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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Date **18 April 2002**

'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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Acknowledgements

I thank my supervisors Associate Professor David Booth and Associate Professor Ken Brown for advice, encouragement and guidance during the course of my candidature. Discussions with colleagues at the Marine and Freshwater Resources Institute (MAFRI) and interstate fisheries research institutions were instrumental in developing my constructs and opinions about abalone resource assessment. I am particularly grateful to Mr Cameron Dixon, Dr Anthony Hart, Dr Ian Montgomery, Dr Rick Officer, Mr Bruce Taylor, Dr Vlad Troynikov and Mr Terry Walker who, as fellow employees and project collaborators at MAFRI, freely exchanged their knowledge and ideas with me.

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).

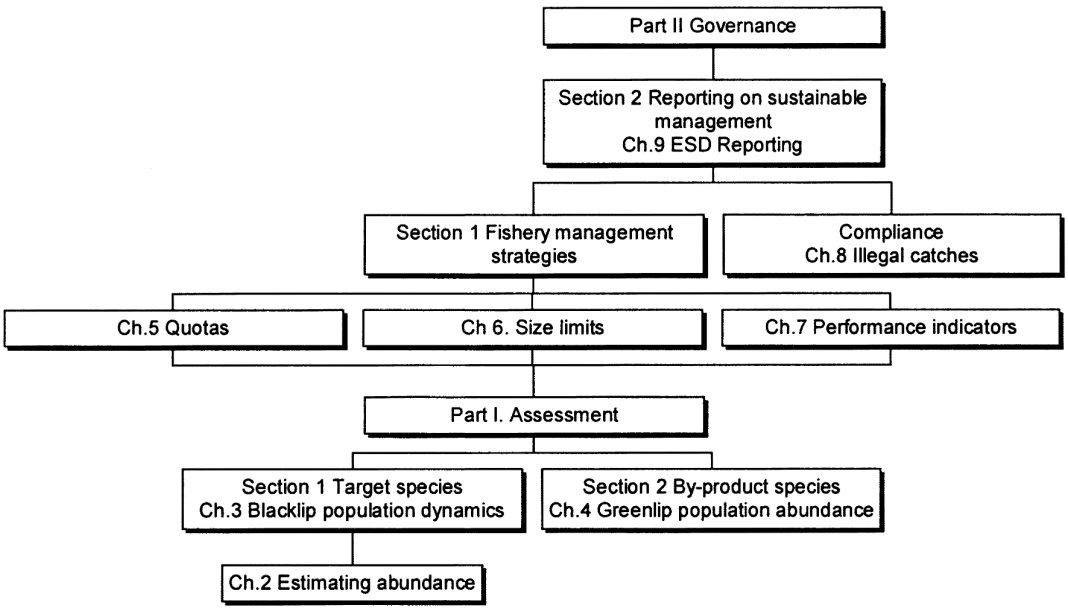

Figure 1. Diagram depicting hierarchy of linkages among the respective thesis chapters.

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.