IMPACT ASSESSMENT OF RESEARCH ON THE BIOLOGY AND MANAGEMENT OF COCONUT CRABS ON VANUATU

FIS/1983/081

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The Australian Centre for International Agricultural Research (ACIAR) operates as part of Australia's international development cooperation program, with a mission to achieve more-productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

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Foreword

ACIAR's impact assessment reports provide information on project impacts which helps to guide future research activities. While the main focus of these commissioned reports is on measuring the dollar returns to agricultural research, emphasis is also given to analysing the impacts of projects on poverty reduction.

Coconut crabs, which are found throughout the Vanuatu archipelago, are an important subsistence crop for rural communities in Vanuatu, and one of the few cash crops for many small, remote communities. The crabs are susceptible to severe exploitation, and their numbers may fall rapidly under intensive harvesting.

ACIAR and AIDAB (now AusAID) funded a suite of projects starting in 1985 with the ultimate aim of providing a science-based foundation for sustainable management of Vanuatu's coconut crab resources, for the benefit of the Ni-Vanuatu people. Outputs included knowledge about coconut crab biology and the status of coconut crab stocks in two provinces. Recommendations to improve management of the fishery were incorporated into Vanuatu's Fisheries Regulations in 1991.

ACIAR commissioned this impact assessment study to assess the economic value of this fishery-management innovation. A bionomic model of the population dynamics of coconut crabs provided inputs into a novel economic model to estimate the effects of shifts in the supply of crabs for sale or home consumption. The model predicts benefits from improvements in cash incomes for the estimated 600 plus crab-collecting households on Vanuatu.

This report is also available on our website at <www.aciar.gov.au>.

Peter Core
Director
Australian Centre for International Agricultural Research

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Acknowledgments

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Finally, I especially want to thank Rick Fletcher for being so generous with his time and expertise. His detailed knowledge of coconut crab research and development, and of Vanuatu, proved invaluable. Without his help, this study would not have been possible.

Details of project evaluated

ACIAR project ID	FIS/1983/081 – Growth and recruitment study on coconut crab (*Birgus latro*) population in Vanuatu
Collaborating organisations	Queensland Department of Primary Industries (QDPI), Brisbane, Australia; Ministry of Agriculture, Livestock, Forests and Fisheries (MALFF), Vanuatu; Fisheries Department (FD), Vanuatu; University of Queensland, Brisbane, Australia
Project leaders	Dr I.W. Brown (QDPI); Mr J. Crossland (FD)
Linked project(s)	None
Principal researchers	Dr D.R. Fielder (UQ); Mr R. Kaltongga (MALFF)
Duration of project	1 September 1984 –17 June 1988
Total ACIAR funding	AUD426,276
Project objectives	To measure growth rates by a system of 'mark and recapture' using transmitter or freeze-branded tags which are designed to survive repeated moultings. A survey carried out by the Port Vila-based staff of the Fisheries Department will gather information from the local fish market. A concurrent rearing program is also proposed. A study of ways to improve marketing of the crabs will test the preservation and food quality of crabs which have been cooked and frozen before shipment to the markets. The research team also hopes to improve the survival rate of crabs caught by traditional methods and take live to market.
Location of project activities	Luganville, Espiritu Santo, Vanuatu

Summary

Starting in June 1985, ACIAR funded a three-year project entitled ‘Growth and recruitment study on coconut crab *Birgus latro* population in Vanuatu’. Then, in 1991, the Australian International Development Assistance Bureau (AIDAB; now the Australian Agency for International Development, AusAID) funded a project to resurvey crab stocks and develop initial management plans for the Torba and Sanma provinces. ACIAR later funded follow-up projects: in 1993, to survey and develop a stock-assessment guide and extension material on coconut crabs; in 2002, to survey current stocks and review management arrangements; and in 2003, to complete the stock-assessment surveys by local staff, and to develop a comprehensive management plan for the Vanuatu coconut crab fishery.

The ultimate aim of the above suite of projects was to provide a scientific foundation for improved management of the Vanuatu coconut crab resource that would benefit the Ni-Vanuatu people. The key output from the first project was a set of recommendations to improve management of the fishery. The recommendations were embodied in *The Fisheries (Coconut Crabs) Regulations No. 158 of 1991*. Recently, a comprehensive draft set of revised and enhanced management regulations has been produced from the last two projects, and is being considered by the Vanuatu Government. Other notable outputs included numerous scientific publications, enhanced competency of local staff to carry out stock-assessment surveys and to develop and implement fishery management plans, and heightened awareness of the dangers of over-exploitation among coconut-crab-collecting communities. These outputs enable, but are not sufficient for, beneficial economic impacts to be realised.

A new set of regulations to improve management of a fishery, enabled by research and development (R&D) outputs, is a fishery-management innovation. Because a biological natural resource is a dynamic system, there will be a lag of several years between the successful uptake of a fishery-management innovation, and improvements in stock abundance sufficient for economic benefits to be realised. A bionomic model of the population dynamics of coconut crabs was developed to estimate past counterfactual, and potential future impacts of fishery management on the size of the stock of legal-size adult coconut crabs, and on the size of the commercial harvest and the subsistence catch.

Results from this bionomic model were key inputs into a novel economic model developed to estimate economic benefits from resource-stock-induced shifts in the supply of crabs collected for sale or for home consumption. The typical pattern of negative net returns in the early years of an impact-assessment study was exacerbated by delayed uptake of the fishery-management innovation due to a lack of government resources to implement and enforce the 1992 crab fishery regulations. Another cause was the intrinsic lags necessary for stocks of a renewable resource to recover once over-exploitation is controlled. Subsequently, the magnitude of the positive annual net returns was limited by the small size of the market for the commercial harvest, and the larger, but still modest size, subsistence catch. As a result, the net present value (NPV) over a 30-year period is only A$809,014, the benefit–cost ratio is 2.4, and the corresponding internal rate of return (IRR) is 11%. If the duration of the analysis were extended to 50 years, these economic impact measures would increase to a NPV of A$2.5 million, a benefit–cost ratio of 4.7 and an IRR of 13%.

The primary beneficiaries of this suite of research projects have been poor rural households in remote parts of Vanuatu, who gained from supplying the commercial harvest and from the considerably larger subsistence catch. In addition, the impact of cash incomes on poverty levels is predicted to be significant for the estimated 600-plus crab-collecting households on Vanuatu. A small number of collecting households in Sanma Province reported cash earnings from commercial crab harvesting of from A$2000 to A$2700 per household. In the latest household income and expenditure survey, conducted in 1998, the annual average income of rural households, including subsistence production, was about A$6700 for the Sanma Province, but less than A$2000 for the Torba Province.

1 Introduction

Birgus latro, commonly known as coconut or 'robber' crab, is a close relative of hermit crabs. It is the largest land crab in the world, attaining weights of up to 5 kg. Because of its size and terrestrial habit, it is highly regarded as a food item in those parts of the Indo-Pacific where it is still reasonably common. The coconut crab is prized for the delicate flavour of its flesh, intriguing behaviour and strange appearance. In many parts of the Pacific Islands, over-harvesting due to a combination of intense demand for this resource, and deficient management, has decimated coconut crab populations.

Vanuatu is a group of over 80 mountainous islands, mostly of volcanic and coralline origin, in the South Pacific Ocean. It extends over an area of over 12,200 km^2, of which 5500 km^2 is considered arable land. It is about three-quarters of the way from Hawaii to Australia, and lies in the middle of a triangle formed by Fiji, Solomon Islands and New Caledonia.

The Republic of Vanuatu gained independence from France and the UK in 1980. The population in July 2003 was estimated to be 199,414. The economy is based primarily on subsistence or small-scale agriculture, which provides a living for 65% of the population. Fishing, offshore financial services and tourism — with about 50,000 visitors in 1997, are other mainstays of the economy. Primary natural resources include manganese, hardwood forests and fish, which are defined to include coconut and other land crabs. A village subsistence fishing survey conducted in 1983 indicated that over half of the country's rural population engages in fishing.

The Department of Fisheries is responsible for the control (regulation), development and management of all fisheries resources within Vanuatu, and thus is responsible for management of the exploitation of coconut crabs. Due to the decline in prices of agricultural products, especially copra, coconut crabs have become a target species and form an important component of the income of the inhabitants of the more-remote islands.

1.1 The Vanuatu coconut crab fishery

Coconut crabs are found throughout the Vanuatu archipelago, although they are not uniformly distributed between provinces, or even between islands within a single province. The most productive fisheries are in the provinces of Sanma[1] (especially in the northeast region of Santo Island,

[1] The Sanma Province covers the Santo/Malo regions, and the Torba Province the Torres/Banks regions.

and on Aore and Mavea islands), Torba (especially islands within the Torres group, and the Banks islands of Moto Lava and Gaua), Penama (Maewo), and Tafea (Erromango). There also are locally abundant populations on some of the other, more-remote islands.

For many rural communities in Vanuatu, crabs are an important subsistence crop, and often are a substitute to fish as an alternative source of protein. In areas where crabs used to be abundant, reportedly some rural families ate crabs so often that the children complained.

Crabs also form one of the few cash crops available to many small communities in remote parts of Vanuatu. In some remote areas, such as the Torres Islands, the collection and sale of these crabs is virtually the only cash crop that is potentially available. Revenue generated from this fishery is often used to fund the education of the children from these regions. Hence, any threat to this resource would have serious implications for the fight against poverty in some of the poorer and more-remote regions of Vanuatu.

By the early 1980s, Vanuatu was one of the few remaining countries where substantial stocks of the crabs remained (Brown and Fielder 1991). Nevertheless, improved transport and declining prices for almost all other agricultural commodities, as well as greater demand from increased tourism, put extra pressure on populations of *Birgus latro*. This led to concerns that these stocks were being exploited at unsustainable levels.

Techniques used to collect crabs are very simple, effective and inexpensive. The most common custom is for individuals or small teams to cut a trail through the bush, and to lay out a number of coconut baits. Normally, the only equipment required is a bush knife, a torch and a bag, although access to a boat may also be necessary in more remote locations to get the crabs to an airfield. After dark, the baits are revisited, and crabs attracted to the baits are caught by hand, and trussed-up using lengths of vines to immobilise them, particularly their claws. In areas where the crabs are abundant, it is easy to gather large numbers in a short time, but in some cases, crabs may have to be smoked out of their hiding places.

Crabs that are legal size are often shipped to town markets, restaurants or wholesalers in a live form. Mortality of live crabs that have to be transported long distances can be quite high due to the remoteness of the catching location and poor transport infrastructure. The fate of the undersize crabs attracted to the baits varies amongst fishers. Some take them home for local consumption, others eat them at campfires, and some are released for potential future collection.

It is difficult to know how many participants there are in this fishery. According to the 1998 Vanuatu Household Income and Expenditure Survey, there were 5766 rural households in the two main crab-collecting provinces (Sanma and Torba). In the Sanma Province, the Coconut Crab Taskforce estimated that up to 10% of households in that province participated in the coconut crab fishery at least occasionally. The participation rate in the Torba Province may be even higher. As noted above, there is also some harvesting of coconut crabs in the other provinces, so perhaps as many as 600 to 700 households could be involved throughout Vanuatu.

Undoubtedly, there is large variation between households in the level of participation. Furthermore, many households probably collect crabs only for home consumption. Given the wide distribution of locations and the quantum of crabs collected, Fletcher (pers. comm. 2004) has estimated that about 100–200 people are likely to be involved in the commercial coconut crab fishery throughout Vanuatu.

The commercial fishery supplies mainly the restaurant market for coconut crabs in Port Vila, and to a lesser extent in Luganville on Santo. For tourists and residents, their appeal as an exotic dish is based as much on marketing the crab’s unique characteristics and behaviour as on its culinary appeal.

Management of the fishery will be discussed in detail below, but it is noteworthy that there was no effective management of the fishery before the start of the first ACIAR-funded project in 1985. The fishery was completely unregulated until 1983, when a minimum size limit and a ban on the capture of females carrying eggs (berried females) were introduced. Such regulations are most unlikely to control over-exploitation even if they are enforced, but in any case there was little if any enforcement.

1.2 Scope of impact-assessment study

The original project at the core of this impact-assessment study was initiated by a direct request from the Director of Fisheries, Ministry of Agriculture, Livestock, Forestry and Fisheries (MALFF), Vanuatu. In response to this request, Ian Brown (Queensland Department of Primary Industries, QDPI) and Don Fielder (University of Queensland, UQ) conceived a project for scientific research on the biological parameters of the coconut crab. This became the ACIAR-funded project FIS/1983/081, ‘Growth and recruitment study on coconut crab *Birgus latro* population in Vanuatu’. The project began in June 1985, and was completed in June 1988.

This year, ACIAR decided to commission a quantitative impact assessment of the returns to the Vanuatu economy from investment in the above ACIAR-funded project, and subsequent follow-up ACIAR/AIDAB[2]-funded projects. Specifically, the benefit–cost analysis in this study also encompasses the following projects:

- a 1991 AIDAB-funded project to resurvey crab stocks and develop initial management plans for the Torba and Sanma provinces
- a 1993 ACIAR-funded survey and development of a stock-assessment guide and extension material
- a 2002 ACIAR-funded survey and review of current stocks and management arrangements
- a 2003 ACIAR-funded project to complete surveys by local staff and the development of a comprehensive management plan.

In addition to a benefit–cost analysis of this suite of projects, an attempt was made to assess the potential impact of the coconut crab research projects on poverty in Vanuatu. Possible impacts involving changes to the management of coconut crab resources in other Pacific Islands also were investigated.

1.3 Study outline

The ultimate aim of the above suite of projects was to provide a scientific foundation for improved management of the Vanuatu coconut crab resource that would benefit the Ni-Vanuatu people. However, the principal and immediate output from successful scientific research into the biology of any renewable resource is likely to be new knowledge and a better understanding of the population dynamics of the natural resource that merely enables improved fishery management.

Project outputs might be embodied in tangible form (e.g. publications, capacity-building), and/or transmitted by extension activities (e.g. training courses, seminars). While such outputs are not sufficient for beneficial economic impacts to be realised from the R&D, they are necessary. Hence, the first step in assessing the achievements of the above suite of projects is to document project outputs produced directly by project participants. Section two of this report contains more details on the aims and outputs of the suite of coconut crab projects.

[2] Australian International Development Assistance Bureau; now the Australian Agency for International Development (AusAID).

To generate economic impacts, project outputs ultimately must affect some form of economic activity. Where the direct output of research is a process innovation that increases yield and/or reduces production costs, the economic impact of the R&D can be evaluated with a basic, commodity market model of research benefits such as the 'Dynamic Research Evaluation for Managers' (DREAM) software package.

The research project on the growth and recruitment of coconut crabs has not generated any process or product innovation, but a set of recommendations to improve management of the fishery was embodied in *The Fisheries (Coconut Crabs) Regulations No. 158 of 1991*. In this paper, a new set of regulations to improve management of a fishery enabled by R&D outputs will be termed a fishery-management innovation.

Even if beneficial in theory, promulgation of fishery-management plans does not guarantee that economic benefits, such as greater economic returns to crab collectors, and/or lower prices for consumers, will be realised. Factors external to the projects determine the extent to which realised impacts fall short of potential impacts. In particular, successful implementation of fishery-management plans is necessary, albeit not sufficient, to limit catch levels and thereby restore crab stocks to sustainable levels necessary for potential economic benefits to be realised. These regulations, and the effectiveness of their implementation, are described in section three, followed by a review of the available evidence on changes to the status of coconut crab stocks from the start of the initial project to the time of this study. Then, a bionomic model developed to predict future stock and catch levels for the 'with R&D' scenario, and to estimate past and future levels for the counterfactual 'without R&D' scenario is described. The principal results from this model are presented in the last part of section three.

Estimation of the economic benefits to consumers and producers from research that enables a fishery-management innovation involves some particular challenges relative to the application of the well-established procedures for evaluation of the impacts of a process or product innovation. The nature of these problems, and the method used in this study to estimate economic measures that can be attributed to the suite of coconut crab R&D projects, are outlined in section four. This is followed by the results of the economic impact analysis. An attempt to quantify the poverty impacts of the research makes up the last part of this section.

Section five contains the conclusions of the economic-impact-assessment study.

2 Aims and outputs of coconut crab projects

2.1 Overview of research projects on coconut crab

Coconut crabs cannot sustain severe exploitation (Fletcher 1992), and their numbers can be reduced quickly when subject to intensive harvesting (Fletcher et al. 1991b) because their growth rate is slow. They require about 10 years to reach a market size (Fletcher et al. 1991a). Emerging evidence of a decline of coconut crab stocks in Vanuatu, which was one of the few remaining areas in the Pacific where they had been abundant, led to concerns that these remaining stocks be managed to ensure that they are not overfished as has occurred elsewhere (Amesbury 1980), and even in Vanuatu (Fletcher 1988).

Consequently, Ian Brown (QDPI) and Don Fielder (UQ) developed a proposal in 1983 for an ACIAR-funded, three-year project to determine the biology of coconut crabs in Vanuatu. Because prudent management of the exploitation of coconut crabs is vital, an initial assessment of the stocks of coconut crabs was included in the project to provide a basis for sustainable management of crab resources in Vanuatu and the region.

Rick Fletcher (determining growth, population dynamics and impacts of fishing) and Craig Schiller (reproductive and larval biology) were the staff who carried out the research on Vanuatu. This project was successful in determining the growth rate, spawning season and other aspects of the population biology of this species (see Brown and Fielder (1991) and Fletcher and Amos (1994) for details). Based on the results of these initial studies, a series of recommendations for the future management of the crabs was provided to the Vanuatu Government (Fletcher 1988; Brown et al. 1991). Subsequently, Fletcher obtained further funding to carry out the series of follow-up projects described below.

In 1991, AIDAB (now AusAID) funded a project to resurvey crab stocks, and to develop a set of management recommendations based on information collected in both the initial and ensuing projects. One output from these additional surveys was new information that endorsed the regulations based on biology (e.g. minimum legal sizes, protection of berried females) that had been in place since the early 1980s. The primary outcome was several recommendations for initial, regionally based management plans (closed seasons, and quotas on the total numbers of crabs that could be collected each year) for the Torba and Sanma provinces, which were the main regions where the crabs were commercially collected.

ACIAR then funded a further survey, and the development of a stock-assessment guide and extension pamphlet in 1993 to assist in the ongoing local management of the stocks. Recently, it funded two further projects, the second of which was largely complete at the time of this impact-assessment study.

Then, in early 2002, the Vanuatu Fisheries Department sought assistance to review the management arrangements for coconut crabs, which by that time had been in place for almost 10 years. A project responding to this request was funded by the fisheries program of ACIAR. Between October 2002 and April 2003, an extensive range of surveys was initiated to re-examine the current status of stocks of coconut crabs in areas of Vanuatu previously studied, and to complete an initial assessment of crab stocks for areas where significant collections of crabs had only recently started. In November 2003, ACIAR extended this funding to allow Rick Fletcher to collaborate with his Ni-Vanuatu counterparts to re-assess crab stocks in the four main collecting areas, to consult with the various local stakeholder groups, and to finalise a revised management plan for Vanuatu that had clear local ownership and commitment.

As little was known about either the abundance of crabs, or the harvest potential of other regions of Vanuatu from which crabs have been sourced during recent years, the surveys provided vital information about the potential of these resource stocks. The surveys of the established crab-collecting regions allowed trends in stock abundance to be estimated for the review of the efficacy of the management arrangements that were introduced 10 years previously. The review sought to determine whether the existing management arrangements had been sufficient to conserve the remaining crab stocks, and whether they were efficient in their operation. A further aim was to make suggestions for additional controls that could improve the management of this important resource.

Nearly 20 years after completion of the first studies, these surveys revealed that significant stocks of coconut crabs still remain in Vanuatu, and that there are grounds for hope about the longer-term future of the crabs. The findings about the success of the then current management arrangements were less positive, although stocks of crabs have at least been maintained over the past 10 years. While regulations appear to have been useful in some locations, in other regions the current arrangements have had no evident effect. Thirteen recommendations were made from this report, including additional or different arrangements in most regions.

The further funding from ACIAR in 2003 also enabled local staff to complete the stock-assessment surveys, and to develop a comprehensive management plan for coconut crabs on Vanuatu. A comprehensive set of draft management regulations is currently being considered by the Vanuatu Government.

2.2 Aims of the coconut crab projects

The objective of the 1985–1988 ACIAR-funded project FIS/1983/081 was to investigate specific aspects of the dynamics of coconut crab populations, details of which are necessary precursors to the formulation of rational management policies. Specific aims were to:

- estimate the coconut crab's growth rate
- determine the effects of exploitation on the density and structure of natural populations
- assess methods for distinguishing the glaucothoe (immature young) of *Birgus* from those of other sympatric coenobitids ('land' crabs)
- document the diet and feeding behaviour, habitat requirements and moulting frequency of the post-larval and juvenile stages
- investigate and improve the survival rate of coconut crabs caught using traditional methods and determine the preservation and food-quality characteristics of crabs which have been cooked and frozen 'on site' before shipment to the markets.

The aims of the 1991 AIDAB project entitled 'Stock assessment and management of coconut crabs in Vanuatu' were to:

- re-examine the stocks of coconut crabs in Vanuatu
- determine if the newly introduced management proposals would be sufficient to conserve the remaining stocks
- suggest ways that controls could be successfully implemented and their effects assessed.

The 1993 ACIAR-funded project entitled ‘Coconut crab in Vanuatu’ aimed to:

- conduct a further survey, and train local staff in survey methods
- develop a stock-assessment manual and extension material to assist in the ongoing local management of stocks of coconut crabs.

The ACIAR–funded project entitled ‘Review of coconut crab management in Vanuatu’, implemented in 2002, aimed to update information on the status of crab stocks in Vanuatu, and suggest revised management plans for this important resource. Specific terms of reference were:

- re-assess the stocks of coconut crabs in the Torba and Sanma provinces where management has been in operation for 10 years
- assess the relative impact of current management arrangements on markets for the crabs and the benefits and costs to each of the above regions
- using the results of the previous two activities, and in conjunction with stakeholder input and market surveys, review existing management arrangements for the Torba and Sanma provinces
- provide estimates of the status of stocks within the Tafea Province, which has been identified as having potential for ongoing commercial harvesting but for which formal management arrangements have not been developed
- propose initial management arrangements for the Tafea Province
- develop firm recommendations for future management action in the Tafea Province, following broad stakeholder consultation on the proposed arrangements.

The aims of the 2003 ACIAR-funded project entitled ‘Completion of coconut crab management in Vanuatu’ were to:

- facilitate the finalisation of the management plan for coconut crabs to cover the arrangements needed for the next five years

- ensure that local fisheries staff have the skills, experience and tools to undertake regular monitoring of the crab stocks and the production of the fisheries within each of the main collecting areas
- provide the materials needed to assist in the education of local villagers and officials for the protection of their local stocks of crabs.

2.3 Project outputs

The contribution of the above projects to knowledge about coconut crab biology and the status of stocks of *Birgus latro* in two provinces of Vanuatu has been documented in an extensive range of publications, which are listed in the bibliography to this report. The scientific findings about coconut crab stock dynamics and, in particular, the key biological subjects of growth and recruitment, arising from the first project were published in 1991 in ACIAR Monograph No. 8. In the conclusion to that monograph, Brown and Fielder (1991) summarised the overall finding as follows:

> The biological and population characteristics of coconut crabs conspire to make the species particularly vulnerable to exploitation. They are terrestrial, relatively easy to catch, slow growing, and their recruitment success seems to be highly variable. With intensive harvesting a coconut crab population can be depleted very quickly, and the stock may only begin to recover many years after collecting has ceased…The results of this study have given biological credence to fears that the species is in danger of suffering increasing rates of local extinction.

Knowledge that coconut crabs grow slowly, that recruitment of juveniles is problematic, and that stocks of adult crabs are vulnerable to over-exploitation, will not provide material benefits to the people of Vanuatu unless such knowledge is used to improve the management of the collection, consumption, and marketing of coconut crabs. A series of recommendations based on the findings of the first study was provided to the Vanuatu Government to assist with the formulation of a management strategy for the crab fishery. As a direct consequence, a management plan for the Santo/Malo and the Banks/Torres regions was drawn up, and gazetted in July 1991 as *The Fisheries (Coconut Crabs) Regulations 1991*. The content of this management plan and its implementation, and estimation of the economic impacts of changes to the regulations of the coconut crab fishery on Vanuatu, are discussed in later sections of this report.

Primary outputs of the follow-up projects included augmentation of knowledge about the status of stocks of coconut crab on Vanuatu, and a more comprehensive understanding of how they change over time. This extra knowledge has been incorporated into an enhanced draft management plan for the coconut crab fishery that is currently under consideration by the Vanuatu Government. There was also further on-the-job training of staff of the Fisheries Department in assessment of stock status. This training was supported by a stock-assessment manual based on the earlier work.

Simple educational and instructional brochures also were produced, along with related educational programs for local communities in coconut-crab-collecting areas in Vanuatu and, more broadly, in the Pacific Islands region. Given the lack of government resources to implement and enforce fishery-management plans, such outputs to raise awareness and understanding of the biology of the coconut crabs among the Ni-Vanuatu may provide the best basis for the steps needed to restore depleted stocks of their valuable natural resource.

Another important output of these projects was the intellectual advancement of the people involved in the projects. The enhanced competency of Fisheries Department staff to carry out field surveys and assessment of the status of coconut crab stocks, and to develop and implement fishery-management plans, has enhanced the prospects of more effective and beneficial management of the coconut crab fishery. More generally, both the Ni-Vanuatu and the Australian staff working on the projects developed generic skills, and gained a broader understanding about how all fisheries operate. This understanding is transferable to other fisheries, and is likely to improve the management of other fisheries in Vanuatu and Australia. Furthermore, some of the Ni-Vanuatu staff employed on this first project were empowered to enrol for further studies, and to obtain additional qualifications vital for ongoing development of a fledgling nation.

Following the end of the ACIAR-funded Vanuatu project, one of the project staff obtained FAO/UNDP funding to undertake a pilot survey of coconut crabs on the central Pacific island of Niue. This first assessment of the country’s coconut crab stocks drew heavily on techniques developed and experience gained during the Vanuatu project. Another extension of the ACIAR-funded coconut crab project was research funded by the Australian National Parks and Wildlife Service and McQuade Dredging Pty Ltd to examine egg release/hatching and larval recruitment in the coconut crab on Christmas Island in the Indian Ocean.

Potential and realised outcomes from these outputs are discussed in the next chapter.

3 Realised and projected impacts from crab R&D

Project outputs alone are not sufficient to give rise to economic impacts. The primary output of the suite of projects on coconut crabs has been additional knowledge about the biology of the crab, and about stock abundance of *Birgus latro* in some provinces of Vanuatu. This knowledge has enabled changes to regulations governing the collection, consumption, and marketing of coconut crabs, as well as further changes to fishery-management plans that have been proposed, but not yet implemented.

Fishery-management regulations, in turn, merely create the potential for the generation of economic benefits. For this potential to be realised, the regulations need to modify the collection and/or marketing of crabs in a way that increases future value created from the fishery. Unfortunately, effective implementation of fishery-management regulations cannot be taken for granted. When resource stocks have been over-exploited and severely depleted, active enforcement of fishery regulations usually is necessary because current catch levels and short-run returns often have to be sacrificed in order to restore stocks to healthy levels. Success factors for the effective application and enforcement of fishery regulations are typically external to the research projects. In particular, government services are essential for effective management of the coconut crab resource.

This section is arranged as follows. A description of past and proposed changes to regulations for this fishery is followed by a discussion of the implementation of the current regulations and the prospects for successful implementation of proposed regulations. Then, evidence that management of the coconut crab fishery has in fact improved the status of crab stocks will be reviewed. Specification of 'without R&D' and 'with R&D' scenarios follows, as a basis for the assessment of the consequential economic impacts. In the last section of this chapter, a bionomic model developed to predict future changes in crab stocks and catch levels will be described, and results from the model will be presented. Findings from an attempt to assess the impact of the suite of R&D projects on poverty on Vanuatu follows, and the section concludes with a brief discussion of the possibility of research spillovers.

3.1 Regulation of the collection and marketing of coconut crabs

Before the start of the original project, there were just two regulations applying to harvesting of coconut crabs. First introduced in 1983, these regulations consisted of a minimum size limit of 9 cm carapace length, and a ban on the capture of berried females.

On the basis of the findings from the initial ACIAR-funded project, a management plan for the Sanma and Torba provinces was drawn up, and gazetted in July 1991 as *The Fisheries (Coconut Crabs) Regulations 1991*. These regulations expanded rather than replaced the existing regulations for a minimum legal size [9 cm cephalothoracic length (CTL) = 43 mm thoracic length (TL)] plus a ban on the catching of berried females. Separate annual catch quotas plus closed seasons for the Sanma and Torba provinces were the main additional features of the new management plan, which was first applied in 1992.

The primary aim of these regulations was to enable conservation of crab stocks. In each region, the closed season extended over the main period of spawning of the crabs, with the intent to help maintain recruitment. The closed season for the Santo/Malo region covered the period November–March each year, and for the Torres/Banks group, the closed season was from September to October.

The quotas for the major collection areas were set to limit the annual catch to about 30% of that estimated to have been taken previously . For the Santo/Malo region, a total allowable catch or quota of 2000 crabs was permitted during the open season (1 April–31 October), while for the Torres/Banks region, the quota was 5000 crabs during its open season (1 November–31 August).

At the time, it was noted that a number of additional measures might be necessary to minimise further problems. In particular, to allay concerns that restaurants in Vila would circumvent a reduced supply from traditional areas in the short term by buying more crabs from less traditional areas, a further quota of 1000 crabs for the remainder of the country was suggested. To date, no action has been taken to introduce such a measure.

The unanticipated, and much greater problem, has been a lack of effective application and enforcement of existing regulations by the Fisheries Department for most of the time since their introduction. All government departments in Vanuatu are under-resourced, but the Fisheries Department is arguably more pressed than most for funds to carry out even basic fishery-management activities. For most of the 1990s, this predicament has been compounded by a failure to implement management regimes due to industrial action in the Vanuatu public service, which led to many key staff being sacked. Most were not reinstated or replaced for six to eight years, so the Fisheries Department effectively had no capacity for any management functions because the remaining staff were fully occupied carrying out routine administrative duties.

As a result, for about a decade following the introduction of enhanced regulations for management of coconut crabs in 1992, there was no effective management of the fishery. Not only were regulations not enforced, but also, until about 2001, there was little if any monitoring to detect non-compliance.

Evidence that the respective annual catch quotas for the Sanma and Torba provinces of 2000 and 5000 crabs had no discernable impact on the commercial harvest for the decade from their first introduction in 1992 comes from market surveys. For instance, a quite recent survey conducted in 2002 found that at least 18,000 crabs were sold in Vila, and a further 2000 in Santo restaurants and markets. This level of sales is not markedly different from that found in a similar survey conducted in 1991, although even earlier estimates of the number of crabs sold were considerably higher.

While results from several surveys of restaurants in Vila, and monitoring of markets and hotels in Santo, provide a reasonably complete picture of the main markets for the commercial catch, they did not include crabs sold elsewhere at small local markets. In addition, other market outlets, such as recent direct sales to cruise ships, were probably missed. Under-reporting is another possible source of bias. Thus, the above figure of 20,000 crabs sold in 2002 is probably an underestimate of actual sales and, even if it is not, the commercial catch exceeded total quotas by some 13,000 crabs. Hence, it is clear that the annual commercial catch alone continued to exceed, by massive margins, the quotas for the decade after 1992. Nevertheless, there was an apparent decline in the use of crabs by Vila restaurants by the time of the 2003 survey.

In addition to the ‘commercial’ market for coconut crabs, the ‘subsistence catch’ for domestic consumption is a significant component of total catch. While the total numbers of crabs collected for domestic consumption by the crab-collectors’ households are not known, it is highly likely that non-market demand is the principal part of total demand for coconut crabs. In fact, if the findings from an improvised survey[3] can be believed, home

[3] Described later in this report.

consumption for all of Vanuatu probably exceeded 150,000 per annum when crabs were more abundant, and current levels are almost certainly still greater than 55,000 animals per annum, despite much depleted stocks in many areas.

In theory, this part of the fishery is subject to the 1991 regulations, but in practice it has received even less attention by fishery managers than has the collection of crabs for sale. As noted above, it is illegal to capture berried females, or to take crabs with a carapace length of less than the minimum size limit of 9 cm. Nevertheless, there is evidence of continuing collection of undersize crabs. As a crab with a 9 cm carapace length would weigh about 0.5 kg, smaller crabs collected for sale would be regarded by most commercial outlets as being of less than marketable size. Hence, it is highly likely that many undersize crabs are still taken for home consumption, and it is very doubtful whether the minimum size regulation has been effective in preventing overfishing and stock depletion.

The consequences of ineffective implementation of existing regulations are manifest in the findings from stock-status surveys discussed below, and largely explain why there has been little improvement evident in the status of a number the stocks of coconut crabs.

Since the more recent ACIAR-funded projects in 2002–03, there have been several encouraging developments. In the Sanma and Torba provinces, attempts are now being made to monitor numbers of crabs collected and, if necessary, to close the open season early. In the 2002 annual report of the Fisheries Department, it was reported that there had been over-harvesting of crabs from the Torres group of islands in the 2000 and 2001 seasons. As a result, more funds had been allocated for officers to travel to the Torres to carry out awareness programs and monitoring surveys. Separate quotas also had been set for each island in the Torres group.

Some local communities and provincial governments have unilaterally taken responsibility for management in their own region. In the Sanma Province, a coconut crab taskforce has been set up by the provincial government to provide much-needed support for the Fisheries Department staff in managing the coconut crab fishery. In 2003, the taskforce helped monitor the numbers of crabs being collected. When the quota of 2000 crabs was reached after just six weeks of the seven-month open season (1 April–31 October), the provincial government banned further harvesting for the rest of 2003.

Another notable development over recent years has been the establishment of a number of conservation reserves in which all coconut crab collecting is *tabu*. There have also been some extensive and reportedly effective educational campaigns to improve understanding, in local communities, of crab biology and the need for conservation.

In a recent review of the coconut crab fishery, Fletcher (2003b) wrote:

> Whilst the level of success of the current management arrangements within different areas has been mixed, overall they can be classed as successful in at least maintaining most of the stocks of crabs during the past 10 years. There are some locations where they appear to have been extremely useful, in other locations greater compliance with the current arrangements is needed, whilst some regions require either additional or different arrangements.

An amended and extended version of the legislation for management of the coconut crab fishery has been drafted recently, but at the time of the field visit to Vanuatu in 2004, the government had not passed these amendments. Nor had it declared, under existing regulations, an extension to the closed season that would have effectively introduced a two-year ban on harvesting coconut crabs in the Sanma Province.

3.2 Evidence on the status of coconut crab stocks

The size of the coconut crab population on Vanuatu is one of the statistics required to estimate the economic benefits generated by exploiting this renewable natural resource. Harvesting costs are inversely related to stock abundance, while the size and composition of the resource stock is a key determinant of the sustainable level of coconut crab harvests, and of market price.

Since 1985, Dr Rick Fletcher and various Ni-Vanuatu colleagues have conducted a series of field surveys to determine catch per unit of effort (CPUE) for many, but not all, parts of the Torba and Sanma provinces. In 2003, the first field survey was conducted on Maewo in the Penama Province, and Erromango in the Tafea Province. Following methods described in Fletcher and Amos (1994), Fletcher used a catchability coefficient (12,000) calculated by Fletcher et al. (1990b) to convert CPUE figures to preliminary estimates of population size for each area for which the corresponding CPUE figure was representative. These preliminary estimates for up to five different years are given in Table 1.

Table 1. Estimated numbers of adult coconut crabs for Sanma and Torba provinces.

Region	1985	1987	1991	1993	2002
NE Santo	35,200	15,400	6,200	8,400	8,400
Other Santo	30,600	18,600	3,000	3,000	18,600
Torres	444,000	308,800	214,700	not available	271,400

Between 1985–87 and 1991–93, there was a significant decline in the number of coconut crabs in those areas of Vanuatu where surveys were conducted. Despite some variation from site to site, there were significant drops in measured abundance of legal-size crabs at most locations. For instance, the number of legal-size crabs remaining in the Santo region in 1987 was estimated to be 31,600. By 1991 it had fallen to 8900, a drop of almost 23,000. This suggests that a net total of 6000 legal-size crabs a year had been removed from this region. The comparable estimate of the net disappearance rate for the Torres region was approximately 6000 to 12,000 legal-size crabs per year. The finding that crabs present at most locations in 1992–03 were, on average, smaller than those measured during the initial survey was also significant. The loss of the larger sizes of coconut crabs on all islands indicated that exploitation of marketable-size crabs had been intense.

By the time of the 2002–03 surveys, the situation had at least stabilised in almost all areas surveyed, and improved somewhat in several areas. However, before the introduction of the current management regime, a previous survey revealed that crab abundance levels were already very low in many, but not all, of these areas. Thus, many of these areas were already over-exploited.

Strikingly, some of the areas that had recorded noteworthy improvements and/or could sustain higher catch rates were close to recently established conservation reserves, or were in remote locations where access to commercial markets was constrained by lack of transport. Data from areas exploited only recently for commercial harvesting suggest that there are still healthy stocks of coconut crabs in some parts of Vanuatu, although even in these areas, some sites close to population centres are showing signs of local depletion.

Overall, Fletcher concluded that the current status of the coconut crab resource in Vanuatu is still reasonably healthy. The fact that the spawning stock (defined as the numbers of females of spawning size) of coconut crabs in the Vanuatu archipelago had not declined substantially between the 1991–03 and 2002–03 surveys engenders optimism that recruitment has not collapsed. Another positive indication is the increase in relative abundance in some areas.

3.3 Scenario development

Estimates of the magnitude of the material benefits to the people of Vanuatu from better management of the collection, consumption and marketing of coconut crabs in the next chapter are based on differences in outcomes between ‘without R&D’ and ‘with R&D’ scenarios.

In most ex-post impact-assessment studies, many of the relevant outcomes for the ‘with R&D projects’ are observable and/or verifiable. As a result, the development of the ‘with R&D projects’ can be relatively objective and evidence based, in contrast to development of the counterfactual ‘without R&D projects’, which necessarily must be hypothetical and subjective.

Due to several novel characteristics of the coconut crab R&D projects, many subjective judgments had to be employed in the development of both scenarios for this study. In common with other successful types of ‘maintenance R&D’ that prevent deterioration in economic benefits, little or no change in the status quo is not noteworthy, and is rarely documented. Moreover, it seems that key data on the importance of the coconut crab resource to the subsistence economy of rural Ni-Vanuatu have never been collected, which exacerbated problems in collecting evidence on realised quantitative economic benefits. Due to such data-free zones, realised outcomes at the time of impact assessment were less discernible than might have been the case for other types of R&D.

Furthermore, beneficial outcomes from a fishery-management innovation also depend on other exogenous ‘success factors’. In particular, due to government inability to act earlier, intended outcomes of the initial project have only recently started to eventuate. Finally, even though there was almost a 20-year time lag between the start of the first project and this impact-assessment exercise, the last of the suite of projects being evaluated was completed at about the same time as this study. Inevitably, impacts from these most recent supplementary projects, such as further enhancements to fishery-management plans and consequential benefits, will not be evident for some years. The problem of substantial time lags between inception of the R&D projects and evidence of beneficial outcomes is compounded when the objective of the R&D is to improve the status of a biological renewable resource stock that responds only slowly to the adoption and successful implementation of a fishery-management innovation.

For these reasons, most of the likely beneficial outcomes of this suite of projects will be realised after the completion of this impact-assessment study, and therefore had to be forecast rather than observed. A bionomic model was developed to simulate the population dynamics of coconut crabs, and to predict future changes in population levels as well as future levels of the commercial harvest and the subsistence catch. First though, the two scenarios for the period from 1985 to date are described.

Notwithstanding the paucity of data, the 'with R&D' scenario is described first, as more of it can be based on objective evidence than can for the 'without R&D' scenario. The later scenario had to be deduced entirely from prior predictions, limited evidence from similar situations in other countries, and extrapolation from scientific and economic knowledge and theories.

3.3.1 The 'with R&D projects' scenario to date

Outcomes to date for this scenario have been modest, mainly because financial problems in the public service that were not anticipated at the inception of the first research projects hampered effective implementation of *The Fisheries (Coconut Crabs) Regulations 1991*. However, recent developments outlined above should result in much-improved outcomes in the foreseeable future.

Available results from stock-assessment surveys reveal important differences in past and current status of crab stocks between areas in Vanuatu. Hence, the crab-collecting areas of Vanuatu were divided into the following three regions for the purpose of the analysis of economic impacts:

Sanma Province

The Sanma Province was the base for the ACIAR-funded projects, so there is relatively good information available about stock status since 1985. Based on data from stock-status surveys, crab stocks already were severely depleted by 1985, but the numbers of adult crabs continued to decline to perilously low levels in the early 1990s. Clearly, large numbers of crabs continued to be collected during this period, although actual levels of exploitation are unknown due to a total lack of evidence on the subsistence catch, and only scant evidence on commercial harvests. Given numerous stock extinctions in other countries, the fact that crab stocks in the Sanma Province were not wiped out is a positive outcome. It is consistent with anecdotal evidence that the first ACIAR-funded project raised awareness among crab collectors of the threat to sustainability of the fishery, and in that way reduced the aggregate level of crabs collected for sale as well as for home consumption.

For the purpose of this study, it was assumed that, before the start of the first study, about 10,000 crabs were being collected in the Sanma Province each year for sale, but the numbers collected declined steadily to about 3000 per annum for most of the 1990s. In the last two or three years, existing fishery-management regulations have been enforced more rigorously by the Fisheries Department, and supported by the recent activities of the Coconut Crab Taskforce. A potential breach of the quota in 2003 was prevented by the early closure of the collecting season. As a result, the commercial harvest fell to 2500 crabs in 2002, and to 1500 in 2003. Following a two-year ban in 2004–05, it should be possible to gradually restore the commercial harvest as crab stocks recover to sustainable levels. Eventually, a maximum sustainable yield might allow over 16,000 crabs per annum to be harvested.

In an attempt to form some impressions about levels of exploitation for home consumption, a small number of crab collectors in the Sanma Province were interviewed during this impact-assessment study. Details of the survey method are given in Appendix 1.

Before commercial harvesting, most crab collectors reported that typical households collected about six to nine crabs per week for domestic consumption. Based on these answers, and estimates that there were up to 300 crab-collecting households in the Sanma Province, historical subsistence-catch levels could have been well in excess of 100,000 crabs per annum. A more conservative figure of 60,000 crabs per annum was assumed in this study as a baseline level of crab collecting that apparently did not cause crab abundance to decline, and in that sense was sustainable.

Subsequently, when crab abundance levels did decline due to commercial harvesting, reportedly there was some reduction in the number of crabs collected for home consumption, although a decline in the average size of crabs collected was the main reason for a more significant reduction in the amount of crab meat consumed. Based on the survey findings, it was assumed that approximately 35,000 crabs were collected in the Sanma Province for domestic consumption in 1985, but that this had fallen to between 11,000 and 16,000 crabs per annum during the 1990s. It is axiomatic that subsistence catch levels eventually must decline if stock abundance falls to very low levels and, in part, the presumed decline in the subsistence catch at that time can be attributed to decreased crab abundance. It is more likely, though, that the impact of the ACIAR-funded projects in creating greater awareness among crab-collecting communities about the risks of over-exploitation caused most of the early reduction in crabs collected for home consumption.

During the past decade, crab stocks have recovered slightly in some locations, despite considerable evidence of continuing significant subsistence catches. According to Rick Fletcher (pers. comm.), this could be due mainly to the establishment of a number of conservation reserves where crab collecting is nominally *tabu*. Again, the establishment of these reserves can be attributed largely to the impact of the ACIAR-funded projects on the enhanced understanding of the Ni-Vanuatu people of the biology of coconut crabs. These reserves provide a reservoir that can provide an ongoing supply of recruits to adjoining areas where crabs are exploited. In this scenario, it was assumed that the size of the subsistence catch could be sustained indefinitely at about 20,000 crabs per annum, so long as these conservation reserves are maintained.

The sustained period of little change in crab abundance in the Sanma Province suggests that the system is delicately balanced, with sufficient recruits to the adult population each year to sustain reasonable levels of crab collecting. Hence, effective application and enforcement of quotas and other management regulations that reduced current harvesting levels by a significant amount should result in crab stocks recovering relatively soon. Once this has been achieved, it should be possible to increase the number of crabs collected from this region to substantially higher levels.

Torba Province

Results from stock-assessment surveys dating back to 1985 are also available for several locations in the Torba Province. At the time of the first survey in 1985, measured stock abundance was so high (a CPUE of 5 crabs on Hiu Island, and 4.1 crabs on Tegua Island) that previous levels of exploitation were almost certainly quite low. However, the subsequent rapid decline in CPUE indicates that there was very heavy levels of exploitation in subsequent years. For the purpose of this study, it was assumed that the level of the commercial harvest in the Torba Province in 1985 was about 40,000 crabs per annum, and had fallen only moderately to 30,000 crabs per annum by 1990.

This intensive level of exploitation must have abated during the 1990s, because most stocks recovered to a relatively healthy state by the time of the 2002 survey. Unlike in the Sanma Province, weak and deteriorating transport links to the main markets for coconut crabs helped constrain commercial exploitation of crab stocks in the Torba Province. However, the fact that stock-assessment surveys were a key part of the first ACIAR-funded project in both provinces also played a part, because crab collectors became more aware about the vulnerability of crab stocks to over-harvesting. In this scenario, it was assumed that the number of crabs harvested in the Torba Province for sale declined steadily from 30,000 crabs per annum in 1990 to only 8000 crabs per annum in 2000.

More recently, harvests have declined more rapidly as attempts were made to enforce existing regulations including, in particular, compliance with the quota of 5000 crabs per annum. An almost total reliance on air freight in recent years has made it much easier to monitor and enforce quotas. Over-harvesting was reported as early as 2000 and, in the 2002 collecting season, the quota was cut to 3500 crabs. In fact, due to a shortage of freight capacity, only 1797 crabs were recorded as being air freighted to the Port Vila restaurant market that year,[4] although it was assumed that the total commercial harvest was somewhat larger at 3500 crabs per annum in 2002 and 2003.

Fisheries Department officers estimated that close to 20% of the 1160 rural households in the Torba Province regularly collected crabs for home consumption. This is a higher percentage than for the Sanma Province, but wages per rural household in the Torba Province are very much lower, and only slightly more than 10% of those for the Sanma Province. Assuming that consumption per household was approximately the same as for sample survey households in the Sanma Province, the size of the subsistence catch was 'guesstimated' to be about 54,000 per annum in 1985. By the end of the 20th century, it was assumed to have declined to around 43,000 per annum, due to a combination of declining stock abundance and greater awareness, due to the activities of the first ACIAR-funded project, of the need to limit exploitation levels.

Crab stocks in this region have already recovered to levels that are quite a lot higher than for the Sanma Province. Based on crab abundance as measured by CPUE, crab stock levels were judged to be close to, and possibly slightly greater, than those necessary for maximum sustainable yield. Hence, it should be possible to increase levels of the commercial harvest quite quickly in the future.

Rest of Vanuatu region

This region includes the remote parts of other provinces in Vanuatu that apparently have not been heavily exploited in the past, including Maewo and Erromango Islands. A recent survey of some of these locations revealed that most of the crab stocks are still in a healthy state, and not over-exploited.

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[4] See Annual Report of the Fisheries Department (2003, p.16).

The only evidence available on which to base assumptions about the size of past commercial harvests was a significant discrepancy between reported sales to restaurants and markets, and apparent supply from the two main crab-collecting regions. On this foundation, it was assumed that the commercial harvest in the rest of Vanuatu region increased rapidly from negligible levels during the 1980s to about 13,000 crabs per annum by 1999, and to even higher levels more recently to compensate for falling supplies from the other two regions.

There are approximately 20,000 rural households in the rest of Vanuatu region, but as there are fewer crab habitats than in the Sanma and Torba provinces, it was assumed that only 100 households regularly collect crabs for home consumption in this region. For this reason, it was assumed that the subsistence catch has declined steadily from about 25,000 crabs per annum in 1985 to about 21,000 crabs per annum at present.

Crab stocks do not seem to have been overfished in most of the rest of Vanuatu region. Given good management, they should be able to sustain significant levels of harvesting indefinitely. In fact, a modest increase in the numbers currently collected probably could be sustained without adverse long-term consequences.

3.3.2 *The 'without R&D projects' scenario*

At the inception of the first ACIAR-funded project, over-harvesting had already wiped out stocks of coconut crabs in a number of other countries. There also was evidence of a dramatic decline in crab stock abundance in some areas of Vanuatu. Early results from the ACIAR project supported the belief that crab stocks in the Sanma and Torba provinces would collapse if harvesting continued at then current levels. If this happened, crab stocks in other regions of Vanuatu would inevitably be over-exploited and their viability threatened.

Hence, the without R&D scenario assumes that effort devoted to harvesting coconut crabs would respond only marginally to declining abundance levels until the resource stocks were virtually exhausted. Until this happened, there would be little decline in the number of crabs collected for either sale or home consumption in the Sanma and Torba provinces. When the model was applied, it predicted that the fishery in the Sanma Province would have crashed as early as 1989, and by about 2003 in the Torba Province. Nationally, the level of the commercial harvest would be maintained by a progressive shift in effort to previously lightly exploited crab stocks on other islands. Eventually though, all stocks of coconut crabs on Vanuatu would be wiped out by 2011, with the result that all benefits from collection of crabs for commercial sale would cease. Predicting whether all domestic consumption would become impossible is more problematic. In order to avoid over-inflation of the research benefits, it was assumed that a basic subsistence level of 16,000 per annum of crabs just under legal size could be collected indefinitely.

3.3.3 *Bionomic model of the coconut crab fishery*

Future changes in population levels of coconut crabs, and future levels of the commercial harvest and the subsistence catch for the 'with R&D' scenario, as well as past and future changes for the 'without R&D' scenario, were predicted from a bionomic model developed for the purpose. For each of the three regions identified above, the core of the population dynamics bionomic model is a simple differential equation. It relates the number of legal-size crabs in region j at the end of each year t, $X_{j,t+1}$, to the number of legal-size crabs at the start of the year, $X_{j,t}$, the current net natural growth, $R_{j,t}$, and the current level of the commercial harvest and subsistence catch, $H_{j,t}$ and $C_{j,t}$, respectively:

$$X_{j,t+1} = X_{j,t} + R_{j,t} - H_{j,t} - C_{j,t} \qquad (1)$$

The net natural growth function for region j, $R_{j,t}$, is a modified form of the standard logistic function that is widely used in fishery models:

$$R_{j,t} = r.X_{j,t}.(1 - X_{j,t}/K_j)^2 + Z_j \qquad (2)$$

In addition to the time-dependant and region-specific size of the stock of legal-size crabs, $X_{j,t}$, net natural growth is a function of a common intrinsic growth coefficient, r, a region-specific environmental carrying capacity coefficient, K_j, as well as a region-specific 'recruitment reserve' term, (Z_j). The recruitment reserve term is included because there are a number of conservation reserves in each region where crab stocks are in a relatively healthy state. As larvae are sufficiently mobile for locally depleted adult stocks to regenerate with recruits from the larvae of other populated islands (Brown and Fielder 1991), it is likely that unexploited stocks of juvenile crabs will provide at least a temporary buffer to adult recruitment when adult stocks are severely depleted. Furthermore, note that the term $(1-X_{j,t}/K_j)$ in equation (2) is squared in order to introduce a leftward skew in $R_{j,t}$ as a function of $X_{j,t}$.

The ACIAR-funded projects were not designed to estimate model coefficient values for coconut crabs for the regions of Vanuatu, but no other scientific research has been conducted that could provide any sort of estimates. Based on some years of experience of stock-status assessment in Vanuatu, Dr Rick Fletcher kindly provided preliminary estimates of actual and potential population size for those areas where sample surveys had been conducted. These preliminary estimates for sampled areas were scaled-up using the best available information, then aggregated to derive estimates of actual and potential stock size for Vanuatu. The former were used to help calibrate the bionomic model, while the latter was used as the basis for estimating the environmental carrying capacity coefficient, K_j.

An iterative procedure that fitted modelled values as closely as possible to available evidence on the size of adult crab stocks, and on commercial harvests and subsistence catch levels, was used to choose values for the other coefficients in the model.

The specific variants of equation (2) actually used to simulate the 'without R&D' scenario and the 'with R&D' scenario for the three regions were as follows:

$$\text{Sanma Province:}\quad R_t = 0.5.X_t.(1-(X_t/722{,}400))^2 + 10{,}000 \quad (3)$$

$$\text{Torba Province:}\quad R_t = 0.5.X_t.(1-(X_t/713{,}600))^2 + 5{,}000 \quad (4)$$

$$\text{Rest of Vanuatu region:}\quad R_t = 0.5.X_t.(1-(X_t/356{,}800))^2 + 1{,}000 \quad (5)$$

For the 'with R&D' scenario, it was assumed that existing fishery management regulations would be applied effectively from now on, and also would be extended to other crab-collecting islands in Vanuatu. Where crab stocks were predicted to recover, it was assumed that the size of the subsistence catch would slowly be restored to historical levels. It was also assumed that, as crab stocks recovered, fishery managers would gradually increase quota levels for the commercial harvest in all three regions to attain maximum sustainable yield.

Conversely, for the 'without R&D' scenario, it was assumed that fishery management regulations would not be introduced for any of the three coconut-crab-collecting regions. As a result, rural households would continue to maintain traditional levels of crab collecting effort for both the subsistence catch and the commercial harvest up to the time when crab stocks crashed.

3.3.4 *Overview of modelled R&D impacts on crab numbers for Vanuatu*

For each of the three regions defined above, estimates of adult crab stocks, and numbers collected for sale or home consumption, were generated from the bionomic model for the 50 years from 1985. Figures depicting predicted crab numbers for each of the three regions separately under the 'without R&D' and 'with R&D' scenarios are included in Appendix 2. Figures 1–3 illustrate the aggregated results for the whole of Vanuatu.

Figure 1 depicts a rapid decline in crab stocks under both scenarios for 10 years from 1985, after which the two series diverge. Under the 'without R&D' scenario, predicted stock levels continue to fall, and eventually are completely depleted by 2012. Under the 'with R&D' scenario, the decline has been gradually arrested, as the awareness-raising effects of the ACIAR-funded project were complemented by increasingly effective implementation of existing fishery regulations. Even so, the modelling exercise suggested that the perilously low levels of crab stocks in the Sanma Province have been so for more than a decade. Even quite small increases in numbers of crabs collected could have resulted in these stocks collapsing, which most likely would have triggered the eventual destruction of the remaining Vanuatu crab stocks. Instead, the model predicts stocks will recover, provided that the current two-year ban on crab collecting in the Sanma Province is enforced, and that quotas in future years are effective in limiting the number of crabs collected.

Figure 1. Estimated adult crab stocks by year, for all Vanuatu.

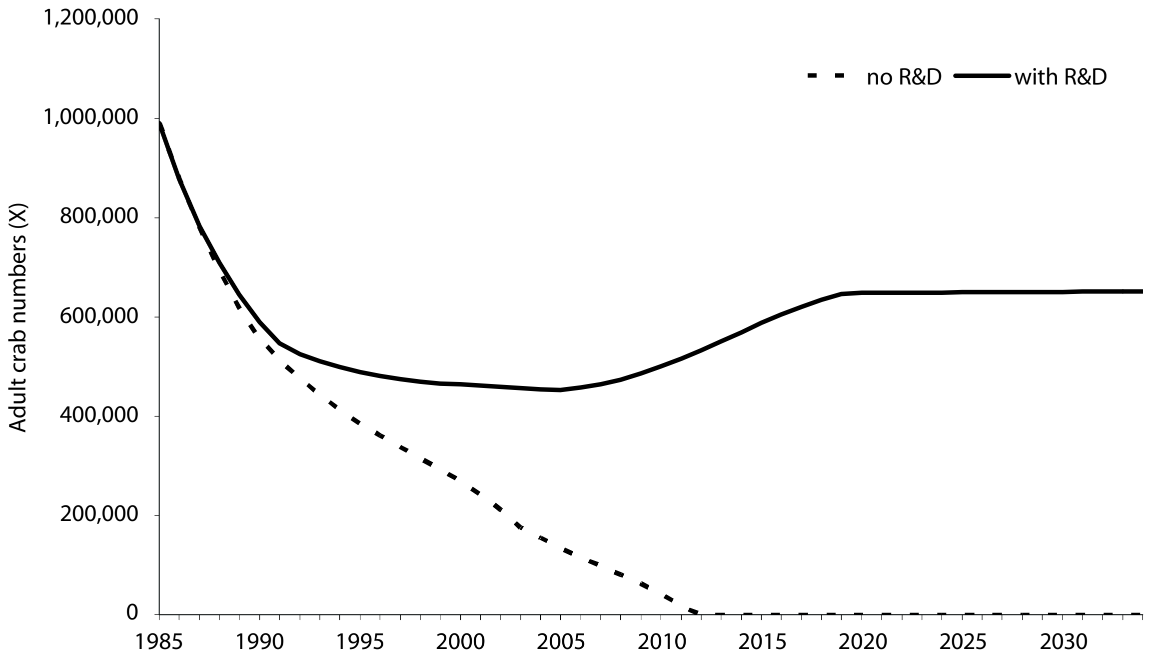


Figure 2. Estimated commercial crab harvest by year, for all Vanuatu.

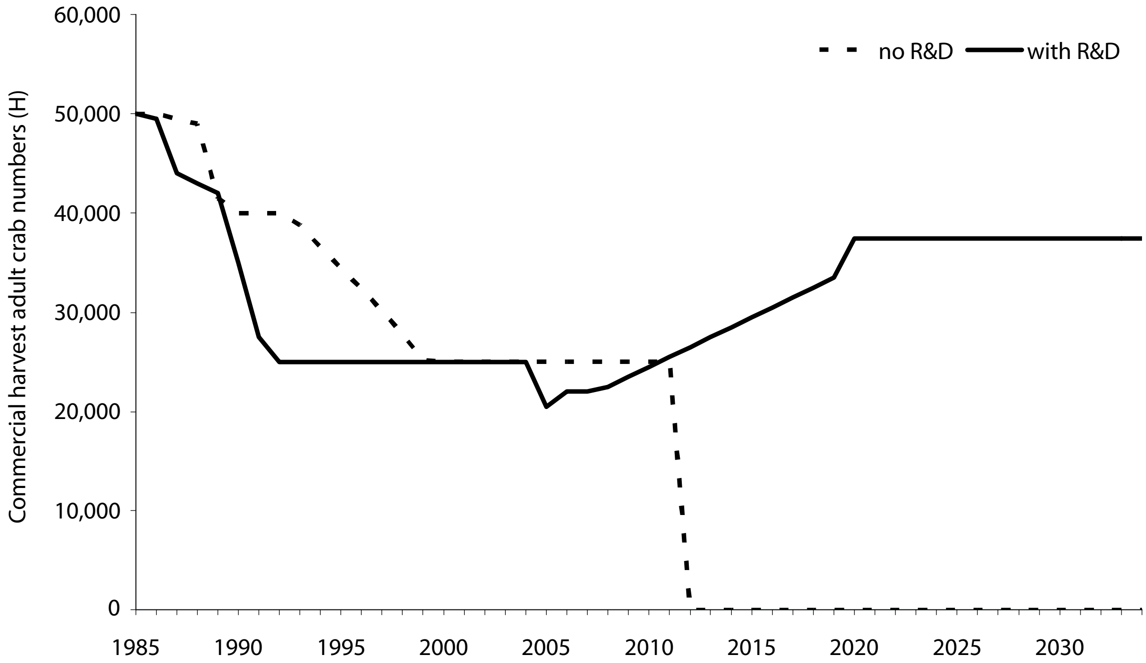
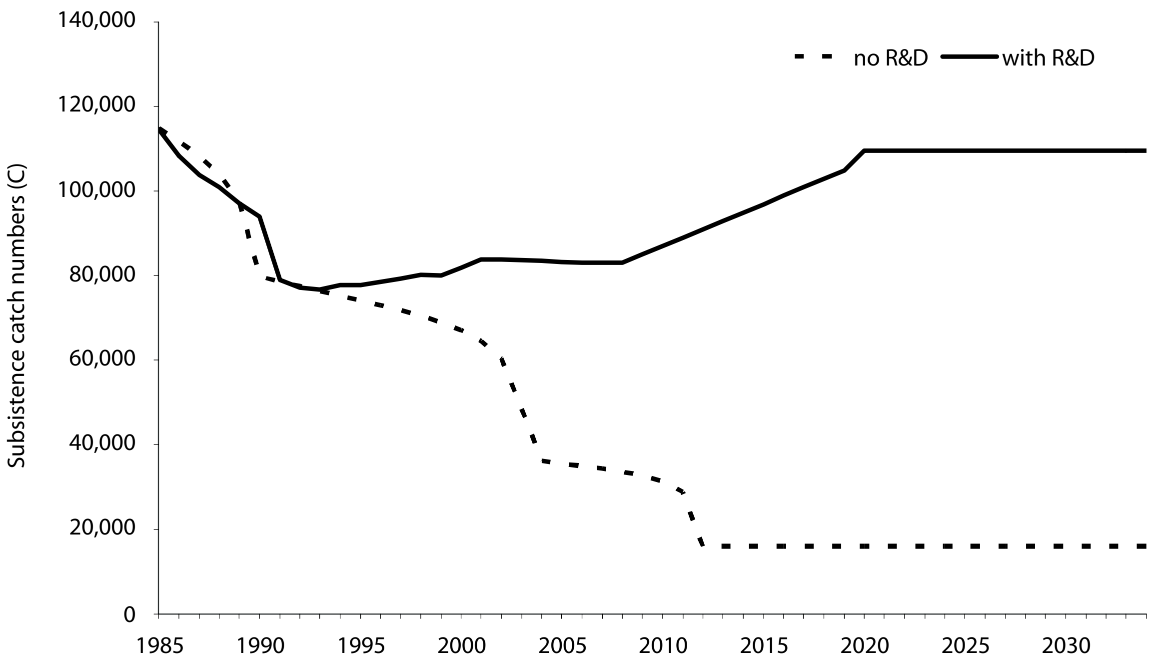


Figure 3. Estimated subsistence crab catch by year, for all Vanuatu.



Under the 'with R&D' scenario, much of the early decline in the commercial harvest (Figure 2) can be attributed to declining crab stocks in the Sanma Province, and deteriorating access to markets for the Torba Province. The predicted difference between the two scenarios for the first two decades was due to the impact of the R&D projects in educating crab collectors about the need to conserve crab stocks. In recent years, there have been further falls in the commercial harvest in these two regions, due to the enforcement of quotas, but nationally these falls have been offset by increasing supplies from the rest of Vanuatu. Big differences between the two scenarios are predicted in the future as crab stocks crash under the 'without R&D' scenario, but recover under the 'with R&D' scenario. From about 2020, a commercial harvest of about 37,000 crabs per annum could be sustained under the 'with R&D' scenario, while no crabs of marketable size would be available under the 'without R&D' scenario.

The subsistence crab catch was assumed to be relatively insensitive to the size of crab stocks but, as shown in Figure 3, still declined under both scenarios for more than a decade as crabs became scarcer and smaller. Thereafter, the time path of the subsistence catch diverged between the two scenarios in a similar manner to that for crab stocks. After the crash in crab stocks under the 'without R&D' scenario, it was assumed that only 16,000 crabs of marginal size, recruited from conservation reserves, would continue to be collected for home consumption each year. By contrast, the subsistence catch under the 'with R&D' scenario in 2012 exceeded 90,000 crabs per annum, and was predicted to continue growing, to nearly 110,000 crabs per annum.

4 Economic-impact analysis of coconut crab management on Vanuatu

4.1 Spillovers from research on coconut crabs

Coconut crabs are not unique to Vanuatu, so there is potential for research benefits to spillover to other countries. Brown and Fielder (1991) cite early reports that the species' original distribution stretched from the Seychelles (western Indian Ocean) to the Tuamotu Archipelago in the eastern Pacific. However, despite the species' wide distribution, viable populations of coconut crabs appear to be restricted mainly to island environments, and the crab is virtually unknown in East Africa, on the Indian subcontinent, and in mainland Asia. Changing land-use patterns due to population growth and economic development have had an adverse effect on coconut crab resources in a number of areas. As a result, the species is no longer found in many of the above areas because of habitat destruction and/or uncontrolled exploitation that has annihilated coconut crab stocks.

A mail survey conducted in 1984 indicated that, even then, abundant or viable populations of coconut crabs were restricted mainly to sparsely populated Pacific Islands, such as Solomon Islands, Truk, Guam, Tokelaus, Niue and the Marshall Islands, as well as the Republic of Vanuatu. Furthermore, stocks were dwindling in many of those countries. At that time, only Guam and Vanuatu had introduced minimum legal size limits as an interim management measure, but a number of countries indicated that management plans would be formulated if the appropriate baseline data were available. Identified attempts to extend the findings of the ACIAR-funded projects to other countries were described in the section on project outputs.

Notwithstanding the clear potential for the project to generate spillover benefits, and evidence that there was some follow-up research and extension of project results in the ensuing years, communication with project staff and several experts in the region failed to uncover any credible objective evidence that these efforts had improved the management of coconut crabs in other countries. It seems that no potential spillover benefits from the ACIAR-funded projects have been realised. Likewise, efforts made to identify any tangible economic impacts from this suite of projects on any groups in Australia were not successful.

4.2 Analytical method used to quantify economic impacts

Because of the lack of evidence that there were any tangible economic spillovers, the economic impact analysis was restricted to estimating national benefits in Vanuatu. There were no evident distortions due to subsidies and/or taxes that could have biased estimation of the economic impacts of research on coconut crabs. However, estimation of the economic benefits to consumers and producers from research that enables a fishery-management innovation involves some special challenges as compared with the application of well-established procedures for evaluation of the impacts of a process or product innovation.

First, there are some similarities between the impacts of research to develop a fishery-management innovation and those for so-called ‘maintenance R&D’. For the most common types of research, the supply curve for the ‘with R&D’ scenario shifts down over time relative to the ‘without R&D’ scenario as the process innovation is adopted. On the other hand, as the environment deteriorates, or biotic or abiotic stresses intensify, or the resource stock is depleted, the counterfactual supply curve for the ‘without maintenance R&D’ scenario tends to shift up over time relative to the ‘with maintenance R&D’ scenario, which may be stationary. Not all computer packages developed to evaluate the economic benefit of productivity-enhancing innovations can replicate the typical pattern of supply shifts for maintenance R&D. Hence, it was not possible to use standard economic-impact-assessment models, such as DREAM, to estimate the welfare measures of the economic impacts of coconut crab research on the Ni-Vanuatu people. Instead a purpose-built and fully flexible model was developed for this study.

Second, while the development of all types of innovation requires other non-research inputs, the type of inputs needed differ from one class of innovation to another. The technological, marketing, and entrepreneurial skills typically needed to bring a process innovation to market are likely to be privately supplied, and the cost will depend on market forces. By contrast, developing a fishery-management innovation typically involves drafting regulations and gaining legislative assent for a management plan. Like other forms of public-policy development, it requires mainly public-sector inputs, involving administrative, legislative and political skills. Quantifying and valuing these inputs is extremely difficult, so the costs of A$20,000 for the 1992 regulations and A$20,000 for the assumed 2004 regulations, that were estimated for this study by government sources, may not be accurate.

Third, whereas there is a direct link between uptake of a process innovation and realised economic impacts, such links are more tenuous for a fishery-management innovation. The equivalent of adoption of a process innovation is successful implementation of the fishery-management regulations. As most fishery-management innovations are introduced to arrest over-exploitation of a fish stock, the regulations are designed to constrain catch levels, at least in the short run. Thus, successful implementation requires public-sector services to ensure monitoring of compliance with, and enforcement of, fishery regulations. This needs to be an ongoing task that, if anything, gets harder rather than easier over time because it normally precludes fishermen from maximising short-run net returns.

As discussed above, while these public-sector inputs were not forthcoming for a number of years after completion of the first ACIAR-funded project, they will need to be supplied continuously from now on if future predicted R&D impacts are to be realised. In the analysis, it was assumed that there would be no further disruption of supply, and that the cost of these ongoing services would be A$25,000 per annum.

Fourth, because of the dynamic stock externality intrinsic to any renewable resource-stock management problem, the marginal social cost of harvesting includes both the direct private cost of harvesting the marginal unit of the catch, and the opportunity cost of exploitation (user cost). User cost is the discounted value of the increment to future catches from foregoing one unit of catch in the current period, and therefore represents the future cost associated with the current harvest. Hence, the socially optimal sustainable harvest will be less than that in an unregulated fishery where households will collect crabs so long as private catching costs are less than average revenue received. For this reason, prices in a regulated fishery commonly will be greater than market equilibrium levels, and the standard assumption in commodity market models for evaluating research benefits that the market price equals the marginal cost of the catch is invalid for research on natural resource management problems.

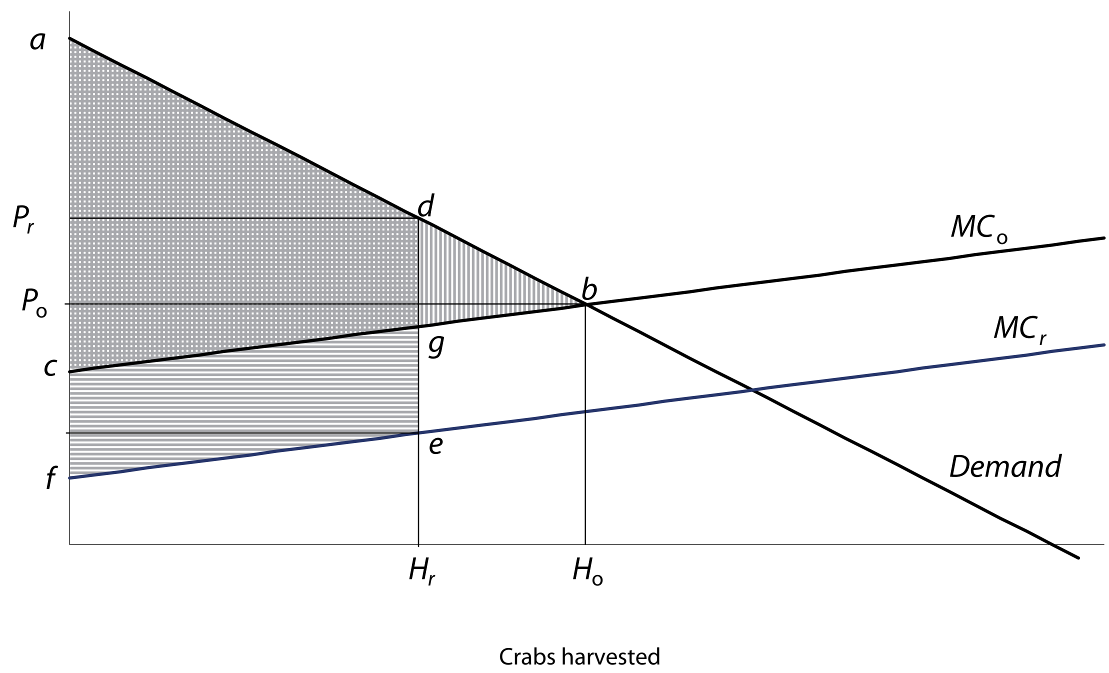
In theory, and given sufficient information, it is possible to calculate both the optimal steady-state harvest, and the optimal time path of harvests and stock levels from any given starting point to such an end. However, this approach was not feasible for this study because of the complete lack of data about the user cost of collecting coconut crabs. Instead, user cost was accounted for indirectly by specifying that the private cost function for collecting crabs was a non-linear function of level of crab stocks predicted by the above bionomic model. Even though the time path of changes in the resource stock generated by the model is not optimal, this method does capture, albeit imperfectly, the intertemporal stock externality, provided that the analysis covers a sufficiently long period.

Note that uptake of a fishery-management innovation does not result in an immediate shift of the supply curve for harvested fish. Shifts in the harvesting supply curve are driven by changes in resource-stock abundance. Because a biological natural resource is a dynamic system, there often are considerable lags between uptake of the fishery-management innovation and changes in stock abundance. In fact, the immediate effect of uptake of a fishery-management innovation may be an upward shift of the supply curve. Only subsequently, after stock abundance has improved, will the supply curve shift down and economic benefits start to be realised.

The economic benefit attributable to the uptake of a fishery-management innovation in any given year is the difference between the economic benefit from the regulated fishery where catch is limited and the economic benefit from an unregulated fishery. This is illustrated in Figure 4, where market outcomes for the unregulated fishery in the 'without R&D' scenario are denoted by the zero subscript. Catch level, H_o, and market price for the catch, P_o, are determined by the intersection of the private marginal catching costs, MC_o, with the demand curve, and the economic benefit is represented by the area *abc*.

For a regulated fishery under the 'with R&D' scenario, the associated outcomes are denoted by subscript '*r*'. Stock levels are assumed to be greater for this scenario, so the marginal cost curve of collecting crabs, MC_r, is lower than that for the unregulated fishery harvest. However, the size of the crab harvest H_r, is determined by the fishery regulations, and is typically less than H_o. Market price, P_r, is determined by the demand for this level of supply of crabs. Thus, the annual economic benefit for this scenario is depicted by the area *adef*. The difference between this economic benefit, and that for the counterfactual scenario, is depicted by the area *cgef* less the triangle *dbg*, and is the net economic benefit in the particular year represented by Figure 4 from uptake of the fishery-management innovation.

Figure 4. Imputed net annual economic benefit from uptake of a fishery management innovation.



In summary, the method used to estimate the costs and benefits from the suite of coconut crab R&D projects was as follows:

1. The annual nominal costs of research incurred by ACIAR and AIDAB/AusAID, the commissioned organisations — the Queensland Department of Primary Industries) and the University of Queensland, and by the Fisheries Department of Vanuatu were quantified.

2. Uptake to date of project results, and of related complementary project outputs, to improve management of the fishery by the national government, by provincial governments, and/or by local communities were identified. The potential for further uptake of project outputs into improvements to the future management of the coconut crab fishery also was evaluated, and taken into account in developing the 'without R&D' and 'with R&D' scenarios.

3. A bionomic model of the population dynamics of coconut crabs was developed for this study to estimate past counterfactual and potential future impacts of current plus predicted future fishery-management regulations on:
   - the size of the stock of legal-size, adult coconut crabs
   - the number of crabs collected for sale to restaurants or other market outlets (the commercial harvest)
   - the number of crabs collected for domestic consumption (the subsistence catch).

A modified economic model was developed to estimate prices received for the commercial harvest and to derive quantitative measures of the economic benefits from supply shifts driven by changes to the stock of legal-size, adult coconut crabs due to the suite of R&D projects. Similarly, the economic benefits from the subsistence catch were quantified using this model, by assuming that changes to crab stocks also would shift the supply curves for crabs collected for home consumption in a comparable manner.

Net present values, benefit–cost ratios, and internal rates of return were calculated for both a 30-year and a 50-year period from the start of the first project in 1985.

4.3 Project costs

The nominal costs of the suite of projects evaluated in this impact assessment study were provided by ACIAR and Rick Fletcher, and are set out in Table 2.

Table 2. Costs by year and institution for the suite of R&D projects on the biology of the coconut crab on Vanuatu.

		ACIAR budget (A$)				Other organisation budget (A$)				Grand total
		QDPI/UQ[a]	In-country costs	Fisheries Department	Total ACIAR	QDPI	UQ	Fisheries Department	AIDAB	
1985	ACIAR project FIS/1983/081	20,275	69,224		89,499	10,000	10,000	10,000		119,499
1986		20,275	84,468	12,300	117,043	10,000	23,600	10,000		160,643
1987		4,400	83,318	12,300	100,018	10,000	23,600	10,000		143,618
1988		13,446	47,333	6,150	66,929	10,000	10,000	10,000		96,929
1989					–					–
1990					–					–
1991	AIDAB project				–			3,000	10,000	13,000
1992	ACIAR project				7,000			3,000		10,000
1993					–					
1994					–					
1995					–					
1996					–					
1997					–					
1998					–					
1999					–					
2000					–					
2001					–					
2002					–					
2003	ACIAR project	28,200		8,750	36,950			3,000		39,950
2004	ACIAR project	13,990		4,100	18,090			3,000		21,090
Sum		100,586	284,343	43,600	435,529	40,000	67,200	52,000	10,000	604,729

[a] Queensland Department of Primary Industries/University of Queensland

In addition to these direct project costs, there were other costs for the development and implementation of the fishery-management innovation. These costs have nowhere been documented, and assumptions had to be based on discussions with government staff in Vanuatu. Total costs of developing and legislating for *The Fisheries (Coconut Crabs) Regulations*

No. 158 of 1991 were estimated to be A$20,000. It was assumed that the same amount will be incurred during 2004 to legislate for amendments to these regulations. In addition, it was assumed that the ongoing cost of monitoring and enforcement of these regulations would be A$25,000 per annum.

4.4 Imputation of economic benefit from coconut crab management on Vanuatu

The conventional time horizon for the analysis of the economic impacts of ACIAR-funded projects is 30 years, so benefit–cost measures for the suite of coconut crab projects were calculated for the 30 years from commencement in 1985. Arguably, a longer time frame could be justified in this case, given the unusual circumstances, which include the long time span from the first to the last project, and the unforeseeable delays in the uptake of project outcomes for reasons explained eariler. Another reason for assessing benefits over a longer period is to ensure that the opportunity cost of exploitation of the crab fishery is captured sufficiently by the net present value of the annual net economic benefit estimates from uptake of the fishery-management innovation. Consequently, benefit–cost measures also were calculated over a 50-year time frame. In both cases, nominal values were converted to present values using a discount rate of 5%.

Imputation of economic benefits generated by collecting coconut crabs is beset by numerous problems, not the least of which is a paucity of data. In order to estimate annual net economic benefits, elasticities of supply and demand, as well as market prices, are required in addition to predicted levels of the annual commercial harvest and the subsistence catch of coconut crabs, and of stock size, from the bionomic model. However, no estimates of parameter values for the elasticity of market demand for coconut crabs, or for the elasticity of supply by crab collectors, could be found, so estimates had to be conjectured from first principles. Fortunately, it is quite easy to show that the economic benefits are not very sensitive to variation in elasticity values, so it is unlikely that there will be considerable error margins in these estimates.

Tourist promotions regularly feature the opportunity to eat a coconut crab as a highlight of a visit to Vanuatu, so demand for a restaurant meal of coconut crab is likely to be relatively inelastic, despite the availability of substitutes such as other crustaceans. Furthermore, the price that crab collectors receive to supply this market often is less than 50% of the price tourists pay to eat a coconut crab. In this study, a value of –0.64 was assumed for the elasticity of demand faced by coconut-crab collectors.

The cost of purchased inputs required to collect coconut crabs is negligible, and the main component of collecting costs is the opportunity cost of household labour. In most of the rural areas of Vanuatu where coconut crabs are common, alternative opportunities to earn cash incomes are quite scarce, and especially so for households that do not own much land, and/or live in remote regions. For these reasons, market supply of coconut crabs was judged to be quite elastic, and a value of 1.81 was used in this study.

Due to a series of surveys of markets for coconut crabs conducted as part of the ACIAR-funded projects, better quality data are available on market prices for crabs. Of course, the market price paid for crabs varies amongst the buyers. For instance, while a number of recent sales have realised only about 600 Vatu/kg, in rare cases up to 2000 Vatu/kg has been paid. In the economic model, it was assumed that the price in 1985 was only A$3/kg. Thereafter, real demand was assumed to grow by 1% per annum under both scenarios. As noted above, for the 'with R&D' scenario these shifts in demand, together with shifts in available supply as a result of the implementation of fishery regulations, determined predicted price, which rose to about A$5.50/kg by 2004. Crabs caught for home consumption were assumed to have the same value as crabs taken to market.

Lastly, the nature of the relationship between level of catching costs and stock size needs to be specified. Again, little empirical evidence was available, although Fletcher and Amos (1994) did conclude that there was 'a "hypo-depletion" type of model for the relationship between CPUE and stock abundance'. This finding is consistent with marginal catching costs generally being relatively insensitive to stock size, but increasing strongly as crabs become more and more scarce. For this reason, the intercept of the harvesting supply curve for both scenarios was assumed to vary inversely with the square root of relative crab abundance. Market prices for crabs in the 'without R&D' scenario were determined by the intersection of this supply curve with the demand curve. Predicted prices for both scenarios are illustrated in Figure 5.

4.5 Economic benefit estimates

The results of the benefit–cost analysis of the suite of coconut crab R&D projects are presented in this section. Estimated annual net benefits from the R&D projects are illustrated in Figure 6.

Figure 5. Estimated market prices for coconut crabs in Vanuatu.

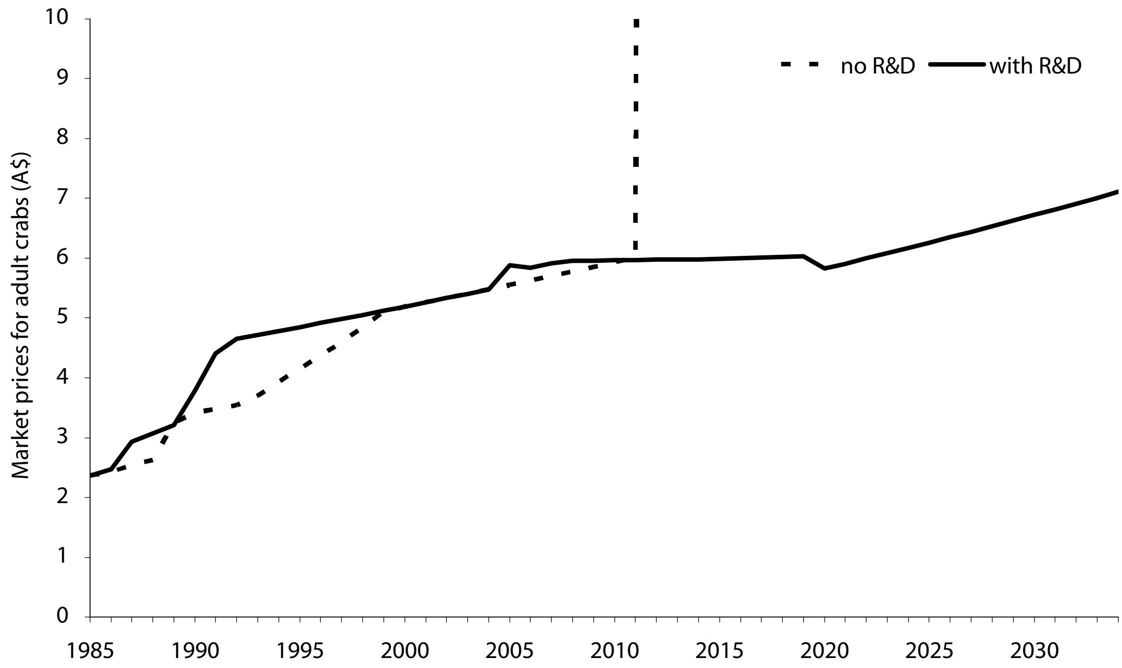
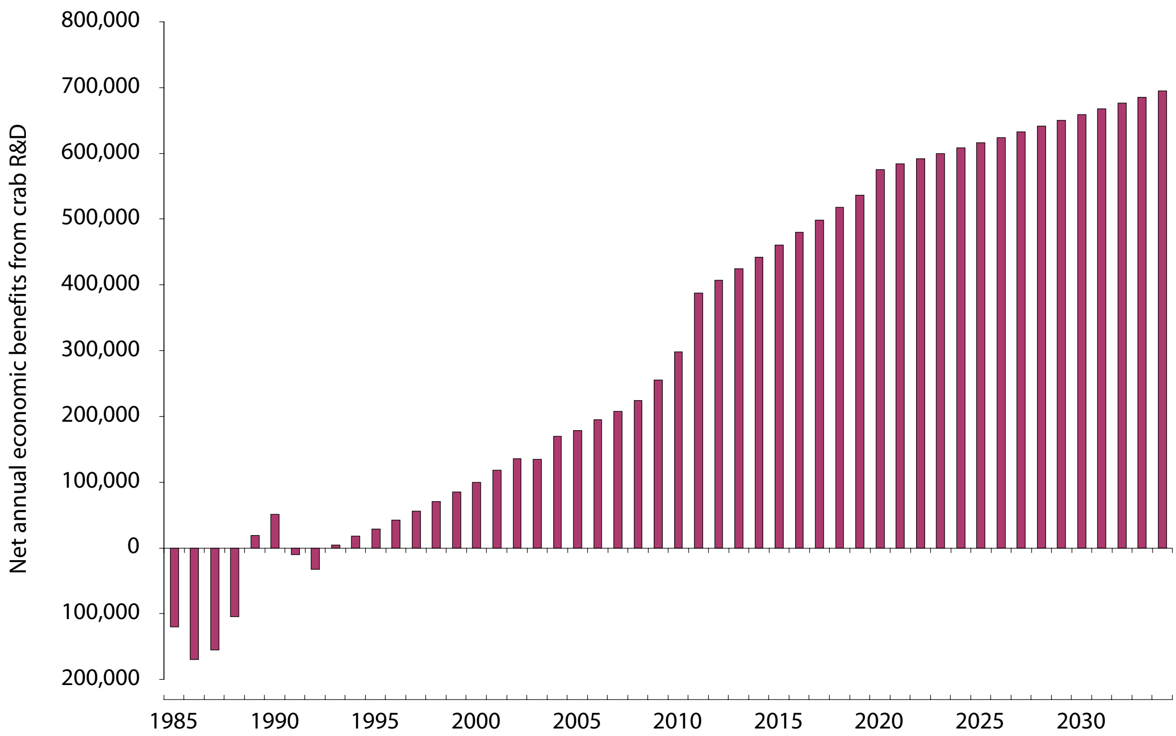


Figure 6. Estimated annual net benefits from coconut crab research projects.



Like all research projects, net returns in the early years are negative because project costs are incurred at the outset, while benefits take some time to be realised. This pattern is, for several reasons, more pronounced in this case. As explained earlier, realisation of significant benefits from uptake of the fishery-management innovation was delayed for nearly 10 years by lack of government resources to implement and enforce the 1992 crab-fishery regulations.

During this hiatus, project impacts were small, because they were limited to the effect of project activities in raising awareness among crab-collecting communities of the importance of conserving crab stocks. As can be seen from Figures 1 and 2, while the long-run impacts of crab collectors becoming more conservation-minded are beneficial, the short-run consequence initially was to shrink the commercial harvest and reduce the net economic benefit relative to the 'without R&D' scenario. From about 1995, this began to be offset by an increasing subsistence catch under the 'with R&D' scenario relative to the 'without R&D' scenario. However, the most significant benefits from the coconut crab research projects will not be realised until about 2012, when crab stocks are predicted to collapse under the 'without R&D' scenario.

The estimates of the various summary economic measures for the suite of R&D projects being evaluated in this impact assessment study are summarised in Table 3.

Table 3. Economic impact measures for coconut crab research.

	Net present value 30 years (1985 $A)	Net present value 50 Years (1985 $A)
No research and development		
Project costs	0	0
Commercial harvest	1,271,020	1,271,020
Subsistence catch	2,706,397	2,706,397
With research and development (R&D)		
Project costs	596,919	669,006
Commercial harvest	1,721,714	2,311,121
Subsistence catch	3,661,635	4,819,867
Net R&D benefit	809,014	2,484,566
Benefit–cost ratio	2.4	4.7
Internal rate of return	11%	13%

By the standards of results from most impact assessment studies of the economic returns to R&D, the values in Table 3 are quite modest. Over a 30-year time frame, the NPV is only A$809,014, and the benefit–cost ratio 2.4, and they rise to only A$2,484,566 and 4.7, respectively, if the projects are evaluated over a 50-year period. The corresponding internal rates of return are 11% and 13%. The main reasons for this have already been canvassed above at some length. In essence, they are:

- a substantial delay occurred in the uptake of the fishery-management innovation due to a lack of government resources for implementation and enforcement
- after uptake of the fishery-management innovation, a further delay was inevitable before benefits from it could be realised, due to the population dynamics of a renewable natural resource
- a common characteristic of the uptake of fishery-management innovations is that in order to redress over-exploitation of a renewable resource stock, costs initially need to be incurred in the form of foregone harvests so as to realise long-run benefits
- the market for coconut crabs is small relative to most commodities.

The other notable aspect of these results is the importance of recognising that research benefits derive from protecting future levels of the subsistence catch as well as of the commercial harvest. In fact, the former is just about twice as the latter. If the subsistence catch were excluded from the analysis, the net present value of benefits linked to the commercial harvest over a 30-year period of $450,694 would be less than discounted project costs of $596,919. This observation highlights the fact that the primary beneficiaries of this suite of research projects have been poor, rural households in remote parts of Vanuatu. In the next section, an attempt is made to quantify the poverty impacts of the ACIAR-funded coconut crab research projects.

4.6 Poverty impacts

By most measures, Vanuatu is a very poor country. For instance, according to a Secretariat of the Pacific Community/UNFPA spreadsheet of indicators for Vanuatu available on the Vanuatu Statistics Office website, 26% of the population in 1998 existed on an income of less than US$1 per person per day. Furthermore, 51% of households fell below the monthly household income poverty line of 35,000 Vatu, or A$455.

Another national poverty measure is overseas development assistance received as a percentage of gross national income. According to OECD data, the average value for Vanuatu over the period 1990 to 2001 was 20.5%, as compared with 2.6% for Fiji, 8.6% for Papua New Guinea, 17.4% for the Solomon Islands, and 17.9% for Tonga.

Crab collectors live in rural areas, and rural households are significantly poorer than urban residents. In the 1998 Vanuatu Household Income and Expenditure Survey, it was reported that there were 26,157 rural households. Average annual income per household was A$6250, of which just under half was wage income. However, 30% of rural households had an annual income of less A$1800. In the Torba Province, which is the principal crab-collecting region, over 55% of rural households had an income of less A$1800 per annum. The average annual income of rural households in 1998, including subsistence production, was about A$6700 for the Sanma Province, but less than A$2000 for the Torba Province.

As expected, no information was available about the composition of the income of crab-collecting households. In an attempt to collect a limited amount of primary data on possible poverty impacts, a very small impromptu survey of crab collectors from Hog Harbour, Port Olry and Malo Island was carried out during a visit to Espiritu Santo in April 2004. Details of the survey method and questions asked are given in Appendix 1.

All of the survey respondents gave surprisingly consistent answers to questions about numbers of crabs collected for sale and home consumption. In 2002, when the open season for collecting crabs lasted for seven months, estimates of annual revenue from commercial crab harvesting ranged from A$2000 to A$2700. By comparison, the average wage income of rural households in the Sanma Province in 1998 was less than A$4000 per annum. However, all of the crab collectors interviewed were substantial landowners with access to markets for other cash crops. As a result, they had significantly higher household incomes. It was not possible to obtain accurate details of household income during the survey, but the impression was given that household income was at least double, and possibly five times as much as, the provincial average.

As noted above, in the main crab-collecting region of the Torba Province, there are few alternative opportunities to earn wages or sell cash crops. In fact, while the average total income of most rural households was less than A$1800 per annum, average annual wage income was less than A$500 per household. This is a lot less than the reported income from sale of crabs in the Sanma Province. Prices received by crab collectors in the Torba Province are significantly lower than in the Sanma Province due to higher transport costs to reach the main market in Port Vila, so income from crab collecting could be the main, and even the only source of cash income for many households in this region. However, no evidence was available to confirm or reject this speculative conclusion.

Clearly, loss of the rare opportunity to earn cash income would have an extremely severe impact on poverty in many of the crab-collecting areas in Vanuatu. It is noteworthy that, in 2003, when the crab-collecting season in the Sanma Province was shortened by five months, survey respondents estimated that income from this source fell by more than 67%. If, as is likely, there is a total ban for the next two years, lost annual income is likely to exceed A$2000 per household. However, such a loss would be only temporary. Crab stocks are predicted to recover fully by 2020, when income from the commercial harvest in the Sanma Province could be as much as six to seven times greater than in 2001–02. For the Torba Province, there is insufficient evidence to speculate about the actual magnitude of the poverty impacts. Based on predictions of the size of the commercial harvest that could be sustained in future, at least a doubling of cash income from this source for the 200 or so very poor crab-collecting households in the Torba Province would not seem to be out of the question.

Conversely, if the crab fishery crashed completely, both commercial harvests and subsistence catches would be lost indefinitely. For about 600 rural households spread across several Vanuatu provinces, such an outcome would be catastrophic.

5 Conclusions

The ACIAR-funded project FIS/1983/081, ‘Growth and recruitment study on coconut crab *Birgus latro* population in Vanuatu’, and a subsequent suite of projects, have been very successful, and have produced an impressive number of outputs. Notable outputs include numerous scientific publications, enhanced competency of local staff to carry out stock-assessment surveys and to develop and implement fishery-management plans, and heightened awareness of the dangers of over-exploitation among coconut-crab collecting communities.

However, the ultimate aim of the above suite of projects was to provide a scientific foundation for a fishery-management innovation for the Vanuatu coconut crab resource that would benefit the Ni-Vanuatu people. The key output from the first project was a set of recommendations to improve management of the fishery, and was embodied in *The Fisheries (Coconut Crabs) Regulations No. 158 of 1991*. Recently, a comprehensive draft set of revised and enhanced management regulations has been produced from the final two projects in the suite, and is under consideration by the Vanuatu Government.

The above outputs enable, but are insufficient for, successful uptake of a fishery-management innovation that can restore crab stocks to a more healthy state, and thereby generate beneficial economic impacts. To date, recovery of most crab stocks has been modest at best, in part due to a lack of government resources to implement and enforce the crab-fishery regulations introduced in 1992. This problem has now been resolved, and predictions from a bionomic model of the population dynamics of coconut crabs indicate that stocks of adult coconut crabs, and the consequential size of the commercial harvest and the subsistence catch, will recover quite quickly so long as current and proposed new regulations are complied with in the future. However, because a biological natural resource is a dynamic system, it is predicted that full recovery of the fishery, and improvements in stock abundance sufficient for potential economic benefits to be realised, will take a further 10 to 15 years.

A novel economic model was developed to estimate economic benefits from resource-stock-induced shifts in the supply of crabs collected for sale or home consumption. The typical pattern of negative net returns in the early years of an impact-assessment study was exacerbated by delayed uptake of the fishery-management innovation mentioned above, and the intrinsic lags necessary for a renewable resource to recover once over-exploitation is controlled. Subsequently, the magnitude of the positive annual net returns was limited by the small size of the market for the commercial harvest, and the larger but still modest-size subsistence catch. As a result, the net present value over a 30-year period is only A$809,014, the benefit-cost ratio is 2.4, and the corresponding internal rate of return only 11%. If the duration of the analysis was extended to 50 years, these economic impact measures increased to a net present value of A$2.5 million, a benefit–cost ratio of 4.7 and a rate of return of 13%.

The primary beneficiaries of this suite of research projects have been poor rural households in remote parts of Vanuatu, who benefited from supplying the commercial harvest, and from the considerably larger subsistence catch. The impact of cash incomes on poverty levels also is predicted to be significant for the estimated 600 plus crab-collecting households on Vanuatu. A small number of collecting households in Sanma Province reported cash earnings from commercial crab harvesting of A$2000 to A$2700 per household. In the latest Household Income and

Expenditure Survey, conducted in 1998, the average annual income of rural households, including subsistence production, was about A$6700 for the Sanma Province, but less than A$2000 for the Torba Province.

6 Bibliography

Amesbury, S.S. 1980. Biological studies on the coconut crab (*Birgus latro*) in the Mariana Islands. University of Guam Technical Report No. 17, 39p.

Brown, I.W. and Fielder, D.R., ed. 1991. The coconut crab: aspects of *Birgus latro* biology and ecology in Vanuatu. Canberra, ACIAR Monograph No. 8, 136p.

Brown, I.W., Fielder, D.R. and Fletcher, W.J. 1991. Conclusions. In: Brown, I.W. and Fielder, D.R., ed., The coconut crab: aspects of *Birgus latro* biology and ecology in Vanuatu. Canberra, ACIAR Monograph No. 8, 99–102.

Fletcher, W.J. 1988. Coconut crab biology and resources in Vanuatu. In: Proceedings of resources, development and environment of Vanuatu conference, September 1987, 17p.

— 1992. Stock assessment and management of coconut crabs in Vanuatu. Project report to the Fisheries Department, Republic of Vanuatu, 57p.

— 2002. Project application: Review of coconut crab management in Vanuatu. Mimeo.

— 2003a. Project application: Completion of coconut crab management in Vanuatu. Mimeo.

— 2003b. Stock assessment and review of management for coconut crabs in Vanuatu. Final project report to the Fisheries Department, Republic of Vanuatu, 76p.

Fletcher, W.J. and Amos, M. 1994. Stock assessment of coconut crabs. Canberra, ACIAR Monograph No. 29, 32p.

Fletcher, W.J., Brown, I.W. and Fielder, D.R. 1990a. Growth of the coconut crab *Birgus latro*. Journal of Experimental Marine Biology and Ecology, 141, 63–78.

— 1990b. Use of standard and inverse Leslie experiments to estimate the abundance of the coconut crab (*Birgus latro* L) in Vanuatu. Fisheries Research, 9, 317–324.

Fletcher, W.J., Brown, I.W., Fielder, D.R. and Obed, A. 1991a. Moulting and growth characteristics. In: Brown, I.W. and Fielder, D.R., ed., The coconut crab: aspects of *Birgus latro* biology and ecology in Vanuatu. Canberra, ACIAR Monograph No. 8, 35–60.

— 1991b. Structure and dynamics of populations. In: Brown, I.W. and Fielder, D.R., ed., The coconut crab: aspects of *Birgus latro* biology and ecology in Vanuatu. Canberra, ACIAR Monograph No. 8, 61–86.

Lavery, S. and Fielder, D.R. 1991. Genetic characteristics. In: Brown, I.W. and Fielder, D.R., ed., The coconut crab: aspects of *Birgus latro* biology and ecology in Vanuatu. Canberra, ACIAR Monograph No. 8, 87–98.

Schiller, C. 1992. Assessment of the status of the coconut crab *Birgus latro* on Niue Island with recommendations regarding an appropriate resource management strategy. Report to the Food and Agriculture Organization of the United Nations, 69p.

Schiller, C., Fielder, D.R., Brown, I.W. and Obed, A. 1991. Reproduction, early life-history and recruitment. In: Brown, I.W. and Fielder, D.R., ed., The coconut crab: aspects of *Birgus latro* biology and ecology in Vanuatu. Canberra, ACIAR Monograph No. 8, 13– 35.

Appendixes

I Details of impromptu survey

The priority during the six working days in Vanuatu was to interview officials involved with the projects, to identify all potential impacts, to determine the degree to which these potential impacts had been realised or were likely to be realised in the near future, and to collect information needed to estimate the magnitude of economic benefits and costs attributable to these projects.

During the time available, it was possible to conduct a small survey of crab catchers, albeit of limited scope, and based on rather unconventional methods. The main aims of the survey were to gain some anecdotal evidence about:

- (apparently sustainable) catch levels before commercial harvesting
- the increase in catch levels after start of commercial harvesting
- income from crab collecting, both before commercial harvesting and currently
- other current sources of cash income
- awareness of current and prospective coconut crab regulations
- impact on poverty of either a ban on collection, or a collapse of crab stocks.

Approximately 26 crab catchers were interviewed over a period of two days during a trip to the northern area of East Santo, where much of the project research was based, and opportunistically in Luganville. As the interviewees were not chosen by scientific sampling procedures, the data collected are not necessarily representative even of their local communities. All of the crab collectors interviewed were either residents of the communities of Hog Harbour, or of Port Olry, or of a village on Malo Island in the south of Espiritu Santo.

In no sense did the survey comprehensively cover even Espiritu Santo, let alone other regions in the Sanma Province, or more importantly, other provinces. From the poverty data presented earlier, it can be seen that income levels in the rural parts of the Sanma Province are significantly higher than those in Torba Province, which is now the main source of supply of crabs. At best, the results are illustrative of the situation in some parts of the Sanma Province. Purportedly, Hog Harbour and Port Olry are in one of the relatively more affluent regions of the Sanma Province; and residents of Malo Island are reportedly better off than inhabitants of neighbouring small islands. Hence, the survey results almost certainly provide a distorted picture of the plight of crab collectors in the Torba Province and other poorer regions, but do establish some sort of lower bound on the impact of a potential loss of income from crab collecting on poverty in rural communities with few alternative sources of cash income.

A counterpart from the Fisheries Department interpreted questions and answers to/from *Bislama*. No formal questionnaire was used, due in part to a lack of familiarity with local language and culture. The scope of each interview also had to be adapted to the particular circumstances, including the number of people present, and the amount of time that they were willing to spend answering what must have seemed a strange set of questions.

In most interviews, questions along the following lines were explored:

▶▶▶▶ Questions about the situation before commercial harvesting

- When you only collected crabs to eat, how abundant were the crabs, and/or how easy were they to catch?
- How big were most of the crabs that were eaten?
- Each time that you collected crabs for your household to eat, how many crabs did you collect?
- How many times per week did your household have a meal of crabs?

▶▶▶▶ Questions about the situation soon after the start of commercial harvesting

- When commercial harvesting started, how many crabs did you collect per week to sell, and for how many weeks per year?
- How big were most of the crabs collected?
- What price were you paid per crab?
- Did your household still eat crabs? If so, how many crabs were eaten at each meal, and how many times per week were crabs eaten?

▶▶▶▶ Questions about the situation in the last two years

- In the last two years, how many crabs did you collect per week to sell, and for how many weeks per year?
- How big were most of the crabs collected?
- What price were you paid per crab?
- In the last two years, did your household still eat crabs? If so, how many crabs were eaten at each meal, and how many times per week were crabs eaten?

▶▶▶▶ Questions about other current sources of cash income

- On average, how much money did you receive each time that you took copra to market? (or questions about quantities and prices)
- How many times each year did you take copra to market?
- (Equivalent questions for other sources of cash income, such as cocoa, cattle, fish and crayfish, fruit and vegetable, royalties from timber, transport services, tourism services etc.)

▶▶▶▶ Questions about interviewees' awareness of current and prospective coconut crab regulations, and potential impacts

- What regulations concerning collecting, eating, and selling coconut crabs are you aware of?
- What possible new regulations concerning collecting, eating, and selling coconut crabs are you aware of?
- If there is a total *tabu* on collecting coconut crabs for the next two years, how will you cope?

2 Modelled R&D impacts on crab numbers by regions

Sanma Province

Figures A1, A2 and A3 illustrate model predictions for the Sanma Province for the 50 years from 1985 for commercial crab harvests, for subsistence crab catches, and for stocks of adult crabs, respectively.

Note that the actual measured depletion of adult crab stocks in the Sanma Province in the early 1990s under the 'with R&D' scenario fell to much lower levels than those predicted by the bionomic model. It is a possible that this discrepancy is due to sampling error in the field surveys, but a much more likely explanation is the highly simplified nature of the bionomic model of these stocks. All attempts to improve the 'goodness of fit' between simulated and measured values for crab stocks failed. In all cases where model coefficient values were chosen to achieve better tracking of the actual decline in crab stocks during the decade of the 1990s, the model predicted the rapid and terminal decline of adult crab stocks, irrespective of assumed levels of commercial harvest and/or subsistence catch. As there already is nascent evidence of some recovery in crab stocks in the Sanma Province, model coefficient values were chosen to fit this outcome, as well as the possibility of an eventual recovery of simulated levels of adult crab stocks to sustainable levels in the event that the fishery continues to be managed effectively. In particular, with the selected coefficient values, and so long as the recent two-year ban on harvesting is rigorously enforced, and subsequent catch levels are only gradually increased, the model predicts that it should be possible to reach annual sustainable harvest levels of 4000 adult crabs per year by about 2012.

Torba Province

Model output for 50 years from 1985 for the Torba Province for adult crab stocks, for commercial crab harvests, and for subsistence crab catches, are illustrated in Figures A4, A5, and A6.

Rest of Vanuatu region

Model output of adult crab stocks, commercial crab harvests, and subsistence crab catches, for the rest of Vanuatu for the 50 years from 1985 are illustrated in Figures A7, A8, and A9.

Figure A1. Estimated adult crab stocks by year in the Sanma Province.

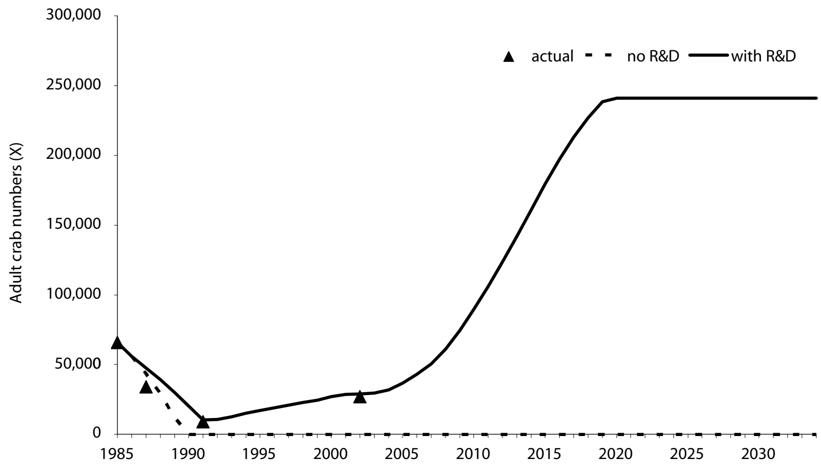


Figure A2. Estimated commercial crab harvest by year in the Sanma Province.

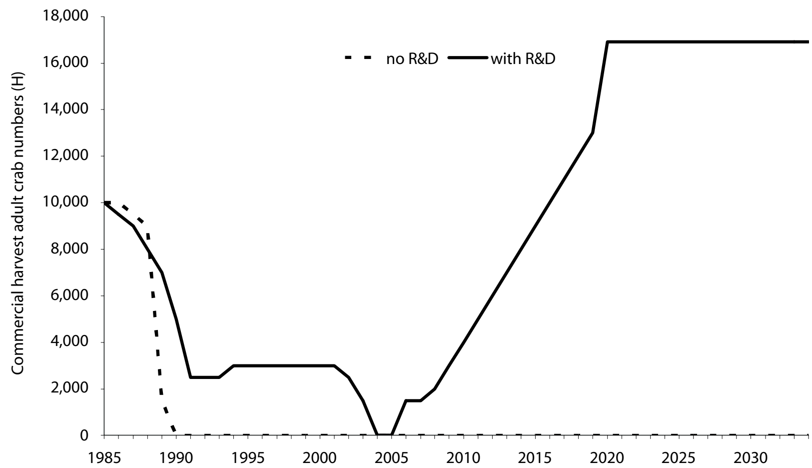


Figure A3. Estimated subsistence crab catch by year in the Sanma Province.

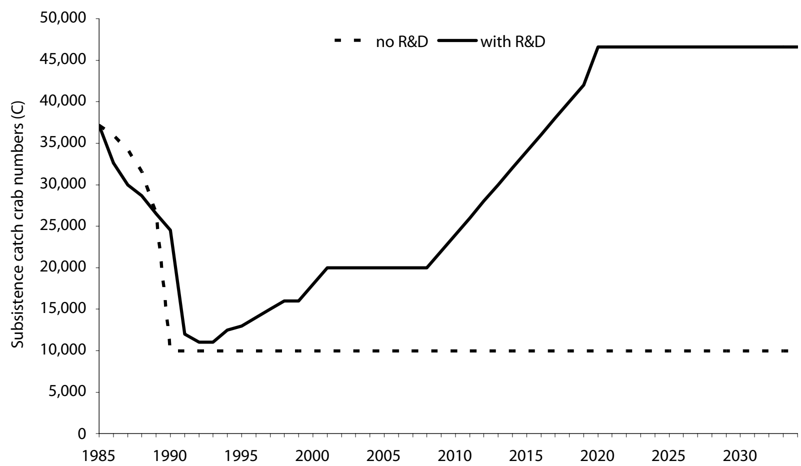


Figure A4. Estimated adult crab stocks by year in the Torba Province.

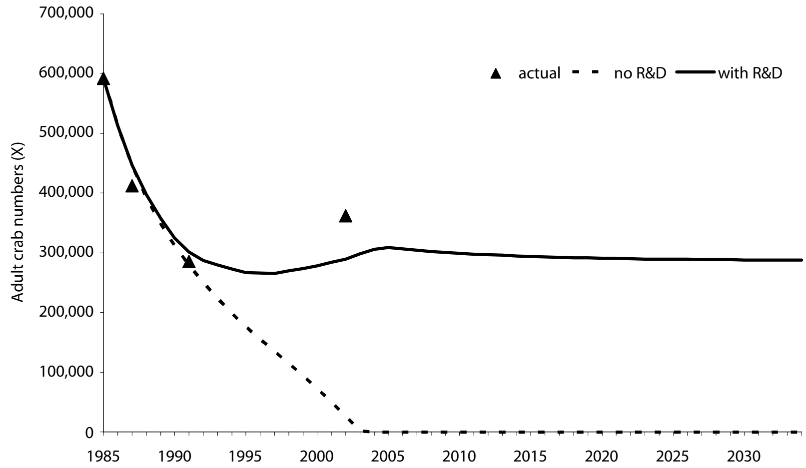


Figure A5. Estimated commercial crab harvest by year in the Torba Province.

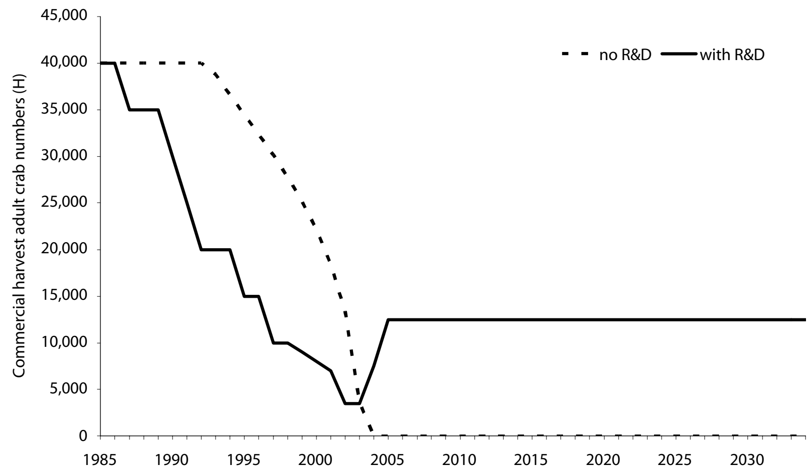


Figure A6. Estimated subsistence crab catch by year in the Torba Province.

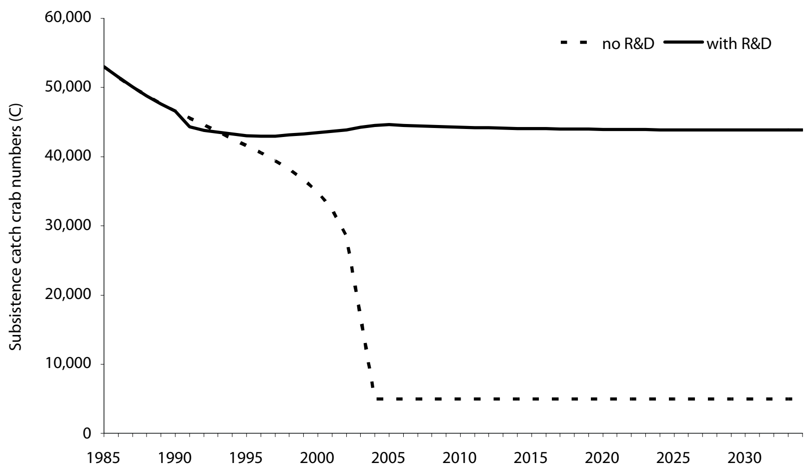


Figure A7. Estimated adult crab stocks by year in the rest of Vanuatu region.

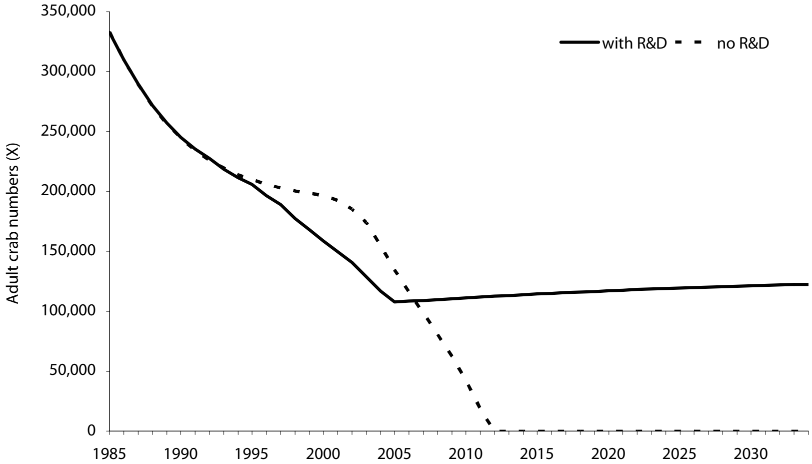


Figure A8. Estimated commercial crab harvest by year in the rest of Vanuatu region.

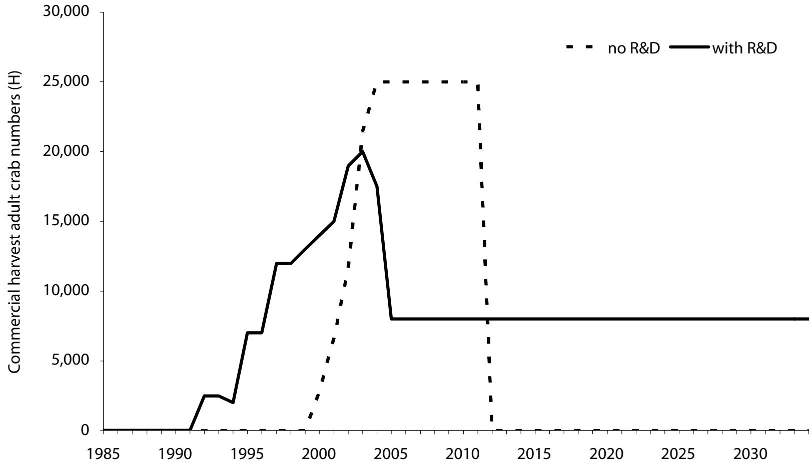
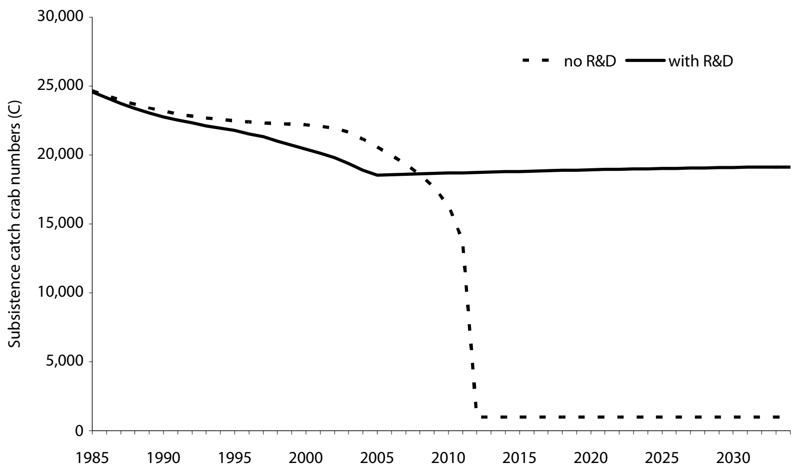


Figure A9. Estimated subsistence crab catch by year in the rest of Vanuatu region.



3 Information Sources

Statistical Year Book of Vanuatu – 2002

National Accounts of Vanuatu (1983–2001)

National Accounts of Vanuatu (1997–2002)

2000 Vanuatu Labour Market Survey

2000 Informal Sector Survey

1999 Census Main Report

1999 Demographic Analysis Report

1998 Vanuatu Household Income and Expenditure Survey

1997 Vanuatu Visitors Survey

1994 Vanuatu Domestic Visitors Survey

1993 Agriculture Main Report

1993 Agriculture Technical Report

Pacific Region Information SysteM (PRISM) programme at the Secretariat of the Pacific Community

Secretariat of the Pacific Community/UNFPA MDG Indicators for Vanuatu (provisional)

IMPACT ASSESSMENT SERIES

No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics (1998)	Control of Newcastle disease in village chickens	8334, 8717 and 93/222
2	George, P.S. (1998)	Increased efficiency of straw utilisation by cattle and buffalo	8203, 8601 and 8817
3	Centre for International Economics (1998)	Establishment of a protected area in Vanuatu	9020
4	Watson, A.S. (1998)	Raw wool production and marketing in China	8811
5	Collins, D.J. and Collins, B.A. (1998)	Fruit fly in Malaysia and Thailand 1985–1993	8343 and 8919
6	Ryan, J.G. (1998)	Pigeon pea improvement	8201 and 8567
7	Centre for International Economics (1998)	Reducing fish losses due to epizootic ulcerative syndrome — an ex ante evaluation	9130
8	McKenney, D.W. (1998)	Australian tree species selection in China	8457 and 8848
9	ACIL Consulting (1998)	Sulfur test KCL–40 and growth of the Australian canola industry	8328 and 8804
10	AACM International (1998)	Conservation tillage and controlled traffic	9209
11	Chudleigh, P. (1998)	Post-harvest R&D concerning tropical fruits	8356 and 8844
12	Waterhouse, D., Dillon, B. and Vincent, D. (1999)	Biological control of the banana skipper in Papua New Guinea	8802-C
13	Chudleigh, P. (1999)	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039
14	McLeod, R., Isvilanonda, S. and Wattanutchariya, S. (1999)	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008 and PHT/1990/008
15	Chudleigh, P. (1999)	Use and management of grain protectants in China and Australia	PHT/1990/035
16	McLeod, R. (2001)	Control of footrot in small ruminants of Nepal	AS2/1991/017 and AS2/1996/021
17	Tisdell, C. and Wilson, C. (2001)	Breeding and feeding pigs in Australia and Vietnam	AS2/1994/023
18	Vincent, D. and Quirke, D. (2002)	Controlling *Phalaris minor* in the Indian rice–wheat belt	CS1/1996/013
19	Pearce, D. (2002)	Measuring the poverty impact of ACIAR projects—a broad framework	
20	Warner, R. and Bauer, M. (2002)	*Mama Lus Frut* scheme: an assessment of poverty reduction	ASEM/1999/084
21	McLeod, R. (2003)	Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in Southeast Asia	AS1/1983/067, AS1/1988/035, AS1/1992/004 and AS1/1994/038
22	Bauer, M., Pearce, D. and Vincent, D. (2003)	Saving a staple crop: impact of biological control of the banana skipper on poverty reduction in Papua New Guinea	CS2/1988/002-C

IMPACT ASSESSMENT SERIES

23	McLeod, R. (2003)	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011 and AS2/1993/001
24	Palis, F.G., Sumalde, Z.M. and Hossain, M. (2004)	Assessment of the rodent control projects in Vietnam funded by ACIAR and AUSAID: adoption and impact	AS1/1998/036
25	Brennan, J.P. and Quade, K.J. (2004)	Genetics of and breeding for rust resistance in wheat in India and Pakistan	CS1/1983/037 and CS1/1988/014
26	Mullen, J.D. (2004)	Impact assessment of ACIAR-funded projects on grain-market reform in China	ANRE1/1992/028 and ADP/1997/021
27	van Bueren, M. (2004)	Acacia hybrids in Vietnam	FST/1986/030
28	Harris, D. (2004)	Water and nitrogen management in wheat–maize production on the North China Plain	LWR1/1996/164

ECONOMIC ASSESSMENT SERIES (DISCONTINUED)

No.	Author and year of publication	Title	ACIAR project numbers
1	Doeleman, J.A. (1990a)	Biological control of salvinia	8340
2	Tobin, J. (1990)	Fruit fly control	8343
3	Fleming, E. (1991)	Improving the feed value of straw fed to cattle and buffalo	8203 and 8601
4	Doeleman, J.A. (1990b)	Benefits and costs of entomopathogenic nematodes: two biological control applications in China	8451 and 8929
5	Chudleigh, P.D. (1991a)	Tick-borne disease control in cattle	8321
6	Chudleigh, P.D. (1991b)	Breeding and quality analysis of canola (rapeseed)	8469 and 8839
7	Johnston, J. and Cummings, R. (1991)	Control of Newcastle disease in village chickens with oral V4 vaccine	8334 and 8717
8	Ryland, G.J. (1991)	Long term storage of grain under plastic covers	8307
9	Chudleigh, P.D. (1991c)	Integrated use of insecticides in grain storage in the humid tropics	8309, 8609 and 8311
10	Chamala, S., Karan, V., Raman, K.V. and Gadewar, A.U. (1991)	An evaluation of the use and impact of the ACIAR book *Nutritional disorders of grain sorghum*	8207
11	Tisdell, C. (1991)	Culture of giant clams for food and for restocking tropical reefs	8332 and 8733
12	McKenney, D.W., Davis, J.S., Turnbull, J.W. and Searle, S.D. (1991)	The impact of Australian tree species research in China	8457 and 8848
	Menz, K.M. (1991)	Overview of Economic Assessments 1–12	