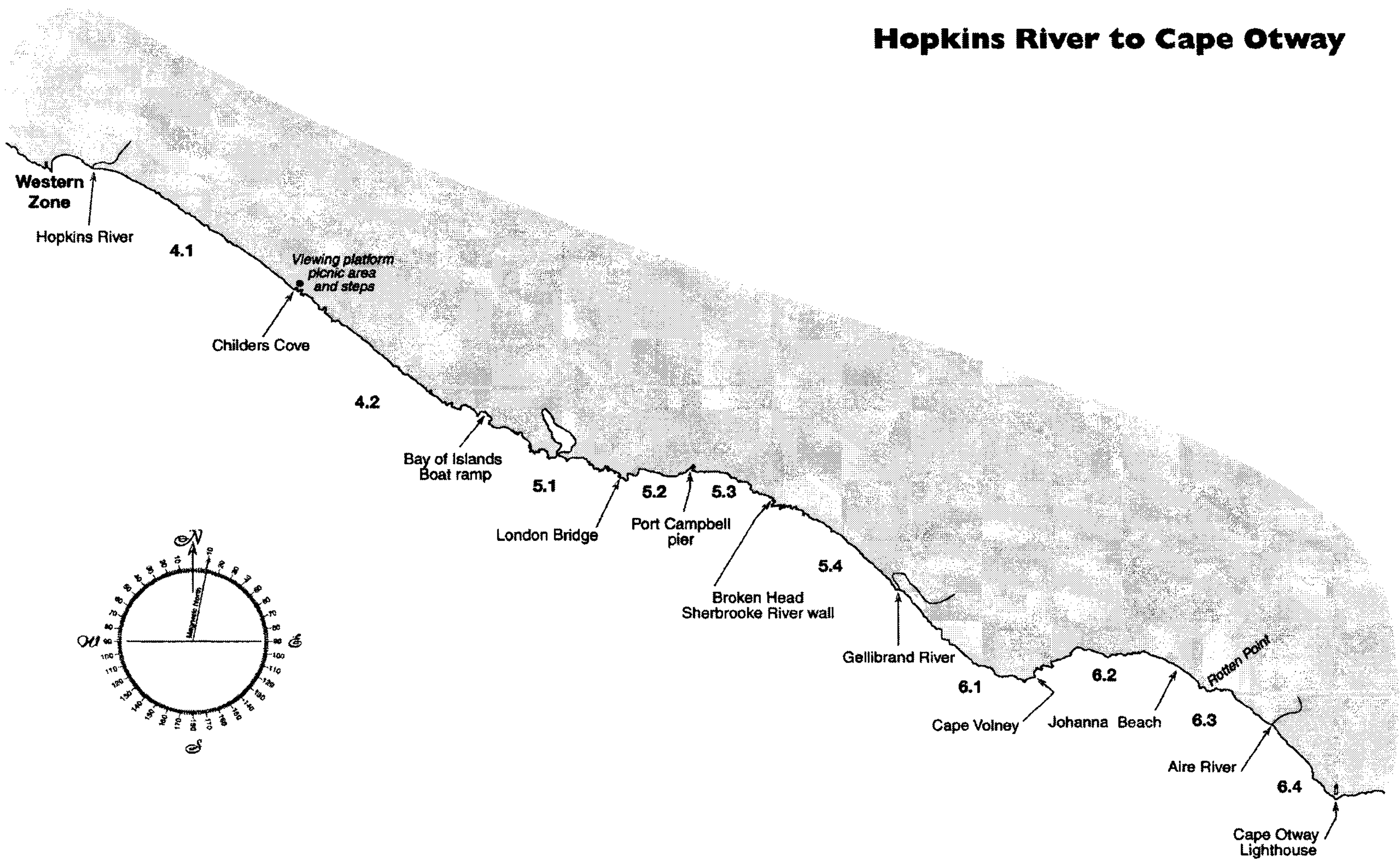


Victorian Abalone Reef Codes: Western zone, MapWZ3. (Port Fairy)



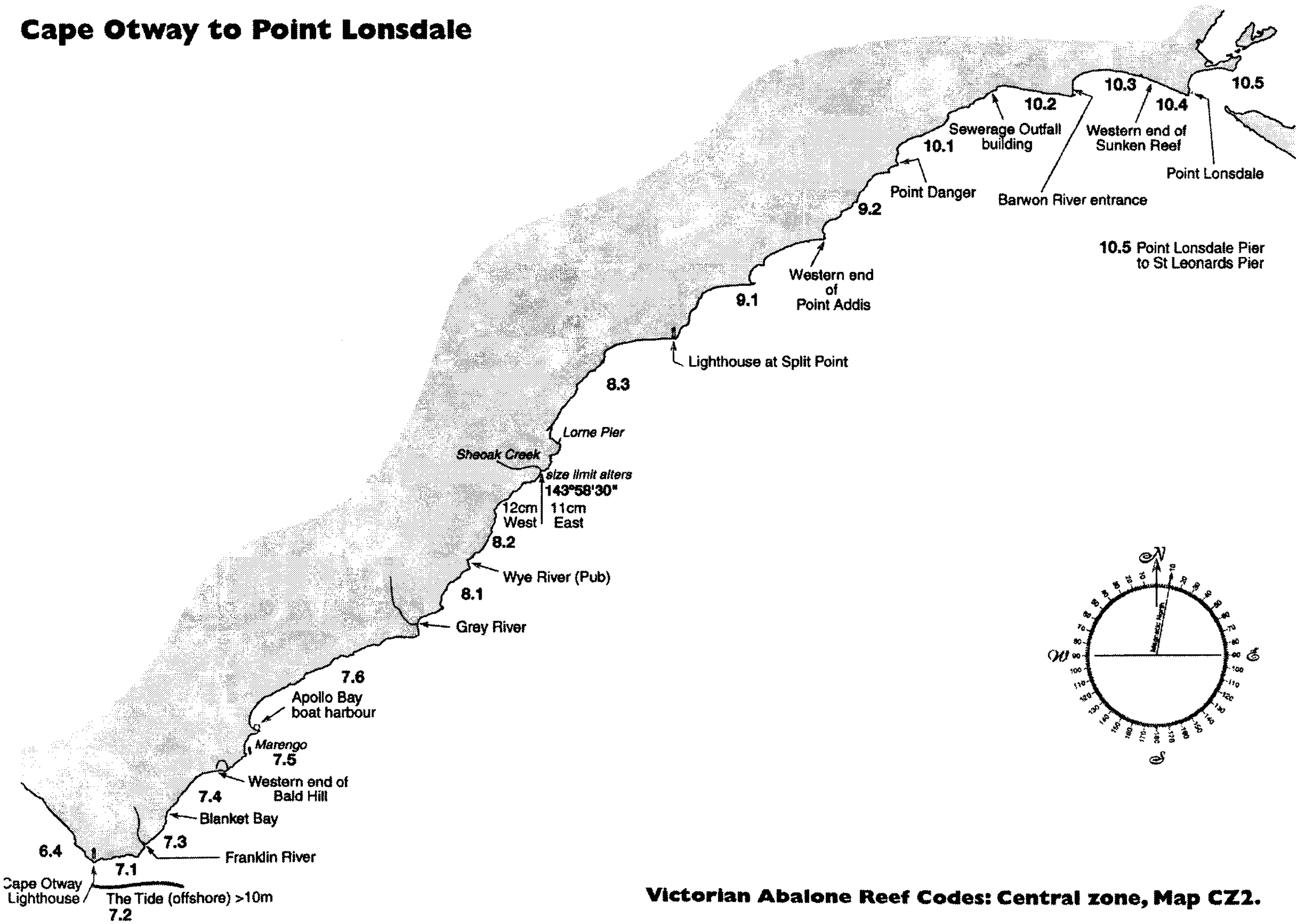
Victorian Abalone Reef Codes: Western zone, MapWZ4. (Port Fairy to Warrnambool)

Hopkins River to Cape Otway



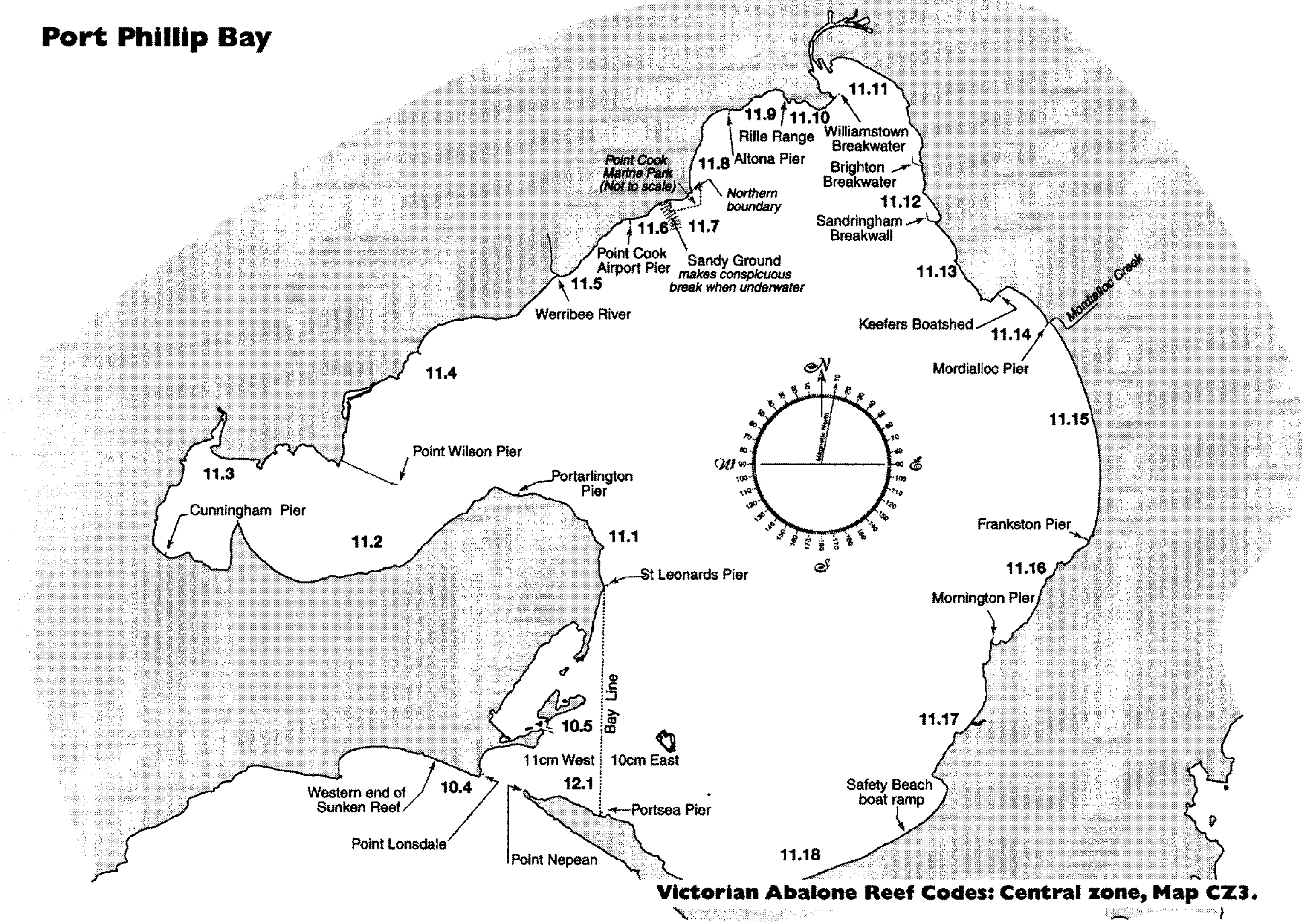
Victorian Abalone Reef Codes: Central zone, MapCZ1.

Cape Otway to Point Lonsdale



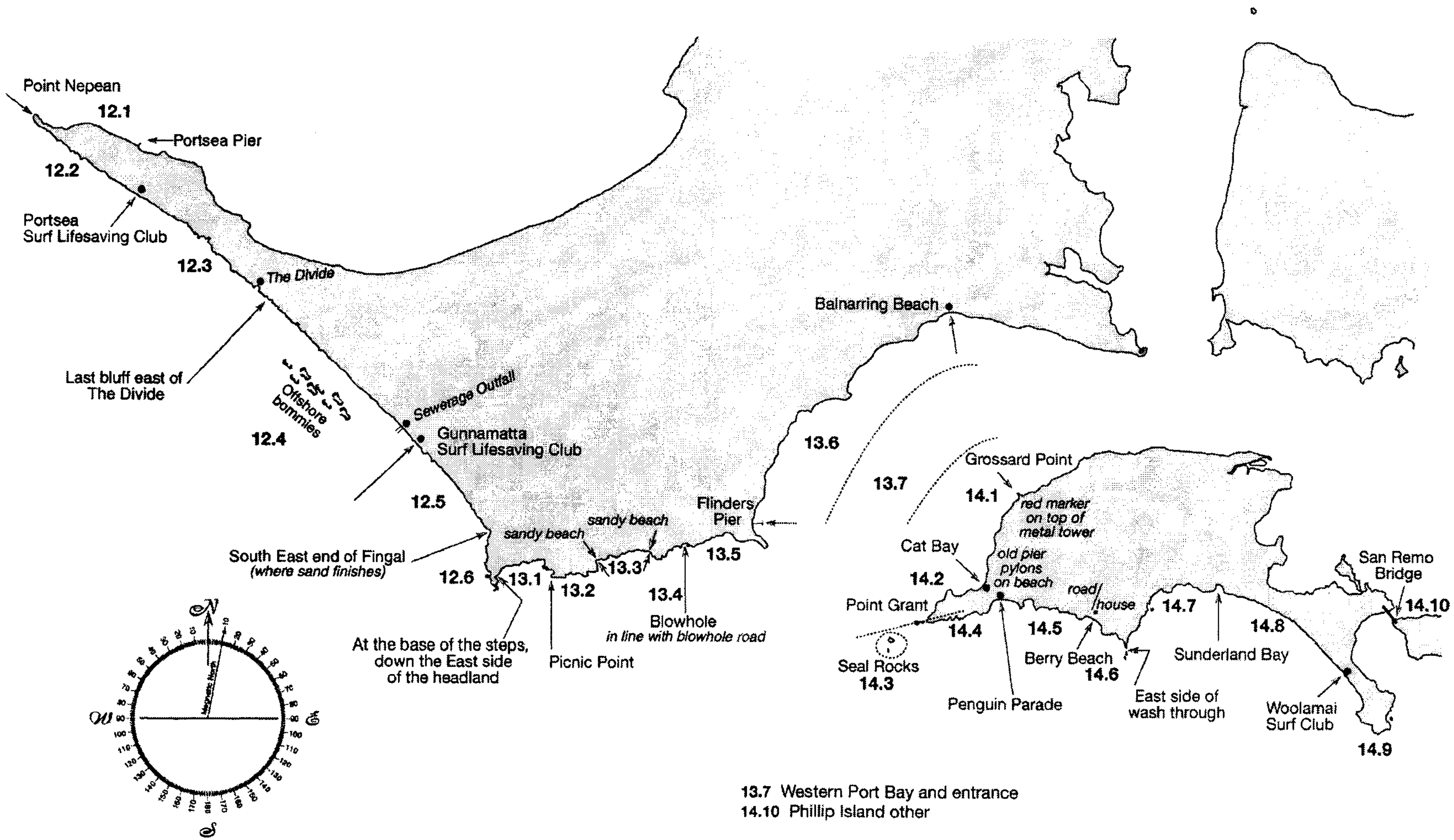
Victorian Abalone Reef Codes: Central zone, Map CZ2.

Port Phillip Bay



Victorian Abalone Reef Codes: Central zone, Map CZ3.

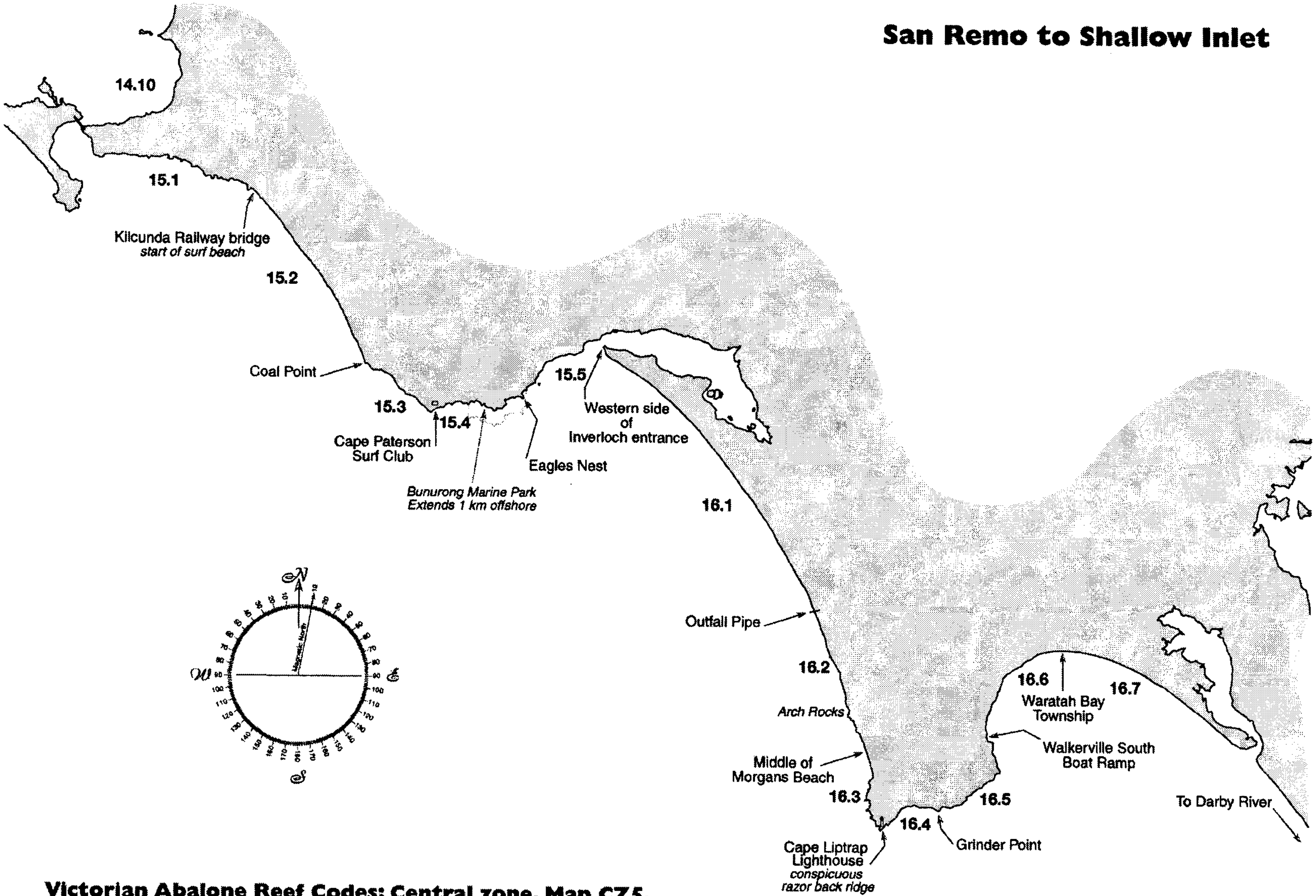
Point Nepean to San Remo



13.7 Western Port Bay and entrance
14.10 Phillip Island other

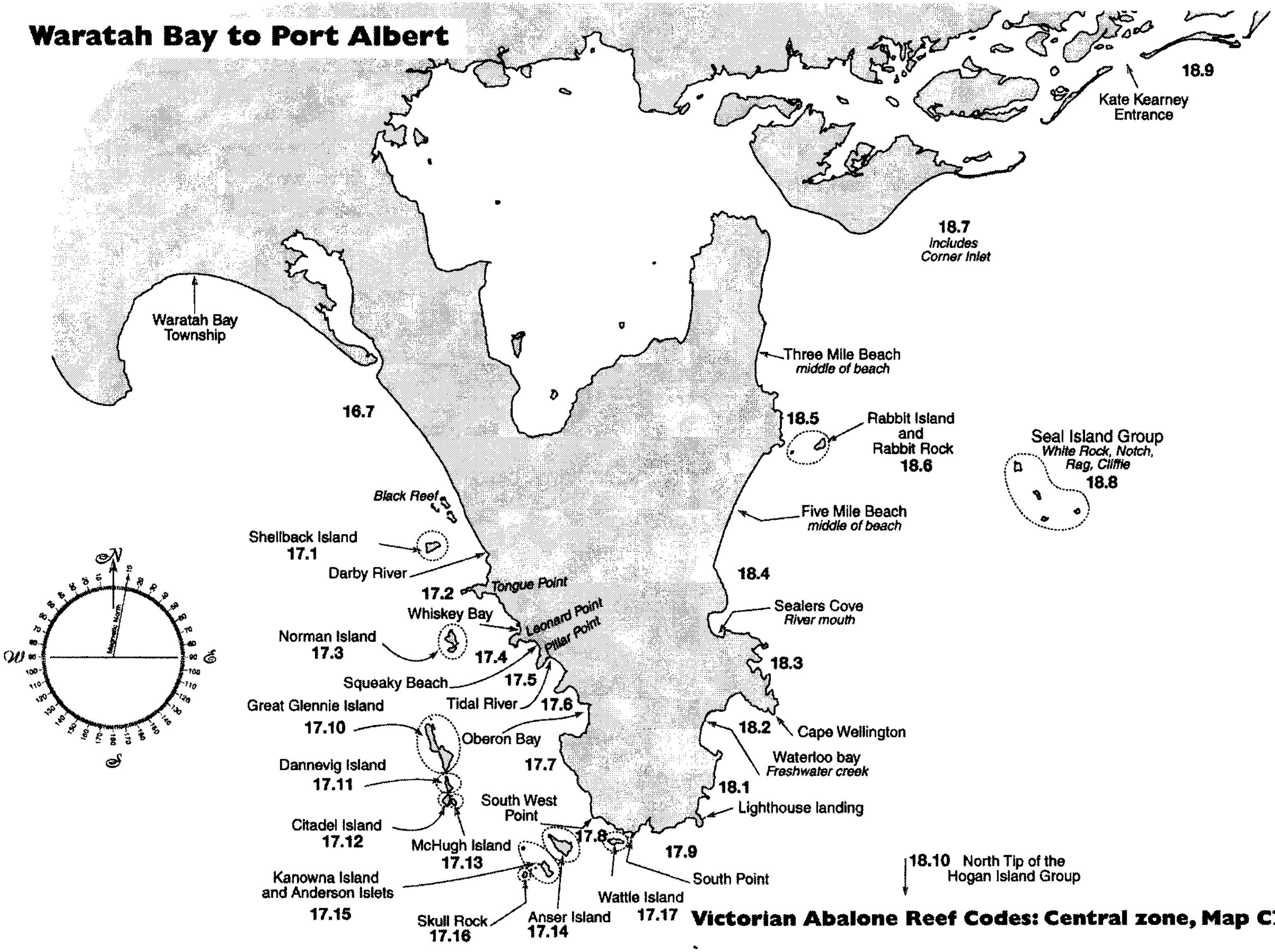
Victorian Abalone Reef Codes: Central zone, Map CZ4.

San Remo to Shallow Inlet



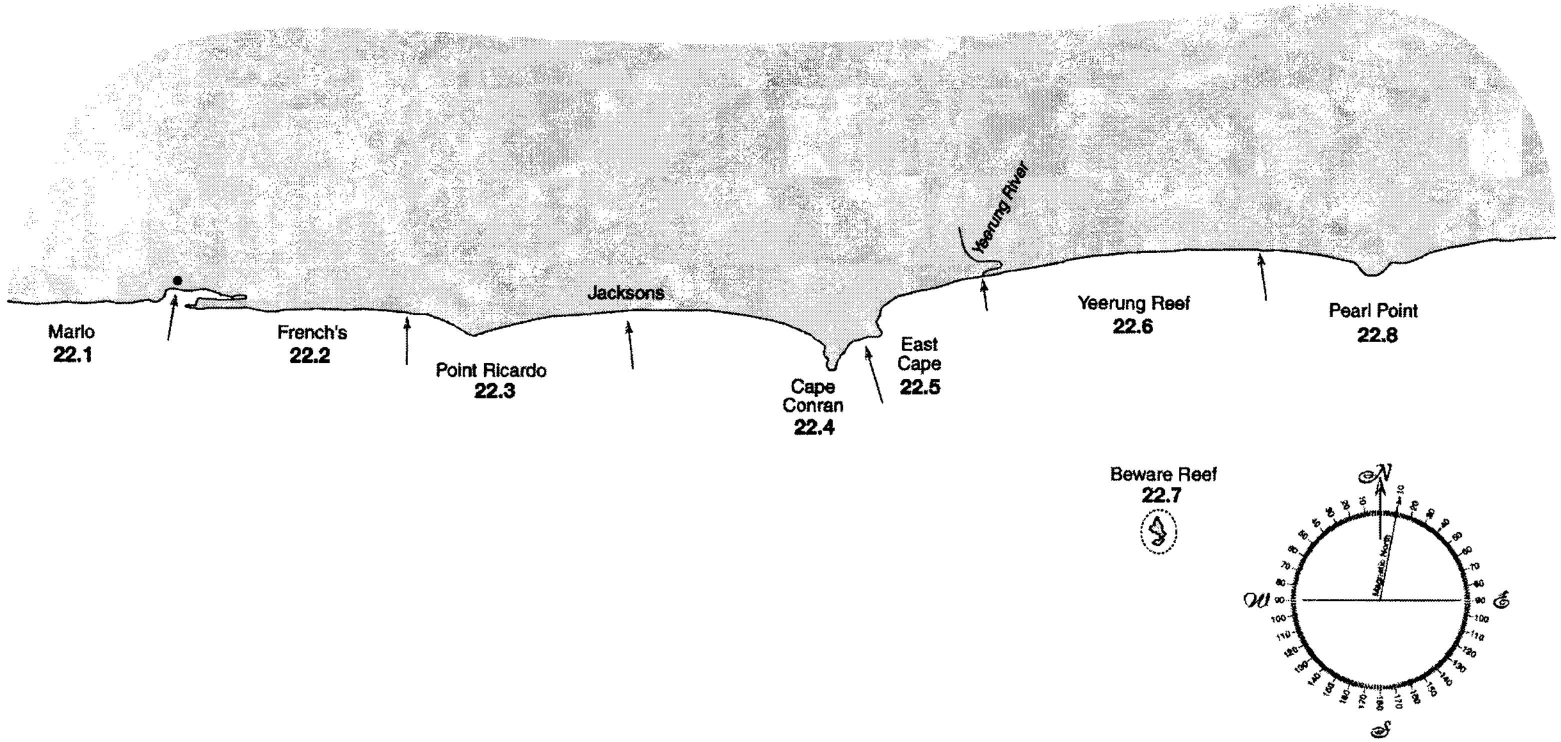
Victorian Abalone Reef Codes: Central zone, Map CZ5.

Waratah Bay to Port Albert



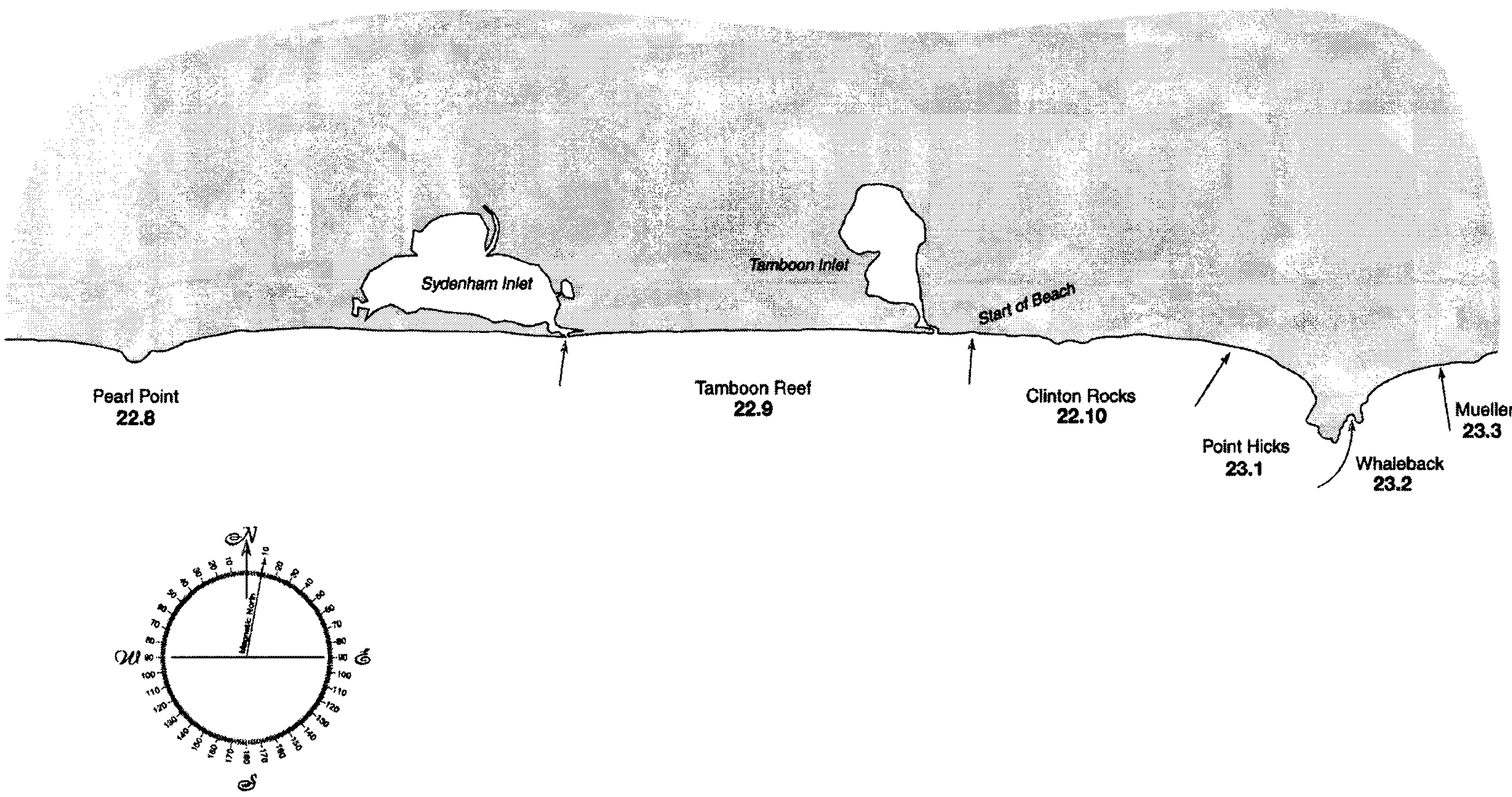
Victorian Abalone Reef Codes: Central zone, Map CZ6.

Marlo to Pearl Point



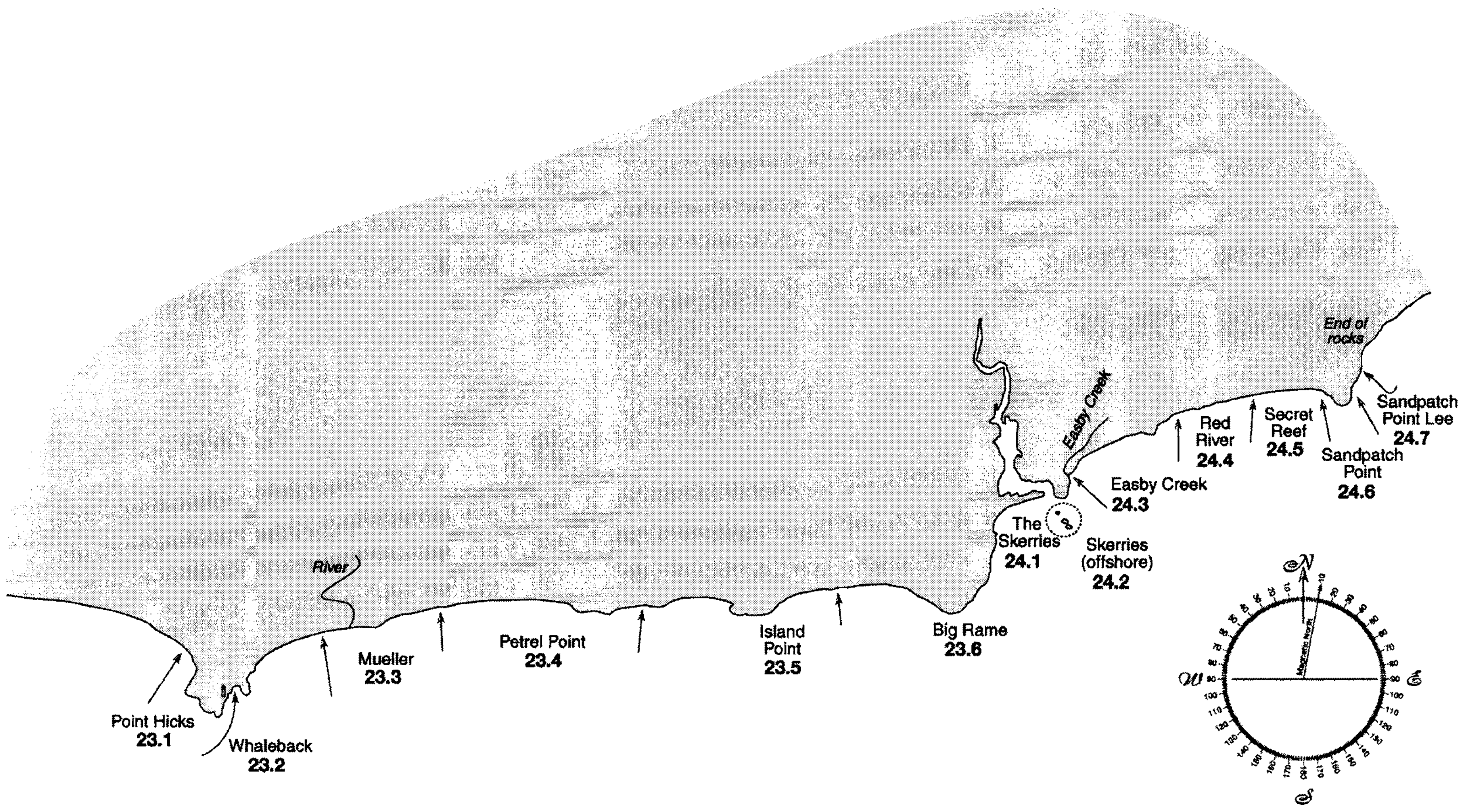
Victorian Abalone Reef Codes: Eastern zone, MapEZ1.

Pearl Point to Point Hicks



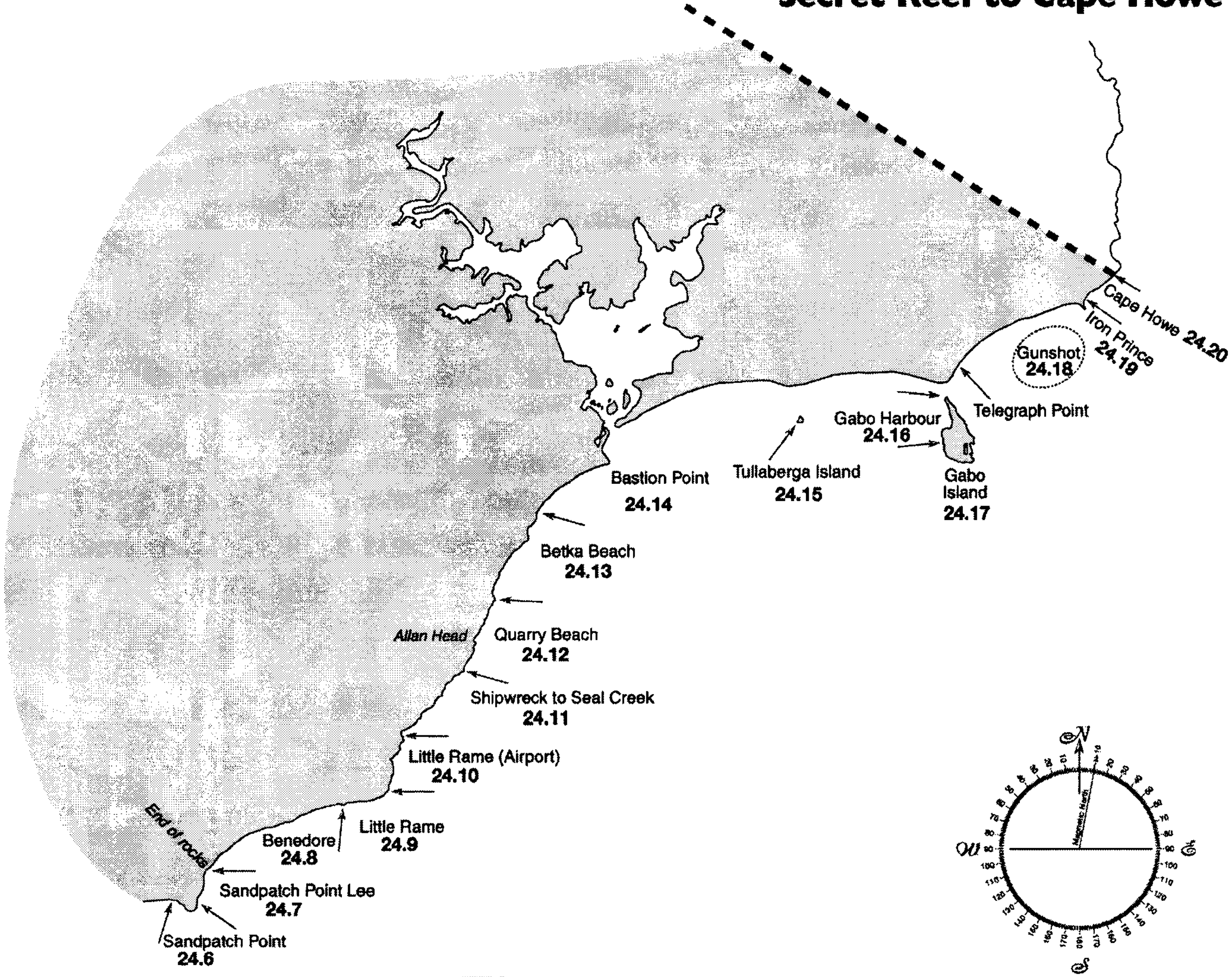
Victorian Abalone Reef Codes: Eastern zone, MapEZ2.

Point Hicks to Secret Reef



Victorian Abalone Reef Codes: Eastern zone, MapEZ 3.

Secret Reef to Cape Howe



Victorian Abalone Reef Codes: Eastern zone, MapEZ4.

Chapter 10 Discussion

Current situation

When posing the question about whether Victoria's abalone resources are sustainable it is important to be cognisant that there can be many levels of sustainable resource use. In essence a fishery can be sustained at both high and low levels of productivity; however, only the higher level may deliver acceptable profits. Without profitability a fishery can be difficult to manage. To restore profitability in the short term the only solution is to reduce effort. This is one of the most difficult things to achieve and often requires the Government to buy back licences at taxpayers expense. For a fishery such as the Victorian abalone fishery this would mean considerable cost given the high level of capital invested in fishery access licences (during 2001 one licence sold for more than $A6 million and others have more recently been rumoured to be on the market for about $A8 million).

New management paradigms

In 1997 at the 3rd International Abalone Symposium held in Monterey, North American researchers were talking about the need for a new paradigm of abalone management in California because the existing regime had failed. Although most of the commonly used input controls were applied, with the exception of British Columbia and to a lesser extent Alaska (Farlinger & Campbell 1992), there were no output controls to limit the catch to provide optimum returns. Prior to closure of the fishery in the same year, Californian divers were earning about one tenth of their Victorian counterparts (D. Thompson 1997, personal communication, October).

We have moved a long way towards establishing the infrastructure required for sustainable management of abalone in Victoria; however, we may also require a shift in management paradigm if we are to truly sustain current resource levels. This thesis has described an assessment process for abalone resources that is among the best in the world. It is underpinned by a substantial amount of research into the biology of blacklip and greenlip abalone. However, some major knowledge gaps persist, particularly for the period of life history from spawning to reproductive maturity. Elucidation of a stock recruitment relationship, a research objective for the last two decades, is ostensibly intractable at the scale over which the fishery operates (see McShane 1995). However, conservation of a minimum spawning component under environmental conditions unfavourable to recruitment is an essential element for the sustainability of each abalone population (Shepherd & Baker 1998, Shepherd et al. 2001).

Prince (1989) concluded from his studies that abalone occur as multiple stocks functioning largely independently. Evidence that was gathered for Victorian abalone populations supported this hypothesis (McShane et al. 1988, McShane & Smith 1991). The study by Gorfine and Dixon (2001) presented in Chapter 5 showed that localised population dynamics are reflected in the behaviour of fishers and the way they distribute their effort. It was these types of observation by Prince et al. (1998) that lead them to espouse the virtues of Territorial User Rights Fisheries (TURFs). To develop a TURF, an abalone fishery would be subdivided into lots and distributed as freehold among small consortiums of abalone divers with each consortium responsible for self-governance of their particular lot.

There is some recognition among Victorian fishery managers and industry that finer scale management areas are necessary (Abalone Management Plan 2001). This is not a recent revelation, as evidenced by comments from Sanders and Beinssen (1972) three decades ago about the need to split the original Western Zone of the fishery into two management zones. However, it was only when recently faced with impending quota reductions that serious consideration was given to further subdivision. Indeed, a sub-zonal catch limit, to be initially administered via a memorandum of understanding between Fisheries Victoria and the Victorian Abalone Divers Association, has been developed for Port Phillip Bay during the 2002-03 quota year. However, there is a range of obstacles in terms of legislative and regulatory changes and allocation issues that will impede or slow any progression towards more formal finer-scale management. There is a risk that any changes that involve only minimal subdivision of existing zones will be insufficient for effective management. To be comparable with the TURF concept a more radical approach is required.

Certainly it would be more conservative to assume that the fishery operates on a fine spatial scale than a broad one. It would also provide the necessary management structure to demand sufficient resources for fine-scale assessment. Costs would obviously be higher, but a shift toward more direct cost-recovery from users of the resource could offset some of this. Currently the Victorian Government spends only about 0.5% of the gross value production (GVP) of the fishery on assessment. This is the same proportion of GVP that the Fisheries Research Development Corporation allocates to wild abalone research; an amount that the FRDC has described as inadequate (Macarthur Agribusiness 1998).

Role of resource users

The Japanese and Mexican abalone fisheries are underpinned by cultural and social institutions that allow fine scale fisheries assessment and management with strong fisher involvement. In Japan the coastal regions are divided into a series of fishing cooperatives with each having exclusive control over marine resources within its own boundaries (Hahn 1989a). In Mexico a system of 19 area-based fisher co-operatives has prevailed since the Second World War (Guzman del Próo 1992). Since the late 1980s these co-operatives have employed their own biologists to conduct stock assessments jointly with the Mexican federal government's Instituto Nacional de la Pesca, or INP (Ramade-Villanueva et al. 1998). The advice from both government and co-operative employees is seen as complementary, although often the scientific advice is overshadowed by political and socio-economic considerations (Guzman del Próo 1992).

We may also be able to learn from lesser-developed countries in the Pacific region that have actively maintained or restored customary fishing practices to provide increased prospects of sustainability (see Williams & Corral 1999). The pan-Melanesian concept of *kastom* is defined in Hviding (1998, p. 253) as '...selective representations of the past... constructed in and for the present'. Such traditionally based practices have been established over millennia and it has only been since European colonisation that this has changed. Now that many of these countries have regained their independence their governments, aided by external organisations such as the South Pacific Fisheries Commission, Food and Agriculture Organisation, United Nations and World Wildlife Fund, have reviewed the efficacy of modern fishing practices and found them wanting (Johannes 1998).

In Rarotonga, in the Cook Islands, where tribal landownership extends into the sea, the indigenous Polynesians have established a system of rotational closures across all species (personal observation). These Raui or reserves prohibit all fishing within their boundaries and are periodically rotated to moderate the impact of fishing and permit recovery of stocks. In Vanuatu similar systems prevail where Melanesian tribal ownership and control of marine resources provides a sound basis for stewardship (Johannes 1998). Traditionally ni-Vanuatu women used to collect a range of invertebrates for food and a Women's Marine Tenure Project has been established to gather difficult to access knowledge about this aspect of culture in an attempt to restore or perpetuate these practices (personal observation 2001, Vanuatu National Museum, September). In Marovo Lagoon, New Georgia Province in the Solomon Islands the World Wildlife Fund has initiated a project to establish communal marine resource management policies. These policies embrace sustainable fishing practices, provide protection for threatened and tabu species, enable village oriented marine ecotourism, and promote the creation of reserves for resource protection and recovery (World Wildlife Fund 1998, see also Hviding 1998).

Although mention of Indonesia and fishing in the same sentence conjures up images of dynamite fishing on coral reefs, the inhabitants of the island of Haruku practice a several hundred-year-old tradition called *sasi*. *Sasi* is a collection of practical principles that aim to protect the quality and population of biological resources to ensure sustainable harvests to provide benefits that are equitably distributed among all villagers (FAO 1995a).

These examples highlight that sustainable practices can be achieved at the local community level where a strong sense of stewardship prevails (Adams 1998). Unlike Western fisheries regulations these non-codified customary practices provide for much local flexibility to adapt to changing circumstances (Hviding 1998, FAO 1995a). Hviding (1998) suggests that the closest Western equivalent is 'enabling legislation'.

Role of marine parks

One of the more contentious contemporary issues in fisheries is the concept of harvest refugia in the form of no-take Marine Protected Areas (MPAs) and their perceived benefits as a management tool. A system of marine parks that includes areas of productive abalone, rock lobster and urchin fishing grounds is being progressively implemented in Victoria. These parks were not intended to be fishery management reserves, but rather to preserve representative areas of different marine bio-regions. The location and size of these proposed MPAs was hotly debated among fishers and conservationists, with much associated lobbying of the Victorian state government.

However, there was general support for the concept among commercial fishers provided that the impact on their livelihoods was minimised. These fishers, along with many recreational divers and anglers, currently claim that their concerns were mostly unheeded. This is despite the excision of some relatively large areas from within the originally proposed marine park boundaries to redcue the impact on fishing.

Several authors have suggested that refugia are necessary if abalone populations are to be sustained into the future (Dugan & Davis 1993, Shepherd & Brown 1993). From a fisheries scientist's perspective there are significant advantages in having areas supporting healthy abalone populations that are not subject to any fishing mortality. If these encompass a diversity of habitats throughout the range of the targetted species an opportunity presents to discriminate between the effects of fishing and other environmental impacts (Schroeter et al. 2001). Including 'no-take' areas of habitat in monitoring programs will contribute to reducing uncertainty in fishery assessments (Pitcher & Pauly 1998). However the benefits for sustaining or rehabilitating multiple populations of a sedentary organism with limited larval dispersal are equivocal (Buxton 2001), unless the protected areas are appropriately located (Rogers-Bennett et al. 2000), large and numerous as advocated by Walters (1998a). Temporary fishery reserves or rotational closures, like those described above for the Cook Islands, are a different proposition that are likely to deliver benefits by providing for periods of stock recovery before populations collapse. This management option requires close cooperation between resource users and Government and strong enforcement to prevent illegal fishing. Indeed, Rogers-Bennett et al. (2000) found that California pink abalone stocks declined to zero within remote parts of the Anacapa Island MPA that were not under direct observation of the reserve manager. Failure to enforce no-take areas is an often-voiced criticism by Victorian abalone divers about the value of MPAs.

In some instances the effects of closures on previously exploited populations may be counter-intuitive to commonly held expectations. Indeed there is limited evidence that increased abundance of large southern rock lobsters within Tasmanian MPAs may have lead to increased predation of juvenile blacklip abalone (C. Mundy 2002, personal communication, October). In a study comparing abalone and urchin interactions within and outside marine reserves in northern California, Karpov et al. (2001) concluded that fishing for both red urchins and red abalone enhanced abalone densities.

Fishery reserves have so far not been considered as part of the future management arrangements for Victorian abalone resources. However, a substantial number of our fixed monitoring sites are within the boundaries of the proposed MPAs, and in the event that the proposals are successful these will continue to be surveyed annually. In a provocative essay, Walters (1998a) challenges conventional approaches to assessment and management asserting that failures have occurred because we have not had robust ways of coping with environmental variability and scientific uncertainty and consequently fishery governance systems have generally failed to react to problems in a timely fashion. He proposes a radical shift in paradigm that would see much of the current fishing grounds closed and access to the resource limited to relatively few areas, arguing that a common feature of successful fisheries is the existence of large space-time refuges.

Co-management

Involvement of the community and key stakeholders in fisheries management is an emerging trend in the Western world, and Australia is no exception. Co-management is a cornerstone of the *Victorian Fisheries Act 1995* (Vic). However, the model adopted in Victoria is described as consultative, as opposed to co-operative and delegated models (ENRC 2000). Whereas the delegated model places responsibility for management decisions with stakeholders who then communicate their decisions to the government, the consultative model involves the government making the decisions after consultation with stakeholders. The co-operative model lies somewhere between these extremes. There is a view that the most successful and persistent instances of co-management involve models closer to the delegated than the consultative end of the spectrum (ENRC 2000). Unlike TURFs, the consultative approach tends by its nature to deny strong involvement at the community level. Garcia et al. (2000) caution against not undervaluing the expert judgements that can arise for compiling information from fishers and indigenous communities. Although the consultative model does not preclude the collection of grass roots information from resource users and custom owners, it does nothing to ensure its inclusion in the assessment process, nor does it involve resource users in the actual decision making. Resource users are more likely to comply with management strategies if they have shared in the responsibility for developing these strategies.

Caddy (1995) suggests that fisheries scientists should only become involved in resource management at the point at which a stock becomes endangered. Gauldie (1995, p.2060) concurs, expressing an opinion that 'The issue of interest to the public good that requires continuing government and fishing industry support is something closer to minimum sustainable population…'. In other words, maximising sustainable yield is the domain of economists and is a matter for industry not government. However, others may express the view that the government does have a role in maximising yield to derive the most revenue, in terms of economic rent, for the greater public good. It is also easier to envisage ecological sustainability and effective governance if economic profitability is high rather than low.

In contrast to Caddy's opinion and the prevailing view among some Government agencies responsible for fisheries management, Shepherd (2001) has recently questioned whether co-management is delivering sustainable fisheries outcomes. He cites the South Australian abalone fishery as an example of industry stakeholders having inequitable influence over management decisions to the extent that stock assessment advice has been unheeded. Commenting on rights-based fishing, Walters (1998) reminds us that the public has not knowingly relinquished ownership of fisheries resources and questions the validity of the assumption that fishers own the surplus production that stocks may produce.

A recent parliamentary inquiry into fisheries management in Victoria found a number of deficiencies in the application of co-management. However, the committee conducting the inquiry concluded that 'Co-management is a worthy concept and the Victorian model should be retained and improved' (ENRC 2001). Brown (1998) suggests that co-operative management can lead to better-informed decision-making and reduce conflict and uncertainty over resource use.

Based on the most recent Victorian abalone fishery assessment described by Gorfine et al. (2002) in Chapter 3, co-managers were recently faced with the need to decrease total catches in two of the three abalone management zones. In the Western Zone this could be fully achieved through the introduction of beach weighing that will reduce the number of abalone harvested per kilogram. However it will take several months to effect the necessary regulatory changes. The paper by Gorfine (2001b) in Chapter 5 provides support for the veracity of this option to use wet weight rather than drained weight to decrement individual quota allocations. An estimate of 5% has been agreed as the likely effective reduction in catch. This is the minimum reduction expected and its adoption is considered precautionary when compared with the selection of larger values estimated from the work in Chapter 5.

However, beach weighing will achieve only half the reduction required in the Central Zone and additional measures should also be considered. Opportunities to shift effort within the zone from regions where stocks are declining to those where stocks are increasing are limited. The only modelled region within the Central Zone where an increase in catch can be sustained is Wilsons Promontory and this area is currently proposed as a location for an extensive Marine Protected Area that will exclude fishing activities. Nonetheless, the current assessment outcomes have put sub-zonal quota management on the agenda and operational requirements for its introduction are currently being investigated. A vessel monitoring system (VMS) linked to real-time reporting of catches, similar to those used in trawl fisheries in Australia, is one option that may satisfy these requirements. However, there are technical difficulties accommodating currently used VMS equipment on small open boats (S. McCormack 2002, personal communication, 16 April).

An appropriate balance of co-management decision-making power between major stakeholders is required to ensure responsible recommendations about future management are made to the Victorian Minister for Natural Resources. To date industry stakeholders have dominated advisory and management committees, although the most recent composition includes a person with expertise in conservation. The current Commercial Abalone Fishery Committee (CAFC) has been reluctant to depart from traditional approaches based on representation and adopt the intended expertise based approach. This may change as people with expertise in recreational diving and indigenous issues are appointed to future abalone committees under the newly instituted Abalone Management Plan.

Coombes et al. (2001) point out that indigenous Australians have much to offer in ensuring ESD because it is fundamental to Aboriginal philosophy. They further emphasise that Aboriginal people have a right (as reflected by Native Title) to engage in the management of natural resources and environment. This custodianship and customary use of abalone by Aboriginal clans in Victoria, described in Chapter 1, demonstrates that they have a legitimate interest in the sustainability of abalone resources and should be genuinely involved in the co-management of the fishery.

Indeed, during the recent inquiry into fisheries co-management in Victoria, a representative of the Gunditjmara Native Title Holders and Mirimbiak Aboriginal Nations submitted that as custodians of the country, Aboriginal people wanted to participate in the management of all fisheries, and called for the establishment of a statewide indigenous fishing committee. In response, the Environment and Natural Resources Committee conducting the inquiry recommended 'That the Governor-in-Council give consideration to initially designating ...(as a peak body)... an organisation which the minister considers represents indigenous fishing interests;...' (ENRC 2001).

There is a risk that co-management will not deliver the benefits anticipated when it was introduced and that management of the abalone fishery will revert to a more centralised Government-dominated management process. It is imperative that current participants strive to use the system to ensure sustainable management of Victorian abalone resources rather than subvert this objective to protect their personal short-term financial interests. When key stakeholders are not directly engaged in the management decision making process, feedback loops, essential for timely responses to changes in resource status, become convoluted and the information flow diffuse.

Encouragingly, a workshop held in California during 2000 provided a constructive forum where abalone divers, scientists and fishery managers discussed strategies for restoration and future management (CDFG 2000a). This represents somewhat of a turn around from the hostile adversarial relationship that I witnessed between Californian divers and researchers in 1997 soon after the fishery closed. Indeed, the workshop report describes Californian divers' enthusiasm to become more involved in research and monitoring activities (CDFG 2000a). This positive relationship has been the rule rather than the exception in Victoria throughout the history of the fishery (see Kurz 1967 appended) and several of the papers in this thesis were based on studies that featured direct involvement of abalone divers. It is vitally important that these relationships are maintained during periods when the fishery is perceived as not performing well, more so than when stocks are healthy.

One of the difficulties in abalone fishery management is the tyranny of spatial scale when dealing with what is essentially an array of multiple sub-stocks associated with metapopulations distributed, albeit unevenly, along the entire Victorian coastline. In an ideal world resource users could be entrusted to self-manage. However, the diversity of interests among resources users is too broad for the Government not to play a strong role in facilitating responsible management on behalf of all citizens and providing the necessary legislation to enforce sustainable management practices. In Australian society a more pragmatic approach to managing coastal fisheries resources at an appropriate scale may be to partially devolve responsibility for the delivery of management to local Government councils. This has occurred to some extent with terrestrial coastal resources, where local committees of management are responsible for land use and conservation decisions. However, this initiative would necessitate radical changes including diversion of the payment of revenues from the state government to municipal councils and expansion of existing infrastructure in environmental resources portfolios. It is highly improbable that ratepayers will be prepared to support an initiative such as this unless it could be demonstrated to increase the municipal revenue base to provide an improved return to the local community rather than the state government. State governments would be understandably reluctant to relinquish these revenues.

Notwithstanding the preceding comments about the importance of the role of Government, the Eastern and Western Zones of the Victorian abalone fishery have demonstrated the potential for localised informal control. In the Eastern Zone, the Abalone Fishermen's Co-operative Ltd based in Mallacoota has existed since the infancy of the fishery and still retains the majority of licence owners in that Zone. AFCL processes abalone on behalf of its members and has been responsible for a large number of local management initiatives. These have included setting daily catch limits, establishing variable size limits that suit the perceived or estimated growth and productivity characteristics of local stocks and participation in stock restoration activities. In the Western Zone a processing company at Port Fairy, Sou'west Seafoods Pty Ltd, has similarly had the majority of licence owners as shareholders for most of its history. Originally when the fishery was divided at Lakes Entrance into Eastern and Western management zones, it was the pioneers of the current Western Zone that voluntarily adopted initiatives for self-regulation. The initiatives included inspecting each others catches to ensure compliance with size limits and placing bag limits on the more heavily exploited reefs. These divers lobbied the Government for an additional subdivision into Central and Western Zones when it became apparent that divers based east of Warrnambool were not prepared to comply with these self-regulating strategies (Sanders and Beinssen 1972). Although acknowledging that co-operative management is not suited to all fisheries, Brown (1998) asserts that clearly defined boundaries and historic roles in resource stewardship, as have characterised the Victorian abalone fishery, are elements that enable it to work well.

As described in Chapter 5, it is more likely that evolving management arrangements, now driven by global economic and free enterprise paradigms, will result in shifts away from practices that, although not perfect, were a step in the right direction. This is of all the more concern because previous formal and informal management initiatives did not go far enough given the size and diversity of the abalone resources in each zone. Future changes towards a more economically competitive industry structure will require some compensatory mechanisms to generate incentives that ensure effective resource stewardship. We are already seeing signs of a difference in concern for sustainability between quota owners and divers in Tasmania. Shareholders will treat their investment in an abalone fishery like any other business venture and sustainability of the resource will not necessarily be their highest priority. We have argued similarly about contract divers (Gorfine & Dixon 2001); however, it is the divers in Tasmania that are supportive of the most recent quota reduction rather than the quota owners. The reason for this may relate to the tendency for contract divers to get a smaller proportion of the landed value as landings increase. Evidence of this can be seen in the differentials among payment rates for New South Wales, Victorian and Tasmania divers. In New South Wales, where daily landings have typically been about 100 kilograms per day, divers receive about A$12–15/kg, in Victoria the rate varies within the range A$4–8/kg and in Tasmania within A$3–5/kg. In other words the divers share is unlikely to increase despite quota increases.

The opportunity to develop innovative assessments of sustainability is constrained by the prevailing management regime. However, there are certainly existing opportunities for more research and high priority for collection of additional data to model the fishery. The new and emerging management infrastructure should be subject to a cycle of review and continuous improvement. For this reason new Victorian Abalone Management Plan has 5-year outlook period after which it will be reviewed.

Ecosystem approaches and interspecies interactions

The need for more spatially explicit management of abalone is dwarfed by the emerging need for incorporating ecosystem management objectives. As Mace (1997) points out, well-articulated objectives exist in numerous international agreements but there has been little practical adherence to these. Implications for assessing the impact of multi-species removals on ecosystem health were briefly mentioned in the previous chapter. As outlined in Chapter 1, in many parts of the world including Australia, abalone exist sympatrically with urchins and rock lobsters. In many of these communities urchins are the dominant invertebrates (Tegner & Dayton 2000). Studies in South Africa have highlighted important associations between these three invertebrates (Day & Branch 2000a, 2000b, Mayfield & Branch 2000 and Tarr et al. 1996). In Australia the relationships are less clear with the exception of the well-researched and documented competition between the black sea urchin (*Centrostepahanus rodgersii*) and blacklip abalone (Andrew & Underwood 1992) along the eastern seaboard from NSW to north-eastern Tasmania.

No research has been undertaken on the interaction between the Victorian abalone and rock lobster fisheries, the two most valuable of the state's fisheries resources (Fisheries Victoria 2002), and little is known about environmental determinants of rock lobster abundance and recruitment (Hobday & Smith 2000). Small fisheries for urchins and periwinkles also occur in Victoria and there is emerging interest in the harvest of holothurians. However, rock lobsters are a known predator of urchins (Mayfield and Branch 2000) with potential downstream impacts on abalone (Day & Branch 2000a). The Victorian southern rock lobster fishery commenced in the 19^{th} century (D. Molloy 2002, personal communication, February). It is reasonable to speculate that removal of rock lobsters from the same habitat as abalone during the 100 or so years preceding the start of the abalone fishery in 1962 might have affected the pre-fished abalone biomass. This implies that among the various limitations of estimates of pre-fished biomass is a lack of information about the true carrying capacity of the ecosystem in its unexploited state.

It is important to consider the broad suite of interactions among coincidental fisheries, including the important roles played by urchins and periwinkles, both as sources of prey for rock lobsters and as competitors of abalone in assessing the ecological sustainability of the abalone removals. Such fishing related interactions between rocky reef dwelling invertebrates have been documented in California. Removals of urchins by commercial divers along the coast north of San Francisco have led to recruitment of abalone into deeper depth strata that they have not previously occupied (Tegner & Dayton 2000). A similar result is predicted for NSW if the urchin fishery were to expand substantially (Andrew & O'Neill 2000). In these scenarios the removal of large numbers of lobsters would be expected to indirectly result in decreased abalone abundance. However, it is possible that in some circumstances abalone are an important prey component of rock lobsters, in which case the opposite effect may occur. Speculation such as this illustrates the importance of well-controlled manipulative experiments before we can progress to multi-species models and assessments.

Pauly et al. (1998) discuss the issue of fishing down marine food webs in which there is a global transition towards the targetting of species at lower trophic levels as the higher order predatory fishes are progressively fished out. One can readily imagine predator removal giving rise to an increased abundance of lower order species, until these in turn are depleted and effort is transferred further down the trophic web. Although invertebrate fisheries have not expanded greatly in Victoria during the past decade, they now contribute the most catch weight and all but 10% of the value (Fisheries Victoria 2002). The previously mentioned interest in establishing a holothurian fishery in Victoria and the frequent approaches to Fisheries Victoria by people evaluating the potential for investment to expand the urchin fishery attest to the validity of the concerns expressed by Paul et al. (1998). Although not an example of effort shifting towards lower trophic levels, recent emergence during the past five years of a live capture fishery for demersal reef fishes in rocky subtidal habitats represent an expansion in the variety of species now harvested from this type of ecosystem. The total weight of landings of wrasse and morwong is relatively modest at an annual average of 82 tonnes (Fisheries Victoria 2002); however, the importance of these species in their functional role as predators of abalone is currently unknown.

Pitcher and Pauly (1998) argue that multi-species based fisheries assessments within an ecosystem based management framework aimed at ecosystem rebuilding should be the primary objective. They claim that despite the general acceptance of sustainability as an objective that it is the wrong goal for fishery management and will lead to reduced biodiversity and compromise future economic benefits. However, they acknowledge that there has been a lack of clear quantifiable goals among attempts to re-instate ecosystems. Indeed the types of models that Pitcher and Pauly (1998) advocate (Ecopath and its sibling simulation software Ecosim and Ecospace, see Pauly et al. 2000) require answers to many of the questions about ecosystem interactions already discussed. Furthermore some of the criticisms that they make of fisheries assessment and management in general do not apply to Australian abalone fisheries. In particular, the capacity for spatially explicit analysis of abalone stocks overcomes one of their main concerns. Also, Pitcher and Pauly (1998) do not consider the role that ITQ management would play in restricting the freedom of fishers such as abalone divers to target alternative species should their fishery collapse. The losses that would be sustained against the large capital investments in fishery access licences would make it difficult to start new fishing business based on other less profitable species.

Environmental impacts on the fishery

In Chapter 1 I outlined some of the main disease considerations for Victorian abalone and contrasted these with overseas experiences. Two persistent elements stand out from an examination of the examples presented, firstly the role of elevated water temperature in promoting infection and secondly the exotic origin of some disease causing organisms. Although the only major disease to affect abalone populations in Australia is endemic, there has been a range of exotic introductions into Australia during the past 15 years that have potential to affect abalone and their supporting ecosystems. As well as the role of temperature in causing disease there is also the role of shifts in temperature pattern on abalone nutrition and reproductive output. Given that abalone recruitment is episodic, large shifts in environmental parameters have the potential to substantially diminish future stock recruitment. Global warming and intensification and increased frequency of El Niño Southern Oscillation events may exact a large toll on abalone populations in Australia.

Future prospects

The Victorian abalone fishery has the necessary infrastructure and processes either established or close to being formalised to ensure its sustainable management. However, the critical issue of using this infrastructure to deliver sustainable outcomes remains to be comprehensively demonstrated. Current scales of assessment and management are likely to be too coarse to be fully compatible with the population biology of blacklip abalone. Limited dispersal of larvae within the management zones limits the potential for recruitment to depleted reefs from areas where abalone remain abundant. In other words, management zones are effectively comprised of multiple units of stock that require separate assessment and management. These units of stock are difficult to delineate and are likely to vary in size according to particular characteristics such as hydrodynamics and reef physiography. Nonetheless, a precautionary approach should mandate management scales of high resolution until unequivocal evidence suggests coarser scales are acceptable. Fine-scale information can always be aggregated whereas coarse-scale information cannot be dis-aggregated.

The dilemma with fine-scale fisheries management is lack of resources, especially within public sector fisheries agencies. The percentage of GVP spent on abalone management in Victoria is arguably too small to ensure sustainability. Government policies aimed at centralised cost-recovery on a user-pays basis are unlikely to redress the shortfall in financial and human resources available for abalone management. Indeed policies such as the National Competition Policy (NCP), recently implemented by both federal and state governments in Australia, militate against resource stewardship and generate disincentives for current industry participants to invest in the future well-being of the resource. This is because the application of NCP potentially gives rise to a situation where benefits from future improvements in fisheries resources have to be shared with an influx of additional participants as Government seeks to auction additional units of fishery access entitlement. Of course, there is also the possibility that the majority of additional quota units will end in the hands of a small number of existing owners.

One is entitled to ask why the fishery has persisted if the current formal management arrangements have such deficiencies. The answer lies in the established yet informal fishing practices of abalone divers that in seeking to maximise profits, collaterally minimise fishing mortalities. However, the maintenance of these practices is not guaranteed by regulations or codes of practice and instead depends on a combination of catch expectations of divers, cost per unit effort, and divers' experience and perceptions about where the best stocks of abalone are likely to be located. It will also depend on the extent to which the existing participants are willing to forego some immediate remuneration to provide greater future surety for their offspring. As new divers progressively enter the fishery to replace the previous generation, many of whom have participated in the fishery since its inception, the parameters upon which their fishing behaviour depends are likely to change. Historical knowledge about the fishing grounds and past performance of the stock will be lost and baselines against which comparisons are made are likely to shift to reflect this lower level of knowledge and experience (see Pauly 1995). These changes may lead to behaviours that are incompatible with resource sustainability.

What is required is a formal structure that promotes appropriate fishing behaviours. The most effective management regimes appear to be those in which fishers have a high level of involvement in the development, implementation and on-going review of management strategies. Gauldie (1995, p.2060) believes that the fishing industry should bear the burden of protecting the capital they have invested and that '... it should not be a government responsibility to pay for the management of profitability of the fishing industry by managing their risk'. The strategies adopted should attempt to formalise those currently informal behaviours that are believed to promote sustainability. This may be a tall order especially if it is their informality that tends to make them successful. One of the biggest challenges will be to recover the costs of formalising and enforcing management arrangements if these cause short-term reductions in industry profits.

It is often difficult to persuade government agencies and resource users of the need to increase their investment in an apparently healthy resource to insure against future declines. Ironically, there is a tendency to spend more money on fisheries experiencing collapse at a time when it is often too late to promote recovery within the lifetimes of existing participants and the additional expenditure is least affordable.

Although funding of Victorian abalone assessment is comparatively high and the fishery could not be considered as data poor (Caddy 1998), the biology of abalone places demands for information that outweigh those required for effective assessment of the status of many other fisheries. Whilst blacklip abalone may appear to be less vulnerable to over-exploitation than other commercial abalone species, localised declines suggest that there is little scope for complacency.

McShane (1990) concluded that the Victorian abalone fishery was in good shape and that there was no imminent danger of collapse. A little over a decade later such confidence in the persistence of a healthy fishery seems misplaced. I'm not suggesting that McShane's (1990) prognosis was ill-founded at the time, nor that the Victorian blacklip abalone resource is verging on collapse. However, there are now clear signs of deterioration that may herald progressive serial depletion of stocks if the fishing grounds continue to contract and the catch becomes concentrated on relatively fewer reefs where abalone remain abundant.

It is time to establish a more comprehensive and spatially explicit suite of management arrangements promoting diver behaviours that effectively prevent any further deterioration in resource status. New electronic digital technologies and analytical methodologies are now available that can greatly enhance the acquisition and analysis of data from fishery independent underwater surveys and from fishery dependent vessel-based reporting. Increasingly powerful computers and sophisticated software used competently will continue to increase our capacity for fishery modelling provided the necessary data are available. There is also an increasing emphasis on ecosystem based assessment and management that requires an expansion in research to test hypotheses about observed patterns and functional processes (see Underwood et al. 2000) in temperate subtidal rocky ecosystems. We should heed the statement by Pitcher and Pauly (1998, p.316) that...living organisms, including fish, evolve in response to selective mortality...and that this process can occur more rapidly than most of us would anticipate. Breen (1992, p.270) suggested that 'Multi-species approaches to abalone stock assessment will become increasingly more important with increasing interest in the harvest of marine algae, sea urchins and other grazers and predators from coastal productions systems...'. The associated expenditure will inevitably be criticised as excessive and perceived to be an over-reaction if further problems fail to manifest or resource status improves. However, this will be a much smaller price to pay than the cost if current declines in abalone biomass start to spiral out of control and Victoria loses its most valuable fishery.

Although a rapidly developing industry, abalone aquaculture in Australia is in its infancy and unlikely to impact on the marketing of wild-harvested abalone in the near future. However, the availability of hatcheries provides some of the infrastructure for future attempts at restoring depleted wild populations.

Conclusions

Overall during its four-decade history, the Victorian fishery for blacklip abalone has been apparently sustainable despite instances of localised depletion and contraction of fishing grounds. Throughout most of this period the fishery has been highly remunerative as indicated by the high capital value of fishery access licences. However, this does not provide grounds for complacency. Recent assessments have shown a relatively high probability that biomass for much of the fishing grounds has been declining during the past decade and that this trend is likely to continue throughout the next decade if current catch levels, including a large and potentially increasing illegal catch, persist.

In contrast, the greenlip abalone resource could not sustain a fishery despite only modest catch levels and has failed to recover in the two decades since it ostensibly collapsed. This difference in sustainability is related to the vulnerability of this species to capture and the small and fragmented nature of suitable habitat. It seems likely that restorative intervention is required if Victoria is to ever have a viable greenlip abalone fishery in the future.

There is little doubt that the largest threats to abalone resources come from illegal removals and unfavourable environmental events, often exacerbated by anthropogenic influences. As the human population grows the potential impact of these threats will inevitably increase, as will the need for more rigorous and innovative abatement strategies. Victoria is no exception in this regard and the capacity to continue to harvest abalone sustainably will be contingent on maintaining sufficient biomass during periods when impacts are severe. How much biomass is sufficient is a vexed question in so far as it tests our knowledge of abalone population dynamics and, based on what we do know, is likely to vary spatially, temporally and inter-specifically. These are circumstances that warrant precaution and vigilance in the conduct of a fishery.

If we are to ensure the future sustainability of Victorian abalone resources then on-going improvement in stock assessment and management is required. This improvement can be attained by continuing to pursue the seemingly intractable ecological questions, utilising new and emerging technologies, fostering the meaningful participation of resource users and ensuring an appropriate regulatory and reporting framework to provide effective governance.

Appendix

Copies of the following documents are included because of particular relevance to topics discussed in the thesis:

King, R.H., C.J. Rayner, M. Kerr H.K. Gorfine & P.E. McShane. 1996. The composition and amino acid balance of abalone (*Haliotis rubra*) tissue. *Aquaculture* 140: 109–113.

Kurz, Kh.P. 1967. Preservation of abalone fields in the Mallacoota area. Unpublished letter on behalf of the Mallacoota Fishermens' Association to Jim Wharton Esq., The Chairman of the Commercial Fisheries Advisory Board, 21 Sep., 2 pp.

McShane, P.E., H.K., Gorfine & I.A. Knuckey. 1994a. Factors influencing food selection in the abalone *Haliotis rubra* (Mollusca: Gastropoda). *Journal of Experimental Marine Biology and Ecology* 176: 27–37.

The papers by King et al. (1996) and McShane et al. (1994a), for which I am a co-author, deal with aspects of abalone feeding and nutrition described in the Introduction. Although not directly connected with the main theme of this thesis, the findings from both studies provided evidence in support of alternatives to contemporary hypotheses (at the time of publication) about feeding preferences and nutritional requirements.

The letter by Peter Kurz (1967) is a reproduction of what is probably the only copy of this document. It's relevance to the thesis is that it provides evidence that some of the desirable attitudes and concerns about resource sustainability espoused by today's Victorian abalone divers prevailed among their predecessors during the formative years of the fishery.

King, R.H., C.J. Rayner, M. Kerr H.K. Gorfine & P.E. McShane. 1996. The composition and amino acid balance of abalone (*Haliotis rubra*) tissue. *Aquaculture* 140: 109-113.

PRESIDENT: B. FUNNELL
SECRETARY: P. KURZ
TREASURER: N. LAND

Mallacoota Fishermens' Association

POST OFFICE, MALLACOOTA
PHONE: MALLACOOTA 50.

21.9.1967

Jim Wharton Esq.
The Chairman of the
Commercial Fisheries Advisory Board,
605 Flinders St. Ext.
Melbourne 3000

Dear Sir,

Re: Preservation of Abalone Fields in the Mallacoota Area

Following up our letter of 25th. August we would like again to stress the urgency of action to prevent the over-fishing of the beds in our area.

Since we wrote to you last (app. 4 weeks ago) two new boats have commenced fishing and at least two more crews are at the present moment equiping their boats to do their best to help harvesting undersized fish.

As mentioned in our last letter we are sincerely concerned about the future of the industry in this area and are prepared to help finance any survey by Marine Biologists to establish how grave the situation really is.

Fishermen in general have not the best of reputation, are accused of a shortsighted point of view etc.. Having been in contact with many of the young professional fishermen in our area I have heard again and again that nobody thinks seriously of staying in the district as there is no assured future. Many of the fishermen are married with family and like the area well enough to consider building homes if only there was some chance of a more settled policy, protecting the Abalone fields and theyr future.

At the present moment we are transforming our 'Association' into a registered Co-Operative Society Ltd. and have the wholehearted support of the majority of divers in Mallacoota, after explaining that one of our major aims will be to do anything we can to assure the preservation of the fields, even should it mean restriction that will cut down the IMMIDIATE earnings of the divers. Voluntary control of 'size-limits' 'distances between boats' etc. will be incooperated in the rules.

25/9

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Mallacoota

Fishermens' Association

POST OFFICE, MALLACOOTA
PHONE: MALLACOOTA 50.

PRESIDENT: B. FUNNELL
SECRETARY: P. KURZ
TREASURER: N. LAND

-2-

As Abalone live a sedentary life we thought it might be possible to contact a 'crash-survey' of a short duration, establishing if the situation warrants a full-scale survey. We believe the Fisheries and Wildlife Department could spare a Marine Biologist for a short time and after his findings decide on intermidiate measures to stop any further inroads into the beds.

As mentioned in our last letter we would only be too pleased to assist any person from the Fisheries and Wildlife Department and would even consider to form a body of respectable persons who would work voluntarily to controll the taking of any undersized fish.

In the last 12 months the diving force increased from 15 divers to 1oo divers and their takings from 65.ooo lbs to 535.ooo lbs. These figures are from the Wildlife Department and do not have to be accurate, as we estimate that many divers and their hauls have never been reported.

We would appreciate if you could let us know if we can hope to receive any assistance from the proper authorities and remain

Your

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Kh. P. Kurz, Secretary

Enclosed: Two copies of our Circular about forming a Co-Op.

15-9-1967

CIRCULAR

After due investigation, consideration and legal advice, a body of divers in Mallacoota have decided to form a Co-Operative Society Limited and would like your support.

In brief the aims of the Co.-Op. are as follows:

1. To work towards conservation of existing Abalone Fields.

2. Through volume to endeavour to receive top market prices for Abalone sold.

3. To facilitate freezing, handling and marketing of product.

4. To obtain various agencies to purchase fishing - gear and other related articles at a discount to members.

5. To generally work for the fisherman on a non-profit basis.

Should you want to give us your support, please return this circular crossed in square "A". Should you consider the aims of the Co.-Op to be against your personal interests and do not wish to join please cross square "B".

For your reply to be effective we would need your decision latest 18-9-67. Please mail to Mallacoota Fishermen's Association, the Secretary, P.O. Mallacoota, Victoria.

Further enquiries can be directed to any member of the present committee and will be answered gladly.

Signed: Kh. P. KURZ, Secretary.

A ☐ ☐ B

NAME ....

SUGGESTIONS ....

"[illegible]" Print. [illegible]

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