IMPACTS OF MUD CRAB HATCHERY TECHNOLOGY IN VIETNAM

ACIAR projects FIS/1992/017 and FIS/1999/076

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Foreword

Mud crab aquaculture has been practised in Southeast Asia for many years, based primarily on capture and fattening of juvenile crabs from the wild. There is an unmet demand for mud crabs and this has led to over-exploitation in many areas. Difficulties with obtaining wild caught juveniles for farming operations plus concerns of over-exploitation have led to major investment into research into hatchery techniques.

This report describes the benefit–cost analysis carried out to quantify the economic impacts in Vietnam from adoption of the mud crab hatchery technology developed by two ACIAR-funded projects. A qualitative assessment of the potential impact on poverty in Vietnam of the projects is also included. Vietnam has substantial natural potential for aquaculture development. The Vietnamese Government has recognised the potential importance of aquaculture for economic development, and has introduced policies to encourage the rapid development of aquaculture production.

The author concludes that the projects have been very successful, the key output being a mud crab hatchery innovation that is projected to break the constraint of the supply of crab seed to mud crab aquaculture farms. Governments in Vietnam have recognised the potential benefit from uptake of this technology and provided resources to promote development of a number of mud crab hatcheries. To date, 14 of these hatcheries have been established in Vietnam. Some longer-term implications for alternative crab farming potential in Australia are also considered.

Information from ACIAR's impact assessment reports is used to guide future research and development activities. While the main focus of these commissioned reports is measuring the dollar returns to agricultural research, emphasis is also given to analysing the impacts of projects on poverty reduction.

This report is Number 36 in ACIAR's Impact Assessment Series and is also available for free download at <www.aciar.gov.au>.

Peter Core
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Acknowledgments

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SUMMARY

Starting in 1995, ACIAR funded two related projects on mud crab aquaculture, namely FIS/1992/017 – Development of improved mud crab culture systems in the Philippines and Australia, and FIS/1999/076 – Development of leading centres for mud crab aquaculture in Indonesia and Vietnam. This report describes the benefit–cost analysis carried out to quantify the economic impacts in Vietnam from these two projects. In addition, their potential impact on poverty in Vietnam was assessed qualitatively.

The ultimate aim of the above projects was to overcome significant barriers to further development of mud crab aquaculture, and to optimise production conditions at all stages of the development of mud crabs. Two of the most important constraints to further development of the industry were identified to be the lack of reliable hatchery technology for production of juveniles to stock ponds, and low pond yields on mud crab aquaculture farms. The perceived need for reliable hatchery technology was also based on a belief that the traditional supply of wild-caught crab ‘seed’ would not be sustainable due to over-exploitation of wild crab stocks.

The primary output of the two ACIAR-funded projects on mud crabs has been the development of hatchery technology for commercial-scale production of crablets of the mud crab species *Scylla paramamosain*. A number of government and private hatcheries in Vietnam have started to use it to rear mud crablets, and uptake is expected to grow as knowledge diffuses about how to operate commercial-scale mud crab hatcheries. This innovation will enable significant and sustainable expansion of mud crab aquaculture in Vietnam, and possibly also in other producing countries.

Mud crab farmers benefit in several ways from stocking their pens with hatchery-reared mud crablets rather than wild-caught mud crablets. Mud crabs are aggressive animals, but cannibalism is reduced when ponds are stocked with hatchery-reared crablets that are uniform in size. Typically, hatchery-reared crablets also are disease-free, and generally healthier because they were raised in hygienic conditions and had suitable feed and shelter. Consequently, it has been shown in field observations and preliminary trials that it is possible to use higher stocking rates of hatchery-reared seed than for wild-caught seed, and to achieve faster growth rates and higher survival rates, so long as the seed is stocked into disease-free ponds.

It was estimated that the unit cost reductions attributable to uptake of the mud crab hatchery technology could be at least 20%, even if there are no benefits realised from higher growth rates. These productivity gains might double if farmers using hatchery seed could grow out three crops per year rather than up to two crops from wild seed. However, the potential benefits from higher growth rates of hatchery-reared crab seed were not included in the analysis because there is no evidence to date that mud crab aquaculture farms will adopt such systems on a widespread scale.

Specification of the counterfactual is a key part of any economic impact assessment study but, by definition, is hypothetical and necessarily subjective. No successful method for commercial-scale hatchery production of mud crab seed existed at the time when the ACIAR projects commenced, but its feasibility had been demonstrated in experiments, and hatchery technology did exist for other aquaculture species of crustaceans, such as shrimp. Nevertheless, the need to develop such an innovation had been recognised, and significant research into the feasibility of larval rearing of mud crabs had taken place before the inception of the ACIAR mud crab projects. Therefore, it was assumed that development of the innovation would have been funded by another organisation had ACIAR not funded the two assessed projects, but that the development of the innovation, and its adoption, would have been delayed by three years.

Given this assumption about the counterfactual scenario, the net present value of the ACIAR projects FIS/1992/017 and FIS/1999/076 was estimated to be A$3.46 million, the benefit–cost ratio 1.9, and the corresponding internal rate of return 16%. While these results are somewhat modest outcomes relative to the most successful research and development (R&D) projects, they still represent a very solid return on ACIAR's investment. Furthermore, relative to a 'without innovation' scenario, the net present value from development and uptake of the mud crab hatchery innovation was estimated to be A$25.4 million.

The sensitivity of the key measures to the assumed length of the lag to innovation development under the counterfactual scenario is tabulated below.

Assumed project start date for counterfactual scenario	Net present value	Benefit–cost ratio	Internal rate of return (%)
1998	A$3.46 million	1.92	16
2001	A$6.45 million	2.71	16
Never	A$25.4 million	7.74	16

The main beneficiaries of the development of the hatchery technology are predicted to be mud crab farmers and/or owners of ponds for semi-intensive and intensive aquaculture. While many of these people are poor in absolute terms, in the main they are not among the 'poorest of the poor' in Vietnam. Hence, the impact of enhanced incomes of crab farming households on poverty levels in Vietnam is unlikely to be significant because most such households already have incomes in the top quintile. Moreover, there may be some adverse impacts on employment opportunities for very poor landless people, so the poverty impacts of the projects are likely to be modest at best.

1 Introduction

Starting in 1995, ACIAR has funded two related projects on mud crab aquaculture: FIS/1992/017 – Development of improved mud crab culture systems in the Philippines and Australia; and FIS/1999/076 – Development of leading centres for mud crab aquaculture in Indonesia and Vietnam.

In a workshop at which he summarised these projects, Fielder (2004) wrote:

> ACIAR first became involved with aquaculture of mud crabs through project FIS/92/17 'Development of improved mud crab culture systems in the Philippines and Australia'. This project was completed and reviewed in 1998. The review panel considered that 'the research teams had identified and developed remedies for several bottlenecks in seed stock production of mud crabs'. However, some of the more exciting results came late in the project and needed verification. An 18-month extension was funded to enable this verification; produce a practical handbook based on project results; and to facilitate the transfer of research to semi-commercial crab production facilities in the Philippines. The review panel also considered that much research was still required before large-scale mud crab farming should be considered ... ACIAR has since funded a second crab program FIS/1999/076 'Development of Leading Centres for mud crab culture in Indonesia and Vietnam'.

In April 2004, ACIAR received a positive adoption assessment study of these projects undertaken by Dr Colin Shelley. The study identified mud crab hatchery technology as the key project output. The exceptional uptake in Vietnam of this process innovation was highlighted, as was the economic impacts that have followed due to aggressive government counterpart support.

Following receipt of the above report, ACIAR believed that there was sufficient evidence of economic impacts from these two mud crab aquaculture projects to initiate an ex-post impact assessment study. Economic Research Associates was commissioned to carry out a quantitative economic impact assessment of the returns to the Vietnamese and Australian economies from ACIAR's investment in FIS/1992/17 and FIS/1999/076.

1.1 Aquaculture in Vietnam

The estimated population of Vietnam in 2003 was 81 million people, of whom 74% live in rural areas. For most of the past two centuries, Vietnam had a turbulent history, and it is only quite recently that stable and peaceful conditions conducive to economic development have been firmly established. While the economy is still based mainly on subsistence agriculture, economic and social conditions for the majority of the Vietnamese population have improved considerably since the introduction of the *doi moi* policy of renovation during the past two decades.

While three-quarters of the landmass of 330,363 km^2 is mountainous, the remaining land area of Vietnam consists largely of rich alluvial plains. Most of the population lives in these coastal areas. Agriculture on the coastal plains is dominated by production from the fertile and highly productive flood plains of the Red River Delta and the Mekong River Delta. In addition, due to a very long coastline of 3,260 km, Vietnam has both significant marine fisheries, and substantial natural potential for aquacultural development. Early on, the Vietnamese Government recognised the potential importance of aquaculture for economic development, and introduced policies to encourage the rapid development of fish and shrimp aquaculture production. For nearly two decades, it has been actively developing aquaculture as well as its wild capture fisheries.

The success of these policies is illustrated in Table 1, which shows, for those provinces with more than 1,000 hectares of water surface, the growth in area developed for aquaculture during the past decade.

Table 1. Area of water surface for aquaculture by province[a] ('000 ha)

Region/province	1995	1996	1997	1988	1999	2000	2001	2002	2003[b]
Red River Delta									
Ha Noi	3	3	3	3	3	3	3	3	3
Hai Phong	12	14	13	13	13	13	14	9	15
Vinh Phuc	2	3	3	2	3	4	4	4	4
Ha Tay	8	7	7	7	7	7	7	8	8
Bac Ninh	3	3	3	3	3	3	3	3	4
Hai Duong	3	6	6	6	6	7	7	8	8
Hung Yen	2	4	3	3	3	3	4	4	4
Ha Nam	4	4	4	4	4	4	4	4	5
Nam Dinh	10	11	10	10	11	12	12	13	13
Thai Binh	9	9	8	8	10	9	10	10	8
Ninh Binh	4	4	4	4	4	4	4	6	6
Region total	*59*	*66*	*63*	*63*	*67*	*68*	*71*	*72*	*77*
North East									
Tuyen Quang	1	1	1	1	1	1	1	2	2
Yen Bai	2	2	2	2	2	2	2	2	2
Thai Nguyen	4	7	3	4	2	2	2	3	5
Phu Tho	3	4	4	3	4	5	5	7	7
Bac Giang	4	4	4	4	3	3	3	3	4
Quang Ninh	8	15	14	14	14	13	14	15	17
Region total	*23*	*34*	*29*	*31*	*29*	*30*	*31*	*36*	*40*

Table 1. (cont'd) Area of water surface for aquaculture by province[a] ('000 ha)

Region/province	1995	1996	1997	1988	1999	2000	2001	2002	2003[b]
North West	*3*	*3*	*3*	*3*	*3*	*4*	*4*	*4*	*5*
North Central Coast									
Thanh Hoa	17	13	13	14	15	11	10	12	12
Nghe An	5	9	10	10	10	12	13	14	14
Ha Tinh	2	2	3	3	2	3	3	4	4
Quang Binh	1	1	1	1	1	1	2	2	3
Thua Thien–Hue	1	2	2	2	2	3	4	4	4
Region total	*27*	*28*	*29*	*30*	*32*	*31*	*33*	36	*38*
South Central Coast									
Quang Nam	4	4	4	5	5	5	5	6	6
Binh Dinh	4	3	3	3	3	4	4	4	4
Phu Yen	1	1	1	2	3	3	3	3	3
Khanh Hoa	4	4	4	7	7	5	5	6	6
Region total	*14*	*13*	*14*	*18*	*19*	*17*	*19*	*20*	*20*
Central Highlands	*4*	*4*	*5*	*5*	*5*	*5*	*6*	*6*	*6*
South East									
Ho Chi Minh City	3	3	3	3	4	4	5	6	7
Ninh Thuan	1	1	0	0	1	1	1	2	2
Dong Nai	27	26	26	26	28	30	30	36	40
Ba Ria–Vung Tau	3	3	3	2	3	4	5	6	5
Region total	*35*	*34*	*34*	*34*	*37*	*42*	*44*	*53*	*58*
Mekong River Delta									
Long An	2	2	2	3	3	3	7	7	9
Dong Thap	3	1	1	2	2	2	2	3	3
An Giang	1	1	1	1	1	1	1	2	2
Tien Giang	10	9	9	9	10	8	9	10	11
Vinh Long	1	1	1	1	1	1	1	1	2
Ben Tre	25	25	21	23	28	29	26	36	37
Kien Giang	13	19	25	27	29	35	43	50	63
Can Tho	8	10	11	13	12	13	14	17	17
Tra Vinh	23	25	30	35	36	53	55	25	26
Soc Trang	3	24	28	26	31	41	53	48	57
Bac Lieu	41	43	42	40	39	54	83	101	111
Ca Mau	160	155	154	162	141	204	254	271	278
Region total	289	317	327	342	333	445	547	570	615
Whole country	**454**	**499**	**504**	**525**	**525**	**642**	**755**	**798**	**858**

[a] Provinces with less than 1,000 ha of aquaculture area not shown.
[b] Preliminary estimate.
Source: General Statistics Office of Vietnam at <http://www.gso.gov.vn>.

The two most-striking features of the data in Table 1 are the rapid growth in area of water surface for aquaculture from 454,000 ha in 1995 to 858,000 ha in 2003, and the overwhelming importance of aquaculture in the Mekong River Delta, which has grown from 64% of total area in 1995 to 72% in 2003.

According to Tung et al. (2004), aquaculture produced 976,100 tonnes (t) of aquatic products from 955,000 ha of area (freshwater farming covered

425,000 ha) in 2002. The dramatic growth in output from all types of aquaculture is illustrated in Table 2, which also provides some indication of the relative importance of the main categories of aquaculture production in Vietnam. Mud crab aquaculture, which is the topic of this report, falls under the heading of ‘Other’ aquaculture production.

Table 2. Aquaculture production in Vietnam (’000 t)

Year	Fish	Shrimp	Other[a]	Total
1990	129.3	32.7	0.1	162.1
1991	132.3	35.8	0.0	168.1
1992	135.5	37.4	0.0	172.9
1993	139.7	39.4	9.0	188.1
1994	178.4	44.7	121.0	344.1
1995	209.1	55.3	124.7	389.1
1996	256.0	49.7	117.3	423.0
1997	279.3	49.3	86.0	414.6
1998	285.6	54.9	84.5	425.0
1999	336.0	57.5	87.3	480.8
2000	391.1	93.5	105.0	589.6
2001	421.0	154.9	134.0	709.9
2002	486.4	186.2	172.2	844.8
2003 (preliminary)	573.4	223.8	168.9	966.1

[a] Includes mud crabs.
Source: General Statistics Office of Vietnam at <http://www.gso.gov.vn>.

1.2 Contribution of aquaculture to economic development

The Vietnamese economy has been growing at a high rate of over 7% per annum in recent years, and has achieved significant reductions in poverty levels over the past 10 years. Tung et al. (2004) note that the incidence of poverty in Vietnam as measured by the international poverty line has been reduced from 37.4% in 1998 to 28.9% in 2002, and that access to basic services like electricity, clean water, health care and education has improved substantially, especially in rural and remote mountainous areas. However, Vietnam is still a very poor country with a high level of absolute poverty. For instance, annual GDP was only US$553.27 in 2003 (UNDP website at <http://www.undp.org.vn/undp/fact/base.htm>). Moreover, the disparity between urban and rural areas is large and growing, and 90% of the poor live in rural areas.

The aquaculture sector was selected by the Government of Vietnam as one of the priorities for rural economic diversification and development. There are millions of inland aquaculture farming and fishing households, and about three million people are employed in the fisheries sector in Vietnam. Tung et al. (2004) note that approximately 80% of households in coastal communities generate their income by fishery activities. Therefore, aquaculture activities are crucial for economic growth in rural areas. The strategy for Sustainable Aquaculture for Poverty Alleviation (SAPA) was designed by the Ministry of Fisheries (MOFI) as the poverty-focused direction for aquaculture development in Vietnam (SAPA 2001). The primary aim of SAPA is to improve the living standards of poorer groups through the development of aquaculture.

According to the Ministry of Fisheries, total aquaculture production was 1,105,300 t in 2003. Many farmers have benefited from opportunities to diversify their production and improve their living standard. Tung et. al. (2004) note that fish ponds are increasingly common in Vietnam, and that 15% of rural households had at least one pond in 2002. Many poor households in coastal regions have managed to escape from poverty by capturing these new income-generating opportunities.

1.3 Scope of impact assessment study

This report describes the benefit–cost analysis carried out to quantify the economic impacts in Vietnam from adoption of the mud crab hatchery technology developed by the two ACIAR-funded mud crab projects. A qualitative assessment of the potential impact on poverty in Vietnam of these mud crab research projects is also included.

By way of background, some salient features of mud crabs and the statistics available on production in the Indo-Pacific region are reviewed in the next section. The variety of ways in which mud crabs are farmed in Vietnam is also described in this section.

Section three provides details on the aims, costs, and outputs of the two mud crab projects. In particular, these outputs include commercial-scale hatchery technology for production of mud crab seed, which was the key process innovation developed during the original project and promoted during the follow-up project. In addition, other capacity-building outputs, such as scientific publications and extension activities (e.g. training courses, seminars) generated by these projects are documented.

In section four, the potential benefits from uptake of the mud crab hatchery technology in Vietnam are discussed, followed by a review of the prospects of spill-overs to other countries in the region from this technology, and the reasons for the lack of realised impacts in Australia to date. Next, issues in scenario development are discussed. In particular, an explanation is provided of the need to draw a distinction between with and without innovation scenarios, and the 'without R&D' and 'with R&D' scenarios when the impact of the research projects is to bring forward in time the development and uptake of the innovation. Various scenarios are then developed, and the 'with R&D scenario' and the counterfactual 'without R&D' scenario are specified.

The potential increase in economic returns for semi-intensive and intensive grow-out of mud crabs from seeding their ponds with hatchery-raised crablets rather than wild-caught crablets is estimated. The evidence available on current and projected adoption of hatchery-supplied crablets by mud crab aquaculture farms in Vietnam is then reviewed. A qualitative assessment of the poverty impacts of the research makes up the last part of this section.

In section five, the economic impact of adoption of mud crab hatchery technology on rent generation from mud crab aquaculture in Vietnam is estimated. The above elements are then consolidated into a benefit–cost analysis, and the benefit–cost ratio and internal rate of return measures are reported. The findings of some sensitivity analyses of the results are reported.

Section six contains the conclusions of this economic impact assessment study.

2 BACKGROUND

2.1 Mud crabs

Several species of the genus *Scylla* are known collectively as mud crabs, Indo-Pacific swamp crabs, or mangrove crabs. In the wild, they inhabit tropical to warm-temperate zone mangrove swamps and nearby tidal muddy habitats throughout the Pacific and Indian ocean regions. In Vietnam, *Scylla paramamosain* is the most prevalent species used in mud crab aquaculture farms. In Australia, all of the effort to develop an aquaculture industry is focused on *S. serrata*, which also dominates the wild catch.

In many countries, mud crabs are highly valued for their size, high meat yield and the delicate flavour of their flesh. Furthermore, they are easy to keep alive for several days, as long as they are kept in cool and moist conditions, and thus can be transported without refrigeration or sophisticated facilities. As a result, mud crabs, and especially gravid females (also known as 'egg crabs'), bring high prices in markets throughout the region (Keenan 1992). Capture of wild crabs is an important source of income for small-scale fishers throughout the Asia–Pacific region. They are easily caught using very simple traps or nets, and form the basis of small but important inshore fisheries for many coastal communities.

Exploitation of the world's mud crabs has increased dramatically over the past 30 years. The latest data from FAO (FAO FIGIS database at <http://www.fao.org/figis/servlet/static?>) show that production has risen rapidly in many countries in the Asian region. Nevertheless, demand for mud crabs has exceeded supply from wild-catch fisheries, and there is emerging evidence that over-exploitation of the mud crab is also starting to affect production in several Asian countries. In some long-developed fisheries, there has been a gradual decline in production in recent years.

Mud crabs are hardy animals that are quite easy to farm as they can withstand salinity fluctuations and low oxygen levels, and are tolerant of some of the diseases that can devastate cultured shrimp. Crab aquaculture probably first developed in China about 100 years ago, to counter a shortfall in supply from the wild (Keenan 1992). In other countries, mud crab aquaculture is still a novel industry, and has developed much more recently than the culture of other aquaculture species, such as shrimp, fish and algae. Traditionally, mud crab farming has been a small-scale activity throughout Southeast Asia. In Taiwan, the Philippines, Malaysia, Thailand, India and Sri Lanka, *Scylla* species have been farmed for only the past 2–3 decades. In Vietnam, mud crab farming has been widespread for only about the past 10 years.

Mud crab farming probably evolved from fishermen retaining small numbers of undersized crabs in order to increase their market value. More recently, various land-based grow-out systems of aquaculture for mud crabs have evolved in several Asian countries. The diverse techniques used to farm crabs are similar to the range of methods used for shrimp aquaculture, and polyculture systems in which two or more aquatic species are raised together are quite common.

FAO statistics (Table 3) show that crab aquaculture has been well-established in a number of countries in the Indo-Pacific region for the past two or more decades. FAO defines aquaculture as farming where ‘Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated’. There are obvious anomalies in these statistics, including, notably, the absence of statistics on aquaculture production of mud crabs in Vietnam, presumably because these are not collected regularly.

Table 3. FAO production figures (tonnes) for Indo-Pacific swamp crab aquaculture

Country	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Australia	1	0	0	0	0	44	44	0	0	0	0
Indonesia	2,605	1,442	2,315	1,906	1,339	5,176	866	5,143	5,126	3,879	9,039
Malaysia	71	296	331	623	381	277	231	188	225	219	311
Mauritius	3	3	5	5	4	2	4	3	1	2	1
Philippines	2,765	5,653	4,085	2,782	2,463	3,759	4,033	4,826	4,968	4,608	4,747
Singapore	284	415	355	342	353	215	45	78	86	75	93
Sri Lanka	0	0	0	0	0	0	0	0	0	0	12
Taiwan	930	1,350	1,257	1,526	797	430	796	381	315	423	239
Thailand	39	25	25	45	132	115	19	9	10	10	10
Total	6,698	9,184	8,373	7,229	5,469	10,018	6,038	10,628	10,731	9,216	14,452

Source: FAO FIGIS database at <http://www.fao.org/figis/servlet/static?>.

2.2 Aquaculture of mud crabs in Vietnam

In addition to harvesting wild stock, mud crabs are now being farmed in many coastal provinces in Vietnam, including Quang Ninh, Hai Phong, Thanh Hoa, Ninh Binh, Nghe An, Thua Thien–Hue, Ba Ria–Vung Tau, Ho Chi Minh City, Ben Tre, Tra Vinh, Soc Trang, Minh Hai, Kien Giang and Bac Lieu.

It is difficult to know how many people participate in this industry. Apparently, no formal surveys have been conducted, there are no known official statistics, and crab farming is typically undertaken together with other activities, such as shrimp and/or fish aquaculture, other primary production such as rice growing, or even as a sideline to paid employment.

Various methods for crab aquaculture have been developed to suit the diverse conditions in different provinces. In broad terms, there are two principal kinds of culture procedures, namely fattening wild-caught crabs that are more or less of a marketable size, but with a low flesh content (so called ‘empty’ crabs), and grow-out of immature seed crabs.

Fattening wild-caught ‘empty’ crabs by stocking them in ponds or in small enclosures in swamps or rivers, and feeding them for 15–40 days to reach marketable size of 300–800 g liveweight, is a long-established activity that can be profitable. It can also be a risky one, as the costs of supplemental feeding are considerable, and high mortalities are possible due to cannibalism and/or disease. Moreover, there may be limited scope for further expansion of crab fattening due to its reliance on wild crab stocks that are claimed to be fully exploited. As this form of mud crab aquaculture will not benefit from increasing availability of hatchery-reared crab seed, it will not be discussed further.

Another form of specialised mud crab aquaculture that currently caters for only a niche market, is the production of soft-shell crabs: small crabs without claws are fed for 15–20 days until they moult and reach market weight of 50–120 g. If the necessary infrastructure can be developed to market this product internationally, the scope for expansion of mud crab aquaculture in Vietnam could be enormous. For the time being though, it is of minor importance, and so it too will be ignored in the remainder of this report.

Grow-out of juvenile crabs to market size is the most prevalent form of crab aquaculture, and has considerable growth potential, so long as the dependence on wild-caught crablets for seed can be broken. In the longer term, development of improved methods of refrigeration for long-term storage and transport will further expand the potential market. In the meantime, the market for live crabs in the region is already considerable, and demand from export markets such as China is likely to grow rapidly as logistic and trade barriers are surmounted.

While pond-based grow-out of juvenile crabs is usually a quite small-scale activity, it has grown rapidly over the past decade or so, to the point where it is now a significant, albeit still small industry in many coastal provinces.

Table 4 gives the sole set of official statistics on crab aquaculture area and production in Vietnam in 2004. The statistics cover both mud crabs and blue swimmer crabs, and were collated by the Vietnamese Ministry of Fisheries from reports of provincial fishery departments.

Table 4. Department of Fisheries statistics on crab aquaculture area and production in Vietnam in 2004

Region	Province	Area (ha)	Production (t)	Yield (kg/ha)
Red River Delta	Quang Ninh	1,200		
	Hai Phong	1,560	1,650	
	Thai Binh			
	Nam Dinh			
	Ninh Binh	1,600	1,005	
Region total		*4,360*	*2,655*	*609*
North Central Coast	Thanh Hoa	2,280	970	
	Nghe An	2		
	Ha Tinh		200	
	Quang Binh	200	110	
	Quang Tri	15	20	
	TT Hue		82	
Region total		*2,497*	*1,382*	*553*
South Central Coast	Da Nang			
	Quang Nam	400	135	
	Quang Ngai			
	Binh Dinh	131	130	
	Phu Yen			
	Khanh Hoa			
	Ninh Thuân	9	5	
	Binh Thuân			
Region total		*540*	*270*	*500*
South East Coast		*0*	*0*	
Mekong River Delta	Long An	25	250	
	Tien Giang			
	Ben Tre	300	637	
	Tra Vinh	3,500	1,196	
	Soc Trang	436		
	Bac Lieu		3,466	
	Ca Mau			
	Kien Giang	181	170	
	Can Tho			
Region total		*4,442*	*5,719*	*1,287*
Country total		**11,839**	**10,026**	**847**

Source: MOFI (2005)

Clearly, the areas devoted to aquaculture, and the resulting levels of production in Table 4 underestimate actual quantities by a considerable margin. Moreover, there are obvious gaps in the data. Some provinces reported area, but not production, while for other provinces, the reverse was the case. Perhaps less obvious is the lack of either area or production data for some provinces (e.g. Thai Binh, Ca Mau and Can Tho), where there is evidence of significant mud crab aquaculture. For instance, in a case study of mud crab aquaculture in Thai Binh province, Overton and Macintosh (2001) found that '…70% of families in Thuy Hai commune (mainly former soldiers and fishermen) farm mud crabs in coastal ponds in Thai Binh Province, Vietnam. Even as a spare time activity, crab farming helps boost income significantly'. In addition, the author saw mud crab aquaculture in Ca Mau, Bac Lieu and Can Tho provinces during a recent field trip to Vietnam.

Another puzzle is the recorded level of yield, which is appreciably higher than all of the anecdotal evidence collected during a field trip to Vietnam. One possible explanation is that much of the area reported in Table 4 was used to produce two crops of crabs per year, and so is best interpreted as yield per hectare per annum, rather than as yield per hectare per crop.
In the absence of other information, it can only be presumed that the relative proportion of shrimp aquaculture classified as intensive and semi-intensive farming (8%), and as extensive and improved extensive farming (92%), is indicative of the relative proportions for crab aquaculture.

Extensive farming is defined as the culture of wild crab seed at naturally occurring density in the water supply, total reliance on naturally occurring food, and no management of water, environment, or disease. The definition of improved extensive farming is the same as for extensive farming, except that some purchased crab seed may be added to naturally occurring wild crab seed to achieve low-to-moderate stocking rates, some supplementary feeding may be undertaken, and intermediate management of water, environmental factors and disease may be practised. Intensive farming is defined as the culture of purchased crab seed in ponds stocked at high density, more or less complete reliance on pelleted or other artificial food to enable rapid growth, and a relatively high level of water, environmental and disease management.

The total potential area of semi-intensive and intensive mud crab culture in Vietnam has been estimated to be well in excess of 40,000 ha (Nguyen Co Thach, pers. comm.). Three provinces, namely Quang Ninh, Minh Hai, and Hai Phong, account for about 35,000 ha. In addition, there are further very large areas of ponds in a number of other provinces, including especially those in the Mekong River Delta that initially were developed for shrimp farming but are also suitable for expansion of intensive mud crab farming given the problems now confronting shrimp farming.

Extensive grow-out systems

The most basic type of extensive farming systems for growing-out mud crabs are based on enclosures in mangrove swamps. These low-input systems, which are quite widespread, include intertidal mangrove pens and extensive shallow mangrove silviculture ponds that utilise wild seed stock and do not rely on any supplemental feeding.

More common are various pond-based systems. At one extreme are extensive and very low input systems, sometimes sited in big ponds that can be as large as 50 ha. Stocking rates typically are very low (0.05/m^2) in these low-input systems, and no supplemental feeding is involved. The only source of crab seed is wild crablets that flow in with the brackish water used to flood the pond. On occasion, this supply of seed may be supplemented by some additional small crablets purchased from fishermen. Polyculture, in which other aquatic products such as wild shrimp and fish are raised with crabs, is common in these extensive systems.

These systems can be quite profitable. For instance, Johnston and Keenan (1999) describe a low-input system common in the lower Mekong Delta. Farmers purchase wild-caught crablets from fishermen at prices ranging from US$2.00/kg for 25–50 g crablets from November to March when crab seed are naturally abundant, to US$3.00–4.00/kg for 80–100 g crablets during June–July when they are relatively scarce. Crabs are stocked at low stocking rates of about 0.05 crabs/m^2 into ponds that are bounded by channels open to the mangrove forests and have intermittent tidal exchange via the farm sluice gate. The crabs rely on natural food supplies from the forest to grow for 3–6 months, by which time they reach a marketable size of 300–800 g liveweight.

In the coastal areas of the lower Mekong Delta, rice has been the traditional crop in the wet season, when large volumes of fresh water keep salinity levels low. During the dry season, rice and other crops cannot be grown because the extensive tidal incursion of seawater increases the salinity level in rice fields. For several decades, it has been common practice for rice farmers in the salinity-affected areas to flood their fields in the dry season with brackish water containing naturally occurring shrimp and/or crab seed. Adoption of this rice–shrimp system in the Mekong Delta has grown substantially over the past two decades, and about 40,000 ha was under production in 2000. For Vietnamese shrimp farmers, grow-out of mud crab seed, which also occurs naturally in brackish water used to flood the aquaculture ponds, can be an important way to diversify income and to insure the somewhat higher return from shrimp farming against the considerable risks involved, such as all stock dying from diseases such as white spot.

Improved extensive systems are normally still based on collecting juvenile crabs from the wild, and usually stocking ponds with wild-trapped seed crabs of 30–50 mm carapace width at densities of about one crab per 5–10 m^2. Although it also is common to rely solely on natural feed, crabs may be fed trash fish, small crustaceans and molluscs. It takes 4–6 months for crabs to grow to a commercial size of 300–500 g, and yields are usually about 200–300 kg/ha/crop.

A common system in some coastal areas is to establish aquaculture ponds just inshore of natural or planted mangrove swamps. These act as a buffer zone against typhoons, as well as providing habitat for juvenile mud crabs that are a plentiful source of seed with which to stock crab ponds each season. The tidal water exchange maintains good quality water in the ponds, which have a simple sluice gate for water exchange, and are surrounded by some form of fencing to prevent the crabs from escaping. Over the years, coastal aquaculture has gradually developed to the stage where some of these formerly large, extensive ponds have been subdivided into smaller, semi-intensive operations.

Intensive grow-out systems

Less common are intensive aquaculture systems in which mud crabs are grown-out in earthen ponds, often converted from shrimp aquaculture, that can be as small as 1,200 m^2. These ponds are artificially stocked at higher stocking rates (1–2/m^2) with purchased crablets. Depending on the stocking rate, any naturally occurring feed is supplemented to a greater or lesser extent with purchased feed, usually low-value ‘trash’ fish or shellfish species. Typically, crabs are fed for 4–6 months to reach market size of 300–500 g. Yields per hectare are a good deal higher than obtained in extensive systems and, under ideal conditions, can be as high as 1.5–2.0 t/ha for each crop, although yields of about 1 t/ha are more common.

In the northern coastal provinces of the Red River Delta, most intensive ponds are stocked in August–September, after the typhoon season. The crabs are harvested in January, and the pond then may be used to rear a crop of black tiger shrimp (*Penaeus monodon*). Alternatively, a second crop of crabs could be grown, or the pond could be left unstocked until the following season’s crab crop.

A variant on these intensive systems is a form of cage culture described by Johnston and Keenan (1999), in which crabs are fed in large (2 × 1 × 1 m) wooden enclosures that are partially submerged within a pond. These provide considerable protection from predators, and allow the crabs to be monitored closely so that they can be harvested at the optimal time.

Crab seed supply

Until recently, all crab aquaculture operations in Vietnam relied on crab seed collected from the wild to stock farm ponds. However, this source of seed is finite, and Allan and Fiedler (2004) have expressed concerns that further expansion of mud crab aquaculture will need an alternative source of supply, as the maximum sustainable yield from wild stocks has been reached or even exceeded in some locations. Hatchery-reared mud crab seed is an alternative source of seed, and is the obvious solution to this supply constraint if the potential for expansion of mud crab aquaculture is to be realised.

Apparently, sea-ranching of mud crabs in Japan did employ this source of seed more than 10 years ago, but seed production was not sufficiently reliable. Before the ACIAR-funded projects, larval rearing of mud crab seed for stocking into aquaculture farms was not commercially viable.

The Vietnamese Government has recognised that crab farming has the potential to provide higher and stable incomes for poor communities throughout the coastal areas of Vietnam. Further development of research facilities to enable training courses on artificial production of crab seed is now a priority of the Vietnamese Government, and funding of approximately 1.5 billion Vietnam dong (VND) (equivalent to US$100,000) has been committed to expand development of mud crab hatchery technology. The ACIAR-funded project was initiated to provide a consistent source of large numbers of crab seed in Vietnam from commercial-scale production, by training hatchery operators in techniques to scale-up experimental seed production.

3 DETAILS OF MUD CRAB AQUACULTURE PROJECTS

3.1 Background

In the second half of the 20th century there was a substantial expansion of many types of aquaculture. This included farming mud crabs, and government and aid agencies started to pay increasing attention to the potential for mud crab culture, including both grow-out and fattening operations, to provide an additional source of income in coastal communities in Southeast Asia. By the 1980s and 1990s, there was widespread interest in the further development of mud crab culture in the Indo-Pacific countries, including Australia. In collaboration with counterparts from the Philippines, Clive Keenan (QDPIF) and Colin Shelley (then at the Northern Territory Department of Primary Industry and Fisheries; NTDPIF) developed a proposal for ACIAR to fund a project to overcome significant barriers to further development of mud crab aquaculture.

The lack of reliable hatchery technology for production of juveniles to stock ponds, and the need to improve pond yield, had been identified previously as two of the most important constraints to further development of the industry. The perceived need for reliable hatchery technology was based on a belief that the traditional supply of wild-caught crab seed would:

- shrink because of the loss of mangrove forests
- not be sustainable due to over-exploitation of wild crab stocks
- not be sufficient to support expanded production to meet increased demand.

3.2 Project FIS/1992/017

Starting in 1995, ACIAR funded a project entitled FIS/1992/017 – Development of improved mud crab culture systems in the Philippines and Australia, with the Bribie Island Aquaculture Research Centre (BIARC) of QDPIF as the commissioned organisation to manage the project. In the Philippines, the South-East Asian Fisheries Development Centre (SEAFDEC) and the University of the Philippines in the Visayas (UPV) were the developing country collaborators, and the NTDPIF also was involved. The project commenced at the beginning of 1995, and concluded at the end of 1999. Initially funded for 3 years, the project was extended for 12 months because positive results from the Philippines came only toward the end of the initial 3-year period.

This large bilateral project was designed to develop technology for hatchery and nursery production of mud crab, and to identify ways to increase pond productivity in the grow-out phase. The stated overall project objectives were to optimise the conditions for the production of mud crabs at all stages of their development in a number of research trials, and to have these improved methodologies adopted by mud crab farmers. Extension funding supported a training course in mud crab hatchery production.

Specific project objectives were:

- to develop mud crab broodstock maturation systems which promote consistent spawning and hatching of good-quality larvae
- to develop improved feeding regimens and water management systems allowing consistent and increased survival of larvae to crab stage
- to develop optimal nursery culture techniques for the rearing of megalopa larvae to juvenile crabs
- to increase pond productivity by increasing stocking density, and improving feeding and water management regimens.

The project achieved all of these objectives. Nevertheless, by the completion of the original project, it was apparent that there was little immediate prospect of widespread uptake in the Philippines of the mud crab hatchery technology developed by the project. On the other hand, both Vietnam and Indonesia had expressed interest in the technology. Vietnam in particular had identified mud crab aquaculture as a priority industry for economic development. By then, considerable interest and expertise in mud crab hatchery technology was available from the original project, and ACIAR recognised the potential to commission a further small project to facilitate the uptake of this innovation.

3.3 Project FIS/1999/076

ACIAR subsequently funded a follow-up project, FIS/1999/076 – Development of leading centres for mud crab aquaculture in Indonesia and Vietnam, for 2 years from April 2000. The main objective of this small project was to facilitate the timely transfer of the mud crab hatchery technology and improved mud crab farming methods from FIS/92/17 by developing 'Lead centres for crab aquaculture' at key institutions undertaking nationally funded mud crab research programs in Vietnam and Indonesia.

Specific project objectives were:

- to upgrade hatchery facilities and staff capability at nominated lead centres in Indonesia and Vietnam
- to adapt and transfer technology to local conditions and species
- to strengthen extension capability and farmer support services
- to produce a hatchery manual for *Scylla* species.

Due to this project, the Research Institute for Aquaculture No. 3 (RIA3) in Vietnam, and more recently RIA2, have become lead centres for mud crab aquaculture in Vietnam.

3.4 Project costs

The nominal costs of the projects evaluated in this impact assessment study were taken from budgets in project documents, supplemented by estimates of expenditure by the Government of Vietnam provided by staff of the Department of Fisheries. These estimates are set out in Table 5.

Table 5. R&D costs (nominal A$) by year and institution for the development of mud crab hatchery technology in Vietnam

Year	Project	ACIAR[a]	QDPIF R&D	NTDPIF	SEAFDC and UPV	RIA3[b]	GRSCF
1995	FIS/1992/017	115,702	91,008	76,442	85,050		
1996	FIS/1992/017	228,140	182,016	152,885	167,800		
1997	FIS/1992/017	211,894	182,016	63,064	178,500		
1998	FIS/1992/017	112,518	91,008	43,064	85,050		
1999						50,000	
2000	FIS/1999/076	37,815	20,081			4,167	1,667
2001	FIS/1999/076	37,815	20,081			4,167	1,667
2002	FIS/1999/076	38,590	20,081			4,167	1,667
2003						6,000	
2004						6,000	
2005						6,000	

[a] ACIAR = Australian Centre for International Agricultural Research; QDPIF = Queensland Department of Primary Industries and Fisheries; NTDPIF = Northern Territory Department of Primary Industries and Fisheries; UPV = University of the Philippines in the Visayas; SEADFC = South-east Asian Fisheries Development Centre, Philippines; RIA3 = Research Institute for Aquaculture No. 3 in Vietnam; GRSCF = Gondol Research Station for Coastal Fisheries, Indonesia.

[b] RIA3 costs include capital cost for research hatchery and ongoing extension costs as well as contribution to project R&D costs.

In addition to direct project R&D costs, other costs were incurred for the establishment of a mud crab hatchery at RIA3, and for training activities to promote the uptake of hatchery-reared crab seed by provincial government hatcheries and by mud crab aquaculture farms. For instance, the Government of Hai Phong Province contributed a substantial amount of land to a combined shrimp and crab farming and hatchery production venture owned by government, but run as a commercial operation. In addition, staff from government Research Institutes of Aquaculture (RIAs) have trained government and private hatchery staff to use the technology developed by the ACIAR-funded projects. These costs have not been documented, and assumptions about them had to be based on discussions with government staff in Vietnam. Estimated nominal costs from 1995 to 2005 totalled A$2.326 million.

3.5 Project outputs

The following were the principal outputs from ACIAR-funded project FIS/1992/017 – Development of improved mud crab culture systems in the Philippines and Australia.

- New knowledge about practical methods for effective broodstock management, larval rearing, and nursery practice to raise crablets that will enable consistent and increased survival of larvae to juvenile crab stage. These systems provide the technological basis for the development of commercial-scale and cost-effective mud crab hatcheries capable of producing large numbers of quality seedstock for mud crab aquaculture farms.

- The contributions of the projects to scientific knowledge about hatching, rearing and farming mud crabs have been documented in an extensive range of publications. ACIAR Proceedings No. 78 (Keenan and Blackshaw 1999), for example, contains reports on scientific findings about successful broodstock maturation systems for consistent spawning and hatching of larvae; feeding regimes and water management systems for increased larval survival to crab stage; optimal nursery culture techniques to rear juvenile crabs from megalopa stage larvae; and stocking density and improved feeding trials to increase pond productivity. A wide network of collaborators also reported on diverse methods of mud crab aquaculture in a range of countries, as well as on the genetics and ecology of various species of *Scylla*.

- SEAFDEC and UPV produced publications for the Philippine industry on how to grow out mud crabs to increase pond productivity.

These outputs were complemented by economic models developed for both the hatchery/nursery and grow-out components of mud crabs. New technical advice to crab farmers on best techniques to rear crablets and how to grow out mud crabs is contained in handbooks produced as part of the project.

- From an environmental perspective, pen culture guidelines were developed for farming crabs in mangroves. Papers were published on pen design, and on how to use various techniques to build pens in different types of mangrove forests. This work demonstrated that farming of mud crabs in pens in mangrove areas can be a benign, environmentally sustainable activity, and can reduce pressure on the wild fishery.

- Capacity development included training several postgraduate students. Another measure of the capacity-building impact of the project is that staff at SEAFDEC are now recognised throughout the region as experts in the field of mud crab culture. An international network of researchers working on crab culture was established to foster the exchange of new ideas and results from this and related R&D, and to maximise both the dissemination of project results and the capture by project participants of significant new knowledge discovered by other research teams. Graduates from training courses in mud crab hatchery production run by SEAFDEC increased human resource capacity in mud crab aquaculture, and ensured that new information on hatchery production, as well as technical advice on the best techniques to rear crablets and grow-out mud crabs, was available for farmers in the Philippines. SEAFDEC also uses its publications in training courses for local and overseas participants.

- As a direct result of the ACIAR-funded research, several projects funded by other agencies to prove the viability of different types of mud crab production were initiated. The projects included European Union (EU) funded trials in both the Philippines and Vietnam on hatchery seed production, mangrove pen grow-out, stock enhancement and mud crab diseases; the German Technical Cooperation Agency (GTZ) funded a farmer trial of pen culture of crabs to determine its economic potential; and a Philippines bank funded a project to demonstrate mud crab farming techniques to the private sector. The Bureau of Fisheries and Aquatic Resources (BFAR) also supported ongoing trials of mud crab culture in the Philippines, using research outcomes from the project, and training courses in mud crab hatchery production have been offered by both UPV and SEAFDEC.

The results from the ACIAR-funded research showed that, when farmers were provided with hatchery-reared crab seed, the growth of the crablets was rapid due to relative uniformity in size, and a consequent relatively high survival rate compared to stocking ponds with wild seed stock. When they were able to obtain hatchery-reared crab seed, farmers reportedly used hatchery-produced crablets with positive economic results.

Hatchery production has been limited and, because they are under-resourced, neither of the two main government hatcheries has been able to supply commercial quantities. However, there is little evident demand for substantial quantities of crab seed in the Philippines, and the vast majority of farmers continue to use wild fishery sourced seed stock. High transport costs, inefficient bureaucracy and a lack of financial support from government have been cited as possible reasons for lack of uptake of hatchery-reared crab seed, and the consequent slow growth of mud crab culture.

Notwithstanding this disappointing outcome, ACIAR made a further small investment in FIS/1999/076 which enabled knowledge about the successful project outputs from FIS/1992/017 to spill over to other countries in the region, including, most notably, Vietnam.

This follow-up project supported nationally coordinated mud crab research and extension in Vietnam and Indonesia. The capacity of each partner institution to provide quality extension assistance to government fisheries departments and industry was enhanced in two ways;

- key project staff from the three partners gained valuable knowledge and experience by collaborating on larval culture at different facilities using alternative hatchery methodologies and culture of other *Scylla* species
- facilities at the partner institutes were upgraded to provide industry-relevant training and to allow quality R&D. Within the project, testing and upgrading of some elements of the larval rearing regime, including live feeds and water sterilisation, led to improvement to the methods being used.

The principal outputs from ACIAR-funded project FIS/1999/076 – Development of leading centres for mud crab aquaculture in Indonesia and Vietnam are:

- core staff at partner country institutions have enhanced knowledge and experience of mud crab seed production

- the staff at RIA3 in Vietnam established a countrywide reputation for being the key centre for mud crab production technology information
- designs and specifications are now available, together with advice and assistance from personnel at the leading centres, for construction and operation of mud crab hatcheries
- 14 commercial scale mud crab hatchery facilities have been constructed in Vietnam using local expertise developed during the project
- some mud crab aquaculture farmers in Vietnam are purchasing hatchery-reared crab seed in preference to wild-caught crab seed,
- training workshops for provincial fisheries staff and farmers held at RIA3 and the Gondol Research Institute for Mariculture in Indonesia were successful in demonstrating all aspects of the hatchery process for mud crabs
- in Vietnam, extension activities stimulated the commercial application of mud crab hatchery technology, and attracted significant government funding for the development of commercial crab hatcheries
- ongoing contact between staff at the centres and industry participants has stimulated feedback on further research and extension needs of the mud crab farmers
- international communication has improved understanding and stimulated feedback on further research and extension needs of the mud crab aquaculture industry
- an international mud crab hatchery manual has been produced.

4 ECONOMIC IMPACTS FROM ADOPTION OF MUD CRAB HATCHERY TECHNOLOGY

This section starts with a discussion of the potential benefits in Vietnam from adoption of the mud crab hatchery technology developed by the two R&D projects being assessed in this study. This is followed by a brief consideration of the prospect of research spill-overs to other developing countries, and of realising benefits in Australia. Next, some of the general issues involved in assessing the economic impacts of R&D outcomes are canvassed as a precursor to describing the specific assumptions underlying the 'with R&D' scenario, and the 'without R&D' scenario. Key issues are: estimation of the effect on production costs of mud crab farms of using hatchery-reared crab seed; evidence available on adoption levels to date; and the assumptions made to predict future levels of innovation adoption. The section concludes with a brief discussion of the possible impact of the project outcomes on poverty in Vietnam.

Estimation of the material economic impacts for the people of Vietnam from ACIAR-funded development and uptake of commercial-scale mud crab hatchery technology is deferred to section 5.

4.1 Potential benefits in Vietnam from uptake of the mud crab hatchery innovation

As already discussed, the primary output of the two ACIAR-funded projects on mud crabs—FIS/1992/017 and FIS/1999/076—has been the development of a process innovation, namely hatchery technology for commercial-scale production of crablets of *Scylla paramamosain*. This innovation will enable significant and sustainable expansion of mud crab aquaculture in Vietnam, and possibly also in other producing countries. Without it, industry development would be constrained by a limited supply of seed crablets from the wild. Furthermore, there are widespread concerns that relying on wild-caught crablets as a source of seed would risk depletion of wild crab stocks.

The original rationale for these two projects was a perceived threat to the long-run survival of wild crab stocks if mud crab aquaculture farms continued to rely solely on wild-caught crablets as the supply of seed to stock their ponds. Notwithstanding what might have happened in other countries, no evidence was uncovered during this study that wild stocks of mud crabs in Vietnam are being seriously depleted. Indeed, an EU-funded project to investigate the status of wild crab stocks in the Can Tho region of the Mekong River Delta apparently concluded that current harvest levels of wild crablets are sustainable.

Nevertheless, planned expansion in the scale of mud crab aquaculture in Vietnam will increase demand for crab seed. Obviously, seed supplies from the wild are finite, so at some point the supply from the wild will become extremely inelastic. In the absence of hatchery technology for mud crabs, further increases in demand for crab seed would result in higher prices for crablets and increased costs for crab farmers, thereby constraining future development of the industry.

For the moment though, the current supply of wild-caught mud crablets is usually plentiful, and the going market price for seed from this source is commonly a little less than prices currently being charged for hatchery-reared seed. There are times of the year, however, when wild-caught seed is simply unavailable, and to the extent that the availability of hatchery-reared seed at these times opens up opportunities for profitable expansion of mud crab aquaculture, these extra profits are clearly a benefit of the mud crab hatchery technology innovation.

The higher prices currently being charged for hatchery-reared crab seed were claimed to be mainly a demand-driven phenomenon. For reasons to be discussed below, many crab farmers prefer hatchery-reared seed to wild-caught crablets and, at this early stage of industry development, the limited supply from current hatchery production cannot keep up with demand. It is expected that this will change over time.

Currently, the development of hatchery capacity to rear mud crab seed is in its infancy, so the short-run supply curve for hatchery-reared seed is quite inelastic. However, the long-run curve is expected to be highly elastic. Already, a number of private hatcheries have started to rear mud crablets, and the number is expected to grow as knowledge diffuses about how to operate commercial-scale mud crab hatcheries. Moreover, the physical pool of potential production capacity is many times greater than current capacity, because the infrastructure needed is already in place in a large number of shrimp hatcheries, and could easily be switched to rearing mud crablets now that the know-how to do so is available. The evidence available from the development of private hatcheries to supply shrimp seed indicates that the supply of hatchery-reared crab seed will be close to completely elastic, as none of the required inputs will be in short supply in the long run, and there are no obvious sources of diseconomies of size.

Moreover, costs of production of hatchery-reared crab seed are expected to fall over time as hatcheries reach full utilisation of production capacity, and as competitive pressures grow with the increase in the number of private hatcheries. To date, the small number of hatcheries that have started production are operating at less than full capacity. As a result, average production costs are high due to diseconomies of small scale, and should fall as capacity utilisation improves. Competition should also exert downward pressure on prices and costs. Hence, the supply curve of hatchery-reared seed should move down over time.

Mud crab farmers might benefit in several ways from stocking their pens with hatchery-reared mud crablets rather than wild-caught mud crablets. Hatchery-reared crablets typically will be disease-free and generally healthier when supplied to mud crab aquaculture farms, because they have had suitable feed and shelter and were raised under hygienic conditions. Consequently, growth rates should be higher and death rates lower during grow-out, so long as the seed is stocked into disease-free ponds.

Another benefit of hatchery-reared mud crablets is their uniform size. Wild-caught crablets, in contrast, vary greatly in size. Mud crabs are aggressive animals, and cannibalism is part of normal behaviour. In grow-out ponds, the level of cannibalism is positively correlated with stocking rate, and negatively correlated with uniformity of size of crabs. Stocking and mortality rates are among the factors affecting the profitability of mud crab aquaculture farms. Profitability is positively related to stocking rate and negatively related to death rates from cannibalism and other causes. Hence, uniformity in size of crab seed both enables higher stocking rates and greatly reduces the problem of cannibalism for mud crab farms, and thereby contributes to greater productivity via both faster growth rates and higher survival rates. Field observations and preliminary trials (Nguyen Co Thach, pers. comm.) confirm that it is possible to stock ponds at higher rates using hatchery-reared seed than when using wild-caught seed, and to achieve faster growth rates and higher survival rates.

In summary, the benefits to Vietnam from the development of commercial-scale mud crab hatchery technology are:

- it enables higher stocking rates, and directly improves growth rates and survival rates for intensive mud crab aquaculture when farmers purchase hatchery-reared mud crablets rather than wild-caught crablets
- over time, it enables falling rather than rising crab seed prices
- it removes one key constraint to future development and expansion of the mud crab aquaculture industry.

4.2 Spill-overs from development of mud crab hatchery technology in Vietnam

One of the common names for the *Scylla* species is the Indo-Pacific swamp crab. As this name implies, the natural range of the mud crab extends throughout much of the Indo-Pacific region. Moreover, mud crab culture is not unique to Vietnam, and mud crab aquaculture is a significant industry in countries such as China, the Philippines, Indonesia and Malaysia. Therefore, there is potential for research benefits to spill over to other countries.

Notwithstanding the clear potential for the project to generate spill-over benefits, there is no evidence of mud crab hatchery technology uptake in other countries, including the Philippines where FIS/1992/017 was based.

For instance, Fielder (2004) writes:

> Subsequent to FIS/1999/076 and in line with the review panel recommendations for FIS/92/17, ACIAR commissioned a proposal for funding a nutrition project aimed at developing an optimal grow-out crab feed. This second proposal was paused following a study tour by the then director of ACIAR through Southeast Asia. Although he observed many crab farms apparently running effectively, he found no evidence that any were using hatchery-produced seed stock. They were still tied to crablets supplied from the wild.

It seems that no potential spill-over benefits from the ACIAR-funded projects have been realised, at least so far.

4.3 Benefits to Australia

There have been a number of attempts to establish mud crab aquaculture ventures in Australia but, to date, there have been no commercially successful ventures for the grow-out of mud crabs. Despite the development of a reliable hatchery protocol for mud crabs at the Darwin Aquaculture Centre, there has been no commercial uptake of this technology. Apparently, hatchery-reared mud crab seed were produced on a trial basis by one company, but aquaculture farms were not willing to buy them to stock ponds for grow-out. Constraints to commercial viability of pond-based crab farming in Australia include low yields due to cannibalism, the need for a supply of expensive live food and labour-intensive harvesting operations. There also are planning constraints in some states. However, with falling prawn prices, aquaculture farms are continuing to look for alternative species to farm. Once significant pond trials of crab aquaculture systems have been undertaken, ways may be found to overcome these constraints.

Overall prospects for crab aquaculture in Australia may be about to change, for two reasons. One is that commercial potential for other crab species in Australia might be better than those for mud crabs. Although ACIAR's investment has been in mud crab aquaculture, development of technology for that species has enabled Australian researchers to quickly achieve success with other species including, in particular, blue swimmer and three-spot crabs for the soft-shell market.

Second, a promising recent development has been the establishment of purpose-built indoor shedding operations that will concentrate on intensive production of soft-shell crabs. In these high-technology, closed-cycle recirculation systems, crabs are caged individually to preclude cannibalism and to achieve high throughput, and highly automated processes keep labour costs low. In Queensland, one small venture based on a system developed in a public–private partnership with BIARC is already operational, growing blue swimmer and three-spot crabs collected from the wild for the soft-shell market. It does not have its own hatchery, and will need a consistent supply of seed to be viable.

No attempt was made to assess the economic impacts of the ACIAR projects on these developments, for two reasons. First, these ventures are in their infancy, and commercial viability has still to be proven. One problem will be providing shedding operations with sufficient stock when there are no hatcheries. Second, most of the technology on which these ventures are relying was not developed from projects FIS/1992/017 and FIS/1999/076, and attribution of estimated benefits to ACIAR funding would therefore be extremely difficult. A larger, highly mechanised and fully automated recirculation system is currently under construction in Queensland. It aims to produce up to 1.6 million (880 t) of soft-shell mud crabs per year. In addition, cast skins will be harvested for chitin production. Computerised camera images monitor growth and feeding, which is carried out using computer-controlled feeders. These types of facilities are much more capital-intensive than simple pond aquaculture methods, but arguably better suited to a high-cost economy like Australia.

4.4 Scenario development

Estimation of the material economic impacts of any R&D project involves quantifying the economic outcomes of the 'with R&D' scenario, as well as the counterfactual 'without R&D' scenario, and taking the difference between them. Hence, the first step in any assessment of the economic impacts of a R&D project is to specify both these scenarios.

To specify the 'with R&D' scenario, those R&D output(s) that potentially could result in beneficial outcomes for producers and/or consumers first need to be identified. Next, linkages between these research outputs and realised or prospective changes in benefit levels must be established. Key variables to estimate can be specified, and the magnitude of the economic outcomes calculated.

Most often, the key R&D output will be a process innovation that improves productivity, and/or saves inputs used in producing an established product. When primary producers adopt such a process innovation, it will reduce the unit cost of production, because of increased yield potential, reductions in output losses, increased efficiency of input use and/or lower costs for inputs. The consequence of innovation adoption is a downward shift of the supply curve which, depending on the elasticities of supply and demand, will reduce product prices and/or increase output levels.

The level of benefit from innovation adoption in any given year is the difference in aggregate costs of production under the 'without innovation' scenario, less the aggregate costs of production under the 'with innovation' scenario. An approximate measure of gross annual innovation adoption benefits can be calculated by multiplying:

- the level of output produced by adopters of the process innovation

by

- the reduction in average cost of production attributable to innovation adoption.

Hence, the two critical determinants of the quantitative difference in economic outcomes between any without and with technology scenarios are the level of innovation adoption over time, and the economic benefit per unit of production from adopting the innovation. The two key sets of information are the time profile of uptake of the new technology, and the 'with innovation' and counterfactual 'without innovation' levels of unit production costs. Ideally, adoption data should be representative of the range of conditions and resource endowments under which the innovation will be employed (Maredia et al. 2001).

For a truly ex-post impact assessment, specification of the 'with R&D' scenario can be relatively straightforward so long as the outcomes are more or less observable. The main problem is partitioning observed changes over time in observed outcomes between those attributable to diffusion of the innovation, and those due to other exogenous causes.

However, in this particular case, although a successful process innovation was developed from the R&D, diffusion of the innovation is still at a very early stage, and quite insignificant in terms of aggregate supply of seed to mud crab aquaculture farms. Consequently, most of the potential outcomes for the 'with R&D' scenario are yet to be realised, and also had to be projected. Nevertheless, and notwithstanding some data deficiencies, the 'with R&D' scenario is based on more objective evidence than the 'without R&D scenario'.

Specification of the 'without R&D' scenario is more problematic, not least because any counterfactual scenario is, by definition, hypothetical. This scenario needs to be inferred from the best available information, but necessarily will involve making a number of subjective assumptions.

One such assumption about the 'without R&D' scenario that often is not made explicit relates to the counterfactual state of technology. In many economic impact assessment studies, it is common to imply that no substitute innovation would have been developed if the particular R&D project being assessed had not taken place. In other words, the 'without R&D' scenario is synonymous with a 'without innovation' scenario.

However, as the Centre for International Economics (CIE 1997) has pointed out, the counterfactual state of technology during the period when benefits of the R&D project are being realised will not necessarily be the same as that prevailing before the research commenced. In fact, normally there are many potential sources of technological change, including spill-overs of equivalent technology from other regions, substitute research outputs from other organisations and endogenous farmer experimentation (Alston and Pardey 2001).

Consequently, alternative sources of equivalent technology to the research outputs being assessed need to be considered when specifying the counterfactual scenario. For instance, the innovation may already exist elsewhere and, in the absence of the assessed R&D, eventually would have 'spilled in' exogenously, so an innovation diffusion profile needs to be embedded in the counterfactual scenario as well as in the 'with R&D' scenario to assess the impacts of the R&D.

So long as the innovation eventually would have become available exogenously, the principal benefit of the particular R&D project will be the earlier realisation of the benefits from innovation adoption (Ryan and Garrett 2003). The difference between the research benefits realised at observed or predicted rates, and a counterfactual scenario of lagged benefit realisation, is a measure of this benefit for the particular R&D project.

Conversely, where some other organisation would need to finance equivalent R&D in order to develop the same or an equivalent substitute innovation for the assessed technology, the impact of the R&D being evaluated would be to bring forward in time both the costs of the R&D and the economic benefits of adoption of the innovation.

The logically consistent way to do so is to first specify both a ‘without innovation’ scenario and a ‘with innovation’ scenario. The latter encompasses development of the innovation by the assessed R&D project, and therefore includes the R&D costs, while the former scenario does not. The annual economic outcomes of each scenario can then be quantified, and the difference between them is a measure of net economic benefits from innovation development and adoption. It is also the time profile of economic outcomes for the ‘with R&D’ scenario. The time profile of economic outcomes for the ‘without R&D’ scenario is simply the same annual values of both costs and benefits lagged by the assumed delay before some other organisation carries out the R&D.

The ‘without innovation’ scenario

When project FIS/1992/017 commenced, there was no known, financially viable alternative method to the RIA3 mud crab hatchery technology for producing commercial quantities of mud crab seed. Furthermore, new scientific knowledge had to be acquired to enable consistent spawning and hatching of good-quality larvae and increased survival of larvae to crab stage. It is implausible to postulate that mud crab farms, or operators of hatcheries for other aquaculture species, would overcome these impediments by trial and error within any meaningful time frame.

Therefore, it is assumed that, in the absence of the innovation, crab farmers would have continued to rely indefinitely on the traditional supply of wild-caught crablets to stock their ponds. As discussed earlier, the sustainable supply of mud crab seed from the wild is limited, and thus extremely inelastic. As demand grows in the future, prices for crab seed and costs for crab farmers will increase, thereby constraining future development and expansion of mud crab aquaculture in Vietnam.

At the moment, wild-caught crab seed is purchased mainly for semi-intensive and intensive grow-out of mud crabs, and only infrequently for more extensive operations. There are no statistics for the area of semi-intensive and intensive culture of mud crabs, and the 11,839 ha recorded for culture of blue swimmer and mud crabs in Vietnam in 2004 clearly underestimated the actual area by a significant margin.

For the purpose of projecting future production from semi-intensive and intensive aquaculture, it was assumed that this form of mud crab culture covered 947 ha (8% of 11,839 ha) of ponds in 2003. Because of the constraining effect of limited supply of crab seed, this area is predicted to grow at an annual rate of only 3%. The average of yield from semi-intensive ponds (700 g/ha) and intensive ponds (1120 g/ha) was assumed to be 910 g/ha. Conversely, the area of extensive mud crab aquaculture was assumed to not use any crab seed, and to grow at 5% per year from a base of 9,708 ha yielding 350 g/ha. Details of the projected area and production from mud crab aquaculture under the 'without innovation' scenario are set out in Table A1 in Appendix 1.

As far as could be determined, there are no studies of the demand for mud crabs. It is known that there are large potential markets in China, and that supply in other exporting countries also is projected to expand. Therefore, it was assumed that the export demand is highly elastic, and will ensure that, in the long run, prices will be more or less independent of production in Vietnam. Of course, prices inevitably will fluctuate, but on average they are likely to remain approximately at current levels of about VND70 million per tonne in real terms.

The 'with innovation' scenario

The innovation in question is a commercial-scale mud crab hatchery technology for *Scylla paramamosain*. By the time of completion of the ACIAR projects at the end of June 2003, this innovation was ready and available for adoption.

For potential benefits from this innovation to be realised, mud crab aquaculture farms must adopt the practice of purchasing hatchery-reared crab seed rather than relying on the supply of crablets from the wild stock of mud crabs. They will do so if hatchery-reared crab seed is cheaper than wild-caught seed and/or if grow-out productivity is greater.

Hatchery-reared crab seed is best suited to semi-intensive and intensive mud crab aquaculture, while relying on wild-caught crab seed to stock grow-out ponds constrains stocking, survival and growth rates. A search for published reports of experimental evidence of productivity of grow-out of hatchery-reared crab seed as compared to wild-caught seed in pond culture in Vietnam was fruitless. Therefore, most of the estimates in this section are based on anecdotal evidence collected during a tour of Vietnam in March 2005 to study the development of mud crab aquaculture.

The budget shown in Table 6 for grow-out of mud crabs in semi-intensive and intensive ponds is based on conservative assumptions, including that hatchery seed is more expensive than wild-caught seed, even though this price differential is likely to turn round over time. Also, it is assumed that productivity gains from stocking with hatchery-reared crab seed are limited to increased stocking rate (by 25%), and higher survival rates (45% rather than 40%). For both sources of seed, it is assumed that final crab liveweight is the same, and that only two crops per year are feasible.

Table 6. Budget for semi-intensive and intensive grow out of mud crabs in Vietnam, assuming two crops per year

	Semi-intensive monoculture		Intensive monoculture	
	Hatchery seed	Wild seed	Hatchery seed	Wild seed
Size of seed	C2 or C3	C5–C9	C2 or C3	C5–C9
Stocking rate (m^2/crablet)	1.6	2.0	1.0	1.25
Number of crablets/ha/crop	6,250	5,000	10,000	8,000
Price of seed (VND/crablet)	650	400	650	400
Survival rate (%)	45	40	45	40
Number of crabs harvested/ha/crop	2,813	2,000	4,500	3,200
Harvest weight (kg/crab)	0.350	0.350	0.350	0.350
Production (kg/ha/crop)	*984*	*700*	*1,575*	*1,120*
Number of days to harvest	180	180	180	180
Feeding rate (percentage of liveweight)	3	3	3	3
Feed (kg/ha)	2,666	2,025	4,266	3,240
Feed price (VND/kg)	5,000	5,000	5,000	5,000
Price (VND/kg) – female	80,000	80,000	80,000	80,000
Price (VND/kg) – male	60,000	60,000	60,000	60,000
Revenue (VND/ha/crop)	*68,906,250*	*49,000,000*	*110,250,000*	*78,400,000*
Cost of seed (VND/ha/crop)	4,062,500	2,000,000	6,500,000	3,200,000
Cost of feed (VND/ha/crop)	13,331,250	10,125,000	21,330,000	16,200,000
Cost of marketing (2%)	1,378,125	980,000	2,205,000	1,568,000
Interest on operating expenditure	1,877,188	1,310,500	3,003,500	2,096,800
Variable costs (VND/ha/crop)	*20,649,063*	*14,415,500*	*33,038,500*	*23,064,800*
Number of crops /year	2	2	2	2
Fixed costs (VND/ha/year)	*69,169,000*	*69,169,000*	*110,670,400*	*110,670,400*
Total cost (VND/ha/year)	*110,467,125*	*98,000,000*	*176,747,400*	*156,800,000*
Total revenue (VND/ha/year)	*137,812,500*	*98,000,000*	*220,500,000*	*156,800,000*
Profit (VND/ha/year)	*27,345,375*	*0*	*43,752,600*	*0*
Average cost (VND/kg)	56,110	70,000	56,110	70,000
Percentage reduction in average cost (K)	20%		20%	

Source: Data collected by Economic Research Associates.

In the budget in Table 6, the fixed costs per hectare per year were imputed by assuming that farmers using wild-caught seed just break even if they grow two crops of crabs per year. The budget clearly demonstrates the potential for greater profitability when farmers stock their ponds with hatchery-reared crab seed rather than wild-caught seed. It also indicates that unit cost reductions attributable to uptake of the mud crab hatchery technology could be at least 20%, even if there are no realised benefits from higher growth rates.

The potential for higher growth rates of hatchery-reared crab seed will be ignored in estimating potential benefits from uptake of the innovation. However, in preliminary trials, hatchery seed did grow faster, and reached marketable weight in 120 days rather than the 180 days normally required for wild seed to reach the same weight. Consequently, it is likely that farmers using hatchery seed could grow out three crops per year rather than the maximum of two crops possible from wild seed. The potential magnitude of the benefits from doing so is illustrated in Table A3 in Appendix 1.

Such assessments undoubtedly overestimate the actual reduction in per unit production costs that will be realised in practice. In part, this is because productivity gains obtained under experimental conditions are typically close to double those obtained under field conditions. In addition, not all crab farmers will switch from wild seed to hatchery-reared crab seed despite the apparent benefits of doing so. While this may be due to ignorance, there often are farm-specific factors that prevent possible productivity gains from being realised.

Semi-intensive and intensive mud crab farms are assumed to be the sole potential adopters of the purchase of hatchery-reared crab seed in lieu of wild-caught seed. Again, this form of crab culture was assumed to cover 947 ha in 2003, but was projected to grow at a much higher rate of 15% per year, in part due to the higher profitability of buying hatchery seed, and in part because the price of wild seed will be held down by the availability of a competitively priced substitute. Conversely, compared to the counterfactual scenario, the area of extensive crab aquaculture is projected to grow more slowly at 3% per year from a base of 9,708 ha yielding 350 g/ha, as at least some extensive crab farmers will upgrade to more-intensive production. Overall, the total area of crab farms is projected to grow to 35,886 ha by 2024, as compared to 28,808 ha for the ‘without innovation’ scenario.

For adopting farmers, the average yield from semi-intensive ponds and intensive ponds was assumed to be 1280 g/ha, reflecting the higher productivity of hatchery seed. Due to the large profits to be earned, adoption of the purchase of hatchery seed is projected to grow by 10% per year of the total production from semi-intensive and intensive grow-out ponds until a ceiling of 80% is reached. It was assumed that the remaining 20% will continue to purchase wild-caught seed. Details of the projected area and production from mud crab aquaculture under the 'with innovation' scenario are set out in Table A2 in Appendix 1.

Again, crab prices were assumed to remain steady at about 70 million VND per tonne in real terms.

The 'with R&D' scenario for Vietnam

As already noted, the principal output of the two ACIAR-funded projects—FIS/1992/17 and FIS/1999/076—was a fully developed and commercial-scale mud crab hatchery technology for *Scylla paramamosain*. The costs of the R&D are detailed in Table 5. Support from the national government in Vietnam enabled Mr Nguyen Co Thach, who was a key collaborator in FIS/1999/076 and an enthusiastic promoter of the new technology, to work with hatcheries on adoption of the innovation. By the time of completion of these projects at the end of June 2003, this innovation was ready and available for adoption.

For potential benefits from this innovation to be realised, two necessary and interdependent conditions need to be met. First, investors need to establish mud crab hatcheries that can supply seed to mud crab farms at competitive prices. Second, farmers need to purchase hatchery-reared crab seed in preference to wild-caught crablets.

To date, 14 mud crab hatcheries are known to have been established. Government support has been important in the early stage of development. The national government made a significant investment to upgrade the original experimental hatchery at RIA3 so that it could produce commercial quantities of seed. RIA2 is now building another commercialised government hatchery in Bac Lieu Province in the lower Mekong Delta. However, it was the Hai Phong provincial government that provided some key infrastructure support to establish the first commercial-scale hatchery, and produced a trial batch of seed crablets in 2003. A number of hatcheries produced significant numbers of crab seed in 2004, including several private shrimp hatcheries that have adopted the mud crab hatchery technology and are either converting existing facilities to produce crablets or building extra capacity. Details of 2004 production, and of estimated production at full capacity for these 14 existing hatcheries are given in Table 7.

Outcomes to date have been modest. Fewer than 2 million crablets were produced in 2004. Sales of hatchery-reared seed to mud crab aquaculture farms were reportedly even less, due mainly to the low level of awareness of availability and potential profitability of using this source of crab seed. This low level of output can be attributed to production constraints during the start-up phase of a new technology rather than to a lack of demand by mud crab farms.

Table 7. Hatchery capacity and production of crab seed in Vietnam in 2004

Region	Province	Hatchery type	2004 production (number)	Production capacity	Ownership type
Red River Delta	Hai Phong		300,000	1,000,000	PPT[a]
	Nam Dinh		20,000	500,000	100% private
	Ninh Binh		25,000	500,000	100% private
North Central Coast	Thanh Hoa			300,000	PPT
	Ha Tinh		0	300,000	PPT
	Quang Tri		0	700,000	PPT
	TT Hue		520,000	700,000	100% private
South Central Coast	Khanh Hoa	RIA3	350,000	1,000,000	PPT
	Khanh Hoa	Family	400,000	1,000,000	100% private
Mekong River Delta	Tra Vinh		200,000		Not known
	Bac Lieu	RIA2		1,500,000	PPT
	Ca Mau				
	Kien Giang				
	Can Tho		na	na	PPT
Total			1,815,000	7,500,000	

[a] PPT = commercialised government
Source: Nguyen Co Thach (pers. comm.)

At a stocking rate of 8,000 crablets per ha, estimated sales of 1.6 million crablets would have been sufficient to stock about 200 ha of ponds, and total output in 2004 from hatchery-reared seed would have been about 200 t. Total production in that year was 10,000 t, according to Ministry of Fisheries statistics. When all of these 14 hatcheries are operating at full current capacity, the supply of hatchery seed should substitute for most of the supply of wild-caught seed currently purchased by semi-intensive and intensive mud crab farms.

Further expansion of hatchery capacity will depend on growing demand from mud crab farmers. However, the rapid expansion in capacity of private shrimp hatcheries suggests that the current capacity of mud crab hatcheries will grow in a similar manner, so long as growth in demand for hatchery-reared crab seed matches the impressive expansion in demand for shrimp seed. MOFI (2004) notes that there are now more than 5,000 shrimp hatcheries, mostly private small-scale enterprises, and that annual shrimp larvae production in 2004 exceeded 25 billion shrimp seed.

Besides, only a relatively small part of total output will be produced from hatchery-reared seed for many years. Although it is possible that improved extensive mud crab farms might benefit from purchasing small quantities of hatchery-reared crab seed rather than wild seed to top-up stocking rates, it is assumed in this impact assessment study that all extensive crab farmers will continue to rely exclusively on naturally occurring and/or wild-caught crab seed.

The 'without R&D' scenario for Vietnam

This without R&D scenario covers the economic outcomes for Vietnam if ACIAR had not funded the two projects—FIS/1992/17 and FIS/1999/076. It is necessarily hypothetical, because it is the counterfactual scenario to what has happened.

No successful method for commercial-scale hatchery production of mud crab seed existed at the time when the ACIAR projects began. While the development of larval rearing of mud crablets had been demonstrated in experiments before the start of these projects, the rate and reliability of survival from eggs to crablets fell far short of the levels necessary for commercial operations. Even though hatchery technology did exist for other aquacultured species of crustaceans, such as shrimp, real resources still had to be committed by someone to develop a financially viable hatchery technology for production of mud crab seed stock. Specifically, R&D was necessary to identify the critical success factors to promote consistent spawning and hatching of good-quality larvae, and how to overcome several bottlenecks in hatchery and nursery culture techniques to ensure consistent and increased survival of larvae to crab stage.

Nevertheless, the need to develop such an innovation had been recognised for many years. Significant research into the feasibility of larval rearing of mud crabs had taken place before the inception of the ACIAR mud crab projects, and the expertise and resources required to independently develop such an innovation existed in a number of countries.

The most likely 'without R&D' scenario for this impact assessment study is that some other organisation would subsequently have funded the R&D needed to yield a comparable innovation. Other aid donors were working in Vietnam on mud crab aquaculture but, in the absence of funding from these sources, it is quite conceivable that the Vietnamese Government would have funded the necessary R&D. In any case, it is almost certain that this process innovation would become available for adoption in Vietnam sooner or later.

Therefore, it is assumed in this scenario that development of the innovation would have been funded by another organisation had ACIAR not funded the two assessed projects, but that the development of the innovation, and its adoption, would have been delayed by 3 years. In particular, note that, because the necessary R&D to develop the mud crab hatchery innovation is assumed to have been merely delayed under this scenario, the required expenditure of real resources must be included in the time profile of costs and benefits, even though lagged by 3 years. In other words, **all** of the estimated costs and benefits for the 'with R&D' scenario first need to be lagged by 3 years, and then included in this scenario. It follows that the benefits of the ACIAR-funded projects that developed the mud crab hatchery technology include both the future R&D costs avoided, as well as the earlier realisation of innovation adoption benefits.

4.5 Poverty impacts for Vietnam

Vietnam is a very poor country, although its economy has been growing rapidly. According to Asian Development Bank statistics, per capita gross national product in 1996 was only US$290 per annum, rising to US$350 per annum by 1998 (ADB website at <http://www.adb.org/>). By 2003, per capita gross domestic product was US$553.27 (UNDP website at <http://www.undp.org.vn/undp/fact/base.htm>).

Moreover, according to the Government Statistics Office of Vietnam, the Vietnam Living Standard Survey for 2002 found that average per-capita annual living expenditure was VND3.2 million, or about A$265 per person per year at current exchange rates. As in other countries, urban values were above, and rural values below, the national average. Furthermore, annual per-capita income in the first quintile was only VND1.48 million, or less than A$125 per person per year. There were also regional differences, but apart from the southeast region around Ho Chi Minh City, the main coastal provinces where mud crab aquaculture is located were among the better-off provinces, with average income levels close to the national average. Therefore, almost any project that generates widely diffused net economic benefits in Vietnam will have a positive impact on absolute poverty.

Despite improvements in recent years, poverty still remains at a high level in all parts of the country. Poverty is concentrated mainly in rural areas, and there is considerable disparity among regions (Table 8).

Table 8. Poverty rates (%) in Vietnam, by region, in 1998 and 2002

Region	1998		2002	
	GSO[a] poverty rate	Food poverty rate (2,100 calories)	GSO poverty rate	Food poverty rate (2,100 calories)
Whole country	37.4	15.0	28.9	10.9
– urban areas	9.2	2.5	6.6	1.9
– rural areas	45.5	18.6	35.6	13.6
North Uplands	64.2	32.4	43.9	21.1
Red River Delta	29.3	8.5	22.4	5.3
North Centre	48.1	19.0	44.4	17.5
Central Coast	34.5	15.9	25.2	9.0
Central Highlands	52.4	31.5	51.8	29.5
Southeast	12.2	5.0	10.6	3.0
Mekong River Delta	36.9	11.3	23.4	6.5

[a] Government Statistics Office
Source: Vietnam Living Standard Survey 1998, and 2002, as quoted by Tung et al. (2004).

Therefore, projects FIS/1992/017 and FIS/1999/076 have had, and will continue to have, positive impacts on reduction of absolute poverty in Vietnam. However, they are unlikely to reduce relative poverty, and possibly could contribute to greater income inequality because the main beneficiaries of the development of the hatchery technology are predicted to be mud crab farmers and/or owners of ponds for semi-intensive and intensive aquaculture. While many of these people are poor in absolute terms, in the main they are not among the 'poorest of the poor' in Vietnam. For the Mekong River Delta, where there is significant aquaculture development, the poverty level is relative to the ownership of arable land.

No economic surveys were found that provided direct evidence about the level and composition of household income of crab farmers. In a survey of rice and shrimp farmers in the My Xuyen and Gia Rai districts in the lower Mekong River Delta, Than et al. (2004) reported that for the three years from 1997 to 1999, average annual household expenditure ranged from VND10.2 million to VND21.6 million. These values are significantly greater than national or regional averages. Farmers who practised intensive shrimp aquaculture had household incomes nearly double that of extensive shrimp farmers. While not recorded, at least some of these farmers also farmed mud crabs.

Crab farming is a small-scale business that has relatively modest entry requirements apart from pond infrastructure. Nevertheless, for the poorest members of society with no capital, this is a significant barrier to entry unless they can lease a pond from the commune or district authority. Hence, the more wealthy and enterprising sectors of the community who can afford to invest in mud crab culture tend to be the principal direct beneficiaries from this activity.

Poorer members of the community also have benefited by providing labour for many aspects of pond operation, such as building and repairing of ponds, harvesting, guarding against poachers etc. Both men and women also buy and sell crabs, either as primary or secondary dealers. Such additional activities spread the economic benefit of crab production more broadly within the community. Therefore, any innovation that attracts new investment in crab farming will tend to have some positive impacts on poverty.

However, the one caveat relates to the negative impact of crab hatchery technology on demand for wild-caught crablet seed. Traditionally, it has been mainly women, and sometimes children, who collected juvenile mud crab by hand from mangroves to sell to crab farmers. If farmers switch to hatchery-raised crablets to stock their ponds, then this source of employment and income will come to an end. While there may be some offsetting impacts from employment of staff by the hatcheries, the people employed are unlikely to be the poorest of the poor. Hence, there may be some adverse impacts on employment opportunities for very poor landless people, so the poverty impacts of the projects are likely to be modest at best.

5 IMPACT ANALYSIS

In brief, the method used to estimate the economic impacts of ACIAR-funded R&D on mud crabs in Vietnam was as follows:

1. The annual nominal costs of research incurred by ACIAR and the commissioned organisations, and by overseas partners, were quantified.
2. Uptake to date of the mud crab hatchery technology, and purchases by mud crab farmers of hatchery-reared crab seed in lieu of wild seed were identified. The benefits to mud crab farmers from stocking semi-intensive and intensive grow-out ponds with hatchery seed rather than wild-caught seed were estimated, and the potential for further uptake of the innovation was projected on the basis of the best available information, and taken into account in developing the 'with innovation' scenario.
3. An economic model was developed to derive quantitative measures of the economic net benefits from supply shifts driven by changes to crab seed purchases to stock ponds for semi-intensive and intensive mud crab aquaculture.
4. Annual net cost and benefits for the 'with R&D' scenario were based on actual direct and indirect expenditure on FIS/1992/017 and FIS/1999/076, and on estimated benefits for the 'with innovation' scenario. The 'without R&D' scenario involved the same annual net cost and benefits for the 'with R&D' scenario, but delayed by 3 years. The difference between the annual net benefits for these two scenarios is a measure of the economic impacts of the ACIAR-funded projects.
5. Net present value, benefit–cost ratio and internal rate of return were calculated for a 30-year period from the start of the first project in 1995.

The subject matter in the first part of this section is the estimation of the time profile of annual innovation benefits for 30 years from the start of the research. Then, on the assumption that the impact of projects FIS/1992/017 and FIS/1999/076 was to bring forward in time both the costs and returns of the development and uptake of the mud crab hatchery technology innovation in Vietnam, measures of net returns to the ACIAR-funded research are calculated. Selected sensitivity analysis is conducted in the next subsection.

5.1 Analysis of the mud crab hatchery innovation in Vietnam

Because of the lack of evidence that any tangible economic benefits have been realised to date in Australia, or of any spill-overs to other countries in the Indo-Pacific region, the economic impact analysis of the mud crab hatchery technology was restricted to estimating national benefits from its uptake in Vietnam.

In most impact assessment studies of common types of research, the industry 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. The novelty in this case is that the industry consists of two interdependent sectors, only one of which is likely to adopt the process innovation. Hence, a purpose-built model based on well-established principles for evaluation of the impacts of a process innovation was developed, and used to estimate economic net benefits from uptake of the mud crab hatchery innovation.

No estimates of parameter values for the elasticity of market demand for mud crabs, or for the elasticity of supply by crab farmers, could be found to calculate annual net economic innovation benefits, so estimates had to be conjectured from first principles. Export demand was assumed to be perfectly elastic at a price of VND70 million because of apparently unlimited potential for exports to China. An elasticity of supply of 10 was assumed for the ‘without innovation’ scenario at the marginal level of output, because a huge amount of suitable infrastructure is available for conversion from shrimp aquaculture to mud crab aquaculture. The average cost of production of mud crabs was assumed to fall by 10% when farmers ‘adopted’ hatchery-reared crab seed instead of wild-caught crablets. Sensitivity of estimated economic benefits to these assumptions about elasticity values is explored below.

It is possible that market distortions due to subsidies and/or taxes may have biased estimation of the economic impacts of the mud crab hatchery innovation in Vietnam. For instance, at least half of the 14 mud crab hatcheries already operating have some form of government ownership, control and/or participation. However, they do have to compete in a market that apparently is open, and it is claimed that they are able to sell crablets at prices that are competitive with the private hatcheries without any government subsidies. Another possibility is that remnants of the old ‘command and control’ economy might distort investment decisions by aquaculture farmers. Government policies in Vietnam have identified development and diversification of shrimp aquaculture as a high priority, and also may encourage and support it in ways that are not transparent. However, in the absence of any evidence, either anecdotal or documented, that input or output markets are being distorted, there was no need to use shadow prices rather than financial costs.

Tables A1 and A2 in Appendix 1contain details of projected area and production from mud crab aquaculture under a ‘without innovation’ scenario and a ‘with innovation’ scenario, respectively. In Table A4, these estimates plus the above assumptions about supply and demand elasticities and innovation-induced supply shifts outlined above were used to calculate annual benefits, in VND, from uptake of the mud crab hatchery innovation in Vietnam. The total nominal value of annual innovation benefits was estimated to be VND757,624 million. This estimate does not include the costs of the development and uptake of the mud crab hatchery technology innovation in Vietnam. Also, note the ‘without innovation’ assumes that this innovation would never have emerged without ACIAR funding.

Table A5 in Appendix 1 shows how these values were converted to nominal, real and discounted net annual innovation benefits in 2004 Australian dollars. The third column of Table 9 also displays real net annual innovation benefits in 2004 Australian dollars, while the fifth column shows discounted net annual innovation benefits in 2004 Australian dollars.

5.2 Estimates of net annual innovation and research project benefits

The conventional time horizon for the analysis of the economic impacts of ACIAR-funded projects is 30 years, and benefit–cost measures for the mud crab projects were calculated for the 30 years from the start of project FIS/1992/017 in 1995. In this case, the benefit of the ACIAR-funded project is simply to bring forward in time both the costs and benefits from development and uptake of an innovation. Hence, a slightly longer time frame is justified for the ‘without R&D’ scenario so that the same number of years of benefits are assessed for both the ‘without R&D’ and ‘with R&D’ scenarios. Consequently, benefit–cost measures were calculated for a ‘with R&D’ scenario from 1995 to 2024, and a ‘without R&D’ scenario from 1998 to 2007. In both cases, real values in 2004 Australian dollars were converted to present values using a discount rate of 5%.

Table 9 provides an estimate of the annual net benefits from the two ACIAR-funded mud crab R&D projects. Real net annual innovation benefits in 2004 Australian dollars in column 3 are lagged by 3 years in column 4 to provide a profile of annual net economic benefits for the ‘without R&D’ scenario. These annual values of net innovation benefits and lagged net innovation benefits in these two columns are discounted, and the discounted net benefit flows are shown in columns 5 and 6 respectively. Column 5 is the estimate of the discounted annual net benefits for the 'with ACIAR funded R&D' scenario, and column 6 is the corresponding estimate for the 'without ACIAR funded R&D' scenario. The difference between columns 5 and 6 is the discounted net annual economic benefit from ACIAR projects FIS/1992/017 and FIS/1999/076.

By the standards of results from many impact assessment studies of economic returns to R&D, the values in Table 9 are quite modest. Over a 30-year time frame, the net present value of benefits to ACIAR projects FIS/1992/017 and FIS/1999/076 in 2004 Australian dollars was $3.46 million. At the time of assessment in 2005, discounted real costs still exceeded realised discounted real benefits by A$351,000, and a final positive outcome will depend on continued uptake of the innovation in Vietnam.

Like all research projects, net returns in the early years are negative because project costs are incurred at the outset. However, positive benefits in the years 1998 to 2002 are not due to benefits from uptake of results from projects FIS/1992/017 and FIS/1999/076, but to the assumed cost savings of avoided R&D by some other organisation.

The benefit–cost ratio of ACIAR projects FIS/1992/017 and FIS/1999/076 is only 1.9, and the corresponding internal rate of return is 16%. One reason for these modest outcomes is the fact that the size of semi-intensive and intensive mud crab aquaculture in Vietnam is quite small, and will remain so for many years, even if it grows as quickly as assumed in this study.

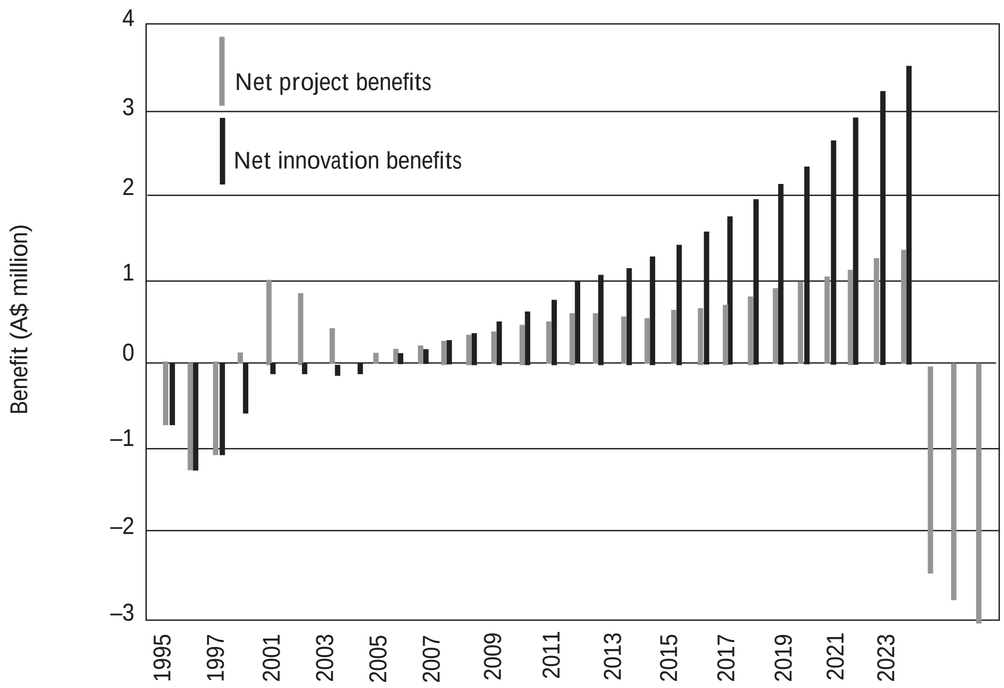
Another key reason is the assumption that some other organisation would have funded the R&D to develop the mud crab hatchery technology 3 years later if ACIAR had not funded projects FIS/1992/017 and FIS/1999/076. If in fact this either never happened, or did not happen for many years, then the benefit from projects FIS/1992/017 and FIS/1999/076 would be much greater. For instance, if the 'without R&D' scenario was that the innovation was never developed, the net present value of R&D is estimated to be A$25.4 million rather than A$3.46 million.

The difference in discounted net annual innovation benefits and discounted net annual ACIAR R&D benefits is illustrated in Figure 1.

Table 9. Annual net benefits to Vietnam of ACIAR-funded mud crab projects

Year no.	Year	Net annual *innovation* benefits in A$'000 (real)	Lagged net annual *innovation* benefits in A$'000 (real)	Discounted net annual *innovation* benefits in A$'000	Discounted lagged net annual *innovation* benefits in A$'000	Discounted net annual *ACIAR project* benefits in A$'000
1	1995	–458		–677		–677
2	1996	–886		–1,246		–1,246
3	1997	–768		–1,030		–1,030
4	1998	–398	–458	–507	–584	77
5	1999	–59	–886	–72	–1,077	1,005
6	2000	–72	–768	–83	–889	806
7	2001	–69	–398	–76	–438	362
8	2002	–68	–59	–71	–62	–9
9	2003	–6	–72	–6	–72	66
10	2004	53	–69	50	–66	116
11	2005	130	–68	118	–62	179
12	2006	235	–6	203	–5	208
13	2007	362	53	298	43	254
14	2008	521	130	408	102	307
15	2009	720	235	537	175	362
16	2010	967	362	687	257	430
17	2011	1,271	521	860	353	507
18	2012	1,495	720	964	464	500
19	2013	1,757	967	1,079	593	485
20	2014	2,063	1,271	1,206	743	463
21	2015	2,419	1,495	1,347	833	515
22	2016	2,834	1,757	1,503	932	571
23	2017	3,315	2,063	1,674	1,042	632
24	2018	3,875	2,419	1,864	1,164	700
25	2019	4,523	2,834	2,072	1,298	774
26	2020	5,276	3,315	2,302	1,446	855
27	2021	6,148	3,875	2,554	1,610	945
28	2022	7,157	4,523	2,832	1,790	1,042
29	2023	8,326	5,276	3,138	1,988	1,149
30	2024	9,677	6,148	3,474	2,207	1,267
31	2025		7,157		2,447	–2,447
32	2026		8,326		2,711	–2,711
33	2027		9,677		3,001	–3,001
Total		60,340	60,340	25,402	21,943	3,459
NPV over 30 years to 2024				25,402	13,785	11,617
NPV to time of assessment				–3,601	–3,250	–351

Figure 1. Discounted net annual innovation and project benefits of ACIAR-funded research on mud crab hatchery technology



5.3 Sensitivity analysis

The lack of evidence for the assumptions made about supply and demand elasticities used to calculate annual benefits from uptake of the mud crab hatchery innovation in Vietnam has been explained earlier. Apart from being based on some plausible first principles and anecdotal evidence, the actual values were deliberately chosen to be conservative, and to underestimate likely benefits from uptake of the innovation.

Estimated annual innovation benefits computed by assuming that the elasticity of supply at the margin under the 'without innovation' scenario is 2, rather than 10, are presented in the third column of Table 10. They can be compared with assessed annual innovation benefits taken from the last column in Table A4 in Appendix 1, and reproduced as the second column in Table 10, that were computed assuming a supply elasticity of 10. When it is assumed that the supply curve is less elastic, the aggregate innovation benefits over the 30-year period are VND2,007,468 million, which is more than double the total of assessed innovation benefits of VND757,624 million.

Under the assumptions made, these estimates of innovation benefit accrue entirely to producers, as the effect of assuming that demand is perfectly elastic is to set consumer surplus to zero. An alternative plausible scenario would be to assume that demand is inelastic but growing at the same rate as supply, in which case real prices would still remain constant over time. For this plausible scenario, innovation adoption would generate significant gains in consumer surplus in addition to levels of producer surplus similar to the assessed innovation benefits. Hence, the assumptions made about supply and demand elasticities do seem to be genuinely conservative, in the sense that they are likely to result in underestimates of the benefits from uptake of the mud crab hatchery innovation in Vietnam.

Table 10. Alternative estimates of nominal annual innovation benefits from the mud crab hatchery technology

Year	Assessed innovation benefit[a] (VND million)	Alternative innovation benefit[b] (VND million)	Intuitive innovation benefit[c] (VND million)
2004	704	1,570	976
2005	1,629	3,655	2,245
2006	2,822	6,365	3,872
2007	4,340	9,827	5,937
2008	6,253	14,195	8,534
2009	8,641	19,649	11,777
2010	11,601	26,402	15,801
2011	15,248	34,704	20,768
2012	17,943	41,949	23,883
2013	21,090	50,517	27,465
2014	24,759	60,624	31,585
2015	29,032	72,516	36,323
2016	34,004	86,479	41,771
2017	39,783	102,842	48,037
2018	46,494	121,986	55,242
2019	54,281	144,349	63,528
2020	63,310	170,435	73,058
2021	73,772	200,827	84,016
2022	85,887	236,195	96,619
2023	99,907	277,312	111,112
2024	116,125	325,067	127,778
Total	757,624	2,007,468	890,327

[a] Computed assuming elasticity of supply = 10.
[b] Computed assuming elasticity of supply = 2.
[c] Computed using intuitive shortcut method. See text for explanation.

Often, the main question for an impact assessment study is the magnitude of aggregate innovation benefits, rather than the distribution of these benefits between consumers and producers. For such cases, a commonly used shortcut is to estimate annual innovation benefits by multiplying the annual level of production by percentage adoption, and then by the percentage reduction in average costs ascribed to adoption of the innovation.

The results of using this intuitive shortcut method are presented in the last column of Table 10. The sum of annual innovation benefits computed using the intuitive shortcut method is VND890,327 million, which is larger than, but similar to the assessed level of innovation benefits used to calculate measures of the rate of return to ACIAR's investment in FIS/1992/017 and FIS/1999/076.

As already discussed, another very subjective assumption was that, some 3 years later, another organisation would have funded the mud crab hatchery R&D had ACIAR not done so. If the start date of the R&D project under this counterfactual scenario was 2001 rather than 1998, the flow of costs and benefits would have lagged by 6 years rather than by 3 years. This change of assumption would increase the estimated NPV of ACIAR funding for the project from A$3.46 million to A$6.45 million, and increase the estimated benefit–cost ratio from 1.92 to 2.71. However, because there are negative flows at both the start and the end of the evaluation period, the IRR would be 16% under either assumption. If alternative funding failed to materialise, the NPV of ACIAR funding would be A$25.4 million, and the corresponding benefit–cost ratio would be 7.74, but the IRR would still be 16%.

6 Conclusions

The ACIAR-funded projects FIS/1992/017 – Development of improved mud crab culture systems in the Philippines and Australia, and FIS/1999/076 – Development of leading centres for mud crab aquaculture in Indonesia and Vietnam, were very successful. Numerous scientific publications and other impressive outputs were produced, but the key output was a mud crab hatchery innovation that is projected to break the constraint of the supply of crab seed to mud crab aquaculture farms that otherwise would impede growth of this industry. Governments in Vietnam have recognised the potential benefit to the Vietnamese people from uptake of this technology, and provided resources to staff at RIA3 who benefited from capacity-building during the latter project to promote development of a number of mud crab hatcheries. To date, 14 of these hatcheries have been established in Vietnam.

Relative to a ‘without innovation’ scenario, the NPV from development and uptake of the mud crab hatchery innovation was estimated to be A$25.4 million. However, based on evidence provided during the impact assessment study, the most likely impact of the ACIAR projects was to bring forward in time the development and uptake of the mud crab hatchery technology. Therefore, it was assumed that, in the event that ACIAR had not funded these projects, development of this innovation would still have been funded by another organisation, but that its development and adoption would have been delayed by 3 years.

Given this assumption about the counterfactual scenario, the net present value of the ACIAR projects FIS/1992/017 and FIS/1999/076 was estimated to be A$3.46 million, the benefit–cost ratio 1.9 and the corresponding internal rate of return 16%. While these results are somewhat modest outcomes relative to the most successful R&D projects, they still represent a very solid return on ACIAR’s investment. The sensitivity of the key measures to the assumed length of the lag to innovation development under the counterfactual scenario is tabulated below.

Assumed project start date for counterfactual scenario	Net present value	Benefit–cost ratio	Internal rate of return (%)
1998	A$3.46 million	1.92	16
2001	A$6.45 million	2.71	16
Never	A$25.4 million	7.74	16

The main beneficiaries of the development of the hatchery technology are predicted to be mud crab farmers and/or owners of ponds for semi-intensive and intensive aquaculture. While many of these people are poor in absolute terms, in the main they are not among the ‘poorest of the poor’ in Vietnam. Moreover, there may be some adverse impacts on employment opportunities for very poor, landless people, so the poverty impacts of the projects are likely to be modest at best.

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APPENDIXES

1 Details of estimated impacts

Table A1. Projected area and production from mud crab aquaculture under the 'without innovation' scenario

Year	Extensive area (ha)	Intensive area (ha)	Total area (ha)	Extensive production (t)	Intensive production (t)	Total production (t)
2003	9,708	947	11,839	3,398	862	4,260
2004	10,193	976	11,169	3,568	888	4,455
2005	10,703	1,005	11,708	3,746	914	4,660
2006	11,238	1,035	12,273	3,933	942	4,875
2007	11,800	1,066	12,866	4,130	970	5,100
2008	12,390	1,098	13,488	4,337	999	5,336
2009	13,010	1,131	14,141	4,553	1,029	5,582
2010	13,660	1,165	14,825	4,781	1,060	5,841
2011	14,343	1,200	15,543	5,020	1,092	6,112
2012	15,060	1,236	16,296	5,271	1,125	6,396
2013	15,813	1,273	17,086	5,535	1,158	6,693
2014	16,604	1,311	17,915	5,811	1,193	7,004
2015	17,434	1,350	18,785	6,102	1,229	7,331
2016	18,306	1,391	19,697	6,407	1,266	7,673
2017	19,221	1,433	20,654	6,727	1,304	8,031
2018	20,182	1,476	21,658	7,064	1,343	8,407
2019	21,191	1,520	22,711	7,417	1,383	8,800
2020	22,251	1,565	23,816	7,788	1,425	9,212
2021	23,363	1,612	24,976	8,177	1,467	9,644
2022	24,532	1,661	26,192	8,586	1,511	10,097
2023	25,758	1,711	27,469	9,015	1,557	10,572
2024	27,046	1,762	28,808	9,466	1,603	11,069

Table A2. Projected area and production from mud crab aquaculture under the 'with innovation' scenario

Year	Extensive area (ha)	Intensive area (ha)	Total area (ha)	Extensive production (t)	Intensive production from wild seed (t)	Intensive production from hatchery seed (t)	Total production (t)
2003	9,708	947	10,655	3,398	862	–	4,260
2004	9,999	1,089	11,088	3,500	892	139	4,531
2005	10,299	1,253	11,552	3,605	912	321	4,837
2006	10,608	1,440	12,049	3,713	918	553	5,184
2007	10,926	1,657	12,583	3,824	904	848	5,577
2008	11,254	1,905	13,159	3,939	867	1,219	6,025
2009	11,592	2,191	13,783	4,057	797	1,682	6,537
2010	11,940	2,519	14,459	4,179	688	2,257	7,124
2011	12,298	2,897	15,195	4,304	527	2,967	7,798
2012	12,667	3,332	15,999	4,433	606	3,412	8,452
2013	13,047	3,832	16,878	4,566	697	3,924	9,187
2014	13,438	4,406	17,844	4,703	802	4,512	10,017
2015	13,841	5,067	18,909	4,844	922	5,189	10,956
2016	14,256	5,827	20,084	4,990	1,061	5,967	12,018
2017	14,684	6,702	21,386	5,139	1,220	6,862	13,222
2018	15,125	7,707	22,831	5,294	1,403	7,892	14,588
2019	15,578	8,863	24,441	5,452	1,613	9,075	16,141
2020	16,046	10,192	26,238	5,616	1,855	10,437	17,908
2021	16,527	11,721	28,248	5,785	2,133	12,002	19,920
2022	17,023	13,479	30,502	5,958	2,453	13,803	22,214
2023	17,534	15,501	33,035	6,137	2,821	15,873	24,831
2024	18,060	17,826	35,886	6,321	3,244	18,254	27,819

Table A3. Budgets for semi–intensive and intensive grow out of mud crabs—assuming faster growth rates for hatchery seed

	Semi-intensive monoculture		Intensive monoculture	
	Hatchery seed	Wild seed	Hatchery seed	Wild seed
Size of seed	C2 or C3	C5–C9	C2 or C3	C5–C9
Stocking rate (m^2/crablet)	1.6	2.0	1.0	1.25
Number of crablets/ha/crop	6,250	5,000	10,000	8,000
Price of seed (VND/crablet)	650	400	650	400
Survival rate (%)	45	40	45	40
Number of crabs harvested/ha/crop	2,813	2,000	4,500	3,200
Harvest weight (kg/crab)	0.350	0.350	0.350	0.350
Production (kg/ha/crop)	984	700	1,575	1,120
Number of. days to harvest	120	180	120	180
Feeding rate (% liveweight)	3	3	3	3
Feed (kg/ha)	1,778	2,025	2,844	3,240
Feed price (VND/kg)	5,000	5,000	5,000	5,000
Price (VND/Kg) – female	80,000	80,000	80,000	80,000
Price (VND/Kg) – male	60,000	60,000	60,000	60,000
Revenue (VND/ha/crop)	*68,906,250*	*49,000,000*	*110,250,000*	*78,400,000*
Cost of seed (VND/ha/crop)	4,062,500	2,000,000	6,500,000	3,200,000
Cost of feed (VND/ha/crop)	8,887,500	10,125,000	14,220,000	16,200,000
Cost of marketing (2%)	1,378,125	980,000	2,205,000	1,568,000
Interest on operating expenditure	1,432,813	1,310,500	2,292,500	2,096,800
Variable costs (VND/ha/crop)	*15,760,938*	*14,415,500*	*25,217,500*	*23,064,800*
Number of crops/year	3	2	3	2
Fixed costs (VND/ha/year)	*69,169,000*	*69,169,000*	*110,670,400*	*110,670,400*
Total cost (VND/ha/year)	116,451,813	98,000,000	186,322,900	156,800,000
	206,718,750	98,000,000	330,750,000	156,800,000
	90,266,937	0	144,427,100	0
Average cost (VND/kg)	39,433	70,000	39,433	70,000
Percentage reduction in average cost (K)	44%		44%	

Source: Data collected by Economic Research Associates.

Note: This version of the grow-out budget forecasts profit margins for adopters of hatchery seed that are even larger than those values in Table 6. It suggests that innovation adopters might reduce average costs per kg of production by a massive 44%.

Table A4. Estimated annual innovation benefits in Vietnam from uptake of the mud crab hatchery technology

Year	Without innovation		With innovation		
	Extensive net surplus (VND million)	Intensive net surplus (VND million)	Extensive net surplus (VND million)	Intensive net surplus (VND million)	Innovation gross benefit (VND million)
2003	11,892	3,017	11,892	3,017	–
2004	12,487	3,107	12,249	4,049	704
2005	13,111	3,200	12,617	5,324	1,629
2006	13,767	3,296	12,995	6,890	2,822
2007	14,455	3,395	13,385	8,806	4,340
2008	15,178	3,497	13,786	11,141	6,253
2009	15,937	3,602	14,200	13,980	8,641
2010	16,734	3,710	14,626	17,419	11,601
2011	17,570	3,821	15,065	21,575	15,248
2012	18,449	3,936	15,517	24,811	17,943
2013	19,371	4,054	15,982	28,533	21,090
2014	20,340	4,176	16,462	32,812	24,759
2015	21,357	4,301	16,956	37,734	29,032
2016	22,425	4,430	17,464	43,395	34,004
2017	23,546	4,563	17,988	49,904	39,783
2018	24,723	4,700	18,528	57,389	46,494
2019	25,959	4,841	19,084	65,998	54,281
2020	27,257	4,986	19,656	75,897	63,310
2021	28,620	5,136	20,246	87,282	73,772
2022	30,051	5,290	20,853	100,374	85,887
2023	31,554	5,448	21,479	115,430	99,907
2024	33,131	5,612	22,123	132,745	116,125
Total					**757,624**

Table A5. Nominal, real and discounted annual net innovation benefits in Vietnam from uptake of the mud crab hatchery technology

Year no.	Year	Annual benefits in Vietnam (VND million)	Annual benefits in Vietnam in A$'000 (nominal)	Research costs in A$'000 (nominal)	Net annual benefits in A$'000 (nominal)	Adjustment factor to convert to 2004 A$ (real)	Net annual benefits in A$'000 (real)	Real discount rate factor (5%)	Discounted net annual benefits in A$'000
1	1995			–368	–368	1.24	–458	1.48	–677
2	1996			–731	–731	1.21	–886	1.41	–1,246
3	1997			–635	–635	1.21	–768	1.34	–1,030
4	1998			–332	–332	1.20	–398	1.28	–507
5	1999			–50	–50	1.18	–59	1.22	–72
6	2000			–64	–64	1.13	–72	1.16	–83
7	2001			–64	–64	1.08	–69	1.10	–76
8	2002			–65	–65	1.05	–68	1.05	–71
9	2003	0	0	–6	–6	1.02	–6	1.00	–6
10	2004	704	59	–6	53	1.00	53	0.95	50
11	2005	1,629	136	–6	130	1.00	130	0.91	118
12	2006	2,822	235	0	235	1.00	235	0.86	203
13	2007	4,340	362	0	362	1.00	362	0.82	298
14	2008	6,253	521	0	521	1.00	521	0.78	408
15	2009	8,641	720	0	720	1.00	720	0.75	537
16	2010	11,601	967	0	967	1.00	967	0.71	687
17	2011	15,248	1,271	0	1,271	1.00	1,271	0.68	860
18	2012	17,943	1,495	0	1,495	1.00	1,495	0.64	964
19	2013	21,090	1,757	0	1,757	1.00	1,757	0.61	1,079
20	2014	24,759	2,063	0	2,063	1.00	2,063	0.58	1,206
21	2015	29,032	2,419	0	2,419	1.00	2,419	0.56	1,347
22	2016	34,004	2,834	0	2,834	1.00	2,834	0.53	1,503
23	2017	39,783	3,315	0	3,315	1.00	3,315	0.51	1,674
24	2018	46,494	3,875	0	3,875	1.00	3,875	0.48	1,864
25	2019	54,281	4,523	0	4,523	1.00	4,523	0.46	2,072
26	2020	63,310	5,276	0	5,276	1.00	5,276	0.44	2,302
27	2021	73,772	6,148	0	6,148	1.00	6,148	0.42	2,554
28	2022	85,887	7,157	0	7,157	1.00	7,157	0.40	2,832
29	2023	99,907	8,326	0	8,326	1.00	8,326	0.38	3,138
30	2024	116,125	9,677	0	9,677	1.00	9,677	0.36	3,474
	Total	757,624	63,135	–2,326	60,809		60,340		25,402

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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
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

IMPACT ASSESSMENT SERIES

No.	Author(s) and year of publication	Title	ACIAR project numbers
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
29	Lindner, R. (2004)	Impact assessment of research on the biology and management of coconut crabs on Vanuatu	FIS/1983/081
30	van Bueren, M. (2004)	Eucalypt tree improvement in China	FST/1990/044, FST/1994/025, FST/1984/057, FST/1988/048, FST/1987/036, FST/1996/125 and FST/1997/077
31	Pearce, D. (2005)	Review of ACIAR's research on agricultural policy	
32	Tingsong Jiang and Pearce, D. (2005)	Shelf-life extension of leafy vegetables—evaluating the impacts	PHT/1994/016
33	Vere, D. (2005)	Research into conservation tillage for dryland cropping in Australia and China	LWR2/1992/009, LWR2/1996/143
34	Pearce, D. (2005)	Identifying the sex pheromone of the sugarcane borer moth	CS2/1991/680
35	Raitzer, D.A. and Lindner, R. (2005)	Review of the returns to ACIAR's bilateral R&D investments	

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6	Chudleigh, P.D. (1991)	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. (1991)	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	