fisheries research

An evaluation of the costs and benefits of selected projects

ABARE

fisheries research

An evaluation of the costs and benefits of selected projects

Michael Stephens
Q.T. Tran
Tony Battaglene
Robert Curtotti
Tim Bull

ABARE Research Report 95.8

ABARE ECONOMICS

FISHERIES RESEARCH & DEVELOPMENT CORPORATION

ISSN 1037-8286
ISBN 0 642 23533 3

Stephens, M., Tran, Q.T., Battaglene, T., Curtotti, R. and Bull, T. 1995, *Fisheries Research: An Evaluation of the Costs and Benefits of Selected Projects,* ABARE Research Report 95.8, Canberra.

Australian Bureau of Agricultural and Resource Economics
GPO Box 1563 Canberra 2601

Telephone (06) 272 2000 Facsimile (06) 272 2001

ABARE is a professionally independent government economic research organisation.

ABARE project 1128

Foreword

Increasing demands on funds available for fisheries research have led to calls from governments and industry for greater accountability in research expenditures. In this study, a benefit–cost framework is used to evaluate the outcomes from six fisheries research and development activities undertaken over the past decade. Particular attention is paid to identifying the factors that may facilitate or impede the full realisation of research benefits over time. These factors include the initial adoption rate of the research results, the scope for leakage of benefits to potential competitors, and current management arrangements. Other important considerations are lead times between research and the realisation of benefits, information needs and the contribution of baseline research to other projects.

Such information will improve the basis of fisheries research investment decisions, and assist in the development of future research activities.

This project complements previous ABARE research into the use of benefit–cost techniques for setting and evaluating fisheries research priorities. Research on this project was supported by the Fisheries Research and Development Corporation.

Bernard Wonder
Executive Director

November 1995

Acknowledgments

The analyses included in this report were undertaken by Q.T. Tran and Tony Battaglene (southern shark stock assessment program), Robert Curtotti (spanner crab fishery research), Michael Stephens, Andrew Lancaster and Mainul Haque (hatchery and nursery culture for the silver lipped pearl oyster), Tim Bull and Michael Stephens (transport and storage of live penaeid prawns) and Michael Stephens (pearl divers diving safety and stock assessment of blacklip abalone in Victoria).

The authors would like to thank the many researchers, representatives of Commonwealth and State fisheries agencies and industry representatives for their help in providing data used in the analyses. The valuable comments provided by ABARE colleagues Roger Rose, David Campbell and Bill Curran are also gratefully acknowledged. In particular, we would like to thank Padma Lal for her input in the early stages of this project.

Research on this project was supported by the Fisheries Research and Development Corporation.

Contents

Box

Figures

Tables

Summary

Increasing demands on public funds have led to calls from governments and industry for greater accountability in research expenditures and hence a need for a systematic evaluation of the benefits from research.

Calls for accountability in research expenditure

The underlying rationale for government involvement in supporting fisheries research and development has been the presence of 'market failure' in research investment. That is, because individuals or private companies may not be able to gain most of the benefits of a successful research outcome, they will underinvest in research and development relative to the level that would maximise the net benefits to society.

Government involvement in R&D is a response to underinvestment by the private sector

A major objective in this study is to demonstrate the types and possible magnitudes of economic benefits that have been generated from selected research projects funded by the Fisheries Research and Development Corporation (or its predecessor the Fishing Industry Research and Development Council) over the past decade.

The aim here is to evaluate the benefits of completed projects

Another objective is to provide feedback on the process of evaluating the benefits and costs of fisheries research and development after the findings of the research have been implemented.

. . . and to provide feedback on the evaluation process

Evaluation of research payoffs

'Ex post' analysis is undertaken after the research has been completed. The aim is to identify the realised benefits that have flowed from the research and to compare them with the costs of undertaking the research project.

'Ex post' analysis compares realised benefits of research with the costs

. . . which provides feedback on research

Ex post benefit–cost evaluation of research projects provides useful feedback from completed research projects and helps to improve the selection of new project proposals.

. . . for the fisheries R&D portfolio

To illustrate the payoffs arising from research across the Fisheries Research and Development portfolio, a number of projects from the four major research programs — natural fish resources, harvesting, aquaculture and marketing — were assessed.

Six case studies were selected for evaluation

Two criteria were used to select research projects or programs for ex post evaluation in this study. First, the results had to have been adopted by industry or management. Second, there had to be sufficient information to evaluate the outcomes of research. The case studies analysed included two stock assessment studies, one aquaculture project, one harvesting safety project, one post-harvesting study and one study which included a combination of stock assessment and post-harvest handling research. No marketing study was found to satisfy the selection criteria.

Three case studies included a series of projects

Three of the case studies evaluated constituted a series of projects which formed a research program — these were research into hatchery and nursery culture for the silver lipped pearl oyster, spanner crab fishery research and the southern shark stock assessment program. Together these projects demonstrate the outcomes from a cumulative research program.

The objective of research is to raise net benefits to the fishery

Fisheries research is usually designed to generate information about the factors that affect the production or consumption of fisheries products and the use of marine resources. The objective of research is to generate information that will allow the net benefits derived from fisheries resources (including both market and non-market benefits) to be raised. However, the benefits will be realised only if the research results are implemented (to make or prevent changes).

For projects into the commercial harvesting and marketing of fish, the benefits of research comprise any additional profit to the industry, together with any benefits to consumers from changes in quality or price.

Benefits include those to producers and consumers

Fisheries research in Australia is generally directed toward an individual fishery or target genus or species. However, there is usually a large number of close substitutes available for the products of these fisheries, either from domestic or imported sources. In these circumstances, domestic demand for the products from a specific fishery or of individual species may be assumed to be highly responsive to changes in the price of those products — that is, a small change in price will result in a large change in the quantity demanded. In such cases, the changes in consumer welfare that result from research induced changes in supply or demand can be assumed to be negligible.

Because there are many close substitutes for fisheries products, demand is very responsive to changes in price

For the commercial harvesting and marketing of fish, therefore, the benefits of research is usually any additional profit to the industry (rent). Where research results in enhanced non-market benefits, these benefits were considered separately.

Benefits may be extra profits or non-market benefits

Research benefits were evaluated by estimating the benefits that were likely to have been generated in the absence of research, and comparing them with the likely benefits generated after research.

. . . and are those attributable to the research

The net benefits from research were estimated as the change in benefits less the expected costs of undertaking the research and implementing the results. Where possible, costs and benefits have been quantified and valued in 1994-95 dollars. However, the ability to assess monetary values of the net benefits of research was largely determined by the availability of suitable information.

Net benefits are the extra benefits from the research less the costs of the research

Benefit–cost analysis is used

Where the availability of information permits, benefit–cost analysis can be used to calculate the present value of net benefits over time arising from investment in research. Where insufficient information is available, the benefit–cost approach may have to be modified.

. . . based on a range of approaches

. . . from modelling

Reflecting the level of uncertainty about the interaction between the many biological and economic parameters affecting Australian fisheries, a number of approaches was used to evaluate estimated research payoffs. For example, in the southern shark stock assessment program case study, a bioeconomic model was used to assess the potential research benefits. The model was used to quantify the effects of changes in key parameters on a number of biological, economic and physical measures for the fishery.

. . . to 'stochastic' analysis, to account for uncertainty

In three of the case study evaluations, 'stochastic' benefit–cost analysis was used to take account of the uncertainty in values of a number of key variables, such as prices, costs and yields, likely to influence the estimated size of economic benefits arising from the research. These case studies were the transport and storage of live prawns, pearl diving safety and spanner crab fishery research. The approach used provided a convenient way of representing the uncertainty associated with the estimated payoffs from fisheries research.

. . . to break-even analysis

In the Victorian abalone stock assessment case study, there was insufficient information to identify meaningful ranges of values for factors affecting the size of the benefits resulting from the research. Consequently, a simple analysis was used to assess the minimum value of benefits necessary for the research to break even.

. . . to qualitative assessments

In the case studies where the nature of some of the benefits were difficult to define or measure in quantitative terms, qualitative assessments were combined with the other types of assessment.

The flow of research benefits varies over time. Initially, there will be a period of research and development costs associated with the project, followed by the release of research results. Depending on the underlying characteristics of the research (such as baseline or applied research), it may take several years before the results are fully applied as a new technology or innovation. It may also take several years for the innovation to be adopted by industry, while potential beneficiaries assess whether or not it is in their best interests to adopt the innovation.

The flow of research benefits varies over time

At some time in the future the innovation will no longer generate additional benefits, but will become diffused through the availability of alternative technologies or increased competition from alternative producers and suppliers, including from overseas.

. . . gets diffused eventually

In the case of a common property resource such as fisheries, the presence of appropriate management arrangements or property rights structures will also influence the extent to which the benefits from research can be maintained over time.

. . . and is influenced by management and property rights

The case studies evaluated in this study provide examples of projects where the results have been implemented by industry or management but are at varying stages of adoption, thereby affecting the extent to which the benefits have been fully realised by the beneficiaries of the research.

The case studies analysed are at varying stages of adoption

Main findings and issues from case study evaluations

The results of the evaluations in this study suggest that appropriately selected fisheries research can result in potentially large benefits to both fisheries producers and the broader Australian community.

Payoffs to fisheries research can be large

... and may be positive for four projects

The benefit–cost analyses show that the potential benefits from four of the projects amenable to quantitative valuation can be expected to exceed the research and implementation costs over the next ten to twenty years.

Factors identified as important to evaluations

The use of ex post analysis to assess the benefits of selected fisheries research also highlighted a number of factors important to evaluating research benefits. These included:

– information

- a lack of information, in some cases, on which to undertake detailed ex post analysis;

– lags

- the long time period between research completion and final realisation of benefits;

– dissipation

- the extent of potential dissipation of research benefits over time;

– leakage

- the leakage of benefits to competitors;

– attribution

- the problem of attributing benefits to the identified project or series of projects (program); and

– baseline

- the baseline nature of some fisheries research.

Lack of suitable information meant assumptions had to be made for the assessments

Most importantly, the choice of analysis depended on the availability of suitable information. In the evaluation of research into the spanner crab fishery, for example, a number of clearly stated and supported assumptions were used in the absence of more detailed information on the catchability and relative abundance of crabs over time.

... assisted by the use of a bioeconomic model in one case study

In the case of the southern shark stock assessment program, the availability of a bioeconomic model provided an important tool for evaluating future expected benefits. This model allowed the research benefits to be measured with greater certainty, since the most important economic, biological and physical relation-ships could be quantitatively assessed and modelled on the basis of existing knowledge.

On the second point of concern, the time taken before the benefits (if any) are realised will vary, depending on the nature of the research undertaken. The length of time will depend on the type of impact expected from the research and the institutional structure within the fishery. For example, the total net benefits realised to 1993-94 from four of the six of the projects amenable to quantitative valuation was negative, implying a net economic cost. But the total return from these projects over ten to twenty years is expected to be positive.

Lags between research completion and realising the benefits may be many years

For biological and management related research, a significant period may elapse between the completion of research and the realisation of expected benefits. Much will depend on the biological characteristics of the species under study.

. . . depending on biological characteristics

For example, for the southern shark stock assessment research program assessed in this study, significant benefits are not expected to accrue until twenty years after the research recommendations were implemented in 1991. This is because school and gummy sharks are generally slow growing and produce only a small number of young, resulting in a lengthy time between management changes in allowable catches and improvements in stock levels. In such a case, management changes can result in short term costs to operators before an improvement in long term profitability of the fishery is realised.

For one case study these lags could be twenty years

. . . meaning short term costs before long term profitability

In contrast, research into harvest technology or marketing may result in the benefits being realised relatively quickly. Such is the case for the research projects into pearl diving safety and the production and marketing of live kuruma prawns. The project into pearl diving safety, for example, is likely to have resulted in the generation of benefits within two years of the initial research because of the reduction in harvesting cost savings following implementation of the research findings.

For some projects, the benefits may accrue quickly

. . . within two years for one project

The long time lag for some projects meant the benefits had to be estimated

... introducing uncertainty to the analysis

Because of the relatively long time between completing the research and realising the benefits, in most cases the benefits had to be estimated using an 'ex ante' approach. That is, for many projects there had been insufficient time for all the potential benefits to have been fully realised. Key factors affecting the risk in estimating future research benefits included product prices, yields and likely adoption rates. The use of 'stochastic' analysis was therefore an important component of the evaluation process, given the considerable uncertainty about future costs, prices and yields.

Benefits will be affected by the dissipation of research results over time

The third point of concern listed above is the dissipation of research benefits over time. The actual and expected flow of benefits is influenced by such factors as the presence of appropriate management arrangements and the rate of technology transfer.

... which is influenced by property rights

... and control over effort

For fisheries research aimed at increasing returns to the harvesting sector, the maintenance of benefits (as measured by rent) will depend on the strength of property rights over the resource. Under an input control management regime, available rents in the fishery will become dissipated in the long run as operators substitute uncontrolled inputs for controlled inputs. The rate of substitution depends on the level of controlled inputs (for example, in the case of the southern shark fishery, restrictions on the number of nets) and the ability to increase other inputs.

Dissipation of benefits would be less under an output controlled fishery than an input controlled fishery

In the case of the southern shark stock assessment program, the presence of input management controls such as licensed gear entitlements was assumed to result in the generation and maintenance of research benefits over time. While this form of management is likely to slow the rate of dissipation of benefits from research when compared with an open access fishery, dissipation is still likely to occur. The benefits estimated from the southern shark stock assessment program may consequently be considered an upper bound of potentially realisable benefits. If the management of the fishery were changed to an output controlled fishery, for example, there would be less likelihood of these potential benefits being dissipated over time.

Benefits from research will be affected by changes in prices resulting from increases in production

The pearl oyster hatchery development program also highlighted the need to identify, before the funding of research, some of the key economic parameters likely to affect the size and probability of realising the possible benefits. This research program has resulted in the successful development of hatchery and nursery culturing techniques for the silver lipped pearl oyster. However, the likelihood of achieving research benefits in this case is highly dependent on the responsiveness of world prices of south sea pearls to increased Australian production, which is presently uncertain.

Benefits may also be dissipated by the leakage of results to overseas competitors

. . . an example here is the pearl oyster hatchery research program

Furthermore, the outcome of the pearl oyster hatchery research program demonstrated the need to develop clearly defined property rights with respect to research results and intellectual property arising from fisheries research. If the results from this research were restricted to Australian producers, the likelihood of maintaining any possible national benefits would be increased. However, several Indonesian firms are currently establishing commercial hatcheries based on the results of the Australian research. In this case, the benefits from research will be dissipated if the leakage of research results leads to increased overseas production and downward pressure on prices of south sea pearls over the medium to longer term. This is the fourth point of concern listed above.

. . . and the kuruma prawn transport and storage project

Similarly, the risk of technology transfer to overseas producers is likely to affect the expected benefits from research into the transport and storage of live kuruma prawns.

So, Australia's position in world markets is important

Consequently, the existence of international competitors and Australia's future market position are likely to play an important role in the future potential benefits from fisheries research. Research into the development of new harvesting technologies is particularly vulnerable to leakage. Therefore, funding of such research should only be undertaken when it is possible to ensure the results may not be used to adversely affect Australia's trading position.

The desired benefits may depend on the cumulative results of many research projects

It is often the case in fisheries research that the cumulative efforts of many research projects (simultaneous or sequential) are needed to provide sufficient information to achieve the desired benefits — the fifth point of concern. When conducting an ex post evaluation, it is important to assess whether the benefits and costs of a suite of related research projects or those from an individual research project in isolation should be evaluated. In most of the case studies evaluated, a suite of related research projects was assessed, reflecting the important linkages between the many individual research projects. For example, a number of related research projects was included in the evaluation of the southern shark stock assessment program and the hatchery and nursery culture for the silver lipped pearl oyster. In these cases, the cumulative effects of individual projects could not be separated.

. . . for example, for the southern shark program and the pearl oyster program

An important assumption underlying the evaluation of a research program is that the particular projects selected are the most appropriate for the research benefits that have been identified.

Many projects rely on the results of baseline research

. . . but the benefits of baseline research are hard to measure

In some cases, many of the projects or programs to be evaluated might include a proportion of research which can be described as baseline research — the final point of concern listed above. This includes research into the basic biology and population dynamics of an individual genus or species (such as research into the basic biology of spanner crabs and abalone for example). It is often difficult to quantify the direct market benefits arising from the baseline research, although the task is made easier when the baseline research can be combined with relevant applied research projects likely to yield (as a package) market and/or non-market benefits.

. . . particularly in isolation from other applied and related research

Concluding comments

Ex post analysis can provide feedback on factors that facilitate or impede the uptake of research results and the final realisation of benefits. Ex post analysis also helps identify the types of research benefits obtained and the subsequent growth or dissipation of those benefits through time. Such benefits may include market benefits (such as enhanced catches or reduced harvesting costs) and/or non-market benefits (such as knowing a particular species of fish exists).

'Ex post' analysis is useful for current and future research projects

This information can then be used as an input in the overall planning and management of research expenditures and, when used with ex ante analysis, can provide a more efficient framework for allocating research resources at the project selection stage.

. . . improving project selection

For example, an ex ante benefit–cost evaluation of a research project provides the starting point for determining whether a project can be expected to yield benefits in excess of costs and, if so, what priority should be given to it relative to competing research proposals. As new information becomes available through the course of research, modifications to the project can be made on the basis of subsequent re-evaluations. When the project is completed, an ex post evaluation will provide some valuable insights into the accuracy of the initial evaluation and what factors were important to any divergences between anticipated and actual research outcomes. These lessons can then be applied in subsequent ex ante evaluations of new project proposals.

. . . on the basis of ex ante versus ex post analysis of specific projects

The case studies reported here identified factors important to realising the benefits from research

The case studies of selected fisheries research, reported here, identified a number of important factors affecting the flow of actual and expected benefits. These factors included the initial adoption rate of research results, the scope for the leakage of benefits to international competitors, and current management arrangements. Other important lessons included the need to acknowledge the contribution of baseline research into fisheries management and production, and the relatively long time period between completing research and realising the benefits from that research.

1

Introduction

Over the past decade there has been increasing pressure on resources for research and development in Australian fishing industries. Increasing demands on public funding have led to calls from governments and industry for greater accountability in research expenditures and hence a need for the systematic evaluation of the benefits from research. Research funding agencies such as the Fisheries Research and Development Corporation (FRDC), for example, are becoming increasingly accountable to industry and government for the efficient management of R&D funds. In 1992-93, the total pool of government and industry funding for fisheries R&D was around $48 million (FRDC 1993).

The underlying rationale for government involvement in supporting fisheries R&D has been the presence of 'market failure' in research investment. That is, in the absence of government support, it is argued that if individuals or private companies are not able to gain most of the benefits of a successful research outcome, the private sector will underinvest in R&D relative to the level that will maximise the net benefits to society.

Fisheries research in Australia has previously been oriented toward population biology and stock assessment studies. More recently, public investment has increased in the areas of harvesting and post-harvesting research, in recognition that such factors play an equally important role in the sustainable management of Australia's fisheries. The relatively recent development of aquaculture in Australia has also led to a considerable level of applied aquaculture research. Changing community attitudes and the adoption by governments of ecological sustainability in fisheries management have consequently placed further demands on the resources available for research, including research into the economic, social and environmental aspects of Australian fisheries.

It is therefore likely that research evaluation methods will play an even stronger role in the overall management and allocation of fisheries research funds, as fisheries managers and researchers increasingly recognise that the resources available for research are limited, and that research expenditures should be directed to those areas with the highest expected returns.

This study was commissioned by the Fisheries Research and Development Corporation to focus exclusively on an ex post benefit–cost evaluation of selected fisheries research and development projects. The main objectives of the study are:

- to demonstrate the types and possible magnitudes of economic benefits that have been generated from selected research projects funded by the FRDC (or its predecessor the Fishing Industry Research and Development Council) over the past decade; and
- to provide feedback on the process of evaluating these projects, with a view to improving fisheries research and development evaluation procedures.

2

Evaluation of research payoffs

'Ex post' analysis is only one part of the evaluation and management process of research and development activities. Ex post analysis is undertaken after the research has been completed (and its recommendations implemented or adopted), with the aim of identifying the realised benefits that have flowed from the research and comparing them with the costs. Ex post benefit–cost evaluation of research projects is useful in providing feedback from completed research projects and improving the selection of new project proposals.

One of the main advantages of an ex post evaluation over an ex ante evaluation (that is, one done beforehand) is that, clearly, there is a greater degree of certainty about estimated research payoffs after the research is completed. Ex post evaluation can therefore be used to compare the actual research payoffs with the expected research payoffs of particular research projects or programs, and can assist researchers and fisheries managers to identify those factors contributing to successful research outcomes.

There have been very few formal ex post evaluations of research payoffs in Australia, which contrasts somewhat with the situation overseas (Johnston 1989). However, in recent years, greater accountability to industry, government and the community of public research and development activities has led to a number of ex post benefit–cost analyses of Australian agricultural research projects. These studies have evaluated the net economic benefits (or returns) arising from a number of publicly funded research projects in the grains, meat and livestock industries, and suggest that the gains from research can be quite significant in some cases. A survey of recent Australian benefit–cost analyses of agricultural research and development projects was undertaken by the Grains Research and Development Corporation (1993).

In the case of fisheries, such ex post evaluations of research projects in Australia have generally been limited (see, for example, Tisdell 1991 and Goodrick and Hardman 1992). Until recently, evaluation and selection of fisheries research has largely been on the basis of expert opinion rather than through formal economic evaluations (Lal, Holland and Collins 1994). However, this situation is slowly changing. Greater emphasis is now being placed on improving returns from fisheries research, and there is a growing need to regularly monitor and assess the benefits of such research. For example, the Australian Centre for International Agricultural Research has continued to develop research evaluation processes for its fisheries research program since the mid-1980s. The FRDC has also developed a systematic research prioritisation and evaluation process for its fisheries research portfolio.

Selection of projects for evaluation

A preliminary study was conducted previously by ABARE to assess the feasibility of conducting formal benefit–cost evaluations of selected fisheries research projects (Stephens and Lal 1993).

The two main criteria used in the study to select research projects (or programs) for ex post evaluation were:

- projects where the results had been adopted by industry or management; and
- projects where there was sufficient information to evaluate the outcomes of research — in most cases this included the availability of both quantitative and qualitative information.

It was not the objective in this study to assess the wider policy issues surrounding the most appropriate level of public and private funding for fisheries research and development activities.

This study was specifically commissioned to assess the types and possible magnitudes of benefits arising from research funded by the FRDC or its predecessors.

It is acknowledged that different selection procedures will allow different interpretations to be placed on the results of the evaluation. The criteria used by ABARE in selecting case studies were oriented toward projects where the main findings or results of the research had been adopted. It should be noted that the case studies selected for detailed ex post evaluations have been chosen to illustrate the types and possible magnitudes of benefits that have been generated from FRDC funding. Therefore, the extent to which the conclusions drawn from this study can be applied to other research projects or the FRDC program in general is likely to be limited and will be influenced by the initial process used to select projects for evaluation.

Illustrative spread of projects across the FRDC portfolio

To illustrate fisheries research payoffs arising from successful research across the FRDC portfolio, a number of projects from the four major research programs — natural fish resources, harvesting, aquaculture and marketing — were assessed. After initially screening a large number of projects from the FRDC portfolio, it was evident that a significant proportion of previously funded research concerned population biology and stock assessment studies, followed by aquaculture and post-harvesting research. Compared with other research programs, there were few marketing studies, which may partly reflect the private good nature of this type of research — that is, individuals have the incentive to carry out the research themselves as they are able to gain most of the benefits of a successful outcome.

It was also evident that, in many cases, previously funded research projects were still being completed or there had been insufficient time for the results to have been fully adopted by industry or management. In addition, the relatively recent development of aquaculture in Australia has meant that many aquaculture projects are still at the research stage or are yet to be significantly adopted at the farm level. There are also a number of baseline studies into fisheries biology and stock assessment which, although completed, are contributing to a broader program of research, and so the results are yet to be fully adopted by management.

The case studies presented in chapter 3 include two stock assessment studies, one aquaculture project, two post-harvesting studies and one study which included a combination of stock assessment and post-harvest handling research (table 1). However, no marketing study was found to satisfy the

1 **Research projects selected for evaluation**

Project title	FRDC research program
1. Transport and storage of live penaeid prawns	Harvesting
2. Hatchery and nursery culture for the silver lipped pearl oyster	Aquaculture
3. Pearl diving safety	Harvesting
4. Spanner crab fishery research	Natural fish resources and harvesting
5. Southern shark stock assessment program	Natural fish resources
6. Stock assessment of blacklip abalone in Victoria	Natural fish resources

criteria presented above. Three of the case studies evaluated also constituted a series of projects that formed a research program (research into hatchery and nursery culture for the silver lipped pearl oyster, spanner crab fishery research and the southern shark stock assessment program), and demonstrate the outcomes from a cumulative research program.

Valuation of research benefits

Fisheries research is usually designed to generate information about the factors that affect the production or consumption of fisheries products and the use of marine resources. The objective of research is to generate information which permits an increase in the net benefits derived from fisheries resources (including both market and non-market benefits). As discussed by Lal, Holland and Collins (1994), the impact of applied fisheries research on social welfare can generally be considered under the following broad headings:

- changes in product prices (usually increases)
- changes in unit costs (usually decreases)
- changes in fish catches (determined by sustainable stocks)
- changes in non-market benefits
- development of new fisheries.

However, it is only by implementing research results (using the results to make or prevent changes) that benefits can be realised. For the commercial harvesting and marketing of fish, the benefits of research comprise any additional profit to the industry and any benefits to consumers in terms of changes in quality or price. The benefit of research to the harvesting sector of the industry can be estimated as the difference between the total revenue *less* the costs of the operation (including a return to capital and management) — commonly known as the rent — produced after the research results had been adopted and the rent that may have been produced in the fishery if the research had not been undertaken.

Similarly, the net benefits of research to consumers can be determined from the difference between consumer welfare after the research results had been adopted and the consumer welfare that could have been expected had the results not been adopted. Consumer welfare can be estimated as the difference between the prices that consumers would be willing to pay for the amount of fish they buy and what they actually pay.

Fisheries research in Australia is generally directed toward an individual fishery or target genus or species. However, there is usually a large number of close substitutes available for consumption of fisheries products, either from domestic or imported sources. In these circumstances, the domestic quantity demanded of products from a specific fishery or individual species may be assumed to be highly responsive to changes in price — that is, a small change in price elicits a large change in demand. This would appear to be a reasonable assumption for many Australian fisheries products that are marketed domestically (Battaglene, Geen and Simmons 1991).

Because commercial demand for fisheries products is assumed to be highly responsive to changes in price, changes in consumer welfare brought about by research induced changes in supply or demand are assumed to be negligible in the following case study evaluations. For the commercial harvesting and marketing of fish, therefore, the benefits of research are made up mainly from additional profit to the industry. Where research resulted in the enhancement of non-market benefits, these benefits were considered separately.

Research benefits were evaluated by estimating the benefits (such as rents) that were likely to have been generated in the absence of research, and comparing them with the benefits generated after research (taking into account the time value of money and likely probabilities of assigning values to parameters). The net benefits from research were estimated as the change in benefits *less* the expected costs of undertaking the research and implementing the results. Where possible, costs and benefits have been quantified and valued in 1994-95 dollars. However, the ability to assess the monetary value of the net benefits of research was largely determined by the availability of suitable information.

Information availability and treatment of uncertainty

Where the availability of information permits, benefit–cost analysis can be used to calculate the present value of net benefits over time arising from investment in research. However, because much of the information needed to obtain precise quantifiable values may not be available, a practical assessment of projects is likely to involve a number of modifications to the benefit–cost approach (Lal et al. 1994). Depending on the amount of information available, this may include stochastic benefit–cost analysis, simple forms of quantitative analysis, qualitative assessments, or some combination of these.

2 Summary of evaluation methods used for selected fisheries R&D projects

Case study	Nature of research	Method of evaluation	Main features of applied method
Transport and storage of live penaeid prawns	Development of live product handling and marketing techniques for the kuruma prawn aquaculture industry	Stochastic benefit–cost analysis	Use of economic prawn farm models for estimating the additional net returns from adopting kuruma prawn farm technology compared to existing black tiger prawn aquaculture industry. Consideration given to expected variability in future prices, yields and adoption rates.
Hatchery and nursery culture for the silver lipped pearl oyster	Development of artificial propagation and nursery culture technology for the silver lipped pearl oyster	Simple benefit–cost analysis with sensitivity analysis of key parameters	Simple estimation of potential net returns from aquaculture pearl production based on assumed range of prices, yields and price flexibilities.
Pearl diving safety	Development of world accepted diving safety standards for the Australian pearling industry	Stochastic benefit–cost analysis	Simple estimation of industry harvesting cost savings assuming lower number of seasonal fishing days using world accepted diving safety standards developed from this research compared to equivalent safety procedures developed overseas. Consideration given to variability in daily vessel running and labour costs.
Spanner crab fishery research	Identification of the population biology and non-damaging crab harvesting practices for the spanner crab fishery	Stochastic benefit–cost analysis	Simple estimation of the additional net returns from increased catches using observed changes in catch per unit effort attributed to management changes that were assumed to arise from the research findings.
Southern shark stock assessment program	Development of biological database and predictive stock–recruitment models for the southern shark fishery	Parametric bioeconomic model	Use of existing bioeconomic model to estimate the net additional returns over time from the adoption of effort reducing measures attributed to the research.
Stock assessment of blacklip abalone in Victoria	Development of suitable stock recruitment assessment techniques for the Victorian blacklip abalone fishery	Simple break-even analysis and qualitative assessment	Use of break-even analysis to identify the minimum stream of future additional returns required to meet total research and implementation costs already incurred. Qualitative assessment also used to assess the relevance of the research to the management problem and the likelihood of research benefits being maintained over time.

Given the uncertainty about the interaction between the many biological and economic parameters affecting Australian fisheries, a number of approaches were adopted in the evaluation of estimated research payoffs (table 2).

In the southern shark stock assessment program case study, a bioeconomic model was used to assess the level of potential research benefits. An advantage of using a bioeconomic model is that it explicitly takes into account the most important biological, economic and physical relationships that interact within the fishery. A bioeconomic model can be used to quantitatively assess the effects of changes in key parameters on a number of biological, economic and physical measures for the fishery.

In three of the case study evaluations (transport and storage of live prawns, pearl diving safety and spanner crab fishery research), stochastic benefit–cost analysis was used to take account of the uncertainty in values of a number of key variables such as prices, costs and yields likely to influence the estimated size of economic benefits arising from research. This method of analysis follows the stochastic approaches to investment analysis used by Anderson (1976) and Beck, Johnston and Fraser (1986), and more recently applied in the context of domestic aquaculture investment by Treadwell, McKelvie and Maguire (1991) and ex ante research investment analysis by Lal, Holland and Collins (1994).

This approach provides a convenient way of representing the uncertainty associated with many cost, price and yield parameters. For each uncertain parameter a triangular distribution was assumed, described by minimum, most likely and maximum values. The values used to define each triangular distribution were based on information provided by industry and researchers, and recently observed product price ranges. A value for each uncertain parameter was then randomly selected from the given distribution and used to calculate the discounted net present value. This procedure was repeated to derive a set of net present values, which were then ranked and printed with the corresponding cumulative probability distribution. This function gives the probability of the estimated net present value being less than any particular level.

In the Victorian abalone stock assessment case study there was insufficient information to identify meaningful ranges of values for factors affecting the size of research benefits, so a simple analysis was used to assess the minimum value of benefits necessary for the research to break even. Qualitative assessments were also combined with the other types of assessment in the case studies where the nature of some of the benefits were difficult to define or measure in quantitative terms.

Timing of research costs and benefits

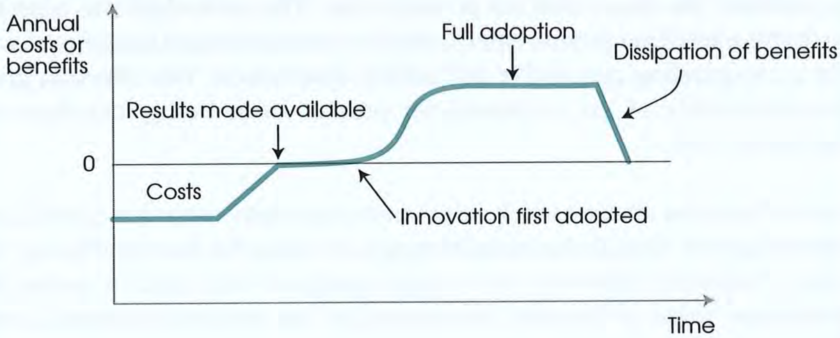
The factors affecting the flow of research benefits can be discussed with reference to figure A, which depicts a typical time profile of costs and benefits associated with a successful research project. Initially, there will be a period of research and development costs associated with the project, followed by the release of research results. Depending on the underlying characteristics of the research (such as baseline or applied research), it may take several years before the results are fully applied in the development of a new technology or innovation. It may also take several years for the innovation to be adopted by industry, as potential beneficiaries assess whether it is in their best interests to adopt the innovation. In the case of a common property resource such as fisheries, the presence of appropriate management arrangements or property right structures will also influence the extent to which the benefits from research can be maintained over time.

The case study evaluations presented in the following chapters provide examples of projects where the results have been implemented by industry or management but are at varying stages of adoption. Consequently, the extent to which the benefits have been fully realised by the beneficiaries of the research varies.

Foster, Linden, Whiteley and Kantrow (1986) have described the factors affecting the benefits of research as falling into two broad categories: factors

A

Typical time profile of costs and benefits of successful research



affecting the feasibility of research, and factors affecting the attractiveness of research. The attractiveness of research can broadly be defined as the maximum possible level of expected benefits. It is influenced by such factors as the size of the relevant industry, the timing of the expected benefits and the scope for wider adoption of results. The feasibility of research is broadly defined as the likelihood of achieving the possible benefits. This is influenced by such factors as the level of technical research success, the rate of adoption by industry or management and the prospect of capturing and maintaining research benefits over time. These factors are discussed in more detail in relation to the realisation and maintenance of actual and expected returns from each of the case studies presented in the next chapter.

General assumptions and conditions

Some of the general assumptions and conditions underlying the evaluation of costs and benefits were as follows:

- General collection and compliance costs associated with the public funding of fisheries research projects were not included in the estimation of net benefits from individual projects. It has been shown elsewhere that the costs of raising public research funds through taxation or producer based levies can be substantial (Curran and Podbury 1994). In the absence of detailed information on the costs of raising public funds, the estimated research benefits should be regarded as an overestimate because the cost of collecting funds are known to be positive.
- In the case of research affecting fisheries that are managed primarily using input controls (such as the southern shark and spanner crab fisheries), it was assumed that the level of benefits generated would be the same as if the fishery were managed using output controls. It is likely that the use of input controls would lead to an increased rate of dissipation of research benefits over time, because of the incentives for operators to increase effort above that required to produce the greatest benefits to the community as a whole. Therefore, the assumption leads to an overestimate of benefits.
- Where possible, costs and benefits of fisheries R&D projects were quantified and valued in 1994-95 dollars.

3

Individual case study evaluations

The six case studies chosen from the Fisheries Research and Development Corporation's portfolio of research projects are:

Project title	FRDC research program
1. Transport and storage of live penaeid prawns	Harvesting
2. Hatchery and nursery culture for the silver lipped pearl oyster	Aquaculture
3. Pearl diving safety	Harvesting
4. Spanner crab fishery research	Natural fish resources and harvesting
5. Southern shark stock assessment program	Natural fish resources
6. Stock assessment of blacklip abalone in Victoria	Natural fish resources

The ex post benefit–cost evaluations of these six case studies are reported in the following sections.

3.1 *Transport and storage of live penaeid prawns*

FRDC research program: harvesting (research leading to price enhancement and development of new markets)

Key issues: stochastic analysis of research benefits; adoption rate likely to influence size of total benefits realised; uncertainty over future price effects on size of potential benefits

Background

In the mid to late 1980s there was considerable interest by the International Food Institute of Queensland in developing opportunities for exporting live kuruma prawns (*Penaeus japonicus*) to Japan.

This led to research being jointly funded by the Fisheries Research and Development Corporation (FRDC) and the Queensland Department of Primary Industries to which the Institute is affiliated. The total nominal cost of the research project was $300 000 (or $325 800 expressed in 1994-95 dollars) spread over the three year period ended 1990-91. The FRDC contributed 46 per cent of this amount.

Research focused on the development of techniques for a system of handling live kuruma prawns from the point of capture, packaging and subsequent distribution to the Japanese seafood market. The Japanese live prawn market is dominated by the kuruma prawn which has a particular appeal to Japanese buyers because of its distinctive red and white stripes. The research allowed methods to be established which could ensure high survival rates (between 95 and 100 per cent) of Australian kuruma prawns during transport to Japan.

The techniques developed through this research have enabled the development of a new industry — the production and marketing of live Australian kuruma prawns for the Japanese seafood market. The first shipment of live kuruma prawns was successfully exported to Japan in 1991, based on the development of a 2 hectare trial farm. By the end of 1993 around 20 tonnes had been successfully exported to Japan, from a total farm area of 9 hectares devoted to kuruma production. Prices received for live Australian kuruma prawns in Japan over this period have been similar to those for the Japanese domestically produced live kuruma prawn, although below the average price received for premium quality Japanese product.

Method

In this case the benefits from research are defined as the net extra benefits to the aquaculture prawn industry from producing kuruma prawns rather than black tiger or 'leader' prawns (*Penaeus monodon*). Kuruma prawn production requires increased capital and operating costs compared with black tiger prawn production; however, the potential net returns are higher, based on higher average prices. The net benefits are defined in this way because before the research was undertaken the main species produced and marketed from prawn farms in tropical and warm–temperate areas on the east coast of Queensland was the black tiger prawn (Hardman, Treadwell and Maguire 1990). Black tiger prawns are supplied predominantly as a fresh chilled product for the domestic market and offer limited opportunities for export compared with live kuruma prawns. It is therefore likely that in the absence of research any expansion of prawn aquaculture in the region would have been devoted to black tiger production for the domestic market.

A benefit–cost study of the projected net benefits of kuruma prawn research was conducted by the Queensland Department of Primary Industries (Goodrick and Hardman 1992). That study used a number of prawn farm models developed by the Economic Services Branch of the Department. Farm operating and capital cost data from these models have been used in the ABARE evaluation since they contain the most recent cost data on prawn farm technology for the production of kuruma and black tiger prawns (tables 3 and 4). However, the industry adoption rates used by Goodrick and Hardman are now considered conservative in the light of recent increases in pondage area devoted to kuruma prawn production.

Capital costs included the cost of suitable land, pond construction, pumping and aeration equipment, cooling tanks, nets and cages and other equipment such as a truck, tractor and four wheeled motor bike. A salvage value calculated at 10 per cent of the purchase price was used for selected equipment such as pumps and motors, generator, rotary hoe, spike tooth harrows, slasher, buckets, blade, fertiliser spreader, truck, tractor, motor bike, aeration units, refrigeration plant and dinghies on replacement. The capital life of equipment ranged from ten years for a truck to three years for cages and nets.

3 Operating costs used for black tiger and kuruma prawn farms of 15 hectares
In constant 1994-95 dollars

	Annual operating cost for year				
	0	1	2	3	4–20
	$	$	$	$	$
Kuruma prawn farm					
Feed	0	834 790	834 790	667 830	667 830
Prawn fry	0	79 500	79 500	63 600	63 600
Electricity	0	79 500	79 500	63 600	63 600
Fertiliser	0	3 980	3 980	3 180	3 180
Repairs and maintenance	0	26 500	26 500	21 200	21 200
Miscellaneous	0	6 360	6 360	6 360	6 360
Harvesting and marketing	0	649 390	811 740	779 270	779 270
Administration and permits	72 385	79 310	60 550	47 510	47 510
Labour					
– manager	31 802	63 600	63 600	63 600	63 600
– permanent	0	135 160	135 160	135 160	135 160
– casual	0	5 300	5 300	5 300	5 300
Black tiger prawn farm					
Feed	0	128 800	172 260	154 560	154 560
Prawn fry	0	79 500	79 500	63 600	63 600
Electricity	0	31 800	31 800	25 440	25 440
Fertiliser	0	3 980	3 980	3 180	3 180
Repairs and maintenance	0	21 200	21 200	16 960	16 960
Miscellaneous	0	6 360	6 360	6 360	6 360
Harvesting and marketing	0	26 500	26 500	26 500	26 500
Administration and permits	41 643	20 480	20 480	20 480	20 480
Labour					
– manager	21 201	42 400	42 400	42 400	42 400
– permanent	0	79 500	79 500	63 600	63 600
– casual	0	5 300	5 300	5 300	5 300

Source: Economic Services Branch, Queensland Department of Primary Industries. Based on 1991-92 costs which have been adjusted by changes in the consumer price index to represent 1994-95 dollars.

The major operating costs for both farm types included feed costs, marketing, electricity supply and labour. Feed costs were higher for producing kuruma prawns than for black tiger prawns, since higher quality feeds are required to produce the colouration and appearance characteristics of live kuruma prawns desired by Japanese consumers. Electricity costs were also higher for a kuruma prawn farm than for a black tiger prawn farm, since aeration equipment is required for longer periods when producing kuruma prawns. Additional labour requirements for the harvesting and processing of kuruma prawns during the grow-out phase resulted in higher labour costs for a kuruma prawn farm than for a black tiger prawn farm.

4 Capital costs used for black tiger and kuruma prawn farms of 15 hectares

In constant 1994-95 dollars

	Kuruma prawn farm		Black tiger prawn farm	
Year	Capital cost	Scrap value	Capital cost	Scrap value
	$	$	$	$
0	1 658 670	0	1 499 660	0
1	115 020	0	51 940	0
2	0	0	0	0
3	12 720	0	4 240	0
4	9 010	0	6 890	0
5	293 640	22 160	227 910	20 880
6	12 720	0	4 240	0
7	9 010	0	6 890	0
8	0	0	0	0
9	12 720	0	4 240	0
10	382 680	30 160	314 840	29 150
11	63 600	6 360	45 050	3 710
12	12 720	0	4 240	0
13	9 010	0	6 890	0
14	0	0	0	0
15	306 360	22 160	232 150	20 880
16	9 010	0	6 890	0
17	0	0	0	0
18	12 720	0	4 240	0
19	9 010	0	6 890	0
20	0	451 000	0	456 620

Source: Economic Services Branch, Queensland Department of Primary Industries. Based on 1991-92 costs which were adjusted by changes in the consumer price index to represent 1994-95 dollars.

A more detailed description of the assumptions used in these models can be found in Ovenden, Kriz, Goodrick and Paterson (1993). Some of the major assumptions for the prawn farm models include:

- a 15 hectare prawn farm operating over a twenty year period (20 per cent of pond area rested on a rotational basis from year 3 onwards);
- constant yields and costs over the life of the project; and
- sound farm management with no disasters.

The estimated ranges of values for uncertain parameters such as adoption rates, prices and yields (described by minimum, most likely and maximum values) used in the analysis are provided in table 5. The evaluation of this research was undertaken over a twenty year period.

5 Assumptions and data used for the evaluation of live kuruma prawn research

Input data	Unit	Minimum	Most likely	Maximum
Maximum benefit period	yr		20	
Domestic black tiger prawn price a	$/kg	9.40	13.60	15.00
Export kuruma prawn price a	$/kg	68.20	79.80	86.10
Max adoption area	ha	45	50	55
Period of research	yr		3	
Years to full adoption	yr		9	
Black tiger prawn yield				
– year 1	kg/ha		3 000	
– year 2	kg/ha		4 000	
– year 3 onwards	kg/ha		4 500	
Kuruma prawn yield				
– year 1	kg/ha	1 500	2 000	2 500
– year 2	kg/ha	1 875	2 500	3 125
– year 3 onwards	kg/ha	2 250	3 000	3 750

a Prices are expressed in 1994-95 dollars.

The total pondage area devoted to kuruma prawn production in the ABARE evaluation was estimated to be 6 hectares in 1991-92, 9 hectares in 1992-93 and 18 hectares in 1993-94. In 1994-95, total pondage area was assumed to be 32 hectares. After 1994-95, total pondage area was assumed to increase by 3.6 hectares a year to reach 50 hectares by 1999-2000. The assumed increases in pondage area were based on actual planned investment in the region of south east Queensland, and may therefore represent a lower bound of total production over the next few years. In the stochastic evaluation of research benefits, a maximum adoption area that varied 10 per cent from the most likely estimate of 50 hectares was assessed.

Projected prices for live Australian kuruma prawns have been based on a representative range of recently observed prices in Japan provided by Agribusiness Marketing Services of the Queensland Department. An expected average price of $79.80 per kilogram was used, based on an observed range of prices of $68–86 per kilogram. Domestic leader prawn prices have been based on a recent survey of prices received by Queensland growers, and range between $9 and $15 per kilogram with an average price of $13.60 per kilogram (Queensland Department of Primary Industries 1994).

Reflecting the recent development of the live kuruma prawn industry, there may exist considerable scope for improving kuruma prawn yields over time.

A variation in kuruma prawn yields of 25 per cent is currently expected in the south east Queensland region (Ovenden et al. 1993). This variation was included in the stochastic evaluation of research benefits. The average expected yield for black tiger prawns was assumed to remain constant, reflecting the comparatively well established production process for this industry. Yields in the first two years for both farm types were also lower than for subsequent years, because of the expected time for farm management to adapt to specific conditions of the site.

The costs associated with this research included direct research and development costs, net costs incurred during the first two years of trial production in 1989-90 and 1990-91, and forgone income from black tiger prawn production during those first two years of trial production. The present value of these costs was estimated at $960 200, based on a real interest rate of 8 per cent and information reported in Goodrick and Hardman (1992).

Results

The results of the ex post evaluation of this research can be summarised into the benefits that have been realised and those expected in the future. At the end of 1993-94, the returns from research were estimated to have covered 88 per cent of research and implementation costs incurred. This largely reflects the low adoption rate for the first few two years together with large research costs during those years. Up to 1993-94, an estimated net economic loss of $0.74 million was calculated on the basis of the net returns from actual export volumes of live Australian kuruma prawns, the estimated returns forgone from black tiger production, total research costs and a real discount rate of 8 per cent. Prices received for live kuruma prawns during the first few years were comparatively lower than those observed in 1992-93, due largely to higher mortalities and lower market acceptance by Japanese buyers during this period.

The expected net economic benefits from this research over a twenty year period are presented in table 6. Depending on the choice of discount rate, the expected net economic benefits are estimated to range between $15.9 million and $21.2 million.

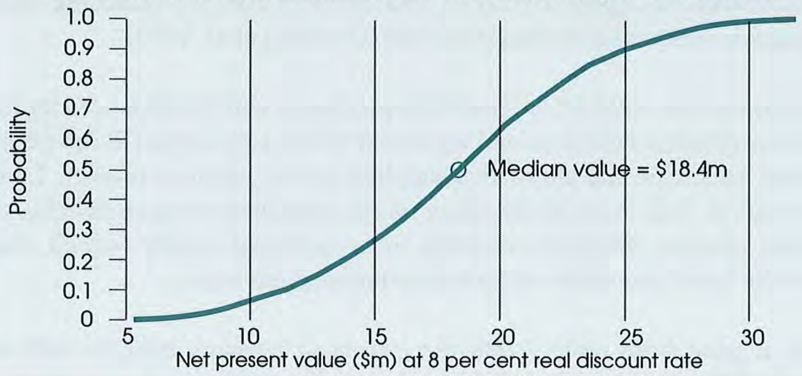
In addition to the expected net present values presented above, the cumulative distribution function of net present values provides a useful summary of the distribution of likely outcomes with the expected research payoffs (figure B). For example, there is a 20 per cent probability that the

6 Expected research payoffs from live kuruma prawn research

		Discount rate		
	Unit	6 per cent	8 per cent	10 per cent
20 year benefit period				
Net present value a	$m	21.2	18.3	15.9
Benefit–cost ratio		25:1	20:1	16:1

a Expressed in 1994-95 dollars.

B Distribution of net present values of live kuruma prawn research



net present value of estimated research benefits will be less than or equivalent to about $13.8 million or more than or equivalent to $22.7 million, based on an 8 per cent real discount rate.

Uncertainty over future prices for live kuruma prawns

The following evaluation of kuruma prawn research has been based on a representative range of recently observed prices for kuruma prawns on the Japanese market. The effect on Japanese kuruma prawn prices of increased Australian supply is uncertain, but is not expected to significantly reduce prices received by Australian growers in the short term. This is because Australian production of kuruma prawns is expected to increase only gradually over the next eight years, and would represent a relatively small proportion of total supply of kuruma prawns in Japan. For example, Australian kuruma prawn production is assumed to peak at around 150 tonnes a year by 1999-2000, representing around 9 per cent of total throughput of live kuruma prawns at the Tokyo wholesale markets in 1991

(Ministry of Agriculture, Forestry and Fisheries 1991). The Tokyo wholesale markets presently account for around 40 per cent of total wholesale trade in live kuruma prawns in Japan (Ovenden et al. 1993).

However, there is considerable uncertainty over the longer term effect of overseas production on kuruma prawn prices, and the risk of technology transfer to other major suppliers. Since the late 1980s, Taiwan has emerged as a major supplier of live kuruma prawns to Japan, which has resulted in a significant fall in the average market price for live kuruma prawns. This trend, however, does not reflect the quality and price differences observed between the various product grades. The Taiwanese product, for example, tends to be smaller with greater variations in colour and form compared with the Australian and Japanese product, and therefore does not attract the same premium as Australian produced prawns (Ovenden et al. 1993).

Nevertheless, the outlook for Australian producers will be influenced by the level of overseas production, and the extent of any substitution in the future between Australian and alternative suppliers on the Japanese market. Table 7 provides an indication of the effect on the estimated research benefits of assumed changes in prices resulting from increased supply (which may reflect the least favourable outlook over the medium term).

It can be seen from table 7 that the estimated research benefits will be strongly influenced by the assumed price for kuruma prawns over time. If the average price received by Australian growers were to fall to around $60

7 Sensitivity of expected net benefits to changes in live kuruma prawn price assumptions (eg least favourable outlook)

			Constant price assumptions		
			$60/kg	**$65/kg**	**$70/kg**
20 year benefit period					
Net present value a	$m		–2.3 b	3.4	9.1
		Annual percentage price fall (cumulative) c			
		1.25%	**1.5%**	**2.5%**	**5.0%**
20 year benefit period					
Net present value a	$m	10.8	9.5	4.3	–6.7 b

a Assumes a real discount rate of 8 per cent. Expressed in 1994-95 dollars. b Assumes the Australian domestic supply of live kuruma prawns is price inelastic. This results in a negative net present value of research benefits when the price is assumed to fall below the break-even price of $61.99 per kilogram. c Based on the most likely price of $79.80 per kilogram.

per kilogram, for example, the estimated net benefits would be negative. This is because the break-even price was estimated at around $62 per kilogram over a twenty year benefit period.

This suggests that the level of research benefits generated will depend most importantly on the ability of Australian growers to maintain a price premium for live kuruma prawns over alternative products such as black tiger prawns. If, for example, Australian producers were unable to maintain a premium for live kuruma prawns on the export market of around $48 above the current domestic market price for black tiger prawns of $13.60 per kilogram, the expected benefits would be negative.

The sensitivity of expected net benefits to price changes is particularly evident if prices are assumed to decline steadily over time. A cumulative price fall of 1.5 per cent a year, for example, results in an expected net benefit of around $9.5 million over a twenty year period. This compares with an expected net benefit of around $18.3 million in the base case evaluation.

Any evaluation of live transport technologies should therefore be tempered by the current level of uncertainty over future prices for live kuruma prawns, and the potential dampening effect of lower average prices from increased supply or substitution from alternative sources. Over a twenty year period, it is also important to acknowledge the potential effect of any underlying changes in tastes and preferences as a result of changing economic and demographic conditions in the major Asian seafood markets.

Concluding comments

Currently, exports of live Australian kuruma prawns to Japan are considered by the Japanese to be of high quality and second only to their domestic product. Kuruma prawns generally receive the highest price for prawns in Japan because of their freshness, cultural significance and perceived superior colour over other prawns. The Australian harvesting period in Queensland (May–September) also coincides with the period of higher prices in the Japanese market when Japanese domestic production is outside the optimal seasons (Ovenden et al. 1993). These factors together with the fact that Japanese kuruma production is not expected to increase significantly over the next few years because of capacity constraints suggest a favourable market outlook, at least in the short term, for the export of live Australian kuruma prawns to the Japanese seafood market.

Based on an increased adoption rate of kuruma prawn farm technology and an assumed maintenance of premium prices for live product with high survival rates, the expected economic benefits from this research were shown to be potentially large. However, if future prices were to fall by around 20 per cent from prices observed recently in Japan for live kuruma prawns, the net benefits from research would be minimal. It is important to consider that the majority of research and implementation costs (such as farm production trials and marketing) have already been incurred, and over the next few years new and existing producers plan to increase the pondage area devoted to kuruma prawn production.

Currently, it appears that only prawn farms south of Bundaberg have water temperatures low enough to successfully grow kuruma prawns (Ovenden et al. 1993). If, however, it is shown that production is possible in other regions, such as northern and central Queensland, then the total returns may be greater than those presented here. Based on the techniques adopted and experience gained from the new industry of farming and exporting live kuruma prawns, there may also exist the potential to apply this knowledge to the export of other live crustaceans.

3.2 *Hatchery and nursery culture for the silver lipped pearl oyster*

FRDC research program: aquaculture (research leading to artificial propagation of stock)

Key issues: early stages of adoption; sensitivity analysis on uncertain parameters; potential dissipation of benefits by overseas competition

Background

In 1993-94, Australian pearl production was valued at around $124 million (ABARE 1994), making it Australia's most valuable aquaculture industry. The Australian pearling industry is presently dominated by production from farming operations of the silver lipped pearl oyster (*Pinctada maxima*).

Oysters used in pearl farming operations are generally harvested from wild stocks off the northern coast of Western Australia. A small number of silver lipped pearl oysters are also harvested off the coast of the Northern Territory for pearl farming operations.

Research into the industry was prompted in the early 1980s by concern over the vulnerability of the industry to fluctuations in natural stock levels (Rose 1994) and concern over the lack of hatchery technology in Australia.

Between 1982-83 and 1990-91, the Fisheries Research and Development Corporation (FRDC) and its predecessor the Fishing Industry Research and Development Council jointly funded with the Fisheries Department of Western Australia a number of research projects focusing on the development of artificial propagation techniques for the silver lipped pearl oyster. The total nominal cost of research was $1.54 million (or around $3.72 million expressed in 1994-95 dollars) of which the FRDC funded approximately 85 per cent. Most of the research was carried out by the Western Australian Marine Research Laboratories.

This research focused on developing the technology to artificially reproduce and grow pearl oysters to culture size. The research on development of pearl oyster hatchery and nursery culture was completed in 1990-91. In the same year a large commercial hatchery was established in Darwin. At present the hatchery in Darwin is producing and supplying spat to a number of domestic pearl producing companies. There is also a proposal for another major hatchery to be developed in Broome, Western Australia.

Method

To estimate the potential economic benefits from this research program it is necessary to identify the effect of increased production on long term industry profits in the Australian pearling industry. However, potential industry profits are difficult to estimate because of the uncertainty about the rate of adoption of pearl hatchery technology, future price trends and the effect on prices of increased supply from Australian producers. In addition, there is little or no information on long term profits being earned by the Australian pearling industry. This uncertainty creates considerable difficulties in estimating pearling industry benefits.

Rate of adoption of pearl hatchery technology

The potential benefits to the Australian pearling industry from this research program arise from the additional production of hatchery produced pearls. In the absence of research, the domestic supply of pearl oysters would have relied entirely on the collection of wild oysters and would have been limited to the current wild quota allocations.

At present, the allocation of wild quota units in the Western Australian pearling industry is set at 572 000 oysters a year. As a result of the research, hatchery produced spat may lead to a potential increase in the total available stock of pearl oysters. Based on the *Western Australian Pearling Act 1990*, an additional 350 000 hatchery oyster options are potentially available to Western Australian pearl producers over the next few years. These options may be converted to annual hatchery quota on a one for one basis for operators who over a three year period have successfully produced hatchery oysters suitable for pearl culture (with a minimum criteria of 1000 hatchery oysters). For example, if an operator was able to demonstrate that 10 000 hatchery oysters a year had been successfully used for three years to produce quality pearls, the operator could apply for 10 000 hatchery options to be converted to hatchery quota (Fisheries Department of Western Australia 1992).

In the Northern Territory, licence arrangements currently restrict the catch of wild oysters to 120 000 a year. In the past, Northern Territory fishing grounds provided a sizable harvest of pearl oysters. In recent years, however, the actual harvest of wild caught oysters has been well below this amount, reflecting reduced fishing effort and poor yields from traditional fishing grounds (Kailola, Williams, Stewart, Reichelt, McNee and Grieve 1993).

With the technology available to successfully produce hatchery oysters, the Northern Territory pearling industry may be in a position to expand local pearl production. The total licence allocation of hatchery produced oysters potentially available to the Northern Territory pearling industry is 300 000 oysters a year. Current use of hatchery produced oysters, however, is still only a small proportion of the total number available under existing licence arrangements. An important factor influencing future potential benefits from pearl hatchery research will be the rate of adoption of hatchery oysters in the Northern Territory, which is presently uncertain.

Difficulties in estimating potential industry benefits

Profit could potentially be estimated using cost data combined with price information. For many industries, this information is collected through industry surveys. However, for the pearling industry, cost of production data required to estimate profit measures are unavailable.

In the absence of cost of production data, an alternative method for estimating profit is to use property right values, such as quota unit values. Assuming a perfectly competitive market where quota units are fully transferable, the market traded price of quota units may be used as a proxy for potential long term profit.

For example, the total value of wild quota units in the Western Australian pearling industry is estimated at $1–2 million per 10 000 oysters (Fisheries Department of Western Australia 1993, 1994). Assuming a productivity rate of 1.58 pearl products per oyster (includes round pearls, half-rounds and other pearl products) and converting perpetual licence values to annual values using a discount rate of 8 per cent, this equates to an estimated annual profit of around $5–10 per pearl product (or only 3–6 per cent of gross returns).

The estimated profit margin using quota unit values is low compared with the average unit export price for all pearl products of around $159. This estimate is very sensitive to the estimate of the value of wild quota units in the Western Australian pearling industry. It is unlikely that quota unit values provide a reliable estimate of long term profit in the Australian pearling industry, since pearl oyster quota units are seldom traded.

Potential impact of increased pearl production from hatchery oysters on prices

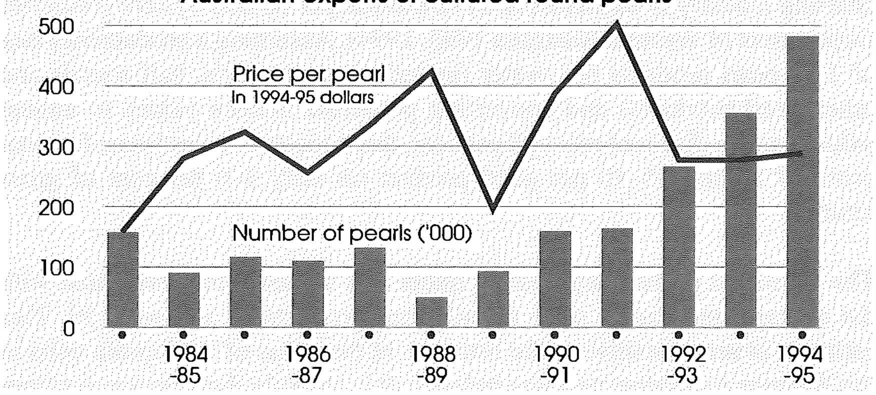
A critical issue in the evaluation of this research program is the potential impact of increased pearl production from hatchery oysters on prices received by Australian producers. This concern reflects the absence of previous empirical studies into demand and supply relationships underlying the south sea pearl industry. The lack of available data on economic parameters, such as the price flexibility of pearls, increases the uncertainty of future potential benefits arising from pearl hatchery research.

Price flexibilities can be used to assess changes in the product price of some primary commodities as a result of changes in the quantity supplied (Tomek and Robinson 1972). In this case, the effect of additional hatchery production on average pearl prices is critical when assessing the potential size of future research benefits. If prices are highly sensitive to changes in production, for example, the effect of increased production on net returns may be negative (implying a net economic cost). If, however, prices are relatively inflexible to changes in production, increased hatchery production may result in net benefits to the Australian pearling industry.

Export prices of Australian cultured round pearls have been highly variable over the past decade, falling to $200 per pearl in 1989-90 before peaking at over $500 per pearl in 1991-92 (figure C). The number of pearls exported

C

Australian exports of cultured round pearls



each year was relatively stable during the 1980s before increasing rapidly in the 1990s. Most pearls from Australia are sold in occasional auctions dominated by a few major sellers. Stocks may be retained for future sale if the reserve prices set by suppliers are not met.

A number of factors may be used to explain the observed movements in price. The general, movement toward higher prices may partly reflect rising incomes and expanding markets, together with improvements in the quality of pearls produced, or reductions in overseas production of substitute products. Large cyclical movements may, in part, be attributable to the investment nature of pearls, which may also lead to speculative price movements.

Future prices for pearls are likely to be determined by a number of factors, such as changes in the supply of south sea pearls and substitute jewellery products and changes in demand brought about by factors such as income growth and fashion trends. In the absence of any quantitative data on the factors influencing pearl prices, future pearl prices cannot be predicted with any accuracy.

It may be possible to estimate future pearl prices on the basis of price trends observed over the past decade. An apparent long term upward trend in pearl prices (as seen in figure C) can be extrapolated for predictive purposes by fitting a linear trend line to observed round pearl export prices over the period 1983-84 to 1994-95. This assumption is supported by the forecast growth in economic activity and real income in the major overseas markets for south sea pearls, including Japan, South East Asia and the United States (ABARE 1995). This projected growth in real income per person is likely to result in increased demand for south sea pearls.

Pearl production increases

Pearl production increases in Australia can be projected using current information on the adoption rate of hatchery produced oysters.

- In the Northern Territory, the current rate of adoption of hatchery produced oysters is low, with only a small proportion of total hatchery oysters potentially available being used by local operators.
- In Western Australia, a larger proportion of potentially available hatchery oysters are currently being used for pearl farming operations.

Australian operators presently using hatchery produced oysters are at varying stages of the production cycle of pearl farming operations. As a result, annual pearl production increases from operators presently using hatchery technology were projected to be 30 000 hatchery oysters in 1995-96 and 60 000 additional hatchery oysters in 1997-98.

For operators not presently using hatchery produced oysters as part of their total farming operations, a total projected adoption rate in 1998-99 and 1999-2000 of 30 000 additional hatchery oysters was assumed. From 2000-01 onwards, a total projected adoption rate of 50 000 additional hatchery oysters a year was assumed until 2009-10. This projected adoption rate reflects current industry expectations that hatchery production will increase only gradually over time, with no significant increase in the short term. As a result, the stock of hatchery produced oysters actively being farmed for pearl production in Australia was assumed to reach a maximum of 650 000 oysters a year by 2009-10, representing a total annual stock of around 1.24 million pearl oysters. The total projected stock of pearl oysters in 2009-10 includes the wild quota allocation of oysters collected in Western Australia, a small number of wild oysters collected in the Northern Territory and total hatchery oyster allocations potentially available in both the Northern Territory and Western Australia.

Productivity rate

An average productivity rate of 0.47 round pearls per oyster was calculated using pearl export data from July 1989 to December 1994. This productivity rate is consistent with recent information provided by the Pearl Producers Association of Western Australia (M. Buckley, personal communication, April 1994). The estimated productivity rate implies oyster mortality rates of 40–60 per cent during the collection and grow-out stages of production. This was used to predict round pearl production increases based on the assumed adoption of hatchery produced oysters by Australian operators.

An average productivity rate of 0.47 round pearls per oyster is equivalent to a total potential production capacity of around 586 000 round pearls a year by 2009-10. The revenue received from round pearl production was multiplied by a factor of 1.7 to take account of the additional production of other pearl products from a single oyster, such as half round pearls. This factor represents the ratio of total export revenue from all pearl products to total export revenue from round pearls over the period July 1989 to December 1994.

It was also assumed that the average cost of producing pearls from hatchery oysters would be the same as the average cost of producing pearls from wild caught oysters. This assumption was based largely on existing economies of scale in pearl culture production from wild caught oysters, and the lack of any significant difference in the seeding and grow-out of pearls from either wild caught or hatchery produced oysters. Unit production costs for pearl oysters were assumed to remain constant over time, and were calculated on the basis of the assumed profit margin on gross returns.

Results

It is not possible to provide an accurate estimate of the benefits from this research program because of the uncertainties surrounding many of the parameters and lack of information. Even if detailed information on costs of production, productivity rates and production increases were made available, there is a high degree of uncertainty about the effect of increased production on future pearl prices because no quantitative analysis on supply and demand characteristics for the south sea pearl industry has been undertaken.

Sensitivity analysis on future prices for south sea pearls

In light of the difficulties in estimating the responsiveness of pearl prices to changes in quantity supplied, sensitivity analysis can be used to evaluate the effect of differing price flexibility assumptions on prices received by domestic producers. However, as the following example demonstrates, such analysis provides a wide range of results and are subject to the underlying assumptions (as presented in table 8 for this example). These assumptions represent only a limited number of future possibilities, and if the assumptions change, the results may also change.

In the absence of any information on price flexibilities, the evaluation of potential research benefits can be undertaken using a range of assumed flexibilities. For this example, constant price flexibilities over time of –0.3, –0.25 and –0.2 were assumed. A price flexibility of less than one is consistent with elastic consumer demand for Australian pearls. In the cases where the absolute value of the price flexibility is assumed to be less than one, the sale of additional pearls would more than offset the effect of lower average prices on gross returns. Projected pearl prices under alternative price flexibility assumptions are presented in table 9.

8 Assumptions and data used for the evaluation of pearl oyster hatchery research

Input variable	Unit	Value
Total hatchery oysters potentially available in Western Australia	no.	350 000
Total hatchery oysters potentially available in the Northern Territory	no.	300 000
Maximum benefit period	yr	15
Period of research	yr	9
Period from spat to final sale of pearls	yr	5
Pearl yield	round pearls / oyster	0.47
Ratio of total export revenues from all pearl products to total export revenues from round pearls only		1.7
Projected adoption of hatchery produced oysters in Australia (cumulative number of oysters) a		
1995-96	no.	30 000
1996-97	no.	30 000
1997-98	no.	90 000
1998-99	no.	120 000
1999-2000	no.	150 000
2000-01	no.	200 000
2001-02	no.	250 000
2002-03	no.	300 000
2003-04	no.	350 000
2004-05	no.	400 000
2005-06	no.	450 000
2006-07	no.	500 000
2007-08	no.	550 000
2008-09	no.	600 000
2009-10	no.	650 000

a Represents the year in which pearls may be harvested from hatchery produced oysters.

Estimated benefits

Reflecting the long time periods associated with pearl culturing production and the initially slow adoption of pearl oyster hatchery options, the economic outcome from this research can be summarised into research and implementation costs already incurred and any potential benefits expected in the future. At the end of 1994-95, the estimated present value of costs already incurred was $4.64 million, consisting of $3.72 million in research costs and $0.92 million in hatchery establishment and operating costs.

Currently, the Australian pearling industry is the dominant supplier of fine quality south sea pearls, with almost 100 per cent of the Australian pearl harvest being exported to the world market. The potential size of the research

9 Illustrative example of projected pearl prices under alternative price flexibility assumptions In 1994-95 dollars

	Total projected quantity with research	Projected base price in absence of research	Projected price with research for an assumed price flexibility of		
			–0.3	–0.25	–0.2
	'000 a	$/pearl	$/pearl	$/pearl	$/pearl
1995-96	295	375	369	370	371
1996-97	295	385	379	380	381
1997-98	323	394	376	379	382
1998-99	337	404	380	384	388
1999-00	351	414	382	388	393
2000-01	375	423	381	388	395
2001-02	398	433	378	387	397
2002-03	422	442	376	387	398
2003-04	445	452	373	386	399
2004-05	469	462	369	384	400
2005-06	492	471	365	383	400
2006-07	516	481	360	380	400
2007-08	539	491	335	378	400
2008-09	563	500	349	375	400
2009-10	586	510	343	371	399

a Number of round pearls from wild and hatchery oyster stock.

benefits will depend on whether Australia's current market position is likely to continue in the future. If other countries expand hatchery production and produce substantial quantities of south sea pearls of comparable quality to the Australian product, Australia's position as the dominant supplier of a scarce resource will be weakened.

A substantial and rapid increase in overseas production within the next few years would cause downward pressure on world market prices for south sea pearls. In these circumstances, there would be little benefit to the Australian industry from pearl hatchery research because of the lower market prices for any additional pearls produced for the export market. The likelihood of increased overseas production has been increased by the leakage of research results and hatchery technology to potential overseas competitors. Several Indonesian firms are currently establishing commercial hatcheries based on the results of the Australian research.

If the potential increase in large scale overseas hatchery production is delayed, Australia will maintain its position as the dominant supplier of fine quality south sea pearls in the medium term. In these circumstances, the realisation of research benefits will depend on the responsiveness of prices to increased Australian production. This is because hatchery production has the potential to overcome biological constraints imposed on the natural stock. Therefore, world market prices of south sea pearls may be directly affected through increased supply. The effect of Australian hatchery production on world market prices for pearls therefore becomes the critical issue underlying the potential size of future research benefits.

As mentioned above, sensitivity analysis can be undertaken to evaluate the effect of alternative price flexibility assumptions on the estimated net benefits of increased pearl production over a fifteen year period (table 10). For the purpose of this example, in the absence of information on industry profit, potential research benefits were estimated assuming two alternative average initial profit margins of 30 per cent and 40 per cent of gross returns.

Potential research benefits are highly sensitive to the assumed price flexibility or responsiveness of prices to increased pearl production. Assuming an initial profit margin for pearl producers of 30 per cent of gross returns, for example, the net research benefits were estimated to vary between an economic loss of $51.7 million and an economic benefit of $62.1 million, assuming a price flexibility of –0.3 and –0.2 respectively.

In the absence of any studies on supply and demand characteristics for Australian export quality pearls, these sensitivity tests provide, at best, an approximate guide to the likely effect on estimated research benefits of assumed changes in prices as a result of increased production.

10 Expected research payoffs from pearl oyster hatchery research under alternative price flexibility and profit margin assumptions

Net present value, in 1994-95 dollars

	Price flexibility		
	–0.3	**–0.25**	**–0.2**
	$m	$m	$m
Average initial profit margin			
30 per cent of gross revenue	–51.7	5.2	62.1
	(–10:1)	(2:1)	(14:1)
40 per cent of gross revenue	5.7	62.7	119.6
	(2:1)	(14:1)	(27:1)

a Assumes a real discount rate of 8 per cent. Benefit–cost ratios are presented in parentheses.

Concluding comments

Research into pearl oyster hatchery and nursery culturing techniques has resulted in the successful development of pearl oyster hatcheries in Australia. Currently, Australia is the world leader in the production of fine quality south sea pearls and produces about 50–60 per cent of world production. In this situation, the potential research benefits depend critically on the responsiveness of world prices to increased domestic production and Australia's future market position in the south sea pearl industry. If prices are highly responsive to changes in production, for example, there may be little benefit to the Australian industry from pearl hatchery research. If, alternatively, prices are generally unresponsive to changes in production, increased pearl production arising from pearl hatchery research may result in net benefits to the Australian pearling industry.

Over the longer term, the potential national benefits may be low, because of the leakage of research results to overseas competitors. Several Indonesian firms are currently establishing commercial hatcheries based on the results of the Australian research. In this case, the benefits from research may be positive only if the leakage of research results does not lead to an increased world production of pearls of quality similar to Australian south sea pearls. The existence of international competitors and Australia's future market position in the south sea pearl industry are therefore likely to play an important role in the size of future potential benefits from pearl hatchery research.

This research outcome highlights the need to identify, prior to the funding of research, some of the key economic parameters such as price flexibilities that are likely to affect the size and likelihood of achieving the possible benefits. Furthermore, this case study demonstrates the importance of establishing appropriate property rights over the use of intellectual property arising from research, and the need to consider the leakage of research results to international competitors when assessing expected ex ante and ex post research benefits.

In addition, there is a shortage of information on which to undertake detailed ex post analysis of this research program. In the absence of this information it was not considered possible to accurately assess any benefits or potential losses accruing to the pearl industry from this research.

3.3 *Pearl diving safety*

FRDC research program: harvesting (research leading to reduced harvesting costs)

Key issues: harvesting cost savings likely to be significant; quantitative and qualitative assessments

Background

Research into pearl diving safety arose as a result of recommendations made by a Coronial Inquiry into Australian pearl diving practices, following a number of serious diving accidents in 1989. Recommendations from this Inquiry included the suspension of existing diving procedures, pending an investigation into the safety of the diving procedures used by the Australian pearling industry. This led to the Fisheries Department of Western Australia initially providing a research grant of $30 000 in 1990-91 (equivalent to $32 374 expressed in 1994-95 dollars) to the Pearl Producers Association of Western Australia to study the safety of industry diving procedures.

In 1991-92, this was followed by the Fisheries Research and Development Corporation (FRDC), the Fisheries Department of Western Australia and the pearl oyster industry jointly funding a three year project into pearl diving safety. The total nominal cost of this research project was around $360 000 (or $373 600 expressed in 1994-95 dollars), of which the FRDC contribution was 42 per cent. This research has focused on the evaluation and modification of existing industry diving procedures in accordance with world safety standards, using the Doppler technique for measuring decompression stress developed by the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM).

Findings from the research project have been adopted by the industry to satisfy their immediate need for pearl diving safety. Several industry dive profiles (which stipulate diving behaviour for a given depth) have been modified in accordance with the Doppler technique, resulting in diving procedures within accepted world safety standards. The research has allowed pearl oyster harvesting costs to be maintained at levels below what would have occurred if the industry were required to adopt internationally recognised diving procedures such as those developed overseas by the DCIEM. The application of the research findings has consequently resulted in considerable cost savings to the Australian pearling industry, while maintaining accepted world diving safety standards.

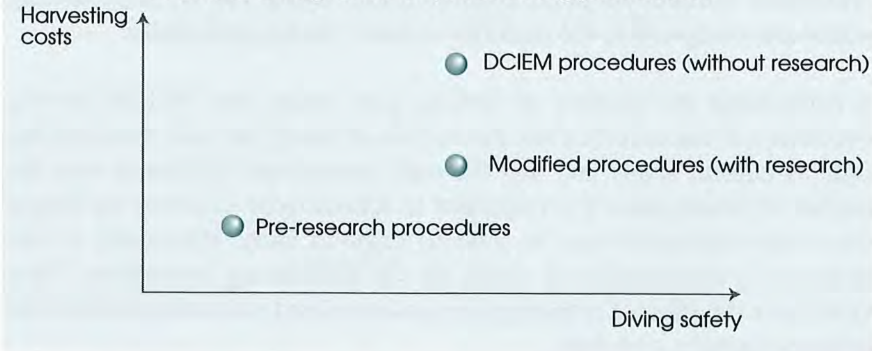
Method

In this case the benefits from research are defined as the benefits to the Western Australian pearling industry from adopting the modified industry diving procedures compared with the alternative DCIEM diving procedures (figure D). The benefits are defined in this way because, in the absence of research, the existing pearling industry diving procedures were likely to have been suspended as a result of the Coronial Inquiry into diving practices, with any continuation of Australian pearl diving subject to the adoption of internationally recognised procedures.

The DCIEM diving procedures (without research procedures) are generally recognised as the safest documented set of diving procedures currently used elsewhere in the world (Pearl Producers Association of Western Australia 1993). It is therefore likely that the DCIEM diving procedures already used as a standard in other diving industries would have been adopted in the absence of the modified diving procedures developed from this research. The modified industry diving procedures (with research procedures) are considered to provide a safety standard in Australian pearl diving equivalent to that of the DCIEM diving procedures, based on the Doppler technique for measuring decompression stress.

D

Assumed relationship between diving safety and harvesting costs for pearl diving procedures



The direct market benefits from this research were the industry harvesting cost savings from adopting the modified industry diving procedures compared with the DCIEM procedures developed overseas. The harvesting cost savings relate to the higher operational efficiency of the modified industry diving procedures compared to the DCIEM diving procedures. The DCIEM diving procedures require a higher number of fishing days to harvest an equivalent number of oysters when compared with the modified industry diving procedures, because less fishing time per day is available to collect oysters using the DCIEM diving procedures.

To evaluate the harvesting cost savings, a comparison was made between the actual number of fishing days observed in 1993 using the modified industry diving procedures and the estimated number of fishing days required to harvest an equivalent number of pearl oysters (based on the wild quota allocations) using the DCIEM diving procedures.

The number of fishing days using the DCIEM diving procedures was implicitly derived by calculating the number of days required to achieve the same amount of 'bottom time' that was observed in 1993 when the industry was using the modified industry diving procedures (box 1). Bottom time is the term used to describe the amount of time that a diver spends on the seabed collecting pearl oysters. Bottom time represents the amount of effective fishing time, as opposed to the amount of time spent at the surface between dives (surface interval) or ascending the water column (decompression stops).

Using the DCIEM diving procedures, the average time required at the surface or ascending the water column is generally longer compared to the modified industry diving procedures, resulting in a lower amount of bottom time per day for the most common depths dived by the pearling industry. This in turn results in an increased number of fishing days required to harvest an equivalent number of pearl oysters when using the DCIEM diving procedures compared to the modified industry diving procedures.

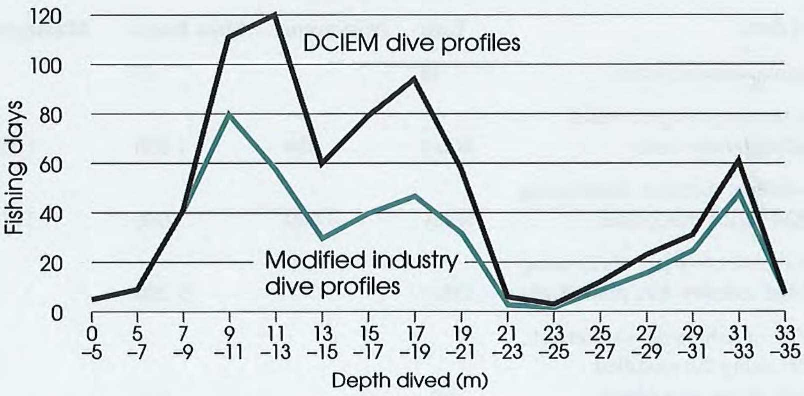
In estimating the number of fishing days using the DCIEM diving procedures, it was assumed that the number of divers per boat remained the same as current levels and that the only operational difference was the number of fishing days. It is important to acknowledge that over the longer term some operators may be able to respond more effectively to the operational requirements of using the DCIEM diving procedures. This would have the effect of reducing the costs associated with using the DCIEM diving procedures over time.

Box 1: Estimated fishing days using the DCIEM and modified industry diving procedures

In 1993, the actual number of fishing days using the modified industry diving procedures was 451. The estimated number of fishing days using the DCIEM diving procedures required to achieve the same amount of bottom time actually observed at various depths in 1993 is estimated at 720 (shown in the graph below). This represents an operational reduction of 269 fishing days as a result of adopting the modified industry diving procedures compared with the DCIEM diving procedures.

The main difference between the DCIEM diving procedures and the modified industry diving procedures is in the midwater range (between a depth of 9 metres and 23 metres). The shallow water bottom times are similar using both sets of diving profiles, since there is generally more time than is necessary to collect pearl oysters in shallow water conditions. Deep water diving conditions also result in similar bottom times using either the DCIEM diving procedures or modified industry diving procedures. The area that increases the number of total fishing days the most using the DCIEM diving procedures is in the midwater depth, which coincides with the depth ranges where most pearl diving occurs (M. Buckley, Pearl Producers Association of Western Australia, personal communication, April 1994).

Comparison between fishing days using DCIEM and industry dive profiles a



a This assumes that the number of divers per boat remains the same, and that the only operational difference is the number of fishing days. This information was provided by the Pearl Producers Association of Western Australia in conjunction with the principal researcher involved with this project.

On the basis of the estimated number of additional fishing days required to harvest the same number of pearl oysters using the DCIEM diving procedures, the net economic benefits of using the modified industry diving procedures were estimated. These benefits have been calculated on the basis of the reported average pearl oyster yield of 31 oysters collected per hour of bottom time (Joll 1993). The general assumptions and conditions used in the analysis are provided in table 11.

The main variable costs associated with pearl oyster harvesting include daily vessel running costs and crew payments, including payments to pearl divers. The effect of assuming a 60 per cent increase in fishing days on daily payments to pearl divers as a result of adopting the DCIEM diving procedures is uncertain.

In the base case evaluation it was assumed that the contract rate paid to pearl divers per oyster remained the same when using either the modified industry diving procedures or the DCIEM diving procedures. This was because the

11 Assumptions and data used for the evaluation of pearl diving safety research a

Input data	Unit	Minimum	Most likely	Maximum
Maximum benefit period	yr		10	
Daily running cost per vessel excluding labour costs	$/day	930	1 030	1 130
Daily labour costs per vessel using DCIEM diving procedures	$/day	3 680	3 680	5 200
Daily labour costs per vessel using modified industry dive procedures	$/day		5 200	
Number of fishing days observed in 1993 using the modified industry diving procedures	no.		451	
Estimated number of fishing days in 1993 using the DCIEM diving procedures **b**	no.		720	
Adoption lag	yr		1	
Period of research	yr		4	

a Based on 1993-94 costs which were adjusted by changes in the consumer price index to represent 1994-95 dollars. **b** This represents the estimated number of fishing days using the DCIEM diving procedures required to achieve the same amount of bottom time observed in 1993 using the modified industry diving procedures.

availability of pearl divers is currently not considered to be restrictive and the total number of oysters to be harvested remains the same in each case. This implies that pearl divers would have received the same total income per season in each case, but would have dived for an additional number of days using the DCIEM diving procedures compared with the modified industry diving procedures. Such an assumption also implies that the opportunity cost of alternative employment or leisure time for existing divers is lower than the returns received from diving.

Although daily payments to divers in the base case evaluation would have been lower based on a reduced amount of oysters being collected per day using the DCIEM diving procedures, total annual harvesting costs would have been higher because the harvesting season would have comprised an additional 269 fishing days for the fleet as a whole. However, it has also been suggested that pearl divers may have negotiated an increase in the contract rate paid to pearl divers per oyster as a result of using the DCIEM diving procedures (M. Buckley, Pearl Producers Association of Western Australia, personal communication, April 1994). The stochastic evaluation of research benefits therefore included a higher bound for pearl diving costs equivalent to maintaining the current daily income from pearl diving.

The effect of assuming higher pearl diving costs in the DCIEM scenario would be to increase the harvesting cost savings from the modified industry diving procedures.

Results

Industry harvesting cost savings

The benefits of harvesting cost savings to the Western Australian pearling industry can be summarised into those benefits which have actually been realised and those benefits expected in the future. At the end of 1994-95, the net economic benefit of the research is estimated at $833 400, using an 8 per cent real discount rate. These benefits reflect the harvesting cost savings to industry for the 1993 and 1994 seasons. By comparison, the expected net benefit over a ten year period is equivalent to $4.45 million, or an annual harvesting cost saving of $582 400 a year (table 12).

The distribution of expected research payoffs over a ten year period is summarised in figure E. It should be noted that these results have been calculated by taking into account the degree of variability in two parameters

12 Expected research payoffs from pearl diving safety research

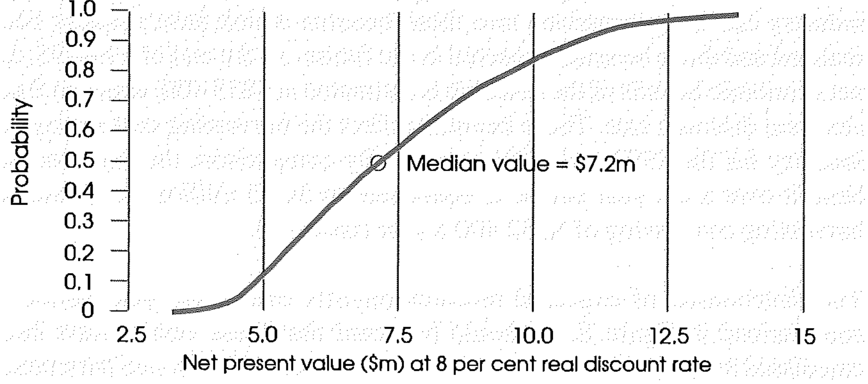
	Unit	Discount rate		
		6 per cent	8 per cent	10 per cent
10 year benefit period				
Net present value	$m	4.65	4.45	4.27
Benefit–cost ratio		11.2:1	10.4:1	9.6:1

only — average vessel running costs (expected to vary by plus or minus 10 per cent) and average diving costs, assuming the adoption of the DCIEM diving procedures (expected to vary between $3700 per day and $5200 per day).

The likely variation in these costs associated with pearl oyster harvesting results in the net present value of research benefits ranging between $3.7 million and 13.9 million, with a 50 per cent probability that the benefits will be less than or equivalent to about $7.2 million. In this case, the expected research benefits are higher than those estimated under the base case evaluation, since the distribution used to examine research payoffs were somewhat skewed in favour of the project.

Of note, the minimum and most likely daily labour costs using the DCIEM diving procedures were assumed to be the same, while the maximum value was assumed to be $5200. This results in an average harvesting cost using the DCIEM diving procedures of $5200 in the stochastic evaluation, compared with an average harvesting cost using the DCIEM diving procedures of $4700 in the base case evaluation.

Distribution of net present values of pearl diving safety research



There may also be additional benefits from a shorter fishing season as a result of using the modified industry diving procedures rather than the DCIEM diving procedures. The current fishing season using the modified industry diving procedures usually occurs between March and August, with the majority of companies completing their fishing operations before June. The rationale for fishing between these months is largely to reduce the level of fishing stress on pearl oysters before the next stage of pearl culture production. This stage requires the seeding of oysters by pearl technicians on the vessel while at sea, and is mainly restricted to the months of June through to August due to the existence of suitable water temperature conditions.

In general, a higher level of mortality occurs following seeding when oysters have been fished later in the season, because there has been insufficient time for the oysters to recover fully from fishing stress. This may have significant implications for an extended fishing season under the alternative scenario of adopting the DCIEM diving procedures, because a higher proportion of oysters may be collected later in the season because of the increased number of fishing days. There may also be additional costs associated with a fishing season beginning earlier in the year (such as January through to February), since visibility may be lower because of the incidence of rains in the wet season together with an increased cyclone risk.

A shorter fishing season using the modified industry diving procedures may have also resulted in capital cost savings to the industry. This is because a number of quota holding companies currently do not own fishing vessels and lease the vessel services of other companies to collect their quota allocation of wild oysters.

If the alternative DCIEM diving procedures were introduced, it is likely that most companies would fish for an extended fishing season in order to collect their full quota allocation. This may have resulted in increased investment in specialist fishing vessels, because of the limited number of existing vessels, which are mostly specially built or converted vessels, suitable for pearling operations. The cost of an average pearl oyster fishing vessel has been estimated at around $1 million (M. Buckley, Pearl Producers Association of Western Australia, personal communication, April 1994). However, because of the potential impact of an extended fishing season using the DCIEM diving procedures on the capital cost structure of the industry is unknown, these costs have not been explicitly taken into account in the analysis.

Maintenance of world safety standards in pearl diving

An important aspect of this research is the maintenance of world safety standards in pearl diving practices. The Australian pearling industry currently employs around 80 to 100 divers each year to collect pearl oysters by hand. Divers use compressed air from surface supplied breathing apparatus. The main occupational hazards associated with pearl diving include the incidence of decompression sickness (such as neurological, respiratory or inner ear conditions), oxygen damage to the lungs and aseptic bone necrosis. The development of modified industry diving procedures (with research procedures) has enabled the degree of risk associated with these hazards to be comparable with diving procedures developed overseas, as measured by the Doppler technique for decompression stress.

To provide an indication of the relative effect on diving safety of adopting accepted world standards, a comparison was made between the number of reported symptoms of decompression sickness prior to and after the modified industry diving procedures were adopted. Based on compulsory diving records maintained by the Pearl Producers Association of Western Australia, a summary of all reported incidents related to decompression sickness (and excluding other medical incidents such as marine organism stings) for the three years ended 1993 is presented in table 13.

Since 1992, when the results from ongoing research were first implemented, there has been an observed decline in reported symptoms of decompression sickness. In 1993, for example, the number of reported symptoms related to decompression sickness represented less than 0.1 per cent of total vessel dives. While the degree of severity of these symptoms is not reported, these

13 Total number of reported symptoms of decompression sickness in the Western Australian pearling industry

	Total number of vessel dives	Total number of reported symptoms	Total number of reported symptoms as a percentage of total vessel dives
	no.	no.	%
1991	4 772	10	0.21
1992	4 693	6	0.13
1993	3 937	2	0.05

Source: Pearl Producers Association of Western Australia pearl diving database.

figures provide a broad indication of the relative safety of diving procedures that are considered to be within accepted world safety standards.

However, it is important to acknowledge that this improvement in diving safety between the pre-research diving procedures and the modified industry diving procedures does not represent additional non-market benefits generated from the research. This is because the DCIEM diving procedures were likely to have been adopted in the absence of research, and are considered to be of an equivalent safety standard to the modified industry diving procedures.

Concluding comments

This research has resulted in significant harvesting cost savings to the Western Australian pearling industry through the use of cost effective industry diving procedures. The savings are made relative to the alternative scenario of using the DCIEM diving procedures. The annual harvesting cost savings to the industry as a whole are likely to maintain Australia's competitive position as a major world producer of high quality south sea pearls.

Furthermore, this research has enabled the occupational health and safety of Australian pearl diving to be maintained within accepted world safety standards. Currently, the Australian pearling industry relies on the collection of wild pearl oysters by hand from pearl divers operating on compressed air from surface supplied breathing apparatus. There may also be additional benefits to other diving industries, such as the Australian abalone industry, from the expertise developed from this project in assessing diving hazards.

3.4 Spanner crab fishery research

FRDC research program: natural fish resources (research leading to catch maintenance)

Key issues: research program versus project assessment; stochastic analysis of research benefits; role of management in realising benefits

Background

The Australian spanner crab fishery extends along the east coast of Queensland and into northern New South Wales. The Queensland fishery contributes the largest proportion of total catch, with production in 1993 of around 1970 tonnes (N. Trainor, Queensland Department of Primary Industries, personal communication, April 1994). Since the late 1980s, the fishery has expanded with the development of the export market for live spanner crabs, mainly to Taiwan. Based on an average export price to operators of $5 per kilogram for live crabs, the gross value of production in the Queensland fishery is estimated at about $10 million.

The estimated catch in New South Wales in 1992-93 was 283 tonnes, valued at around $1.0 million. The New South Wales industry mainly supplies the domestic market (B. Pease, New South Wales Fisheries, Fisheries Research Institute, personal communication, April 1994).

The commercial development of the spanner crab fishery in the early 1980s prompted fishery managers to seek information on the long term sustainability of spanner crab catches, since little was known about the biology of the species. This resulted in the Fisheries Research and Development Corporation and its predecessor the Fishing Industry Research and Development Council jointly funding a number of spanner crab research projects with the Queensland Department of Primary Industries and the New South Wales Department of Agriculture and Fisheries. Since 1981 these projects have focused primarily on the population biology and life cycle of the spanner crab. This was followed by research into the development of non-damaging trapping apparatus for spanner crabs beginning in 1990. A current project is also assessing the development of optimal transport methods for live crustaceans, with the aim of prolonging the survival of crabs and assisting the rapidly expanding industry of live spanner crab exports to the Asian market.

The total nominal cost of the research program was $462 000 (or $1.03 million expressed in 1994-95 dollars) spread over the ten year period 1981-82 to 1990-91, of which the FRDC contribution was around 40 per cent. This, however, excludes the cost of research on optimal transport methods, since this research is yet to be completed and has not been evaluated in this study.

As a result of the research a number of management recommendations have been adopted by Queensland and New South Wales fisheries managers throughout the 1980s and early 1990s. This has included the implementation of a seasonal closure, a ban on the harvesting of spawning female crabs and the promotion of harvesting and handling techniques intended to minimise the number of mortalities from discarding undersized crabs. An active education and promotion campaign by fisheries managers has also contributed to the presently high voluntary adoption by operators of improved crab harvesting practices. These changes in fishing behaviour and management controls are likely to have led to a reduced risk of lower yields and expected returns from the fishery.

However, the extent to which potential research benefits can be maintained over time will depend critically on whether appropriate management controls are implemented in the future. This is because there has recently been a rapid increase in fishing effort in the Queensland fishery, as new operators have been attracted to the fishery by the current high prices received for live spanner crabs exports. Increases in fishing effort beyond levels considered to provide sustainable catches present a major risk to the long term stability of the fishery, and to the realisation and maintenance of research benefits identified from earlier management controls.

Method

In the absence of research, fisheries managers and industry are required to make management and harvesting decisions within an environment of limited biological knowledge. The results from this research have enabled a number of changes to management controls and harvesting behaviour by operators to be implemented on the basis of increased scientific knowledge. These changes are likely to have led to a higher abundance of crabs in both the New South Wales and Queensland fisheries, at least in the short term. This in turn would be expected to result in direct market benefits to operators from improved catches and returns over time, assuming appropriate effort control measures are implemented in the future.

To determine the likely impact of management and harvesting changes on the relative abundance of crabs, an investigation of the catch and effort database in each State was undertaken. The catch per unit effort (CPUE) was calculated for each major fishing zone from 1987-88 to the present, based on average catches per day. For most regions, a sustained increase in CPUE has been observed since 1991-92. However, it was considered difficult to attribute these improvements in CPUE solely to the research induced management changes. This was primarily because of two factors. First, the measure of effort reported (days fished) did not record the intensity of fishing effort such as the number of net lifts per day. As a result, the CPUE estimates may not provide the most accurate indicator of likely improvements in the relative abundance of crabs. Second, the rapid development of previously unfished areas is also likely to have influenced the CPUE for new fishing zones. This was particularly applicable to the Queensland data where rapid development of virgin grounds has caused large variation in CPUE between zones.

Given these limitations, it was considered appropriate to assess the expected research benefits for the largest representative zone of the New South Wales fishery only (zone 1). This zone was one of the first developed in New South Wales, and is likely to be representative of a fully exploited fishery (S. Kennelly, New South Wales Fisheries, Fisheries Research Institute, personal communication, April 1994). In 1992-93, the total catch from zone 1 was 226 tonnes, or around 80 per cent of the New South Wales catch (B. Pease New South Wales Fisheries, Fisheries Research Institute, personal communication, April 1994). This zone has also contributed the highest annual catches since the early 1980s. To determine the projected catches over time in the absence of research, observed changes in the actual CPUE for zone 1 were used (table 14).

Over the period 1987-88 to 1992-93, it was found that actual CPUE declined prior to 1991-92, but increased in 1991-92 and 1992-93. The 1991-92 fishing year corresponds with the year in which the benefits from the implementation of the seasonal closure in November 1989 and the education campaign on net clearing practices may be expected to have begun, as there is approximately a two year period for recruitment to the fishery (Brown

14 Actual and projected catch per unit effort and prices for zone 1 of the New South Wales spanner crab fishery

	Catch per unit effort		Average annual price a
	with research	without research	
	kg/day	kg/day	$/kg
1987-88		317	3.92
1988-89		314	3.87
1989-90		255	3.06
1990-91		108	3.58
1991-92	127	108 **p**	2.71
1992-93	136	108 **p**	2.55
1993-94	136 **p**	108 **p**	4.38
1993-94 to 2001-02	136 **p**	108 **p**	4.38

a Expressed in 1994-95 dollars. Up to 1992-93, prices are average annual prices reported for cooked spanner crabs on the Sydney domestic market, less 20 per cent commission and marketing charges. From 1993-94 onwards, the most likely annual price is assumed to be equivalent to the recent export price received by producers of $5 per kilogram. Assuming a triangular distribution of prices described by a minimum long term domestic price of $3.15 per kilogram and a most likely and maximum export price of $5 per kilogram, this results in an average annual price of $4.38 per kilogram. **p** Projected CPUE based on previous year.

1986). Hence the rise in CPUE from 1991-92 was assumed to be attributable to the research induced management changes and changes in fishing behaviour. This simplifying assumption reflects the absence of more detailed information on the response of recruitment levels to changes in management and effort, and has been based on expert opinion rather than detailed bioeconomic analysis.

From the research reported in Kennelly, Watkins and Craig (1990), it was found that inappropriate handling methods of juvenile discards (such as causing the loss of whole limbs when crabs were removed from the net) resulted in up to 100 per cent mortality after eight days. This mortality rate was found to be reduced to 60–70 per cent over 50 days if only one or more dactyli (the last segment of a walking leg) were lost. Based on these results, it has been argued that methods that reduce damage to discarded crabs can have a significant impact on the abundance of spanner crabs. Reducing these causes of mortality has been the focus of an education campaign by management to promote optimal harvesting methods by operators.

The adoption of appropriate crab harvesting methods has been significant within the industry, and the extra time expended in ensuring juvenile crabs are discarded properly is considered to be minimal. The establishment of crab management advisory committees by industry, scientists and managers has particularly assisted the flow of information from researchers to management and operators on appropriate handling practices.

In the 'without research' case, the CPUE prevailing in 1990-91 was applied to the number of actual fishing days to estimate annual catches up to 1992-93. From 1992-93 onwards, the CPUE was assumed to remain constant at 108 kilograms per fishing day (the level reported in 1990-91). In the 'with research' case, actual catch and effort figures were used up to 1992-93. From 1992-93 onwards, the CPUE was assumed to remain constant at 136 kilograms per fishing day (the level reported in 1992-93).

The total number of days fished was assumed to remain constant after 1992-93 for both the with and without research cases. The estimated and projected catches in the absence of research were then compared with the actual and projected catches with the management changes.

The benefits of research comprised the increase in total revenue arising from higher average catches per day (resulting from the higher abundance of crabs). Up to 1992-93, average annual prices for spanner crabs on the Sydney domestic market were used to derive the returns received from spanner crab catches (table 14). Since mid-1993, operators from zone 1 of the New South Wales fishery have supplied spanner crabs mostly for the live seafood markets in Asia. From 1993-94 onwards, returns were calculated by multiplying estimated catches by projected average prices. The most likely annual price for this period is assumed to be equivalent to the recent export price received by producers of $5 per kilogram. However, depending on the condition and survival of harvested crabs, a small proportion of the total catch continues to be supplied to the domestic market.

The stochastic evaluation of research benefits therefore included a lower bound of $3.15 per kilogram, which represents the average producer price received for cooked spanner crabs on the Sydney domestic market over the period 1990-91 to 1994-95. Assuming a triangular distribution of prices described by a minimum long term price of $3.15 per kilogram and a most likely and maximum price of $5 per kilogram results in an average annual price of $4.38 per kilogram.

The average daily fishing cost was based on information provided by industry, assuming an average vessel length of 7 metres. The net returns from fishing were calculated using expected prices, yields and average daily vessel costs.

It is difficult to assess whether recommendations, such as the promotion of appropriate net clearing practices and the seasonal closure, would have been implemented in the absence of research. For wild capture fisheries, such as the spanner crab fishery, existing performance measures such as CPUE are often used by management as indicators of the status or relative abundance of stocks. However, such measures can be an unreliable indicator of fishing mortality because of changes in environmental conditions affecting stocks (Krebs 1972).

Research which addresses specific information gaps, such as research into population biology and fishing mortality, may consequently provide additional information for assisting management decisions. At the very least, it is likely that the spanner crab research program brought forward specific management changes, such as the introduction of an annual seasonal closure, and the promotion of appropriate net clearing practices to reduce fishing mortality.

The benefits from management changes were therefore wholly attributed to the research in the first instance, in order to provide an upper bound to expected benefits. This assumption is consistent with the stated policy position of New South Wales Fisheries to use 'research results and consultation with industry and other clients to develop management strategy and policy' (New South Wales Agriculture 1991) and the direct contribution of the spanner crab management advisory committee. This committee is the main forum where research recommendations are discussed in consultation with researchers, industry and managers.

For comparative purposes, the effect of assuming a partial contribution of the research to management changes was also assessed, including the effect of attributing 50 per cent and 75 per cent of estimated benefits to the research program.

The major costs associated with this research included the costs of undertaking the research and of implementing the research recommendations. Because of the baseline nature of earlier biological research undertaken in Queensland, these research costs were included in total research costs. The major costs associated with the implementation of research recommendations were management costs, which included salary and travel costs of fisheries managers and scientists involved in the management and consultative process. Other costs included the costs of implementing the education campaign for optimal harvesting practices and the additional costs to operators in undertaking appropriate net clearing practices.

However, the management and monitoring costs for the New South Wales spanner crab fishery were difficult to quantify, as these costs are generally included in the costs for a number of New South Wales fisheries. As some management and monitoring costs, such as the seasonal closure, have not been explicitly reported for the spanner crab fishery, estimates were used based on information provided for the Queensland fishery. However, management costs associated with the proposed introduction of a limited entry fishery were based on estimates prepared for the New South Wales fishery by the Spanner Crab Fishery Management Advisory Committee (1992).

The costs associated with the promotional campaign for net clearing practices included the provision of information in newsletters and associated industry workshops and meetings. The additional costs to operators of undertaking appropriate net clearing practices were considered negligible, since the extra time and effort required in the removal of undersize crabs from the net is less than 10 seconds per crab (Kennelly, Watkins and Craig 1990).

The estimated ranges of values for uncertain parameters (described by minimum, most likely and maximum values) used in the analysis are presented in table 15.

15 Assumptions and data used for the evaluation of the spanner crab research program a

Input data	Unit	Minimum	Most likely	Maximum
Average price of spanner crabs from 1993-94 onwards	$/kg	3.15	5.00	5.00
Average daily fishing cost	$/day	101	112	124
Initial costs for each management change	$	13 119	15 743	18 367
Ongoing costs for each management change	$/yr	2 624	4 723	7 872
Monitoring costs of seasonal closure	$/yr	10 496	11 020	11 545
Initial and ongoing costs of implementing a limited entry fishery	$/yr $/yr		22 041 in 1994-95 4 198 a year from 1994-95 on	

a Based on 1992-93 costs which were adjusted by changes in the consumer price index to represent 1994-95 dollars.

Results

The main contribution of this research to management has been the adoption of several recommendations that are likely to have resulted in higher catches and returns (table 16). Making further market gains, however, will depend greatly on the level of future fishing effort. From an investigation of catch and effort data, CPUE in most regions has increased since 1991-92 from previously declining levels in both Queensland and New South Wales. A rise in CPUE, other factors remaining constant, implies an increase in the relative abundance of stocks.

However, it is difficult to attribute the general increases in CPUE over this period solely to research induced management changes, since a number of other factors are also likely to have influenced changes in CPUE. Brown (1993), for example, has suggested that increases in CPUE for the Queensland fishery may have been partly a reflection of environmental

16 Principal recommendations arising from the spanner crab research program

Recommendations, by project	Year first adopted by management
81/71: Population biology of the spanner crab (Ranina ranina in south east Queensland)	
Harvesting gear restrictions	Early 1980s (Qld)
Minimum sizes for egg bearing females	May 1984 (Qld)
Recreational bag limit of 20 kilograms per person	December 1984 (Qld)
Seasonal closure of the fishery in December	October 1987 (Qld)
86/63: Assessment of the crab fisheries in New South Wales	
Seasonal closure from 20 November to 20 December	November 1989 (NSW)
Seasonal ban on landing female spanner crabs	October 1993 (NSW)
90/05: Development of non-damaging trapping apparatus and methods of limiting damage caused by traditional tangle nets in the spanner crab (Ranina ranina) fishery	
Education campaign for net clearing practices	Implemented throughout 1989–92 (NSW)
Maximum net drop of 10 cm	Under consideration (NSW)
Traps to be limited to one layer of mesh	To be considered in review of existing management plan (NSW)

conditions affecting the long term cycle of abundance, changes in the geographic distribution of fishing effort or improvements in the efficiency of fishing strategies by operators.

In the future, realising potential research benefits from previous management changes will depend critically on the level of effort applied in the fishery. Currently, there are high levels of latent effort in both the Queensland and New South Wales fisheries. In 1993, there were 1064 Queensland endorsements eligible to take spanner crabs, with only 205 of these endorsements being used by specialist spanner crab operators in that year (Queensland Department of Primary Industries 1993).

In the absence of appropriate management controls, potential research benefits are likely to be dissipated through excessive fishing effort and the depletion of stocks. The Queensland Fish Management Authority (QFMA) has recently announced a review of existing management arrangements, with the aim of ensuring sustainable levels of fishing effort (Densley 1994). Several management proposals such as a total allowable catch and a daily catch limit for the spanner crab fishery have been put forward by the Queensland Commercial Fisherman's Organisation Crab Committee for consideration by the QFMA (Honey 1994).

The risk of possible overfishing and dissipation of potential benefits similarly applies to the New South Wales fishery, where currently any holder of a New South Wales commercial fishing licence is eligible to take spanner crabs. However, this situation is likely to change, as recommendations have been proposed for a more restricted limited entry fishery (Spanner Crab Fishery Management Advisory Committee 1992).

Potential harvesting benefits

If appropriate effort control measures are implemented, any improvements in the sustainability of catches from earlier management changes attributable to the spanner crab research program are likely to be maintained.

Assuming a constant level of fishing effort of 1662 fishing days a year from 1992-93 onwards, the potential market benefits from improved harvesting returns were calculated for zone 1 of the New South Wales fishery (table 17). Because of the uncertainty about future management arrangements and levels of fishing effort, potential market benefits are evaluated over a ten year period only. Depending on the choice of discount rate, the expected net

17 Expected research payoffs from the spanner crab research program

	Unit	Discount rate		
		6 per cent	8 per cent	10 per cent
***10 year benefit period* a**				
Net present value (100 per cent contribution)	\$m	1.3	1.01	0.69
Net present value (75 per cent contribution)	\$m	0.71	0.44	0.12
Net present value (50 per cent contribution)	\$m	–0.03	–0.23	–0.53
Benefit–cost ratio **b**		2.0:1	1.7:1	1.4:1

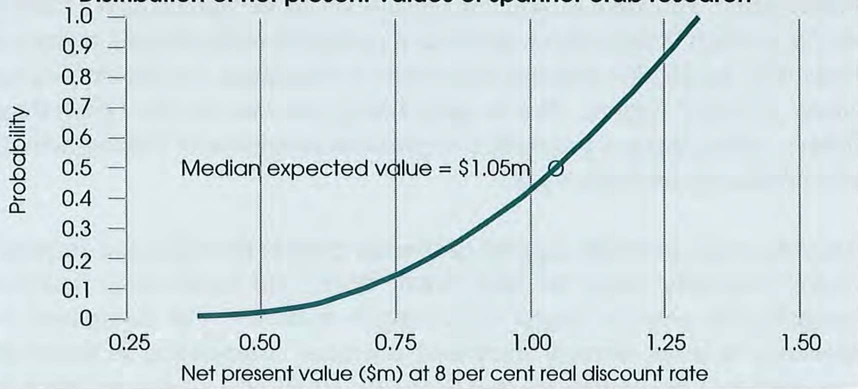
a Expressed in 1994-95 dollars. **b** Assumes the benefits from the management changes are 100 per cent attributable to the research program.

benefits over a ten year benefit period are estimated to range between \$0.69 million and \$1.3 million, assuming the benefits from the management changes were 100 per cent attributable to the research.

In comparison, the benefits from research are expected to fall by over 50 per cent if the research is assumed to have made a 75 per cent contribution to the management changes. If the research is assumed to have made a 50 per cent contribution to the management changes over the period, the expected returns are likely to be negative. This suggests that the expected benefits are likely to be positive only if the research is assumed to have made a strong contribution to the management changes. As discussed earlier, the spanner crab management advisory committee is the main forum where research recommendations are discussed in consultation with researchers, industry and managers.

F

Distribution of net present values of spanner crab research



The distribution of likely research benefits over a ten year period is presented in figure F. At an 8 per cent real discount rate, the net present values are positive under the given ranges for uncertain variables, including daily vessel running costs, prices and management costs. For example, there is a 10 per cent probability that the net present value of estimated research benefits will be less than $0.69 million and a 10 per cent probability that it will be above $1.26 million. Hence, there is an 80 per cent probability that the estimated research benefits lie between these two figures, assuming the research has made a 100 per cent contribution to the identified management changes.

Concluding comments

The implementation of management measures arising from the spanner crab research program are likely to have increased the potential for increased catches and returns from the fishery. For example, the estimated net benefits for a major representative zone of the New South Wales fishery were shown to be positive, based on an assumed higher CPUE over time and a constant level of fishing effort.

However, the extent to which potential research benefits may be fully realised over time depends critically on future fishing effort. Currently, there is a high level of latent effort in both the Queensland and New South Wales fisheries, which may result in unsustainable fishing pressure on available stocks if an excessive number of operators are permitted to enter the fishery. Consequently, the realisation and maintenance of potential benefits will be strongly influenced by the structure of future management arrangements and their effect on future effort levels.

Furthermore, the extent to which the results from one representative zone of the New South Wales fishery can be extrapolated to other fishing regions is limited by geographic differences in relative abundance, and the developing nature of many regions. This is particularly the case for the Queensland fishery, where there is presently a significant expansion of fishing activity into previously unfished areas.

Australia is the dominant supplier of spanner crabs to the Asian and domestic seafood markets, since the New South Wales and Queensland fisheries comprise the world's largest wild capture fisheries. The dissipation of potential benefits through increased overseas competition is therefore considered to be limited by the relatively small size of the resource in alternative wild capture fisheries such as Hawaii. However, over the longer term, the potential for the future development of aquaculture technologies is likely to influence the outlook for Australian spanner crab producers.

It should also be acknowledged that additional research has recently been completed into optimal transport methods of live crustaceans. The results of this research may further enhance the competitive position of Australia in the Asian live crab export market. This may result in additional benefits to the Queensland and New South Wales fisheries through the development or expansion of export marketing opportunities.

3.5 Southern shark stock assessment program

FRDC research program: natural fish resources (research leading to catch maintenance)

Key issues: research program versus project assessment; role of management in realising benefits

Background

The southern shark fishery encompasses State and Commonwealth waters off South Australia, Tasmania and Victoria and is managed jointly by the South Australian, Victorian, Tasmanian and Commonwealth Governments. The fishery is based primarily on catches of gummy and school sharks. Other species, including common saw sharks, southern saw sharks, and elephant fish account for about 15 per cent of the total catch. Most of the catch is taken by fishermen using gillnets and specifically targeting shark. The gross value of production in the southern shark fishery was estimated at almost $16 million in 1993-94, a fall of 9.5 per cent from 1992-93 (ABARE 1994).

Links between research and management in the fishery

Results from a number of biological research projects have been used to assist management in the southern shark fishery. For example, biological data on school shark were collected by CSIRO during the 1940s and early 1950s and on gummy shark by the former Victorian Fisheries and Wildlife Division during 1973–76. Data on school shark were also collected during the latter study. Stock assessments from these studies were inconclusive, although concerns were raised over the status of shark stocks.

In July 1984, the Australian Fishing Council established the Southern Shark Fishery Task Force to develop management proposals for conservation of the resource and its optimum use. Following a second meeting in December 1984, the Task Force recommended that further research be undertaken on the southern shark fishery. This led to the Southern Shark Assessment Project which was funded by the Fishing Industry Research Trust Account

(FIRTA). The purpose of the project was to provide resource assessments to guide and assist management of the fishery (Walker 1987). A regional research unit known as the Southern Shark Assessment Group was established at the Marine Science Laboratories (Queenscliff) for the three year period 1 July 1985 to 30 June 1988, to undertake the Southern Shark Assessment Project.

The project had the aims of establishing a monitoring program for commercial shark landings, investigating the key biological characteristics of gummy shark and developing a dynamic pool model for gummy shark. The Southern Shark Assessment Group provided regular scientific and technical advice to management during the project period. Additional staff were also appointed to the Southern Shark Assessment Group using funds provided by the Australian Fisheries Service to provide scientific and technical advice to the Southern Shark Fishery Management Advisory Committee and the former Southern Shark Task Force (Walker, Moulton, Dow and Saddler 1989).

In 1986 management controls in the form of non-transferable net endorsements were introduced for fishermen using gillnets to catch sharks in Commonwealth waters. The Southern Shark Assessment Group then undertook the Southern Shark Monitoring Project funded by industry levies.

In 1988, the Southern Shark Fishery Task Force accepted biological advice from the Southern Shark Assessment Group that shark stocks were overexploited and that fishing effort should be reduced by around 40 per cent to reduce the catch by around 20 per cent to about 2700 tonnes a year. The Task Force recommended the introduction of an interim management plan, designed to reduce fishing effort and limit the number of vessels operating in the fishery. This plan was introduced in April 1988.

The Southern Shark Database project commenced in January 1990 with the aims of documenting the contents of the existing southern shark database and continuing scientific research on shark in the fishery. In addition, this project also undertook development of a shark fishery model to simulate effects of varying fishing effort and fishing method (including mesh size of gillnets) on catch, stock biomass and number of births.

In November 1990, the Southern Shark Research Assessment Group observed that the interim management plan was ineffective in cutting back fishing effort and shark landings to the level required. The working group suggested that annual landings in the southern shark fishery needed to be reduced to between 500 and 2200 tonnes from the then current levels in excess of 3000 tonnes (Southern Shark Research Assessment Group 1990). In December 1990 the Southern Shark Research Group tabled the findings of scientific research undertaken by the Southern Shark Assessment Group before the Southern Shark Fishery Restructuring Task Force. Using a dynamic modelling approach, scientists suggested that unless catches in the fishery were immediately restricted to between 500 and 1000 tonnes, the fishery faced collapse.

In April 1991, the Commonwealth Government implemented further interim controls in an attempt to reduce catch of shark in the fishery. These controls reduced the number of nets in the fishery by around 33 per cent.

In this case study the research program, comprising the Southern Shark Assessment Project and Southern Shark Database Project, is evaluated. The total cost of these two projects was $974 301 (or $1.23 million expressed in 1994-95 dollars) and was spread over the six year period ended 1990-91. The FRDC contribution to total research funding was 68 per cent.

Method

Because of the very clear links between research findings and the implementation of management controls, the benefits from the 'Southern Shark Assessment Project' and the 'Southern Shark Database Project' are defined as the net benefits to the fishery resulting from the introduction of the effort reduction plan in April 1991. The effort reduction plan is unlikely to have been implemented in the absence of the research program, due mainly to the inability of alternative information at the time to predict stock changes with reasonable accuracy.

Because of the schooling nature of school and gummy sharks, the conventional measure of relative abundance — catch per unit effort (CPUE) — is regarded as an inappropriate indicator of the status of stocks in this fishery. This is because CPUE can significantly lag a real decline in stocks, due to the effects of schooling. In addition, the CPUE database did not provide a consistent time series for evaluating the relative abundance of shark stocks, since previous management changes had occurred in 1988. It is therefore likely that without the research, management changes would not have been taken until shark stocks had decreased significantly.

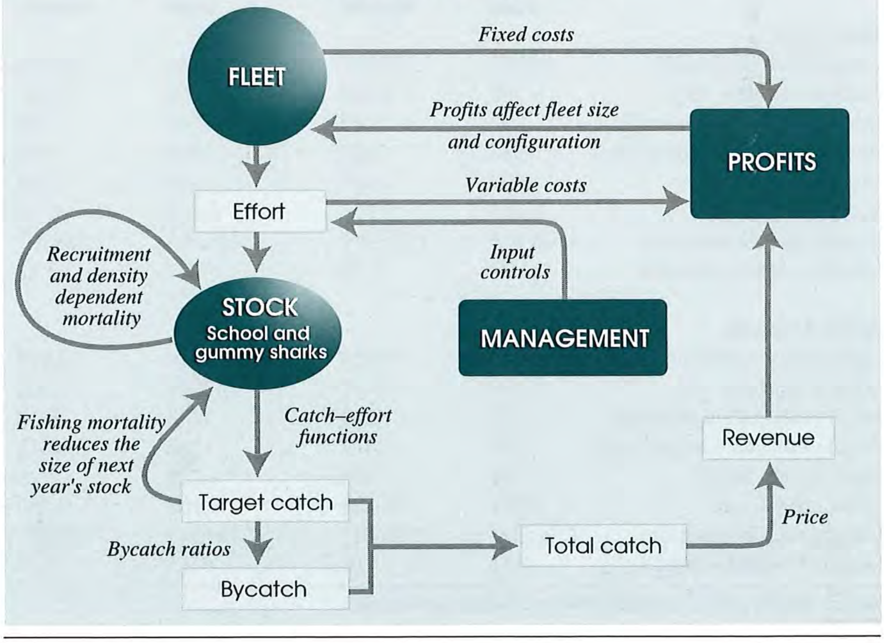
It should also be noted that there are a number of other benefits arising from the research which are difficult to quantify, such as increased scientific knowledge which was used in the development of a southern shark fishery model which can be used in the future. This knowledge may also assist in the management of other fisheries.

To quantify the benefits from the research program undertaken by the Southern Shark Assessment Group, a modified bioeconomic model developed previously by ABARE (Pascoe, Battaglene and Campbell 1992) was used. The ABARE model is an optimisation model, which means that it can be used to maximise a given variable, such as profit, subject to a set of biological or physical constraints. In this case, the model was used to estimate the number of boats and types of gear that maximised the net present value of profits over time, given constraints imposed by the stock structure and management actions.

The principal components of the model are shown in figure G. These fall into three distinct components — biological, physical (fleet structure) and economic. Together these components enable the user of the model to

G

Diagrammatic representation of the ABARE bioeconomic model of the southern shark fishery



estimate the biological, economic and physical outcomes for the fishery under different management strategies.

The model was modified to reflect regional variations in gummy and school sharks in Bass Strait and South Australia. Biological parameters on gummy shark were derived from Walker (1993), while the biological parameters for school shark were modified on the basis of the latest scientific advice (T. Walker, Victorian Marine Science Laboratories, personal communication, May 1994) and revisions undertaken independently by ABARE.

The main biological parameters used in the model are presented in tables 18–19.

The economic data used in the model were derived from logbook data supplied from the Victorian Marine Science Laboratories and an ABARE survey of the fishery conducted in 1993 (ABARE 1993b). The main economic and physical data used in the model are presented in tables 20–21.

18 Biological parameters used in the bioeconomic model of the southern shark fishery

Parameter description	Gummy		School	
	Male	Female	Male	Female
Bass Strait				
Catchability coefficient	0.0157	0.0157	0.0132	0.0132
Natural mortality rate	0.197	0.197	0.101	0.101
Density dependant mortality	0.70	0.70	0.38	0.38
Asymptotic shark length (mm)	1387	2019	1583	1618
'Age' at zero length	–0.90	–1.55	–1.25	–1.28
Shark growth rate	0.253	0.123	0.167	0.160
Length–weight parameter	4.38×10^{-9}	1.22×10^{-9}	2.18×10^{-9}	2.18×10^{-9}
Length–weight parameter	2.97	3.18	3.17	3.18
South Australia				
Catchability coefficient	0.023	0.023	0.019	0.019
Natural mortality rate	0.197	0.197	0.101	0.101
Density dependant mortality	0.70	0.70	0.38	0.38
Asymptotic shark length (mm)	1387	2019	1583	1618
'Age' at zero length	–0.90	–1.55	–1.25	–1.28
Shark growth rate	0.253	0.123	0.167	0.160
Length–weight parameter	4.38×10^{-9}	1.22×10^{-9}	2.18×10^{-9}	2.18×10^{-9}
Length–weight parameter	2.97	3.18	3.17	3.18

Source: Walker (1991); Victorian Marine Science Laboratories.

19 Estimated stocks of shark in Bass Strait and South Australia in 1990

	Bass Strait				South Australia			
	Gummy		School		Gummy		School	
	Male	Female	Male	Female	Male	Female	Male	Female
	'000	'000	'000	'000	'000	'000	'000	'000
Cohort								
0	399.5	399.5	34.0	34.0	99.9	99.9	11.3	11.3
1	292.8	292.7	34.4	34.4	73.2	73.2	11.5	11.5
2	216.0	217.5	35.8	35.8	54.0	54.4	11.9	11.9
3	157.5	158.2	37.8	37.8	93.4	39.6	12.6	12.6
4	85.2	83.8	43.5	43.5	21.3	21.0	14.5	14.5
5	43.8	43.7	36.3	36.3	11.0	10.9	12.1	12.1
6	19.6	21.3	28.5	28.5	4.9	5.3	9.4	9.4
7	9.4	12.0	21.8	21.8	2.4	3.0	7.3	7.3
8	4.5	7.2	12.9	12.9	1.1	1.8	4.3	4.3
9	2.3	5.0	2.7	2.7	0.6	1.3	2.3	2.3
10	1.3	3.8	4.1	4.1	0.3	1.0	1.4	1.4
11	0.8	3.2	1.2	1.2	0.2	0.8	1.9	1.9
12	0.5	2.9	0.7	0.7	0.1	0.7	1.1	1.1
13	0.4	2.6	0.4	0.4	0.1	0.7	0.6	0.6
14	0.2	2.3	0.2	0.2	0.1	0.5	0.4	0.4
15	0.2	2.0	0.1	0.1	0.1	0.5	0.2	0.2
16+	0.1	1.7	0.7	0.7	0.1	0.4	1.0	1.0

Source: Victorian Marine Science Laboratories.

20 Boat economic parameter values in the southern shark fishery

Average per boat

	Fixed cost	Variable cost	Number of boats in each group	
			Bass Strait	South Australia
	$'000	$'000	no.	no.
Boat group				
A10	105.2	31.2	25	15
A6	39.2	15.0	16	9
B	42.3	11.1	22	27

Source: Victorian Marine Science Laboratories.

21 Boat physical parameter values in the southern shark fishery

	Effort before April 1991		Effort after April 1991	
	Bass Strait	South Australia	Bass Strait	South Australia
	kmlh	kmlh	kmlh	kmlh
Boat group				
A10	6 299	7 894	4 199	5 262
A6	1 912	2 800	4 199	2 130
B	1 210	1 118	807	754

kmlh — kilometre net lift hours (measure of effort which is the amount of net in kilometres multiplied by the amount of time it is in the water).
Source: Victorian Marine Science Laboratories; ABARE (1993b).

The prices received for school and gummy shark were assumed to remain constant at $6 per kilogram in Bass Strait and $5.50 per kilogram in South Australia over the time period examined. These prices reflect the average prices received by operators in the fishery over the past few years.

To simulate the effects of the research program on the profitability of the fishery, the model was used to evaluate two alternative scenarios based on effort levels before and after the introduction of the gear limitation plan introduced in 1991 (table 21). The first scenario assumed that the maximum permissible level of effort would correspond with the prevailing levels of effort observed before April 1991. The second assumed that the maximum permissible level of effort would correspond with the actual reduction in effort observed after April 1991. It was therefore assumed that any future benefits (in this case improved long term profits) flowing from the net reduction program in April 1991 were wholly attributable to the research. This assumption is considered sound in the light of the strong links outlined earlier between research and management in the southern shark fishery.

The objective function used in the model was the maximisation of profit within each year, subject to all costs being covered. To assess the expected benefits of the net reduction program over time, two benefit periods were evaluated — twenty years and thirty years. Since the southern shark fishery has been managed under a net limitation scheme since 1988, it was assumed there would be no additional implementation costs of adopting the net reduction plan in 1991. This is because enforcement and compliance costs could be accommodated under existing monitoring procedures for the fishery.

22 Expected research payoffs from the southern shark research program

In 1994-95 dollars

	Unit	Discount rate		
		6 per cent	8 per cent	10 per cent
20 year benefit period				
Net benefit	$m	5.9	4.0	2.5
Benefit–cost ratio		5.0:1	3.5:1	2.2:1
30 year benefit period				
Net benefit	$m	11.5	7.9	5.0
Benefit–cost ratio		9.0:1	5.5:1	3.5:1

Results

The expected benefits of the research program are presented in table 22. Depending on the choice of discount rate, the expected net economic benefits over a twenty year period are estimated to range between $2.5 million and $5.9 million. Based on the most likely outcome and an 8 per cent real discount rate, this reflects a benefit–cost ratio of 3.5. By comparison, the estimated level of benefits realised up to 1994-95 was negative, implying a net economic cost. The estimated present value of the net economic cost was around $2.16 million. This result highlights the fact that in many cases the time period required to realise the benefits from fisheries research is long, because of the time periods involved in the stock recruitment relationships for many commercial species. In this case, the availability of a bioeconomic model to predict expected changes in catches over time as a result of fishing behaviour provided a useful tool for estimating future research benefits.

For example, over a thirty year period the expected net economic benefits were estimated at $7.9 million, reflecting a benefit–cost ratio of 5.5. Because sharks generally produce a small number of young and are slow growing, shark stocks may take a long time to recover in the event of overfishing. It is therefore likely that a thirty year period may provide a more accurate representation of the expected benefits, as the consequences of strategies adopted for management of the shark fishery may take many years to appear.

Concluding comments

An ex post evaluation of southern shark stock assessment research indicates an expected improvement in the long term profitability in the fishery. This mainly reflects the development of a biological database and predictive models which have been used by management to assess the status of shark stocks. Most importantly, the research findings have been used as a basis for introducing management controls and reducing effort levels applied in the fishery. It is likely that without the research leading to management changes, the higher levels of effort may have resulted in a decline in shark stocks, and an associated decline in the long term profitability of the fishery.

In addition, this research program has generated a large number of scientific reports and increased biological knowledge. This information is likely to have a substantial input into the understanding and management of other species, both within the Australian Fishing Zone and internationally.

It is also important to acknowledge that research in the southern shark fishery is an evolutionary process, with various elements of the research program leading to enhanced knowledge of the biology of school and gummy sharks. While the Southern Shark Assessment and the Southern Shark Database research projects have led to the implementation of management controls that have provided substantial benefits to the fishery, it is likely that ongoing monitoring of catches and further economic and biological research will provide more accurate information on the fishery. This new information is likely to reduce uncertainty surrounding the biology of school and gummy sharks, and enhance the current understanding of the fishery, providing substantial benefits to operators through improved fisheries management in the future.

3.6 *Stock assessment of blacklip abalone in Victoria*

> ***FRDC research program***: natural fish resources (research leading to catch maintenance)
>
> ***Key issues***: baseline nature of research; role of qualitative assessments and break-even analysis

Background

This research arose from growing concern over the degree of exploitation of blacklip abalone (*Haliotis rubra*) stocks in Victoria in the early 1980s, and limited availability of reliable data for applied stock assessment research. In 1985, the Fishing Industry Research and Development Council (FIRDC) and the Victorian Department of Conservation and Natural Resources (formerly the Victorian Department of Conservation, Forests and Land) jointly funded research into assessing the status and degree of exploitation of Victorian blacklip abalone stocks. This research was instigated and conducted by the Victorian Marine Science Laboratories. The total nominal cost of FIRDC allocations to the research project was $187 500 (equivalent to $266 200 expressed in 1994-95 dollars), spread over the four years ended 1988-89. Additional financial support was provided by the Victorian Department of Conservation and Natural Resources over the same period, and has been estimated at $281 500 (or $398 300 expressed in 1994-95 dollars).

An early focus of the research was an assessment of the population biology of blacklip abalone as the predominant species caught in the Victorian abalone fishery. Before this study little information was available on the basic biology of the species. This earlier research provided the foundation for more detailed research into stock recruitment relationships of blacklip abalone in Victorian waters. The results of the research have consequently been used for developing suitable methods for assessing the relative abundance of abalone stocks, and assessing the biological consequences of varying levels of fishing effort. This research formed the basis for developing ongoing biological monitoring of the fishery. This monitoring program is considered essential for the effective management of the fishery over time, given the considerable uncertainty about the stability of abalone stocks in general.

Method

In this case the benefits from research are defined as the reduced level of risk associated with stock decline or even collapse of the Victorian blacklip abalone fishery. The benefits are defined in this way because, in the absence of research, fisheries managers and industry would be required to make future management decisions on the basis of limited biological information. A major impact of this type of biological research is the effect it can have on management of the fishery, which can result in a maintenance or an increase in catch while sustaining fish stocks. The benefits generated will therefore have depended on the extent to which management has used this information effectively to minimise the risk of stock decline, and enhanced catches over time. The benefits from research may also include the non-market benefits associated with increased knowledge or awareness of the fishery.

However, quantitative estimation of these benefits is likely to be difficult. This is because the relationship between stock and recruitment is generally ill-defined for abalone (McShane 1988), with the level of risk associated with stock decline dependent on a number of highly variable factors. However, based on overseas experience, the risk of recruitment failure in commercial abalone fisheries is considered to be high. There have been many documented collapses of overseas fisheries (McShane 1992).

In the absence of reliable information on the specific levels of risk associated with current and future management arrangements, a stochastic benefit–cost analysis using a range of potential values may not be appropriate. Instead, a qualitative assessment was used to assess the benefits of research, using such criteria as the relative importance of the research results in addressing the management problem and the likelihood of the research benefits being realised and maintained. In addition, break-even analysis was used to demonstrate the likely magnitudes of benefits that would be required in the future to justify the research and implementation costs already incurred.

Results

Research findings

Because the project was essentially baseline research aimed at assessing the biology and status of blacklip abalone stocks, the biological knowledge and experience gained from the research may have direct relevance to other abalone fisheries. Some of the key research findings for the Victorian fishery included:

- the abalone stock comprises several discrete substocks, each confined to an individual reef or reef complex;
- fecundity is related to age, with egg production beginning at age four years;
- stock recruitment is independent of stock density over the range existing for Victorian abalone;
- settlement of abalone larvae is controlled primarily by water movement, with localised dispersal of larvae and subsequent high survival rates for recruits possible only in sheltered waters; and
- variation in recruitment over time is controlled primarily by larval availability which in turn is influenced by environmental factors such as temperature.

Given the highly variable nature of recruitment to the Victorian abalone fishery, the research findings have been oriented toward evaluating the relative abundance and productivity of blacklip abalone stocks.

Key management recommendations of the research also included:

- catch quotas and size limits as the management tools most suited to controlling productivity of the abalone fishery;
- catch quotas should reflect annual recruitment; and
- monitoring of the relative abundance of abalone stocks will provide information on the sustainability of catch quotas and, over time, provide realistic estimates of sustainable yield.

Contribution of research to management arrangements

The historical stability of the Victorian fishery compared with other abalone fisheries can be attributed to the relatively low number of licensed operators, and associated low exploitation rate (McShane 1992). This apparent stability, despite considerable variation in annual catches, reflects management arrangements used in the Victorian abalone fishery since 1968. These arrangements initially comprised a limited licence entry fishery with licence holders endorsed to fish within one of three management zones: the Western Zone from the South Australian border to Warrnambool, the Central Zone from Warrnambool to Lakes Entrance and the Eastern Zone from Lakes Entrance to the New South Wales border.

In April 1984, transferability of abalone licences was introduced on a two for one basis, because of widespread concern that stocks were vulnerable to overexploitation. In 1988, a total allowable catch regime was implemented, with existing licence holders allocated an equal share of the total annual catch set for each zone. The reasons for introducing the a total allowable catch were largely to restrain the rapid rise in fishing effort, which was influenced by a significant increase in world abalone prices and a demographic shift toward more productive divers as a result of the previous licence restructuring.

The main contribution of the research to management has been the development of an ongoing stock assessment monitoring program. In 1988, the Victorian Marine Science Laboratories instigated a long term monitoring program of abalone stocks. This program is used to assess the relative abundance and size distribution of stocks on abalone reefs, and detect emerging problems such as recruitment failure. The early identification of recruitment failure can allow corrective strategies to be implemented, such as the modification of the total allowable catch as the major management tool. Currently, the total allowable catch for the Eastern, Central and Western zones is 460, 700 and 280 tonnes respectively (Victorian Department of Conservation and Natural Resources 1993). Information from the monitoring program is used to review existing total allowable catch for each management zone. Over time, this would have the effect of reducing the long term risk that there might be a stock decline from commercial fishing and a reduced catch for the Victorian abalone fishery.

However, the quantity of abalone taken by recreational fishers and illegal harvest is generally unknown. In the absence of effective management arrangements, this poses an additional risk to the long term stability of the fishery and the extent to which research benefits may be realised. Restrictions imposed on recreational fishers currently include a daily bag limit and minimum sizes.

Break-even analysis

The present value of research costs already incurred is equivalent to $1.23 million, assuming a real interest rate of 8 per cent. In addition to initial research costs, the present value of the costs of implementing the stock monitoring program over the period 1989-90 to 1994-95 is estimated at $1.32 million. This represents a total present value of research and implementation costs of $2.55 million.

Break-even analysis indicates that the minimum stream of future benefits required to meet all the associated research and implementation costs of the project over a fifteen year payback period is $297 880 a year, using an 8 per cent real discount rate. However, this does not suggest that the research benefits would involve an even flow of annual benefits, given the variability in abalone catches and prices over time.

The benefits from this research would have been influenced by the current size and value of the Victorian abalone industry. Australia is the largest supplier of abalone on the world market, with the Victorian catch accounting for around 30–40 per cent of Australian production. The value of production from Victoria has increased from $25 million in 1991-92 to around $60 million in 1993-94, largely as a result of increased export prices (ABARE 1994). There is little information on current profits being earned by Victorian operators in this fishery. However, previous research indicates that potential long term profits of between 25 and 60 per cent of gross production revenue seem possible for a number of State and Commonwealth managed fisheries (see Campbell and Haynes 1990).

Using these two estimates of long term profit, the total marginal revenue required for the benefits (measured by long term industry profits) to break even with research and implementation costs ranges between $496 500 and $1.19 million a year, assuming a fifteen year payback period. Based on the average price received for abalone in Victoria of $42 per kilogram in 1993-94 (ABARE 1994), this is equivalent to a total marginal catch ranging from 12 to 29 tonnes a year respectively. These marginal catches correspond with 1–2 per cent of the total average annual catch of 1300 tonnes for the fishery over the past five years. This suggests that the generation of research benefits (that is, the reduced level of risk associated with stock decline and maintenance of long term profits) would require the avoidance of only a relatively small decline in stocks and yields over time.

The extent to which future benefits exceed the amount required to meet research and implementation costs will determine the net economic benefits from this research.

Concluding comments

Given the general level of uncertainty about the risks associated with recruitment failure of abalone stocks, an ex post evaluation of the abalone stock assessment project has shown the expected economic benefits to be difficult to quantify. However, the research is considered important from the perspective of reducing the risk associated with stock decline or even collapse of the Victorian fishery. The research is considered to be largely baseline in nature and an input into the development of an ongoing monitoring program of abalone stocks which can be used by management to make better informed decisions. The management history of commercial abalone fisheries throughout the world has shown a high level of risk associated with stock collapse.

The Victorian abalone fishery is also the State's highest valued fishery. Given existing management arrangements, the likelihood of the research benefits being realised and maintained will depend most importantly on the effectiveness of the total allowable catch in controlling fishing effort so as to ensure the long term sustainability of abalone stocks.

4

Main findings and issues from case study evaluations

The results of the evaluations of the six projects (or programs) in this study suggest that appropriately selected fisheries research can result in potentially large benefits to both fisheries producers and the broader Australian community (table 23). The benefit–cost analyses show that the potential benefits from four of the projects amenable to quantitative valuation can be expected to exceed research and implementation costs over the next ten to twenty years. The potential industry beneficiaries of the research assessed in this study included the Queensland aquaculture prawning industry; the Queensland and New South Wales spanner crab fisheries; the southern shark fishery; the Australian pearling industry; and the Victorian abalone fishery.

However, the value of total expected benefits depends on a number of important assumptions underlying the evaluation of research benefits in each case study, and there is considerable uncertainty about the expected flow of future benefits.

23 Summary of actual and expected benefits from selected R&D projects a

Project title	Research costs	Net benefits realised to 1993-94 b	Expected net benefits 10 years	Expected net benefits 20 years
	$m	$m	$m	$m
1. Transport and storage of live penaeid prawns	0.47	–0.74	na	18.3
2. Hatchery and nursery culture for the silver lipped pearl oyster	3.72	–4.64 c	na	na
3. Pearl diving safety	0.47	0.83	4.45	na
4. Spanner crab fishery research	1.26	–0.66	1.0	na
5. Southern shark stock assessment program	2.10	–2.16 c	na	4.0
			Required annual benefits (15 years)	
Break-even analysis				
6. Victorian abalone stock assessment	2.6 b	na	0.49–1.2	

a Assumes a real discount rate of 8 per cent. Values expressed in 1994-95 dollars. **b** Includes research and implementation costs. **c** In this case the level of realised benefits (or costs) are presented for 1994-95. **na** Not evaluated over this period.

The use of ex post analysis to assess the benefits of selected fisheries research highlighted a number of important factors underlying the evaluation of research benefits. Some of the more general factors and issues affecting the ex post evaluation of fisheries research in this study included:

- a lack of information, in some cases, on which to undertake detailed ex post analysis;
- the long time period between research completion and the final realisation of benefits;
- the potential dissipation of research benefits over time;
- the leakage of benefits to competitors;
- the attribution of benefits to the identified project or series of projects (program); and
- the baseline nature of some fisheries research.

Lack of information for ex post analysis

In the case of the pearl oyster hatchery development program, it became obvious that there was insufficient information on which to undertake a detailed ex post analysis of the research. This lack of basic information required to make an assessment, coupled with the high sensitivity of estimates of the level of potential research benefits, means that the benefits from the research program could not be measured quantitatively. This research outcome also highlighted the need to identify, prior to the funding of research, some of the key economic parameters such as price flexibilities that are likely to affect the size and likelihood of achieving the possible benefits.

Time lag between research completion and the final realisation of benefits

As with other agricultural research, it is often not until ten to fifteen years after initial fisheries research that the benefits are fully realised. Fisheries research and development covers a diverse range of management and marketing issues and, depending on the nature of the research undertaken, there will be varying time periods before the benefits (if any) are realised. The length of time will depend on the type of impact from the research and the institutional structure within the fishery. This point is highlighted by reference to table 23, which presents the benefits realised up to 1993-94 and the benefits expected to accumulate ten to twenty years after research completion.

For example, the total net benefits realised to 1993-94 from four of the projects amenable to quantitative valuation were negative, implying a net economic cost. Up until 1993-94, the estimated cost of these four projects was around $8.2 million, representing mainly the large initial research and implementation costs. Insufficient time had elapsed for the results to be fully realised. By comparison, the total net return for two of the projects evaluated over a twenty year period was estimated to be around $22.3 million, while for another two projects evaluated over a ten year period it was estimated to be $5.45 million.

The time lag from the completion of biological and management related research to the expected realisation of benefits usually depends on the biological characteristics of the species under study. Research into fisheries management may result in a significant period between research completion and the expected realisation of benefits. For example, the southern shark stock assessment research program assessed in this study is expected to produce net benefits of around $4.0 million over a twenty year period and $7.9 million over a thirty year period. In this case, significant benefits are not expected to accrue until twenty years after the implementation of research recommendations in 1991. This is because school and gummy sharks are generally slow growing and produce only a small number of young, resulting in lengthy periods between management changes in allowable catches and improvements in stock levels. In such a case, management changes can result in short term costs to operators, before an improvement in long term profitability of the fishery is realised.

In the case of the pearl oyster hatchery development program, the largest proportion of potential benefits are not expected to accrue until twenty years after research completion. This is mainly because of an initially slow adoption rate and a five year period between initial spat production and seeding to the final sale of pearls. In contrast, research into harvest technology or marketing may result in the realisation of benefits relatively quickly. Such is the case for the research projects into pearl diving safety and the production and marketing of live kuruma prawns.

The project into pearl diving safety, for example, is likely to have resulted in the generation of research benefits within two years of initial research. This was due mainly to the direct links between the implementation of research findings and the generation of benefits in the form of harvesting cost savings.

The generation of expected research benefits from the selected projects therefore depends on a range of institutional and biological factors — for example, the timeliness of changes in operations and management resulting from the research findings and, in the case of research affecting stocks, the recruitment dynamics underlying sustainable catches of commercial fish species.

Clearly, one of the main advantages of an ex post evaluation compared with an ex ante evaluation is the greater degree of certainty surrounding estimation of research payoffs, since final research outcomes are generally known. Consequently, ex post evaluations can be used to compare the actual payoffs with the expected research payoffs of particular research projects or programs. However, the results from this study indicate that, in many cases, all of the potential benefits from the research may not be fully realised for many years.

The level of certainty about the estimated research payoffs was also influenced to a large extent by the relatively long periods expected between research completion and the realisation of benefits. In most cases, the generation of research benefits had to be estimated using an ex ante approach, since there was insufficient time for all the potential benefits to have been fully realised. Key factors affecting the level of risk surrounding the estimation of future research benefits included product prices, yields and likely adoption rates. The use of stochastic analysis was therefore an important component of the evaluation process, given considerable uncertainty surrounding future costs, prices and yields.

The availability of a bioeconomic model in the case of the southern shark stock assessment program also provided an important tool for evaluating future expected benefits. This model allowed the research benefits to be measured with greater certainty, since the most important economic, biological and physical relationships could be quantitatively assessed and modelled on the basis of existing knowledge. Most importantly, the level and choice of analysis depended on the availability of suitable information. In the evalu-ation of research into the spanner crab fishery, for example, a number of clearly stated and supported assumptions were used in the absence of more detailed information on the catchability and relative abundance of crabs over time.

Potential dissipation of research benefits over time

Another important issue in the evaluation of fisheries research benefits was the dissipation of research benefits over time. It was important in many of the case study evaluations, because it was affected by a considerable number of factors. The actual and expected flow of benefits is influenced by such factors as the presence of appropriate management arrangements and assumptions underlying the rate of technology transfer.

For fisheries research aimed at increasing returns to the harvesting sector, the maintenance of benefits will depend on the strength of property rights over the resource. Experience in Australian fisheries and internationally suggests that, under an input control management regime, available rents in the fishery will become dissipated in the long run as operators substitute uncontrolled inputs for controlled inputs. The rate of substitution depends on the degree of control over inputs (for example, in the case of the southern shark fishery, restrictions on the number of nets) and the ability to increase other inputs.

In the case of the southern shark stock assessment program, the presence of input management controls such as licensed gear entitlements was assumed to result in the generation and maintenance of research benefits over time. While this form of management is likely to slow the rate of dissipation of benefits from research when compared with an open access fishery, such dissipation is likely to occur. The benefits estimated from the program may consequently be considered an upper bound of potentially realisable benefits. If the management of the fishery were changed to an output controlled fishery, for example, there would be less likelihood of these potential benefits being dissipated over time.

The presence of commercial catch quotas in the Victorian abalone fishery was also considered important to maintaining the potential benefits of the Victorian abalone stock assessment program. However, the lack of effective regulations to control recreational catches may contribute to the potential dissipation of research benefits over time.

Leakage of benefits to competitors

The pearl oyster hatchery development program also highlighted the need to develop clearly defined property rights over research results and intellectual property arising from fisheries research. This research program has resulted in the successful development of hatchery and nursery culturing techniques for the silver lipped pearl oyster.

Depending on Australia's market trading position and the assumed price flexibility for pearls, the potential research benefits to Australian producers may be positive. However, because of the leakage of research results to overseas competitors, there may be losses to Australian producers from this research. This is because several Indonesian firms are currently establishing commercial hatcheries based on the results of the Australian research. In this case, the benefits from research will be dissipated if the leakage of research results leads to increased overseas production and downward pressure on prices of south sea pearls over the medium to longer term.

The risk of technology transfer to overseas producers is also likely to affect the expected benefits from research into the transport and storage of live kuruma prawns.

Consequently, the existence of international competitors and Australia's future market position are likely to play an important role in the level of future potential benefits from fisheries research. Research into the development of new harvesting technologies is particularly vulnerable to leakage. Therefore, funding of such research should only be undertaken when it is possible to ensure the results may not be used to adversely affect Australia's trading position.

Attribution of benefits to the identified research project or programs

As discussed by Lal et al. (1994), it is often the case in fisheries research that the cumulative efforts of many research projects (simultaneous or sequential) are needed to provide sufficient information to achieve the desired benefits. When conducting an ex post evaluation, it is important to assess whether the benefits and costs of a suite of related research projects or of an individual research project in isolation should be evaluated.

In most of the case studies evaluated, a suite of related research projects was assessed, reflecting the important linkages between the many individual research projects. In particular, a number of related research projects were included in the evaluation of the southern shark stock assessment program and the hatchery and nursery culture for the silver lipped pearl oyster, where the cumulative effects of individual projects could not be separated. An important assumption underlying the evaluation of a research program is that the particular projects selected are the most appropriate for the research benefits that have been identified.

In the case of spanner crab fishery research, for example, a current project on developing live transport methods for crustaceans was excluded because of the lack of any direct relationship with the assumed benefits of improved catches over time. It would be appropriate to assess this project after the results have been implemented and there has been sufficient time for the benefits (such as enhanced prices for live crab exports) to be clearly identified. On the other hand, the two projects on pearl divers' diving safety and transport and storage of live penaeid prawns each provided an opportunity to evaluate an individual project that was clearly related to the actual and future expected benefits identified from research.

Baseline nature of some fisheries research

In some cases, many of the projects or programs to be evaluated may include a proportion of research that can be described as baseline research. This includes research into the basic biology and population dynamics of an individual genus or species (such as research into the basic biology of spanner crabs and abalone for example). In such circumstances, it is often difficult to quantify the direct market benefits arising from research. Lindner (1989), for example, describes the outcome of this type of research as partially successful, in the sense that new knowledge cannot be used immediately to generate tangible benefits, but is likely to prove useful as an input to further research.

For some wild capture fisheries, for example, existing performance measures such as catch per unit effort may often be an unreliable indicator of fishing mortality because of changes in environmental conditions affecting stocks. Research which addresses specific information gaps, such as research into population biology and fishing mortality, may consequently provide additional information for assisting management decisions. In particular, the Victorian abalone stock assessment project provided baseline information on the lifecycle and recruitment processes of blacklip abalone. This information was considered fundamental for sustainable fisheries management by providing a basis for setting total allowable catches, and demonstrates the importance of strategic research in fisheries management.

5

Concluding comments

This study has highlighted the role of ex post analysis as a means for improving decision making in the allocation of resources in fisheries research and development activities. Ex post analysis can provide feedback on factors that facilitate or impede the uptake of research results and the final realisation of benefits. Ex post analysis also helps identify the types of research benefits obtained and the subsequent growth or dissipation of those benefits through time, which may include market related benefits (such as enhanced catches or reduced harvesting costs) and/or non-market benefits (such as knowing a particular species of fish exists).

This information can then be used as an input in the overall planning and management of research expenditures and, when used with ex ante analysis, can provide a more efficient framework for the allocation of research resources at the project selection stage. Most importantly, it is the systematic process of benefit–cost analysis which provides the greatest value when assessing research expenditures, by providing a consistent framework in which to identify the key issues surrounding the costs and benefits of research, and presenting those results, where possible, in a quantitative and/or qualitative manner.

For example, an ex ante benefit–cost evaluation of a research project provides the starting point for determining whether a project can be expected to yield benefits in excess of costs and, if so, what priority should be given to it relative to competing research proposals. As new information becomes available through the course of research, modifications to the project can be made on the basis of subsequent re-evaluations. When the project is completed, an ex post evaluation will provide some valuable insights into the accuracy of the initial evaluation and what factors were important to any divergences between anticipated and actual research outcomes. These lessons can then be applied in subsequent ex ante evaluations of new project proposals.

The case studies of selected fisheries research, for example, identified a number of important factors affecting the flow of actual and expected benefits. These factors included the initial adoption rate of research results, the scope for the potential leakage of benefits to international competitors and current management arrangements. Other important lessons included the need to acknowledge the contribution of baseline research into fisheries management and production, the relatively long time period between research completion and expected realisation of benefits and the need for appropriate information to undertake ex post analyses.

Fisheries managers and researchers should be encouraged to use both ex ante and ex post evaluations so that a broader understanding of the processes involved can be developed and applied in the case of fisheries research. The costs of planning and monitoring research projects should also be explicitly accounted for, to determine whether the resources used for such evaluations should be modified or used more efficiently elsewhere (where, for example, the benefits of the evaluation are likely to exceed the costs).

References

ABARE 1993a, *Australian Fisheries Statistics 1993*, Canberra.

—— 1993b, *Fisheries Surveys Report 1993*, Canberra.

—— 1994, *Australian Fisheries Statistics 1994*, Canberra.

—— 1995, *Australian Commodities*, Canberra, vol. 2, no. 1, March quarter.

Anderson, J.R. 1976, *Methods and Programs for Analysis of Risky Gross Margins*, Miscellaneous Publication no. 5, University of New England, Armidale.

Australian Bureau of Statistics 1995, *Foreign Trade: Magnetic Tape Service*, June, cat. no. 5464.0, Canberra.

Battaglene, T., Geen, G. and Simmons, P. 1991, 'Advance Australia's wares: towards a promotion strategy for the Australian fishing industry', *Australian Fisheries*, vol. 50, no. 6, pp. 20–2.

Beck, A., Johnston, B. and Fraser, L. 1986, *Modelling the Effects of Rural Research*, Bureau of Agricultural Economics paper presented at the 30th Annual Conference of the Australian Agricultural Economics Society, Australian National University, Canberra, 3–5 February.

Brown, I. 1986, *Population Biology of the Spanner Crab in South-East Queensland*, Final Report to the Fishing Industry Research Committee, Queensland Department of Primary Industries, Project no. 81/71, Brisbane, February.

—— 1993, *The Queensland Spanner Crab Fishery Situation Statement*, Southern Fisheries Centre, Queensland Department of Primary Industries, Deception Bay, November.

Campbell, D. and Haynes, J. 1990, *Resource Rent in Fisheries*, ABARE Discussion Paper 90.10, AGPS, Canberra.

Curran, W. and Podbury, T. 1994, *Government Research Agencies: A Case Study of the Role for Government in Undertaking Economic Research*, ABARE Research Report 94.2, Canberra.

Densley, B. 1994, 'Spanner crab fishery to be reviewed', *Queensland Fisherman*, March, p. 18.

Fisheries Department of Western Australia 1992, *Pearl Oyster Fishery Policy Guidelines*, Fisheries Management Paper no. 48, November.

—— 1993, *Annual Report 1992-93*, Perth.

—— 1994, *Annual Report 1993-94,* Perth.

Fisheries Research and Development Corporation 1993, *Research and Development Plan 1993-94 to 1997-98*, Canberra.

Foster, R.N., Linden, L.H., Whiteley, R.L. and Kantrow, A.M. 1986, 'Improving the return on R&D', in Industrial Research Institute, *Measuring and Improving the Performance and Return on R&D*, New York, p. 66.

Goodrick, B. and Hardman, J.R. 1992, 'Export of live prawns', *External Rural Research Review*, Food Science and Technology Subprogram, Queensland Department of Primary Industries, Brisbane, December.

Grains Research and Development Corporation 1993, *Gains for Grain: Benefit–Cost Methods in Research Evaluation*, Occasional Paper Series no. 4, Canberra.

Hardman, J.R.P., Treadwell, R. and Maguire, G. 1990, 'Economics of prawn farming in Australia', *Proceedings of the 1990 International Crustacean Conference*, Queensland Museum, Brisbane.

Honey, R. 1994, 'Spanner crabs: developing plan a tough job', *Queensland Fisherman*, December, pp. 10-12.

Johnston, B. 1989, 'Economic criteria and procedures for allocating resources to research', in Bureau of Rural Resources (ed.), *SCA Workshop on Research Priorities and Resource Allocation for Rural R and D*, Proceedings no. 7, Canberra, 2–3 November.

Joll, L. 1993, Pearl oyster fishery research report, Paper presented at the Pearling Industry Annual Meeting, Fisheries Department of Western Australia, Perth, 22 October.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A. and Grieve, C. (eds) 1993, *Australian Fisheries Resources*, Bureau of Resources Sciences and Fisheries Research and Development Corporation, Canberra.

Kennelly, S.J., Watkins, D. and Craig, J.R. 1990, 'Mortality of discarded spanner crabs *Ranina ranina (Linnaeus)* in a tangle-net fishery – laboratory and field experiments', *Journal of Experimental Marine Biology and Ecology*, vol. 140, pp. 39–48.

Krebs, C.J. 1972, *Ecology: The Experimental Analysis of Distribution and Abundance*, Harper and Row, New York.

Lal, P., Holland, P. and Collins, D. 1994, *Benefits and Costs of Fisheries Research in Australia – Evaluating Fisheries Research and Development Projects*, ABARE Research Report 94.3, Canberra.

Lindner, R.K. 1989, 'A framework for priority-setting for fisheries research', in Campbell, H., Menz, K. and Waugh, G. (eds), *Economics of Fishery Management in the Pacific Islands Region*, Proceedings of an International Conference, Hobart, Australia, 20–22 March, ACIAR Proceedings no. 26, Canberra.

McShane, P.E. 1988, *Victorian Abalone Stock Assessment, Program Review Series no. 94*, Fifth Review, November, Fisheries Division, Department of Conservation, Forests and Lands, Queenscliff, Victoria.

—— 1992, 'Exploitation models and catch statistics of the Victorian fishery for abalone *Haliotis rubra*', *United States Fishery Bulletin*, vol. 90, pp. 139–46.

Ministry of Agriculture, Forestry and Fisheries 1991, *Fisheries Statistics of Japan 1991*, Statistics and Information Department, Tokyo, Japan.

New South Wales Agriculture 1991, *Annual Report 1990-91: Incorporating New South Wales Fisheries*, Sydney.

Ovenden, C., Kriz, A., Goodrick, B. and Paterson, B. 1993, *Marketing Live Kuruma Prawns to Japan*, Information Series QI92003, Queensland Department of Primary Industries, Brisbane.

Pascoe, S., Battaglene, T. and Campbell, D. 1992, *A Bioeconomic Model of the Southern Shark Fishery*, ABARE Research Report 92.1, AGPS, Canberra.

Pearl Producers Association of Western Australia 1993, *Pearl Divers Diving Safety*, Project no. 91/15, Continuing Project Application to the Fisheries Research and Development Corporation, Geraldton, Western Australia.

Queensland Department of Primary Industries 1993, *Proceedings of Workshop on Harvesting and Post-Harvest Handling of Live Spanner Crabs*, Brisbane, 9–10 December.

—— 1994, *Aquaculture Production Survey: Queensland 1992-93*, Bribie Island Aquaculture Research Centre, April.

Rose, R. 1994, 'An historical perspective: development of pearl oyster hatcheries in Australia', *Pearl World*, vol. 2, no. 1, p. 7.

Southern Shark Research Assessment Group 1990, *Report of the Southern Shark Assessment Workshop No. 6*, Victorian Marine Science Laboratories, Bureau of Rural Resources, Canberra.

Spanner Crab Fishery Management Advisory Committee 1992, *The NSW Spanner Crab Fishery Discussion Paper*, Sydney, March.

Stephens, M. and Lal, P. 1993, *A Feasibility Study into Ex Post Benefit–Cost Evaluation Of Selected Fisheries Research Projects*, ABARE report to the Fisheries Research and Development Corporation, Canberra.

Tisdell, C. 1991, *Culture of Giant Clams for Food and for Restocking Tropical Reefs*, Economic Assessment Series no. 11, Australian Centre for International Agricultural Research, Canberra.

Tomek, W.G. and Robinson, K.L. 1972, *Agricultural Product Prices*, Cornell University Press, London.

Treadwell, R., McKelvie, L. and Maguire, G.B. 1991, *Profitability of Selected Aquacultural Species*, ABARE Discussion Paper 91.11, AGPS, Canberra.

Victorian Department of Conservation and Natural Resources 1993, *The Victorian Abalone Fishery: Background and Issues Paper*, Melbourne, December.

Walker, T.I. 1987, Southern shark fishery: monitoring and research needs, Background Paper, Southern Shark Task Force Ad Hoc Technical Meeting, Canberra, March.

——, Moulton, P., Dow, N. and Saddler, S.R. 1989, *Southern Shark Assessment Project: Final FIRTA Report*, Internal Report no. 175a, Victorian Marine Science Laboratories, Marine Resources Management Branch, Queenscliff.

—— 1991, *Southern Shark Database Project: Final FIRDTA Report*, Internal Report no. 189, Victorian Marine Science Laboratories, Department of Conservation and Environment, Melbourne, April.

—— 1993, 'Stock assessments of the gummy shark, *Mustelus antarcticus gunther*, in Bass Strait and off South Australia', in Hancock, D.A. (ed.) 1994, *Fishery Stock Assessment*, Australian Society for Fish Biology Workshop, Western Australia, 24–25 August 1993, Bureau of Rural Resources Proceedings no. 14, Canberra, pp. 173–87.