A review and impact assessment of ACIAR's fruit-fly research partnerships, 1984–2007

IMPACT ASSESSMENT SERIES **56**





Australian Government
Australian Centre for
International Agricultural Research

A review and impact assessment of ACIAR's fruit-fly research partnerships, 1984–2007

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

ACIAR seeks to ensure that the outputs of its funded research are adopted by farmers, policymakers, quarantine officers and other beneficiaries.

In order to monitor the effects of its projects, ACIAR commissions independent assessments of selected projects. This series reports the results of these independent studies.

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Foreword

The Australian Centre for International Agricultural Research (ACIAR) has been funding fruit-fly research since its early days. There has been a comprehensive program of research on several areas of this major pest problem and the program has evolved during ACIAR's history.

Two previous impact assessment studies were undertaken in 1998 and 2005 for subsets of the total research program. In the first study it was considered too early to assess the impacts of bait-spray control technologies for the partner countries, but clear benefits to Australia were measured. These benefits came from a significant reduction in response time to an incursion in Cairns, due to the ACIAR-supported research outcomes. The second study assessed the impact of the research on export market access for several South Pacific partner countries.

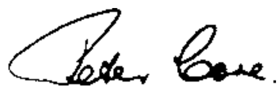
The current study reviewed the full set of 17 projects that ACIAR has supported with many partner organisations and countries. It provides a comprehensive review of these projects and assesses their impact and potential for future impact. It found that these impacts can fall into a range of areas including improved biosecurity to reduce the risk of pest incursions, improved market access for exports, new postharvest treatments for export market access, new field control measures, new fruit crops for some areas, environmental and human health benefits, and capacity building.

Overall the study shows that the return on this substantial research and development investment has been significant. The net present value of all benefits was estimated as $208.1 million (in A$2007). The present value of research investments was estimated at $22.7 million for ACIAR and $50.8 million for all collaborating partners. This gives a benefit:cost ratio of over 5:1 to the total investment and an internal rate of return of 33%.

While the returns on the total investment are significant, the report highlights many important lessons and issues. It shows that, when a total program is looked at, there are some research components that have large impacts and others that have none.

In this case, the latter was not usually a result of the research not generating usable information and technologies; rather that biosecurity and international market access are often too complex for many countries, developing and developed, in our partner region to effectively manage. The report highlights that there is a need to consider many of these issues carefully when developing projects. However, it also emphasises that there is a significant degree of chance in achieving impacts—an accepted part of the risky nature of research.

I look forward to making considerable use of the report in collaboration with our partners to continue the process of improving our investment decision-making from this type of independent analysis.



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Acronyms and abbreviations

ACIAR	Australian Centre for International Agricultural Research
BQA	bilateral quarantine agreement
ERP	emergency response plan
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	the statistical database of the FAO
HTFA	high-temperature forced air
ICMPFF	International Centre for the Management of Pest Fruit Flies
IPM	integrated pest management
NAQS	Northern Australia Quarantine Strategy
NPV	net present value
PIC(s)	Pacific islands countries
PNG	Papua New Guinea
PPD	Plant Protection Department, Vietnam
PRA	pest risk analysis
PV	present value
QDPI	Queensland Department of Primary Industries
R&D	research and development
RMFFP	Regional Management of Fruit Flies in the Pacific program
SIT	sterile insect technique
SPC	Secretariat of the Pacific Community
SPS	sanitary and phytosanitary
VHT	vapour heat treatment
WTO	World Trade Organization

Summary

The involvement of the Australian Centre for International Agricultural Research (ACIAR) in fruit-fly research goes back some 25 years to an initial project in Malaysia. Since that time there has been almost continuous involvement by ACIAR in most areas of fruit-fly control. This report undertakes an impact assessment study of 17 projects dealing with fruit flies.

The 11 core projects focused on the identification and control of fruit flies in the Pacific islands, Bhutan, Papua New Guinea (PNG), Malaysia, Thailand, Vietnam and Indonesia. They were:

- CS2/1983/043 Study of economically important fruit flies in Malaysia and development of control methods
- CS2/1989/019 Biology and control of fruit flies in Thailand and Malaysia
- CS2/1989/020 Identification and control of pest fruit flies of the South Pacific
- CS2/1994/003 Identification and control of pest fruit flies in Vanuatu, Solomon Islands and the Federated States of Micronesia
- CS2/1994/115 Development of economical protein bait sprays from brewery yeast waste for fruit-fly control
- CS2/1996/225 Identification, biology, management and quarantine systems for fruit flies in Papua New Guinea
- CS2/1997/101 A survey of fruit flies in Bhutan and a field control program for *Bactrocera minax* (Enderlein), the Chinese citrus fruit fly
- CS2/1998/005 Managing pest fruit flies to increase production of fruit and vegetable crops in Vietnam
- CS2/2003/036 Managing pest fruit flies to enhance quarantine services and upgrade fruit and vegetable production in Indonesia
- CP/2007/002 Establishment of fruit fly pest free areas
- CP/2007/187 Technical support facility for commercialisation of protein bait production in North Vietnam.

The first of these studies commenced in September 1984 and all, apart from the ongoing studies CS2/2003/036 and CP/2001/187, were completed prior to this impact assessment study.

The research into fruit-fly control raised the prospect of developing a low-cost protein bait based on brewery yeast waste that would enable improved fruit-fly control. CS2/1994/115 and CP/2007/187 were two small projects funded specifically to further develop a cheap and locally available protein bait spray. The objective of developing and efficacy testing a protein bait spray was one of the common threads running through several of the larger projects as well.

ACIAR projects were also funded to look at postharvest heat treatment, use of improved temperate fruits and orchard management, supply chain improvement, and integrated pest management. These projects included:

- PHT/1990/051 Development of heat treatment systems for quarantine disinfestation in tropical fruit
- PHT/1994/133 Development of quarantine disinfestation protocol for an oriental fruit fly (*Bactrocera papayae*) with hot air
- PHT/1993/87 Low-cost disinfestation systems for fruit

- CP/1997/079 Integrated control of mango insect pests using green ants as a key element
- CP/2001/027 Adaptation of low-chill temperate fruits to Australia, Thailand, Laos and Vietnam
- CP/2002/086 Improving postharvest quality of temperate fruits in Vietnam and Australia.

The ACIAR investment in the fruit-fly projects covered in this report commenced in September 1984, and is planned to finish at the end of April 2009. Over this period, ACIAR will have invested A$12.16 million in nominal dollars, or A$15.14 million in constant 2006–07 Australian dollars. The present value (PV) of this expenditure is A$22.87 million. The total investment in these projects by ACIAR and its partners will be A$27.54 million in nominal dollars, or A$33.48 million in constant 2006–07 dollars. The PV of this total expenditure is $50.76 million.

In addition, other agencies funded a variety of complementary fruit-fly research and development projects that in a number of cases contributed to benefits already realised, and/or to benefits likely to be realised in the future. It was not possible to collect accurate and reliable information on the magnitude of many of these costs within the time frame and resources available for this study. Instead, based on a combination of evidence and other information provided by knowledgeable participants in ACIAR and complementary projects, an assessment was made on a case-by-case basis of the proportion of aggregate estimated value of each category of benefit for each country that should be attributed to the ACIAR projects vis-à-vis other complementary projects. Details are provided in the report.

One potential benefit from research that enables better methods for the control and management of fruit flies is to avoid at least some of the losses that otherwise would result from infestation of fresh fruit and leafy vegetable crops. If the research develops new methods to control fruit flies that use less pesticide than previous methods of control, then there also might be benefits to the environment and/or to human health. Such research also can enable the development of new industries that otherwise would be uneconomic due to prohibitive damage to possible crops of fresh fruit and leafy vegetables. Another potential benefit is to reduce the risk of losses that would result from an incursion into a country or area by a damaging, exotic pest fruit fly. In response to such threats, many countries establish sanitary and phytosanitary (SPS) barriers to trade in fresh fruit, so a further potential benefit of fruit-fly research that reduces such threats could be to enable access to new markets for fruit exports.

For this report, the quantifiable potential benefits that might be generated by such research have been categorised as coming from:

- improved biosecurity to reduce the risk of incursion by exotic pest fruit flies
- market access for fruit exports based on non-host status
- market access for fruit exports based on postharvest heat treatment
- field control of fruit flies with protein bait
- introduction of low-chill temperate fruit and improved orchard management.

Another significant benefit to partner countries from the fruit-fly projects has been capacity building. Formal training programs were an important part of many projects. As a result, large numbers of participants acquired specific skills necessary to develop and maintain quarantine systems to keep out exotic pest fruit flies, to generate information necessary to gain market access for fruit exports, and to manage and control fruit flies that damage economically important crops of fresh fruit and leafy vegetables. The extent of capacity building is documented in the report, and the benefits derived from it form a significant and integral component of the above, quantifiable project benefits. However, because both skilled staff and other project outputs are joint necessary conditions for achieving these quantifiable benefits, it was not possible to objectively and reliably separate out the component of these benefits that could be ascribed to capacity building.

Notably, there is an informal element to capacity building that can result from collaboration between Australian researchers and their partner-country counterparts. This can enhance the more general personal and leadership capabilities of all parties and, in the long run, arguably can generate even more significant benefits than those from project-specific training. Typically, such benefits only become evident after a long time and it was not possible to document, let alone quantify, such benefits within the scope of this study and with the resources available.

Extensive efforts were made to assess whether the fruit-fly projects had generated realised benefits to date, and/or were likely to generate prospective benefits in the future for each benefit category in each country. In some cases, where there was no credible evidence of uptake of project outputs, it was assessed that there were no benefits to be estimated. In other cases, quantitative values were not estimated, either because the necessary evidence was not yet available, or because there was insufficient time to uncover such evidence. In the case of environmental and human health benefits, the relationship between project outcomes and impacts on these areas is yet to be determined.

The estimated PV of benefits attributable to the ACIAR projects is A$258.83 million in total, or A$212.63 million when only partner-country benefits are taken into account (Table 1). The estimated benefit:cost ratio is 5.1:1 for total benefits and 4.2:1 for partner benefits. The internal rate of return (IRR) on total benefits is 33%.

The breakdown of attributed benefits is shown in Table 2. Australia derives a significant biosecurity benefit. Fiji is estimated to have derived significant biosecurity and postharvest market access benefits. Vietnam has yet to develop significant exports to countries with high quarantine access standards, such as Japan. The benefits here derive from field control using protein bait. Tonga has derived significant benefits from biosecurity improvements and market access based on non-host status.

The funding for these projects commenced in 1984, and the last project is funded until 2009. There are both realised benefits and prospective benefits, the latter being estimated future benefits from 2006–07. Tables 3 and 4 indicate, respectively, the split between realised and prospective benefits. Most of the biosecurity and market access benefits attributable to the ACIAR projects have been realised, while most of the field control and temperate fruit project benefits are prospective. The report discusses the necessary conditions for these benefits to be realised.

While the total value of benefits generated from the investment by ACIAR and its partners is impressive, the pattern of benefits is variable by type of benefit and by country. The twin lessons that ex ante the returns on individual investments in research are very unpredictable, and ex post are highly variable, are not new lessons but ones that are often forgotten. A related lesson from this thematic and wide-ranging impact assessment is that the high returns to research are often serendipitous. Some realised benefits, such as the cost savings in Australia following the incursion of the papaya fruit fly into northern Queensland, were unanticipated when ACIAR decided to invest in the first fruit-fly project in Malaysia. One of the most important

Table 1. Summary of project economic outcomes

Total PV gross benefits[a]	\$258.83m[b]
PV gross benefits to Australia[a]	\$46.19m
PV gross benefits to partner countries[a]	\$212.63m
PV ACIAR investment in research projects	\$22.87m
PV total cost of research projects (includes ACIAR + partner investments)	\$50.76m
NPV total benefits (after deducting total project costs)	\$208.07m
NPV benefits to partner countries (after deducting total project costs)	\$161.87m
Total benefit:cost ratio	5.1:1
Partner countries benefit:cost ratio	4.2:1
Total benefit internal rate of return (IRR)	33%

[a] Attributed to ACIAR projects

[b] 2007 Australian dollars

Table 2. Summary of the total attributed benefits from ACIAR fruit-fly projects (present value A$million 2007)

Host country	Source	Biosecurity	Market access non-host status	Market access postharvest	Field control with protein bait	Low-chill temperate fruit	Environmental & human health impacts	Capacity-building impact	Total
Bhutan	Appendix C	0	0	0	0	TE	0	TE	TE
Cook Islands	Appendix D	2.000	0.004	0.063	0	0	0	IE/TE	2.067
Fiji	Appendix E	8.834	0.099	0.347	IE	0	NI	IE/TE	9.279
Federated States of Micronesia	Appendix F	NT	0	0	0	0	0	NT	NI
Indonesia	Appendix G	TE	0	0	TE	0	TE	TE	TE
Laos	None	0	0	0	0	0	0	0	0
Malaysia	Appendix H	0	0	0	TE	0	0	NT	NT
The Philippines	Appendix J	0	0	17.563	0	0	0	IE/NT	17.563
Papua New Guinea	Appendix I	0	0	0	0	0	0	TE	TE
Samoa	Appendix K	2.645	0.260	.001	0	0	0	IE/TE	2.906
Solomon Islands	Appendix L	0	0	0	0	0	0	TE	0
Thailand	Appendix M	0	0	13.508	0	TE	0	IE/TE	13.508
Tonga	Appendix N	11.244	16.491	0	0	0	0	IE/TE	27.734
Vanuatu	Appendix O	NT	0	0	0	0	0	TE	TE
Vietnam - S	Appendix P	0	0	0	55.594	0	TE	IE/TE	55.594
Vietnam - N	Appendix P	0	0	0	48.766	35.219	TE	IE/TE	83.985
Australia	Appendix B	43.304	0	2.903	0	0	0	IE	46.207
Total		68.026	16.854	34.385	104.360	35.219	NI, TE	TE, IE, NT, NI	258.844

Legend:
0 = no evidence of uptake/impact.
NI = insufficient information to quantify.
TE = too early to reliably assess.
NT = there was not enough time to quantify in this study.
IE = included in other benefit estimates but not separated out.

general lessons, also widely known but reinforced by the results from this study, is that while successful research project outcomes may be necessary to enable potential benefits, they rarely are sufficient for benefits to be realised. In particular, potential benefits will only be realised if there is uptake of project outputs. However, at the time of project formulation, the necessary conditions for adoption of project outputs often seem to receive insufficient attention. Notwithstanding some 20 years of research on the development of low-cost protein bait sprays from brewery waste, it has still not been conclusively demonstrated that the use of these sprays is a cost-effective alternative to existing practices in most developing countries.

Biosecurity benefits are another example where potential benefits have not always been realised. While a number of Pacific island countries have obtained significant biosecurity benefits, there have been few or no realised biosecurity benefits for some other partner countries. With the benefit of hindsight, some of the necessary preconditions for biosecurity benefits to be

Table 3. Realised attributed benefits from ACIAR fruit-fly projects (present value A$million 2007)

Host country	Biosecurity	Market access non-host status	Market access postharvest	Field control with protein bait	Low-chill temperate fruit
	$m	$m	$m	$m	$m
Bhutan	0	0	0	0	0
Cook Islands	1.541	0.003	0.063	0	0
Fiji	4.157	0.067	0.073	IE	0
Federated States of Micronesia	NT	0	0	0	0
Indonesia	0	0	0	0	0
Laos	0	0	0	0	0
Malaysia	0	0	0	0	0
The Philippines	0	0	16.284	0	0
Papua New Guinea	0	0	0	0	0
Samoa	1.229	0.26	0.001	0	0
Solomon Islands	0	0	0	0	0
Thailand	0	0	10.353	0	0
Tonga	4.917	14.561	0	0	0
Vanuatu	NT	0	0	0	0
Vietnam - South	0	0	0	1.558	0
Vietnam - North	0	0	0	2.924	0.732
Australia	43.304	0	2.333	0	0
Total	55.149	14.892	29.106	4.483	0.732

Legend:

0 = no evidence of uptake/impact.

NI = insufficient information to quantify.

NT = there was not enough time to quantify in this study.

IE = included in other benefit estimates but not separated out.

realised were absent in some countries with long land borders and large numbers of endemic pest fruit-fly species that infest a range of economically important crops and cause severe losses. They also were absent in countries without the financial and organisational capacity and commitment to continue necessary ongoing quarantine activities. The last issue also is a concern in terms of realising future potential benefits from capacity building that has been an impressive outcome from the fruit-fly projects.

Negotiating market access is a complex and difficult activity that can take many years and requires considerable resources. In the South Pacific, only Fiji has been able to continue to grow exports of fruit under SPS protocols negotiated with assistance from the Regional Management of Fruit Flies in the Pacific (RMFFP) program and complementary ACIAR projects. Timeliness also can be important for realisation of potential research benefits. Tonga is the only country that has realised substantial market-access benefits

Table 4. Prospective attributed benefits from ACIAR fruit-fly projects (present value A$million 2007)

Host Country	Biosecurity	Market access non-host status	Market access postharvest	Field control with protein bait	Low-chill temperate fruit
	$m	$m	$m	$m	$m
Bhutan	0	0	0	0	TE
Cook Islands	0.458	0.001	0	0	0
Fiji	4.677	0.031	0.275	IE	0
Federated States of Micronesia	NT	0	0	0	0
Indonesia	TE	0	0	TE	0
Laos	0	0	0	0	0
Malaysia	0	0	0	TE	0
The Philippines	0	0	1.279	0	0
Papua New Guinea	0	0	0	0	0
Samoa	1.416	0	0	0	0
Solomon Islands	0	0	0	0	0
Thailand	0	0	3.155	0	TE
Tonga	6.327	1.930	0	0	0
Vanuatu	NT	0	0	0	0
Vietnam - South	0	0	0	45.842	0
Vietnam - North	0	0	0	54.035	34.487
Australia	0	0	0.571	0	0
Total	12.878	1.962	5.280	99.877	34.487

Legend:

0 = no evidence of uptake/impact.

NI = insufficient information to quantify.

TE = too early to reliably assess.

NT = there was not enough time to quantify in this study.

IE = included in other benefit estimates but not separated out.

based on non-host status. While other countries hope to do so in the future, the realities of negotiating access to premium-price markets are such that these aspirations are unlikely to be realised, especially as conditions for gaining market access are becoming more stringent and standardised as more countries join the World Trade Organization (WTO), and technology developments are overtaking previous requirements. The problems of realising such benefits seem to have been underestimated in the research.

1 Introduction

The fruit-fly problem

> There are approximately 4,500 known species of the family Tephritidae worldwide. They occupy habitats in extremes of climates from cold temperate latitudes to tropical equatorial regions. Further, there are species of "fruit flies" that attack different parts of plants e.g. stems, growing tips, leaves, flowers, fruits, bamboo shoots, to name some. Consequently, almost all above-ground parts of plants are susceptible to attack from fruit flies. All regions of the world contain major pest species of fruit flies that are devastating to horticultural industries. However, the Southeast Asian and Pacific regions have considerably more pest species than any other and therefore have proportionately more economic problems. (Drew and Romig 1997)

Fruit flies are recognised as one of the major pests of fruit and vegetable crops worldwide, and are of major significance in almost all fruit-growing areas of the world, either because they are already present or because they are capable of establishing in areas presently free from them. The fruit-fly species in the subfamily Dacinae are found predominantly in tropical and subtropical regions, and are associated with soft fruits from a very wide range of plants. From Figure 1, reproduced from Collins and Collins (1998), it can be seen that, within the South-East Asian and Pacific region, the largest numbers of Dacinae species are found in Papua New Guinea, Malaysia/western Indonesia and Australia. Around 10% of these fruit flies would be classified as pests, and 1% are regarded as major pests. The adults of most species live for 2–6 months, produce many young and are capable of flying many kilometres across land and water (Bellas 1996).

In 2006 world production of fresh fruit, excluding melons and leafy vegetables that also are fruit-fly hosts, was 526 million tonnes (FAOSTAT 2008). According to Huang (2004) world agricultural trade in fruits and vegetables has grown from a nominal value of US$3.4 billion in 1961 to nearly US$70 billion in 2001, but fruit flies also cause large production losses in substantial subsistence-based agricultural systems. Collins and Collins (1998) cite previous work that estimated economic cost of fruit flies to Australia to be $125 million per annum. This is consistent with an estimate by White and Elson-Haris (1992) that, if fruit flies were not controlled, the potential losses in Australia would exceed $150 million.

Overview of the projects

Eleven of the projects included in this impact assessment were led by Professor Dick Drew, head of the International Centre for the Management of Pest Fruit Flies (ICMPFF) at Griffith University, or by the centre's Deputy Director, Dr S. Vijaysegaran, both of whom are world leaders in fruit-fly taxonomy, ecology and pest management. Apart from project PHT/1990/051 to be discussed below, in chronological order the other 10 projects led by the ICMPFF were:

- CS2/1983/043 Study of economically important fruit flies in Malaysia and development of control methods.
- CS2/1989/019 Biology and control of fruit flies in Thailand and Malaysia.
- CS2/1989/020 Identification and control of pest fruit flies of the South Pacific.

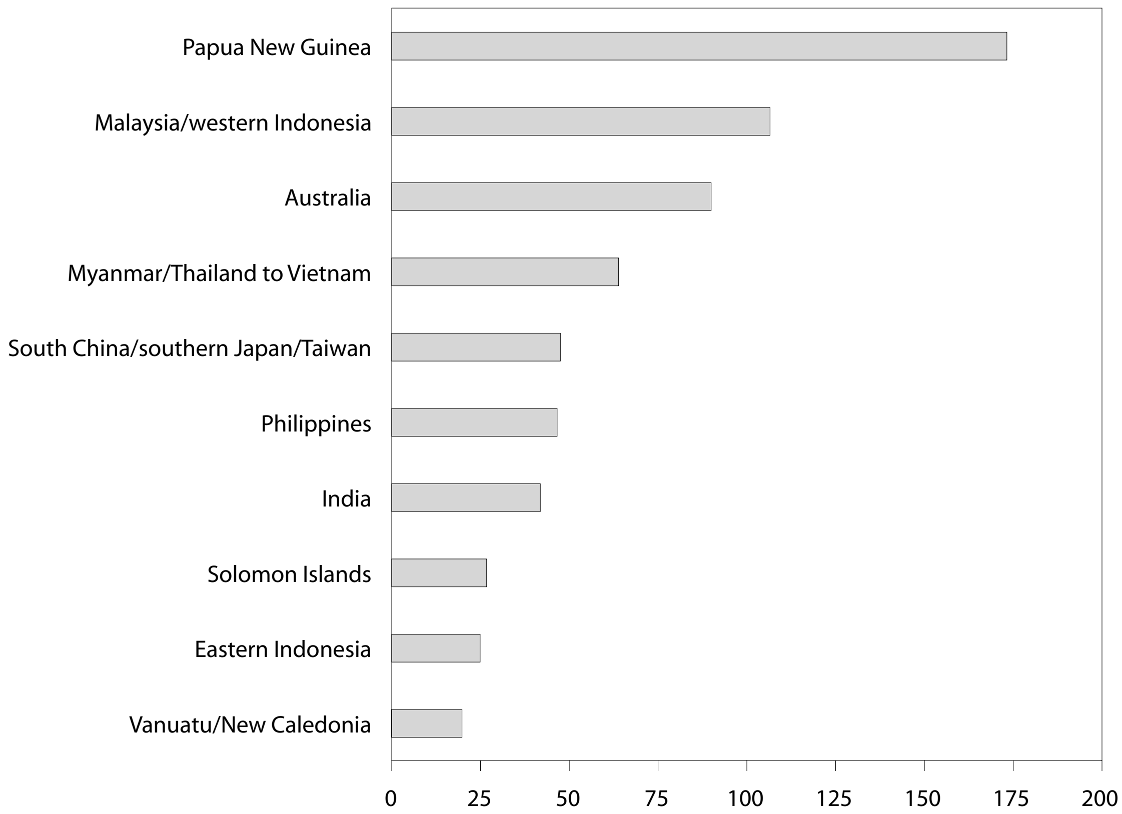


Figure 1. Numbers of fruit-fly species in the subfamily Dacinae, by country

- CS2/1994/003 Identification and control of pest fruit flies in Vanuatu, Solomon Islands and the Federated States of Micronesia.
- CS2/1994/115 Development of economical protein bait sprays from brewery yeast waste for fruit-fly control.
- CS2/1996/225 Identification, biology, management and quarantine systems for fruit flies in Papua New Guinea.
- CS2/1997/101 A survey of fruit flies in Bhutan and a field control program for *Bactrocera minax* (Enderlein), the Chinese citrus fruit fly.
- CS2/1998/005 Managing pest fruit flies to increase production of fruit and vegetable crops in Vietnam.[1]
- CS2/2003/036 Managing pest fruit flies to enhance quarantine services and upgrade fruit and vegetable production in Indonesia.
- CP/2007/002 Establishment of fruit fly pest free areas.

The first of these studies commenced in September 1984 and all, apart from an ongoing Indonesian project (CS2/2003/036), were completed prior to this impact assessment. With the exception of CS2/1994/115 and CP/2007/002, all the above were large to very large projects with several core common objectives, including to:

- conduct extensive trapping and host fruit surveys to determine the number of pest fruit-fly species in host countries, and to document their geographic distribution, seasonality and abundance, as well as the host ranges and potential damage levels for each pest fruit-fly species

1 Professor Drew was project leader for Phase 1, and Dr Vijaysegaran was project leader for Phase 2 of the project from 1 May 2006 to 31 December 2008.

- train partner-country staff in fruit-fly identification and biology, trapping and survey methods, rearing fruit-fly colonies, principles of field control and eradication, and the SPS requirements for trade in fruit and vegetables
- develop and/or promote field control methods, particularly those using protein bait sprays.

CP/2007/002 was a small project funded to run a three-day workshop to acquaint Indonesian quarantine and crop protection staff with the establishment of pest-free areas for fruit flies. Another closely linked small project in which the ICMPFF was involved was:

- CP/2007/187 Technical support facility for commercialisation of protein bait production in North Vietnam.

CS2/1994/115 and CP/2007/187 were two small projects funded specifically to further develop a cheap and locally available protein bait spray from brewery yeast waste for field control of fruit flies. The objective of developing and testing efficacy of a protein bait spray was one of the common threads running through several of the larger projects. For descriptive convenience, all of the above projects will be referred to in this report as the ICMPFF-led ACIAR projects, although this term is not literally correct because the Queensland Department of Primary Industries (QDPI) was the commissioned organisation for some of the earlier projects that pre-dated the establishment of the ICMPFF.

Nearly all of these projects produced most or all of the following outputs, and all generated at least one of them:

- an extended taxonomy of tropical fruit flies, including descriptions of previously unrecorded tephritid fly species, and supported by an authoritatively identified set of fruit-fly specimens
- an enhanced body of scientific knowledge about endemic tephritid fruit-fly species in host countries, and documentation, often in a computer database, of their geographic distribution, seasonality and abundance, as well as host ranges and potential damage levels for each of the species that infests commercial fruit and vegetable crops in host countries
- data that established the non-host status of selected fruit and vegetables, which are necessary to negotiate SPS protocols for export of such fruit and vegetables to premium-price markets
- establishment of laboratories for rearing economic fruit-fly species to provide a consistent supply of insects for use in quarantine treatment research
- knowledge about the identity of parasites of fruit-fly species in host countries, and their significance as natural enemies
- raised awareness in government of large, potential losses from incursions of exotic fruit flies
- the knowledge needed to establish effective border quarantine surveillance procedures for early detection of the entry of exotic fruit flies, in order to prevent an incursion becoming widely established, thereby avoiding or mitigating losses from possible incursions
- raised awareness in government and among fruit producers of the potential for improved field control treatments to mitigate damage due to fruit flies infesting fruits and vegetables
- extension packages of scientifically tested practices for use of bait-spray formulations and selected other field control measures for effective management of fruit fly in fruit and vegetable crops
- partner-country personnel trained in fruit fly identification and biology, trapping and survey methods, rearing fruit-fly colonies, principles of field control and eradication, and the SPS requirements for trade in fruit and vegetables
- partner-country workers trained to carry out field control trials on fruit flies, using protein bait spray formulations and other practices.

In addition to the above projects, ACIAR has invested in seven other projects that wholly or partly involve research on fruit flies. One is CP/2003/042, 'Fruit fly management in Papua New Guinea (PNG)', which is a yet-to-be-completed project led by staff from the New South Wales Department of Primary Industries. In essence, it is an extension of the previous large PNG project. If it succeeds in achieving its aims, the two key outputs will be:

- improved methods of field control of fruit fly in crops such as capsicum
- local staff trained in these methods, and equipped to promote their uptake by growers.

A further three projects, PHT/1990/051, PHT/1994/133 and PHT/1993/877, were led by staff from the QDPI, hereafter referred to as the QDPI-led ACIAR projects.[2] Primary objectives of these projects were to:

- develop physical postharvest quarantine treatments for fruit to facilitate the export of fruit-fly hosts to countries with quarantine barriers against chemical fumigation
- build pilot facilities in partner countries to undertake further research on high-temperature forced air (HTFA) postharvest treatment of fruit-fly hosts
- create in-country capacity by training local staff in postharvest experimental methods.

The primary outputs of these projects in the Philippines, Thailand, Malaysia and Vietnam were:

- established laboratories for rearing economic fruit-fly species to provide a consistent supply of insects for use in quarantine treatment research
- generated the research data on the heat tolerance of pest fruit-fly eggs and larvae needed to certify commercial quarantine treatments based on HTFA
- trained staff in partner countries in the methods to generate the data needed to meet SPS requirements for fruit exports to a number of countries.

2 PHT/1990/051 was led by Dr Drew while he was still employed by QDPI.

The remaining three projects were:

- CP/1997/079 Integrated control of mango insect pests using green ants as a key element
- CP/2001/027 Adaptation of low-chill temperate fruits to Australia, Thailand, Laos and Vietnam
- CP/2002/086 Improving postharvest quality of temperate fruits in Vietnam and Australia.

These three projects differed from the other projects in that research into, or pertaining to, fruit flies was just one component in a project that had wider objectives. The aim of CP/1997/079 was to develop an integrated pest management (IPM) model for mango orchards in Vietnam, Thailand and Australia that combined the use of green ants as a major biological control agent with other agricultural strategies and the selective use of 'soft' insecticides. The primary pests to be controlled by green ants were caterpillars, bugs and beetles, but the effectiveness of the IPM strategy in controlling fruit flies also was evaluated.

The final two projects, CP/2001/027 and CP/2002/086, might loosely be described as industry development projects, in which the aim was to discover ways to overcome constraints to such development.

The primary focus in CP/2001/027 was the introduction from Australia and Thailand of a range of varieties of plum, peach, nectarine, pear and persimmon to upland regions of both Laos and Vietnam to replace poor-quality, locally grown cultivars, and to overcome constraints to high-value production that included, but was not limited to, fruit damage from fruit-fly infestation. CP/2002/086 was an adjunct to CP/2001/027 and had similar aims, except that the focus was post-farm-gate fruit handling throughout the Vietnamese supply chain rather than on-farm production problems.

In a number of cases, the above projects ran parallel to complementary projects funded by other agencies. The most notable example was a series of regional fruit-fly projects in the South Pacific that collectively will be referred to as the Regional Management of Fruit Flies in the Pacific (RMFFP) project. This started in September 1990 with a 1-year project in Fiji, Tonga, Western Samoa and Cook Islands, funded by the Technical Co-operation Program of the Food and Agriculture Organization of the United Nations (FAO). Subsequent extensions were funded by the United Nations

Development Programme (UNDP), the Australian Agency for International Development (AusAID), the New Zealand Agency for International Development (NZAID), and the Secretariat of the Pacific Community (SPC). Support from these agencies took the RMFFP through to December 2000, and eventually encompassed all 22 Pacific island countries and territories (PICTs). McLeod (2005) has estimated total donor support over the period 1991–2002 at approximately A$8.5 million in nominal terms.

Since 2001 the SPC has continued with some of the RMFFP's core elements. The United States Agency for International Development (USAID) also funded some complementary projects. Unlike the ACIAR projects, which were primarily research oriented, the RMFFP included both development and research components. The RMFFP also organised a large number of training courses in which individual agencies cooperated on delivery. Key aims of the RMFFP were to manage the fruit-fly problem by developing inexpensive and environmentally sound field control methods, to strengthen the capacity of quarantine services and establish a quarantine surveillance system, and to overcome quarantine restrictions imposed by importing countries on exports of Pacific island fresh fruit and leafy vegetables.

Agencies that have also played a significant role in tackling fruit-fly problems in the Asia–Pacific region by funding other projects include AusAID, FAO, the Japan International Cooperation Agency (JICA), NZAID, the UNDP and the United States Department of Agriculture.

ACIAR project PHT/1993/877 supplied a new treatment system developed for the Plant Protection Department (PPD) in Hanoi. Through a complementary AusAID Capacity-building for Agriculture and Rural Development (Vietnam) (CARD) project—'Expanding fruit fly treatment development and quarantine training capability in Vietnam'—an equivalent system was set up in Ho Chi Minh City to provide the PPD there with the same capacity.

JICA also has been funding fruit-fly work in Vietnam. The project, 'Improvement of plant quarantine treatment against fruit fly on fresh fruits', will run from 2006 to 2009 and has US$800,000 funding. The project will provide equipment such as vapour heat treatment machines, auto rearing machines, cages for fly rearing, a low-temperature chamber and hot water baths.

Funding

The ACIAR investment in the fruit-fly projects covered in this report commenced in September 1984 and is planned to finish at the end of April 2009.

ACIAR investment in fruit-fly projects

Over this period, ACIAR itself will have invested A$12.16 million in nominal dollars, or A$15.14 million in constant 2006–07 A$. This is depicted in Figure 2, with more detail provided in Table 24 in Appendix 1. The PV of this expenditure is A$22.87 million.

The time sequence of the investments and their cost in nominal dollars are illustrated in Figure 3.

Fruit-fly project funding from ACIAR and project partners

The total investment in these projects by ACIAR and its partners will be A$27.54 million in nominal dollars, or A$33.48 million in constant 2006–07 Australian dollars. This is depicted in Figure 4, with more detail provided in Table 25 in Appendix 1. The PV of this expenditure is A$50.76 million.

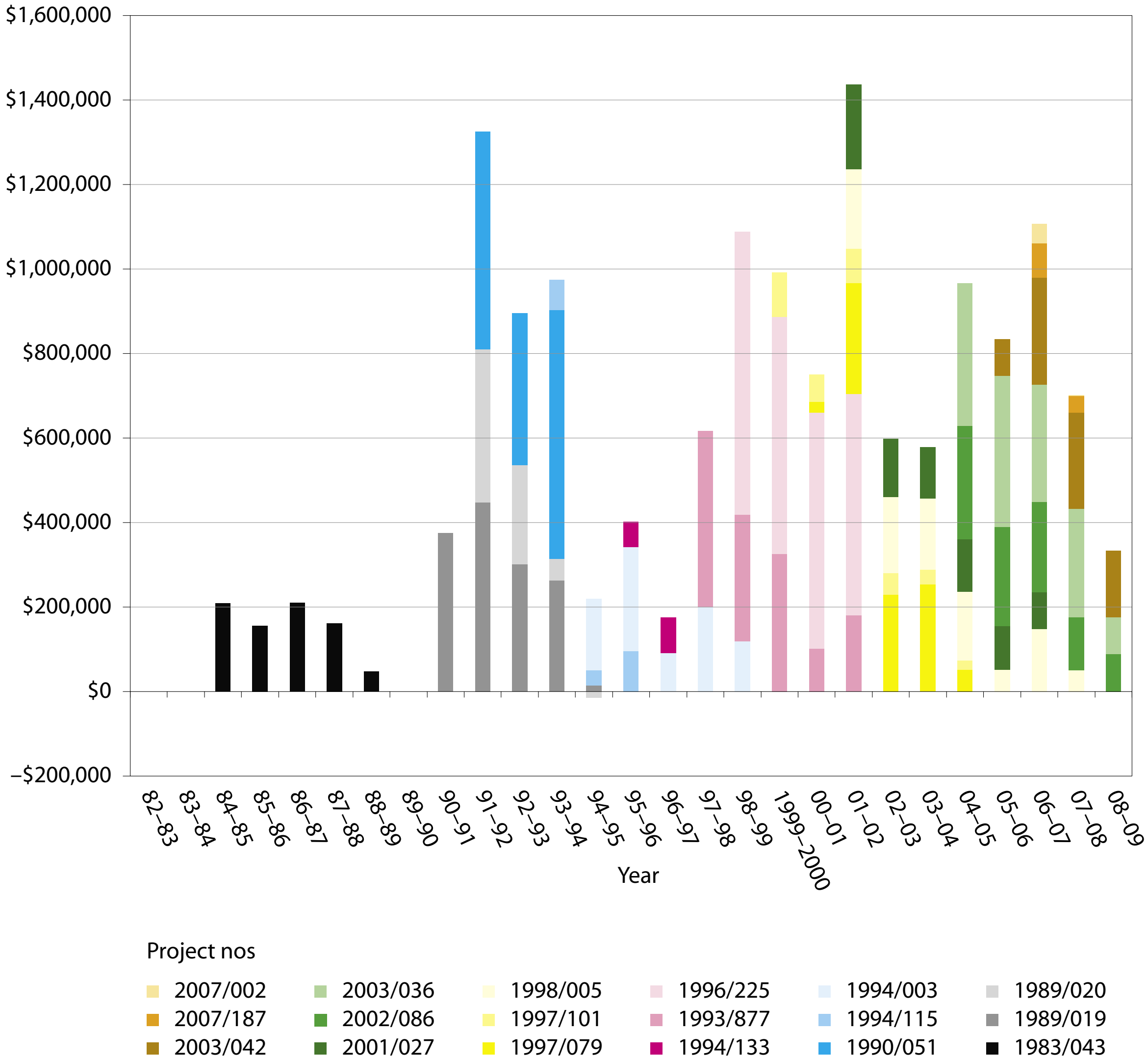


Figure 2. Total ACIAR-only investment in fruit-fly projects (in constant 2006–07 A$)

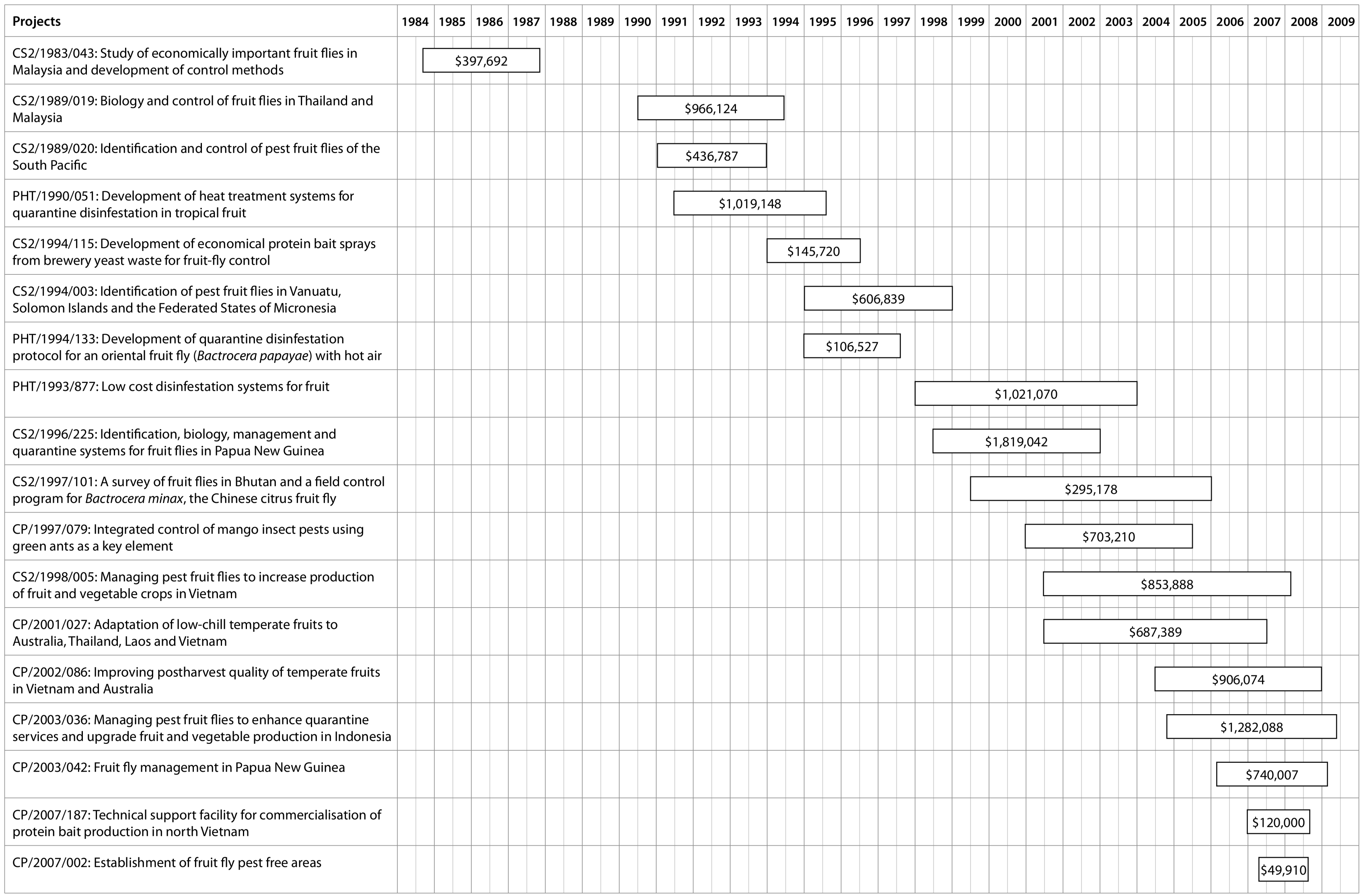


Figure 3. Time profile of ACIAR-only investments in fruit-fly research projects (nominal A$)

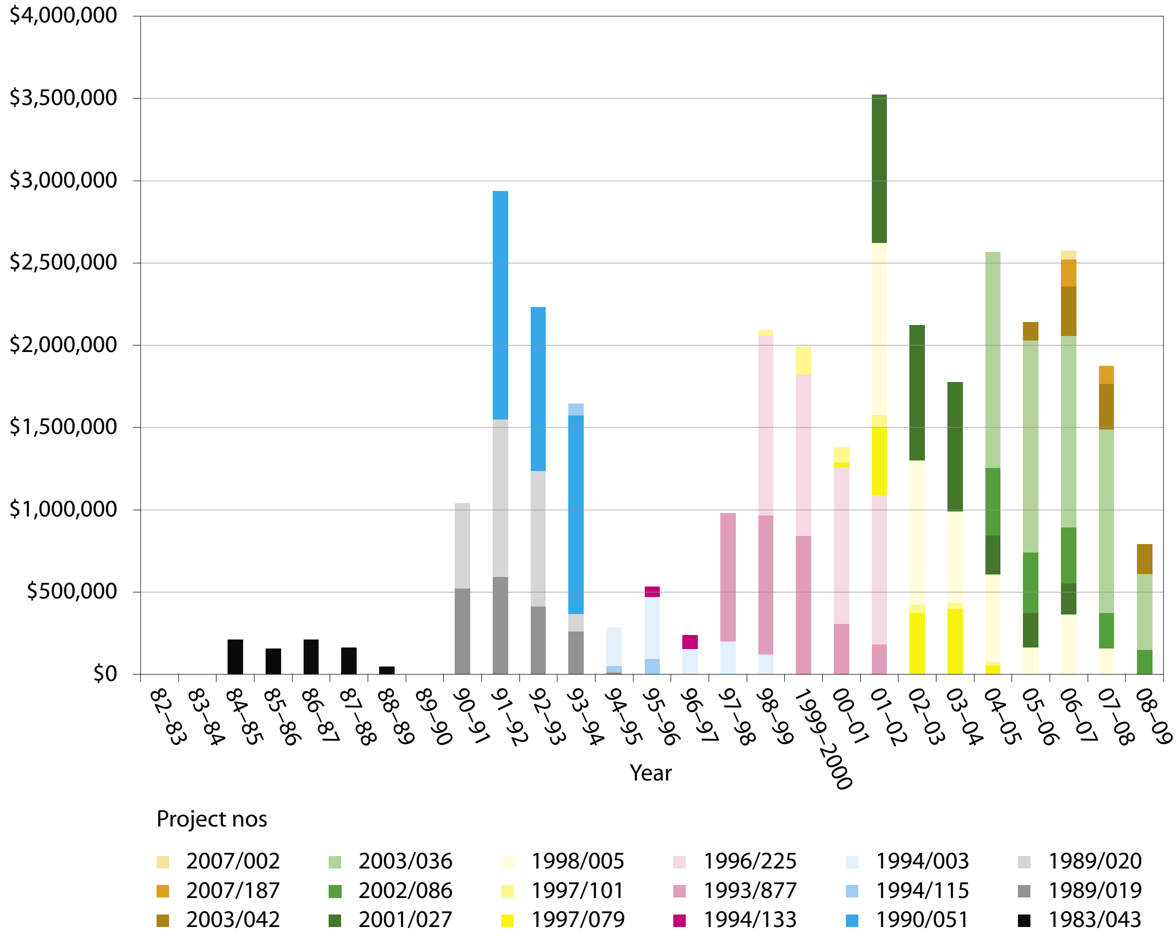


Figure 4. Total investment by ACIAR and its partners in fruit-fly projects (in constant 2006–07 A$)

2 Possible partner-country benefits enabled by fruit-fly research and development

One potential benefit from research and development (R&D) that enables better methods for the control and management of fruit flies is to avoid at least some of the losses that otherwise would result from infestation of crops of fresh fruit and leafy vegetables. If the research develops new methods to control fruit flies that use less pesticide than previous methods of control, then there also might be benefits to the environment and/or human health. Such research also can enable the development of new industries that otherwise would be uneconomic due to prohibitive damage to potential crops of fresh fruit and leafy vegetables. Another potential benefit is to reduce the risk of losses that would result from an incursion into a country or area of a damaging exotic fruit fly. In response to such threats, many countries establish sanitary and phytosanitary (SPS) barriers to trade in fresh fruit, so a further potential benefit of fruit-fly research reducing such threats can be to enable access to new markets for fruit exports.

For this report, the quantifiable potential benefits that might be generated by such research have been categorised as coming from:

- improved biosecurity to reduce the risk of incursion by an exotic pest fruit fly
- market access for fruit exports based on non-host status
- market access for fruit exports based on postharvest heat treatment
- field control of fruit flies with protein bait
- introduction of low-chill temperate fruit and improved orchard management.

Another significant benefit to partner countries from the fruit-fly projects has been capacity building. While the extent of capacity building is documented in the report, and the benefits derived from it form a significant and integral component of the above quantifiable project benefits, because both skilled staff and other project outputs are joint necessary conditions for achieving the above quantifiable benefits, it was not possible to objectively and reliably separate out the component of these benefits that could be ascribed to capacity building.

Although a number of the outputs from ACIAR-funded fruit-fly R&D projects are necessary for the generation of benefits, typically they are not sufficient. In other words, while fruit-fly R&D enables the potential for one or more benefits, the extent to which such potential benefits are realised depends on further activities that typically are outside the scope and beyond the control of the R&D projects.

In this report, the term 'potential benefits' will be used for all possible benefits, realised or not, that are enabled by fruit-fly R&D. The term 'realised benefits' will be used for benefits that, on the basis of credible evidence, had already been realised at the time of this study. 'Prospective benefits' will be used to describe the subset of possible future benefits for which there are good grounds to expect realisation. In particular, solid evidence must exist that there will be future uptake of project outputs, and that such uptake will result in future benefits being realised in order for prospective benefits to be recognised.

Potential market-access benefits in partner countries

Gaining access to export markets increases demand for a country's production of fresh fruit and leafy vegetables. Depending on the cost of increasing production and exporting, it can generate significant benefits to growers. However, due to the risk of introducing exotic pests, most countries have instituted quarantine restrictions on trade, designed to prevent the transmission of pests and diseases. In particular, because many destination market countries, including Japan, the USA, Australia and New Zealand, are free of at least some destructive pest fruit-fly species, they enforce strict quarantine restrictions on imports of tropical fresh fruit and leafy vegetables. These quarantine restrictions impose significant impediments to trade by affecting the ability of developing countries to export these products.

Up until the latter part of the 20th century, fumigation of exports of fresh fruits and leafy vegetables with ethylene dibromide was accepted by most importing countries as an effective way of killing fruit-fly pests. However, concerns about the safety of ethylene dibromide resulted in most premium-price countries banning fumigation with the substance as an acceptable postharvest treatment. By 1995 countries wishing to export fresh fruit and leafy vegetables to these markets had to negotiate an alternative SPS protocol for market access to these countries. This prompted the search for alternative market-access technologies to overcome some of these constraints and facilitate export trade, such as:

- equivalently effective postharvest disinfestation treatments such as low-temperature treatment, high-temperature forced air (HTFA), irradiation, etc. for those fresh fruit and leafy vegetables that are hosts for endemic pest fruit-fly species in exporting countries
- area freedom—proving that no pest fruit flies occur in locations in which export fruit is produced. As at least one pest fruit-fly species is endemic in all of the partner countries involved with the ACIAR fruit-fly projects, there are no cases to date where exports of host fruits have been enabled by project outputs establishing area freedom.
- non-host status testing—proving that a commodity is not a host for endemic fruit-fly species in a country, and proving area freedom for pest fruit flies that do infest the commodity. If it can be established that a fruit is a fruit-fly host at some stages of its maturity cycle but not at other stages, then non-host status protocols may be negotiated for fruit that is at a non-host stage of its maturity cycle. For example, green banana is not a host for most pest fruit-fly species, the most notable exception being *Bactrocera musae*.

Importing countries traditionally determined their own terms and conditions for import of fresh fruit and leafy vegetables in response to market access requests from aspiring exporting countries. Thus negotiation of access protocols is on a bilateral basis. Because postharvest disinfestation treatment is a relatively expensive process, negotiating for market access on the basis of non-host status is the preferred option where the necessary conditions can be scientifically established. However, most tropical fresh fruit and leafy vegetables are hosts for pest fruit-fly species that are endemic in the exporting country, which often is required to prove its disinfestation procedures on a fruit-by-fruit and pest-by-pest basis.

Since completion of the Uruguay Round of Multilateral Trade Negotiations in 1995, quarantine regimes must conform to World Trade Organization (WTO) requirements, including in particular a science-based approach to setting trade restrictive quarantine measures that is commonly described as import risk analysis (IRA) (Binder 2002). Notwithstanding subsequent gradual moves to standardise import protocols, whether a country gains access for its fruit exports into any given market is still determined on a bilateral country-to-country basis. Some countries, such as Singapore, have minimal requirements for fruit imports, while others, such as Australia, New Zealand, the USA, and Japan, have very stringent requirements.

As a result, exports of fruit that gain access to the latter group of markets by satisfying their stringent import protocols command premium prices relative to fruit sold in domestic markets or exported to more open markets. This is a potential source of additional benefits relative to exports to more open markets, but there are considerable barriers that need to be overcome to realise such benefits.

Figure 5 illustrates the benefit from gaining access to a premium-price market by overcoming a quarantine restriction. Producers in the exporting country can sell at wholesale price (P_w) to the rest of the world. Prior to gaining access at P_w, quantity sold was Q_1. The restricted market access can be viewed as a limited opportunity to sell a fixed amount at a premium price. Conceptually, once access is achieved, this can be considered the first block of exports. Thereafter, exports are sold to the rest of the world at *Pw*. In effect, with no supply response, producers divert this amount from existing export markets and receive the price premium on offer as additional producer surplus of (P_r A_1 A_2 P_w).

This area can be considered a close approximation to net benefits. The volume of sales to the restricted market (for example in the case of mangoes from Thailand to Japan) is small relative to total production in the exporting country. Hence, if the additional volume is at the expense of domestic sales, any resultant price increase and loss of consumer surplus in the domestic market will be small. If supply is highly responsive, then any diversion from the domestic market will be offset by expansion of production for domestic sale, with negligible price consequences.

Project outputs necessary to realise market-access benefits

The three Queensland Department of Primary Industries (QDPI)-led ACIAR projects, PHT/1990/051, PHT/1994/133 and PHT/1993/877, were the only ACIAR projects that developed non-chemical disinfestation treatments based on HTFA to enable exports to premium-price markets of those fresh fruit and leafy vegetables for which non-host status could not be established. The necessary outputs these projects produced to enable exports of fruit-fly host fresh fruit and leafy vegetables to premium-price markets were as follows:

- research data on the heat tolerance of pest fruit-fly eggs and larvae to certify commercial postharvest quarantine treatments based on HTFA

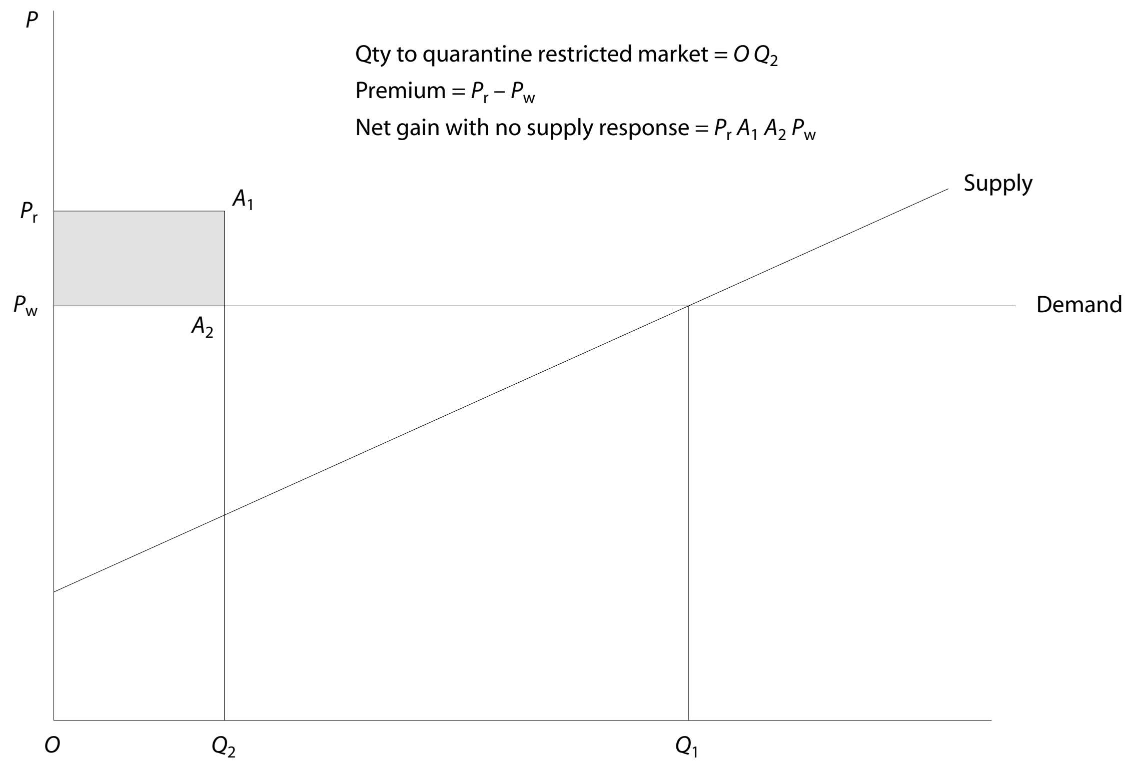


Figure 5. Producer gains from achieving market access to a restricted market

- staff in partner countries trained in methods to generate the necessary data to meet SPS requirements for fruit exports to a number of countries.

Furthermore, in order to carry out scientific research to test for heat tolerance of fruit-fly life stages, it is essential to have access to:

- laboratories for rearing economic fruit-fly species to provide a consistent supply of insects for use in quarantine treatment research.

As part of many ACIAR projects, fly-rearing laboratories were established in most partner countries in South-East Asia and the South Pacific. However, the Regional Management of Fruit Flies in the Pacific (RMFFP) project was the primary agent in the South Pacific for developing a schedule of postharvest treatments to disinfest tropical fruits of fruit-fly pests.

There is one project output from the International Centre for the Management of Pest Fruit Flies (ICMPFF)-led ACIAR projects that is necessary, but not sufficient, for any country wishing to negotiate SPS import protocols to export certain fresh fruit and leafy vegetables to premium-price markets on the basis of non-host status:

- scientifically collected and documented evidence that a commodity is not a host for endemic fruit-fly species in the partner country, and that pest fruit flies that do infest the commodity do not occur in the partner country.

ICMPFF-led ACIAR projects CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1996/225, CS2/1997/101, CP/1998/005 and CP/2003/036 provided this necessary input to establish non-host status for fruit exports from Malaysia, Thailand, Cook Islands, Fiji, Samoa, Tonga, Federated States of Micronesia, Solomon Islands, Vanuatu, Papua New Guinea, Bhutan, Vietnam and Indonesia.

To sum up, ACIAR projects provided significant outputs necessary to enable potential benefits from export of fruit-fly host fresh fruit and leafy vegetables from the Philippines, Malaysia, Thailand and Vietnam. In addition, ICMPFF-led ACIAR projects provided a critical, albeit minor, input to enable potential benefits from export of fruit-fly host fruits from Malaysia, Thailand, Cook Islands, Fiji, Samoa, Tonga, Papua New Guinea, Vietnam and Indonesia. Figure 6 uses an ACIAR pathways template to show how the research undertaken in the various postharvest disinfestation treatments fruit-fly projects leads market access benefits. Figure 7 shows the pathways for benefits of market-access under non-host status.

Other necessary conditions to realise market-access benefits

To gain market access to each potential market, firstly the potential exporter must make a formal application, which typically will join a long queue of applications that require a pest risk analysis to be carried out. The number of years that an application stays in the queue will depend, inter alia, on the resources available to conduct such pest risk analyses, and on the relative importance that each country attaches to facilitating trade in this particular commodity vis-à-vis other commodities. When the importer decides to conduct a pest risk analysis for importation of a fresh fruit or leafy vegetable, the exporter will need to supply all required information to satisfy the importer that granting market access will not only provide protection from an exotic pest fruit fly, but also the appropriate level of protection against the introduction of other exotic pests and diseases. Once a pest risk analysis is completed, further requirements might need to be negotiated before market access is granted.

For applications based on non-host status for fruit flies, it is necessary for a potential exporting country to provide credible evidence that the commodity is not a host for endemic fruit-fly species in the partner country and that pest fruit flies that infest the commodity do not occur in the production region of the partner country. Such information alone is by no means sufficient to be granted market access. As noted above, the importing country will need to be satisfied that there is an appropriate level of protection against the introduction of other exotic pests and diseases. The import of mangosteens into Australia is a case in point. For many potential exporting countries, it is a relatively straightforward matter to supply the required information to establish non-host status for fruit fly, but there also is the risk of introduction of other, potentially more damaging, pests that needs to be considered in an import risk assessment. Thus, the import conditions for import of mangosteen from Thailand to Australia require fumigation to protect against the introduction

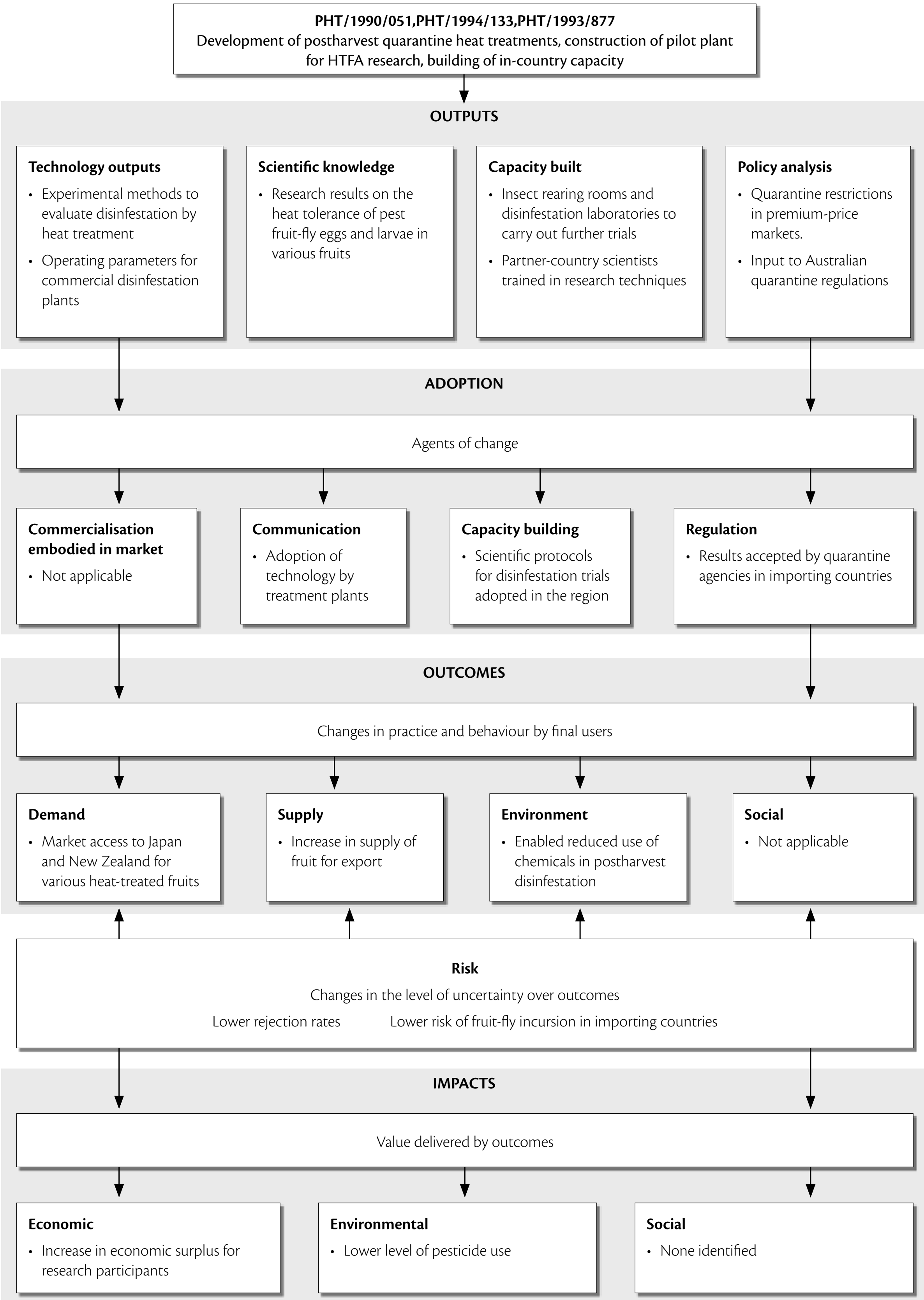


Figure 6. Pathways to benefits from market access based on postharvest heat treatments

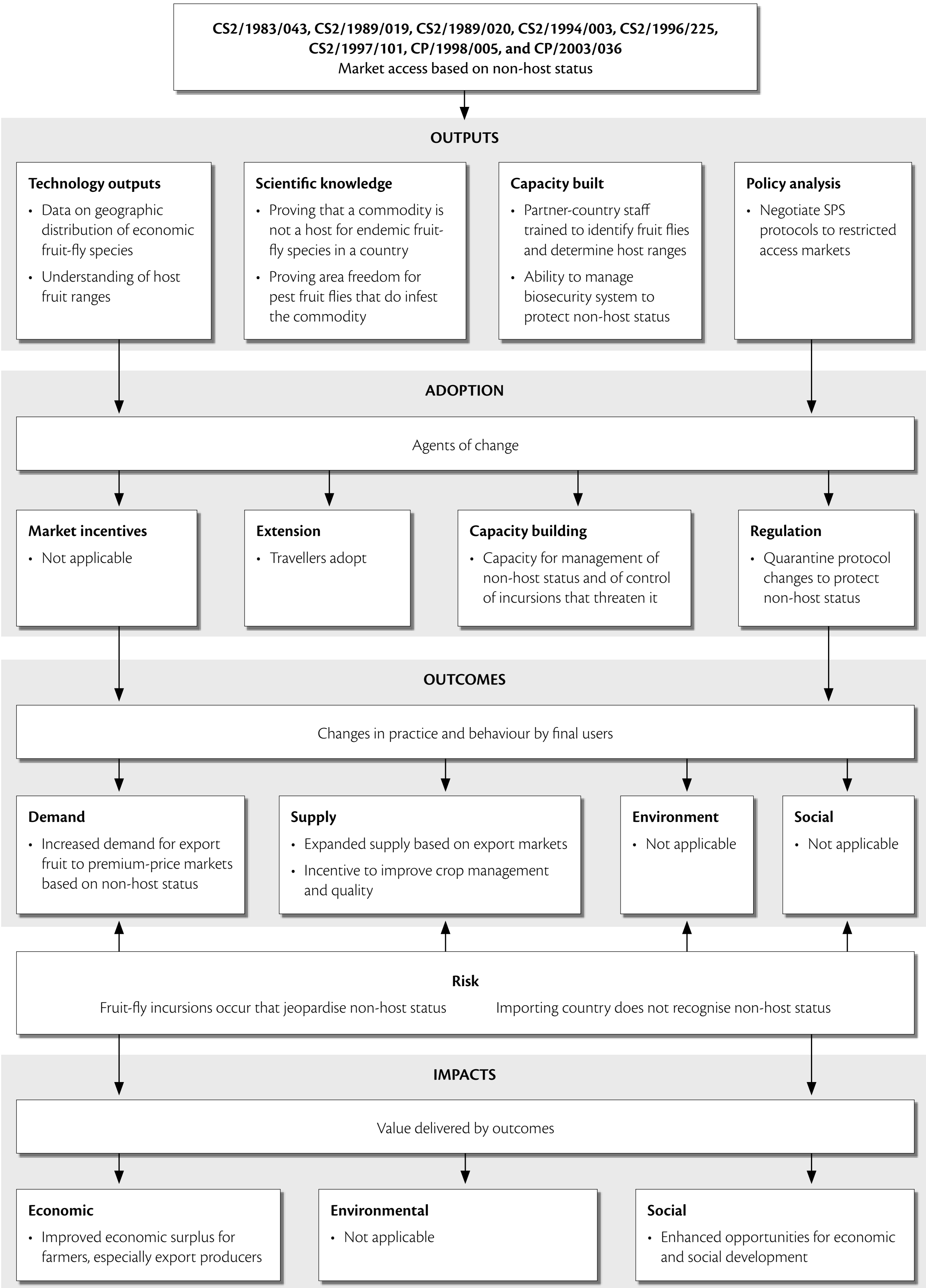


Figure 7. Pathways to benefits from market access based on non-host status

of pests other than fruit flies. Similar comments also apply to applications based on postharvest disinfestation treatments for fruit flies.

Finally, for market access benefits to be realised and attributed, at least in part, to the ACIAR-funded projects, it is necessary that exports of fresh fruit and leafy vegetables to importing countries have increased after the introduction of import protocols negotiated using project outputs. Such export growth may not eventuate for a number of reasons that have nothing to do with successful project outcomes. For instance, in an insightful article, McGregor (2007) discusses a number of reasons for the failure of many Pacific islands countries to realise their considerable potential for export of fresh fruit and leafy vegetables. In contrast to the rapid growth in the value of horticultural exports from other developing countries, he notes that exports of these commodities from the Pacific islands region are lower now than they were in 1980. He lists the main factors that determine capability to export horticultural products successfully as:

- suitable agronomic conditions to grow products with identified markets
- ready access to an international airport or seaport
- availability of air and sea freight capacity to target markets at reasonably competitive freight rates
- private sector marketing capability
- quarantine pest status and management, particularly for fruit flies
- ability to resolve phytosanitary and other market-access issues.

Most Pacific islands countries have suitable agronomic conditions and, while the ICMPFF-led ACIAR and RMFFP project outputs made important contributions to quarantine pest status and management for fruit flies, few countries have ready access to an international airport or seaport with ready availability of freight capacity at competitive rates. Arguably, most are weak in terms of private-sector marketing capability and ability to resolve phytosanitary and other market-access issues. It is doubtful whether the ACIAR and RMFFP projects could have done much about the latter factors even if it had been an objective to so.

Potential biosecurity benefits in partner countries

The term 'biosecurity' pertains to the mitigation of exotic pest damage by preventing introductions, detecting incursions and eradicating resultant populations, or by managing new species as long-term problems, curtailing their impact and preventing their further spread (Waage et al. 2004). The discussion in this section is based, inter alia, on the following publications: FAO (1998), Raap (2001) and Bellas (1996).

Biosecurity results from reducing the risks posed by exotic pests through actions such as exclusion, eradication and control. As summarised by Plant Health Australia (2006), the components of plant industry biosecurity for the threats posed by exotic fruit flies are illustrated in Figure 8.

An important potential benefit from fruit-fly R&D is the greater biosecurity that results from enhanced capacity for early detection and quick response to an incursion of an exotic and economically damaging fruit fly. To the extent that an incursion of an exotic pest fruit fly is detected sooner rather than later, the earlier appropriate action can be taken to contain and/or eradicate the exotic pest fruit fly, the smaller the likely costs of the incursion. Conversely, an incursion that goes undetected and/or is not contained for a lengthy period will be much more costly to eradicate. In particular, if the incursion becomes so well-established that eradication is uneconomic, then the subsequent costs of containment and long-term management will be substantial. Such costs include, but are not limited to, the loss of the benefits of any fruit exports until such time as the importing countries accept revised trade protocols and/or until any eradication program has been successful. Furthermore, the amenity losses suffered by the local population while they identify and increase production of alternative sources of food to compensate for the loss of pest-damaged fruit is another cost associated with an incursion. Hence, the potential benefit from R&D that enables early detection and rapid response to an incursion of an exotic pest fruit fly is the avoided loss of:

- higher eradication costs
- loss of trade benefits

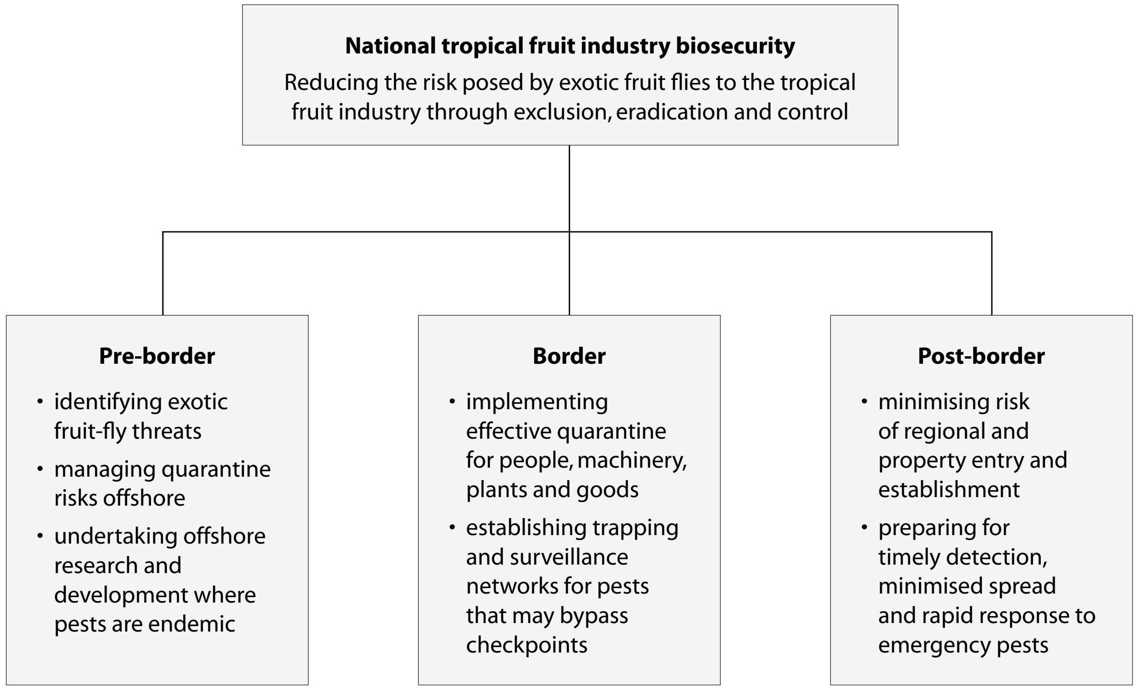


Figure 8. Components of plant industry biosecurity

- costs of containment and long-term management
- reduced production and consumption due to yield loss from fruit-fly infestation
- amenity losses from production or consumption of pest-damaged fruit.

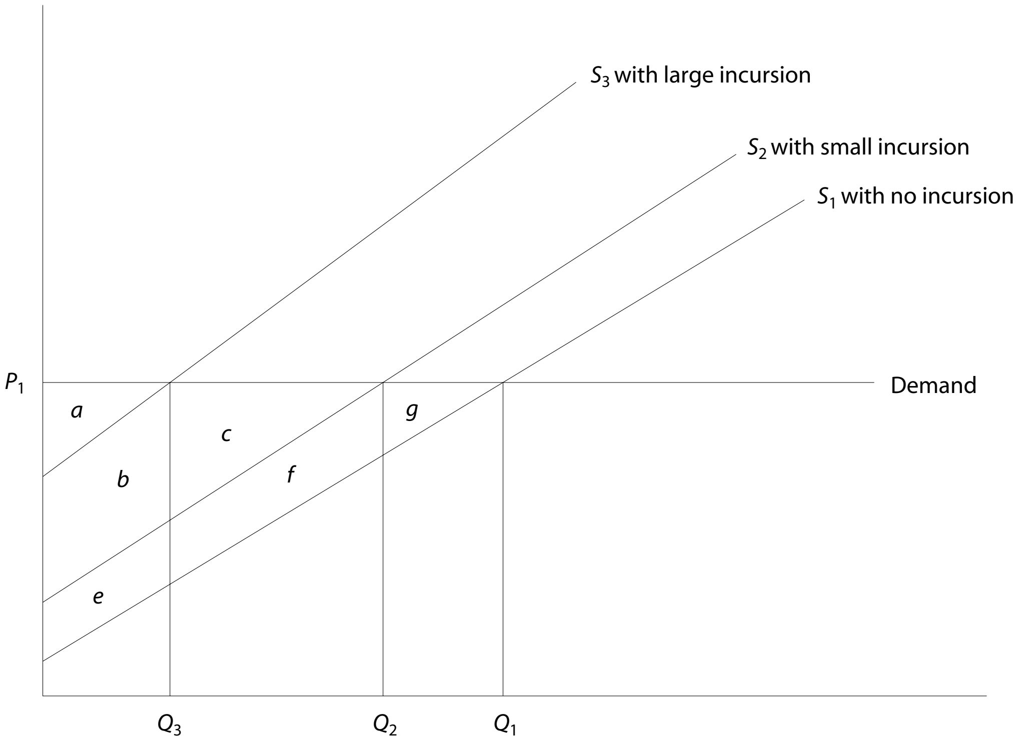
Figure 9 indicates the consequences of preventing a large incursion. With demand as shown, and S_1 being the initial supply curve, market price and quantity are P_1 and Q_1. An incursion results in damage to crops and loss of supply. This shifts the supply curve in, with a larger contraction for a larger incursion. With a small incursion the market price and quantity are P_1 and Q_2. For a larger incursion the price and quantity are P_1 and Q_3.

Initial producer surplus is the total area $a+b+c+d+e+f$. With a small incursion, producer surplus is $a+b+c$ giving a loss of $d+e+f$. Under a large incursion, with supply at S_3, produce surplus is reduced to a, with a loss of $b+c+d+e+f$. The difference, which is the area $b+c$, is the lost producer surplus if small incursions become large incursions. The avoidance of these losses is the potential benefit from biosecurity activities that mitigate the chances of a large incursion. With the basic biosecurity research carried out under the various ACIAR projects, and with the various associated and complementary biosecurity activities in place, it can be argued that a small incursion is still possible but a larger incursion is mitigated. The difference in producer surplus between the two scenarios is attributable to the various activities, including ACIAR projects, that contribute to enhanced biosecurity.

Project outputs necessary to realise biosecurity benefits

The following outputs from the ACIAR projects were necessary inputs to enable potential biosecurity benefits in any given host country:

- a comprehensive taxonomy of tropical fruit-fly species
- supporting infrastructure, such as a suitable taxonomic key, supported by an authoritatively identified set of preserved fruit-fly specimens to enable rapid detection and identification of exotic pest fruit flies, and a laboratory to maintain breeding colonies of key fruit-fly species to support research on introduced flies



Producer surplus loss from small incursion = $e + f + g$
Producer surplus loss from large incursion = $e + f + g + b + c$

Figure 9. Potential benefits from mitigating a large incursion

- documented knowledge about the geographic distribution, host range and seasonal abundance of endemic tephritid fruit-fly species in host countries
- documented knowledge about the host range and ecological niches of high-threat exotic pest fruit-fly species, as well as potential damage levels for each pest tephritid fruit-fly species
- necessary knowledge to establish effective border quarantine surveillance procedures for early detection of entry of exotic pest fruit flies in order to prevent an incursion becoming widely established, thereby avoiding or mitigating losses from possible incursions
- raised awareness in government of large potential losses from incursions of exotic pest fruit flies
- partner-country personnel trained in fruit-fly identification and biology, trapping and survey methods, rearing fruit-fly colonies and principles of fruit-fly containment and eradication.

The ICMPFF-led ACIAR projects and associated projects clearly raised partner-country governments' awareness of likely costs of incursion of an exotic fruit-fly species, which at least led to 'early' implementation of effective quarantine surveillance systems involving trapping and host surveys, as well as simpler elements of border security measures. Arguably, the simplest parts of border security measures, such as establishing effective barrier quarantine checkpoints to intercept and destroy unauthorised imports of fruit-fly hosts, could have been easily copied from elsewhere so, under any plausible counterfactual scenario, implementation eventually would have taken place without this awareness-raising. More problematic is the extent to which earlier raised awareness among the public at large also might have led to greater compliance with quarantine border security regulations, and a lower probability that an infested host would bypass checkpoints.

However, the chance of detecting entry that bypasses these simpler measures is very low unless there also is in-country capacity building based on knowledge of fruit-fly taxonomy and biology, and these other elements of an effective quarantine system require significant scientific expertise that would not have been available without the projects. In particular, there is little doubt that the projects were crucial to the early establishment of quarantine surveillance measures, such as pest trapping and host-fruit surveys, to detect pests that may bypass checkpoints. A central feature of the projects was the development of a more detailed understanding of pest fruit flies in the partner countries and elucidation of the host range and geographical distribution of the different fruit-fly species. Such knowledge is important in developing SPS protocols for the importation of pest-free host fruits. More importantly, most of the ICMPFF-led ACIAR projects trained partner-country staff in how to set up pest trapping systems and conduct host-fruit surveys, and instructed them in fruit-fly taxonomy and how to identify exotic fruit flies species, as well as educating them about fruit-fly biology. Clearly, such in-country capacity building was an essential precursor to the establishment of effective quarantine surveillance measures.

ICMPFF-led ACIAR projects CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1996/225, CS2/1997/101, CP/1998/005 and CP/2003/036 provided some of the necessary inputs to establish effective quarantine systems in Malaysia, Thailand, Cook Islands, Fiji, Samoa, Tonga, Federated States of Micronesia, Solomon Islands, Vanuatu, Papua New Guinea, Bhutan, Vietnam and Indonesia.

Figure 10 uses an ACIAR pathways template to show how the fruit-fly research undertaken in the various relevant projects leads to biosecurity benefits.

Other necessary conditions to realise biosecurity benefits

Geographic isolation can provide a considerable degree of natural protection from exotic pest threats, while the capacity to minimise the risk of pest fruit-fly incursion can be minimal for countries with long, open, shared land borders.

In order to realise potential benefits from high biosecurity, partner-country governments also need to commit sufficient resources to implement, operate and maintain an effective quarantine surveillance system that involves the following elements:

- an early detection system to maximise the likelihood of detecting an introduction of targeted exotic pest fruit-fly species into a country before it becomes established. Typically, an early detection system will include:
  - a monitoring program that involves a permanent network of traps in identified high-risk areas that are baited with pheromone lures, such as methyl eugenol or cuelure, plus an insecticide to kill any flies that enter the trap
  - regular host-fruit surveys that look for evidence of infestation
  - a schedule for regularly identifying flies collected from traps and host surveys as either endemic fruit flies or exotic pests, and reporting results to relevant bodies.
- an emergency response plan (ERP)
  - If an incursion of an exotic fruit-fly species becomes established, the relevant ERP is implemented.
  - The immediate aim of such a plan is to contain the incursion by establishing quarantine areas and putting restrictions on the movement of fruit while a delimiting survey is carried out. This involves intensive trapping and fruit collecting to monitor the range of hosts being infected, and the rate of geographical spread of the pest.
  - After the identity of the introduced pest is confirmed, and sufficient information on the extent of the incursion is available, a decision is taken about whether the long-term response will involve containment and/or eradication, or simply long-term management.
  - If eradication is attempted, methods might include annihilation of males using lure traps, distributing protein bait sprays to kill females before they can lay eggs, destruction of fallen fruit, and implementing the sterile insect technique (SIT) in which large quantities of sterilised male flies are released into the quarantine area once the fly population has been suppressed by other means.

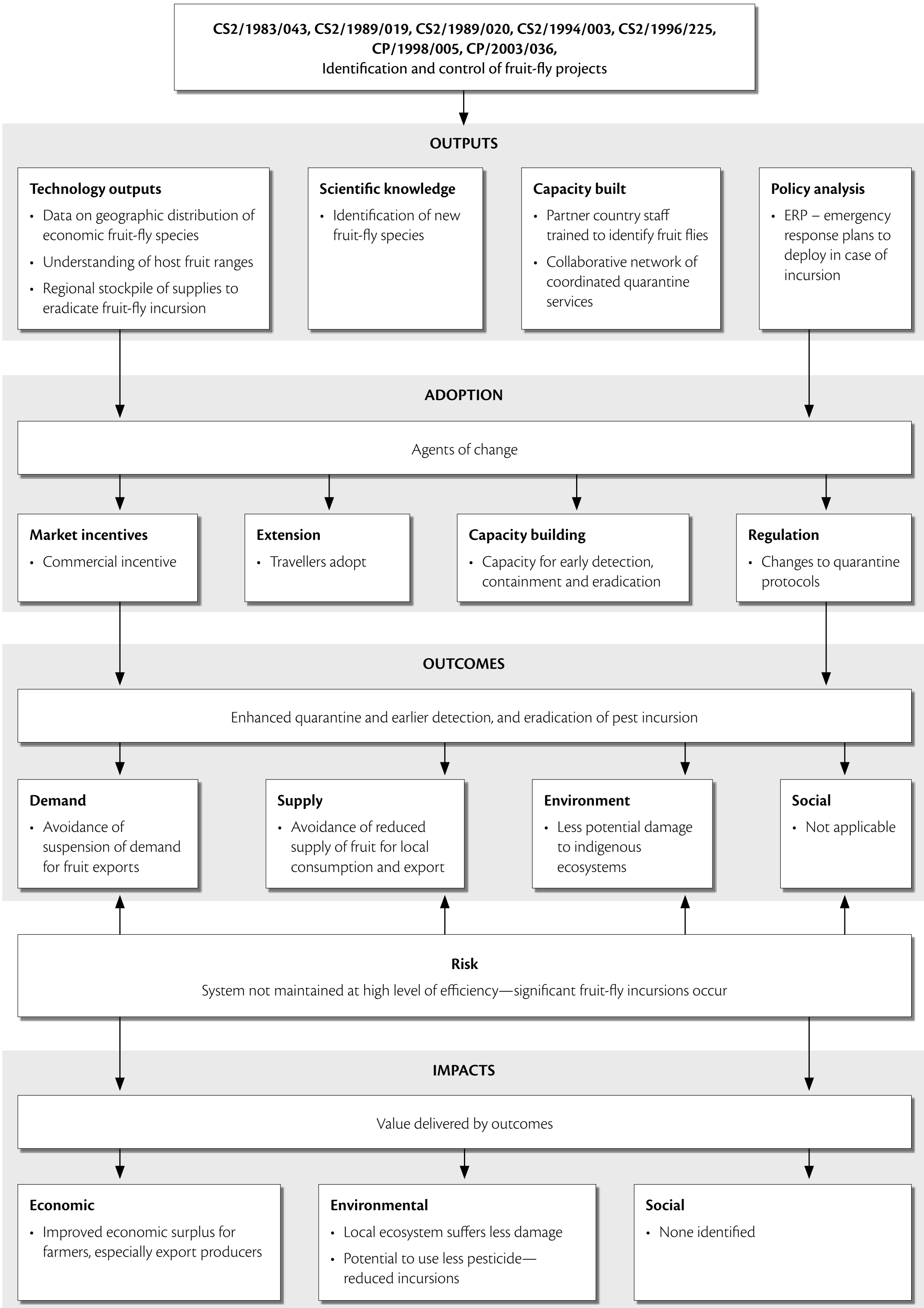


Figure 10. Pathways to benefits from biosecurity research

– If eradication is uneconomic, implement long-term containment and surveillance programs, and develop long-term management methods.

While ICMPFF-led ACIAR projects were not directly responsible for preparation of pest incursion ERPs for timely detection, minimised spread and rapid response to incursion of fruit-fly pests, the formulation of such plans by partner countries, aided by other projects such as the RMFFP, utilised basic knowledge about the taxonomy and biology of fruit flies from the ACIAR projects. Hence, some part of the estimated value of early preparation of these plans legitimately can be attributed to the ACIAR projects.

Potential field control benefits in partner countries

Numerous methods to either control fruit-fly infestations or mitigate their effects have been available to growers for many years. Practices to reduce fruit-fly populations include cover sprays of insecticides, spot sprays of protein bait mixed with insecticide, and field sanitation. Male annihilation, by luring flies into traps containing a para-pheromone able to attract fruit flies from more than 300 metres and baited with an insecticide, can be a particularly effective method of reducing fly populations. However, due to cost, it is normally only used as a monitoring tool for surveillance and in eradication programs. Bagging fruits is used to protect some high-value fruits from fruit-fly infestation, while 'cultural' avoidance practices include production during periods of relatively low fruit-fly activity, early harvest before fruit is fully ripe and susceptible to infestation, and growing less-susceptible varieties.

None of the ACIAR-funded projects developed new methods of field control of fruit flies. However, the development of new ways to produce a cheap, locally available protein bait spray from brewery yeast waste for large-scale field control of fruit flies, and/or scientifically evaluating and promoting extension packages for use of bait-spray formulations and selected other field control measures for effective control of fruit fly in fruit and vegetable crops, were aims of several ICMPFF-led ACIAR projects. In addition, the promotion of a package of other field control methods adapted to suit local conditions was one of the aims both of the so-called industry development projects, and of several ICMPFF-led ACIAR projects.

Protein bait sprays comprise an attractant and a toxicant, and have been used in Australia since 1889. In the mid-1980s, the acid hydrolysate attractant component of bait sprays, which can have phytotoxicity problems, was replaced with a yeast autolysate. The effectiveness of protein bait as an attractant depends on the fact that immature females need a protein meal to develop mature eggs, so 'spot spraying' is adequate and cover spraying of the tree canopy is unnecessary. Experiments and experience have shown that bait spraying is most effective in 'area' treatment programs, such as in large orchards, or where adjacent properties all use the technique.

In Queensland, a yeast autolysate protein bait spray is marketed under the name Mauri's Pinnacle Protein Insect Lure (MPPIL), and can be stored at ambient temperature provided it is kept in a cool, dark place. This protein bait spray has been used to control fruit fly in the major citrus growing areas in Queensland for over 25 years and has proven very successful. Relative to insecticide cover sprays, the following are among the claimed advantages of protein bait sprays.

- They lower the costs of insecticide as less is used.
- Protein bait sprays leave fewer residues in crops and the environment.
- They do not attract and therefore do not harm beneficial insects, such as pollinators and parasites. Hence, they are suitable as a component in integrated pest management (IPM) programs.
- Spot spraying is less time-consuming and requires less labour.
- Farmers also may be able to use simpler, cheaper application equipment.
- Protein bait sprays are more environmentally sound. Spray applications can be directed onto foliage and away from fruits to minimise fruit residue problems.
- The use of coarse sprays at low pressure is less hazardous to the spray operator.

A significant disadvantage of protein bait sprays is that control can be inadequate when there is extreme pest pressure, and especially if re-invasion of the treated area is continuous. This is likely to be the case when the treated area is small in relation to surrounding untreated areas. Also, as the season progresses, control may be less effective as female populations at all stages of sexual maturity develop, because gravid females may be less interested in food than in finding suitable egg-laying sites.

Another problem with earlier protein bait sprays was bait being washed off leaves when it rained. To overcome this problem and improve the effectiveness of bait sprays, CropScience (Australia), in conjunction with the ICMPFF-led ACIAR projects, developed a new formulation using fipronil rather than malathion as the insecticide, combining it with a gel that sticks to tree leaves. The new product, known as Bactrogel™, has been used since late 1998 and is available to countries that have registered the insecticide fipronil.

Field control benefits arise primarily from the increased yields of saleable fruit that farmers receive. In effect the supply curve is shifted down. Figure 11 illustrates this. Without field control, supply is *S1* and producer surplus is area *a*. After the adoption of field control based on protein bait, supply shifts to S_2 for adopting farmers, and the producer surplus grows to area *a+b+c*, a net gain of area *b+c*. The assumption in the diagram is that the adopting farmers will be able to sell at current market prices, based on the protein bait adoption being a relatively small proportion of total production

Project outputs necessary to realise field control benefits

The first two outputs below are essential for field control benefits from the ACIAR projects. The others also are necessary for benefits when use of protein bait spray is a component of field control methods:

- local staff with expertise in methods of field control of fruit flies
- an effective extension package adapted to local conditions
- a cheap and locally available supply of protein bait spray

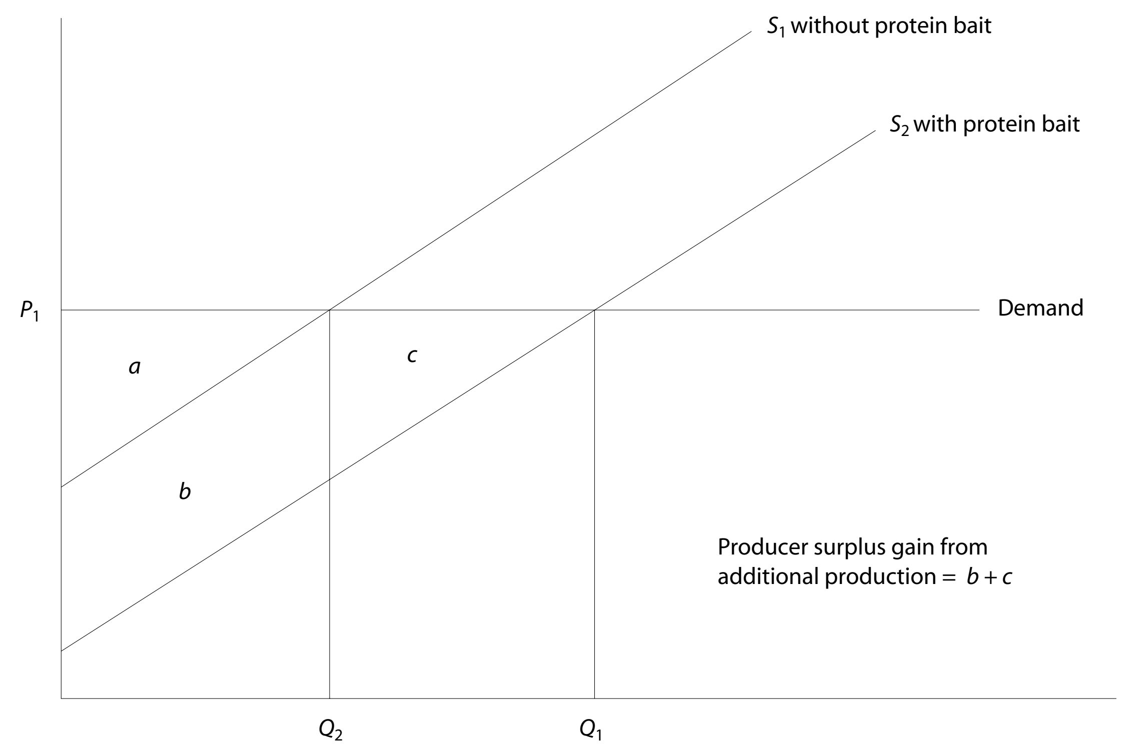


Figure 11. Producer surplus benefits from field control

- application methods for protein bait spray of proven efficacy
- demonstration of protein bait effectiveness.

The various ACIAR projects where protein bait was a component all incorporated farmer and extension ('train the trainer') activities. Field experiments documented effectiveness and were the basis for commercial operators to develop application recommendations. ACIAR projects and researchers in Malaysia and Vietnam contributed directly to the development process for protein bait manufacturing facilities. This was done by researchers working with developers in bait development, field testing, application rate documentation and, in the case of North Vietnam (CP/2007/187), through provision of a small direct financial contribution to assist bringing the development of the manufacturing plant to fruition.

Figure 12 uses an ACIAR pathways template to show how the research undertaken in the various relevant fruit-fly projects with a field control component leads to the realisation of field control benefits.

Other necessary conditions to realise field control benefits

Sustained uptake of all necessary project outputs by potential adopters is necessary, and may be sufficient, for benefits from better field control of fruit flies to be realised. Growers will lastingly adopt new or different field control methods only if there are net benefits from doing so. Adoption of improved methods of field control may reduce fruit-fly infestation and thereby increase fruit quality and/or yields, or may reduce the cost of achieving prior levels of mitigation of fruit-fly infestation.

Potential low-chill temperate fruit benefits in partner countries

The primary focus in CP/2001/027 was the introduction into upland regions of both Laos and Vietnam of a range of varieties of plum, peach, nectarine, pear and persimmon from Australia and Thailand, to replace poor-quality, locally grown cultivars, and to overcome constraints to high-value production that included fruit damage from fruit-fly infestation. CP/2002/086 was an adjunct to CP/2001/02, and had similar aims, except that the focus was on post-farm-gate fruit handling throughout the Vietnamese supply chain rather than on on-farm production problems. The use of protein bait is integral to effective field control in the developing orchards and CP/2001/027 is therefore closely related to the protein bait research.

Beyond the identification and planting of improved varieties, the major challenge for temperate fruit production in Vietnam is to improve orchard practices. The project identified a range of improved management practices that would benefit farmers. Low input practices such as deficit irrigation, mulching, new orchard hygiene systems such spot spraying, new tree training and management systems, postharvest topping, and use of exclusion netting and fruit bagging to eliminate fruit fly have all been trialled in various areas as part of the project. Although considerable effort (e.g. training extension officers and producing manuals) has gone into promoting the new varieties and techniques, uptake will be a slow process. People spoken to as part of this study were aware of the magnitude of this challenge. The areas concerned are very poor, with a high proportion of poorly educated farmers. They have a long history of managing in a certain way (e.g. harvesting hard green to avoid fruit-fly losses). Adjustment and uptake will require ongoing commitment to demonstration areas, and the promotion of the new varieties and techniques by extension officers and committed farmers.

Figure 13 illustrates the approach to measuring the benefits from farmers producing higher quality ripe fruit.

There are two markets. In the hard–green market, farmers follow longstanding practices and harvest hard green, taking whatever yields occur without much orchard management. There is minimal attention to pruning, fertilisers, pest control or drainage. Farmers take whatever they can harvest to market. Prices are low, around P_1. Average cost is lower AC_g leaving a small producer surplus. There is a ripe-fruit market where higher quality fruit is sold. Currently this is characterised by supply S_3 and price P_3. In Vietnam this is the Hanoi market area and much of the S_3 supply comes from China.

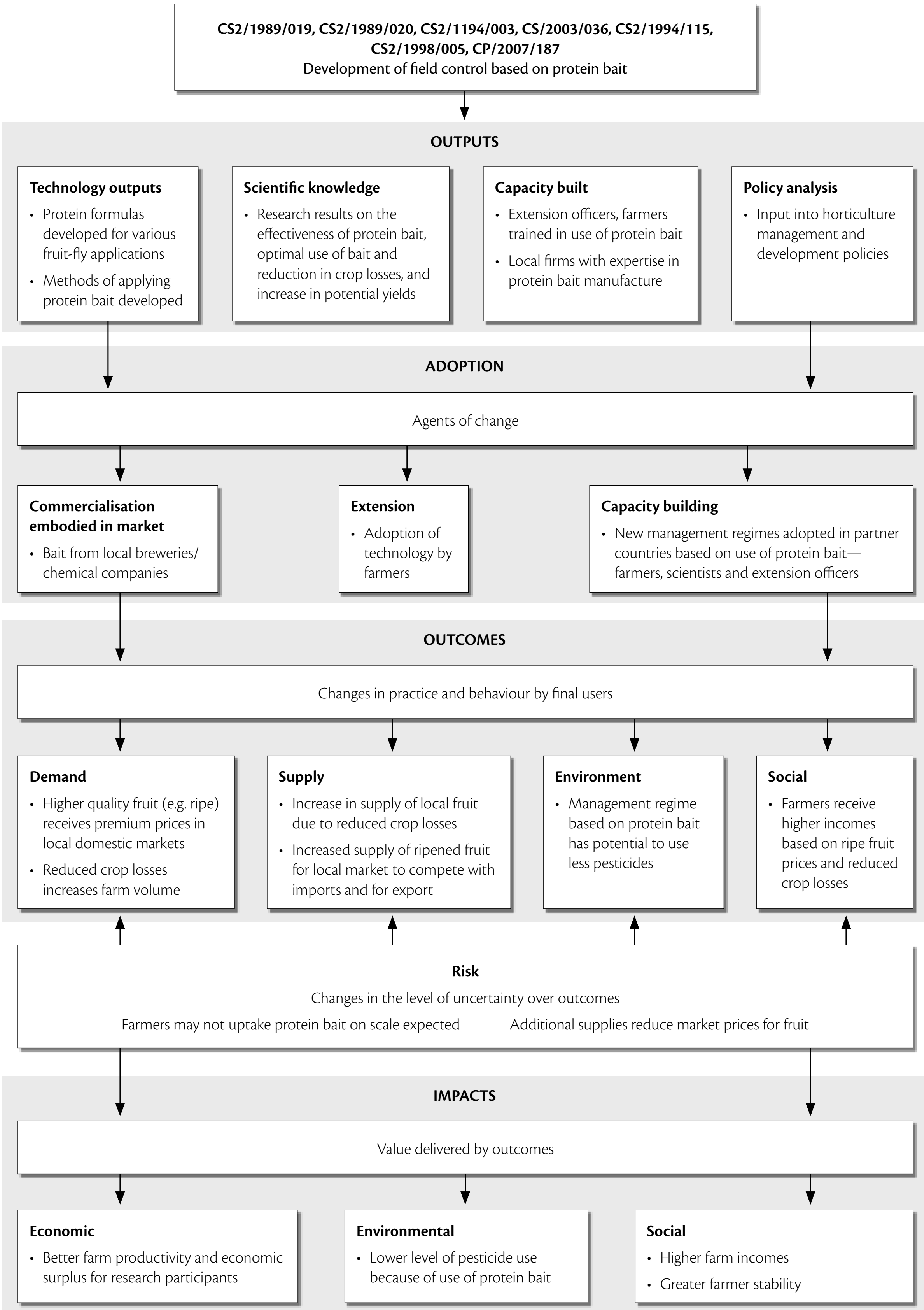
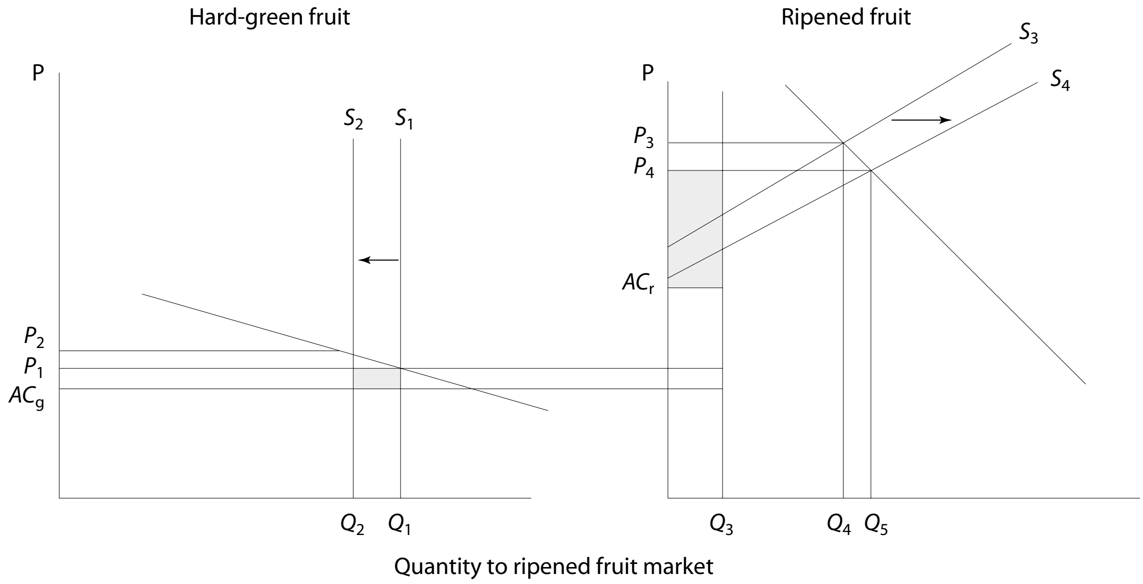


Figure 12. Pathways to benefits from field control based on protein bait



In green fruit market, price = P_1 and qty = Q_1
$Q_1 - Q_2$ diverted to ripe fruit market
Price increases to P_2
AC_g = AC for hard-green fruit
$PS_g = (P_1 - AC_g)\ (Q_1 - Q_2)$

In ripe fruit market, price = P_3 and qty = Q_4
Q_3 added from diversion
Price = P_4 and qty = P_5
AC_r = AC for ripe fruit
$PS_r = (P_4 - AC_r)\ Q_3$

Figure 13. Producer benefits from low-chill temperate fruit

Farmers who adopt the combined low-chill temperate fruit regime with new cultivars, improved orchard management and protein bait will switch to this market. They lose volume $Q_2 - Q_1$ in the hard-green market and supply Q_3 to the ripe fruit market. They will not necessarily be the same volumes, as yields (fruits or kg per ha) vary between the two systems.

After the switch, supply is S_2 in the hard-green market and S_4 in the ripe fruit market. The farmers lose a small producer surplus in the hard green market and gain a surplus in the ripe fruit market.

In the hard-green market the surplus lost is $PSg = (P_1 - AC_g)\ (Q_1 - Q_2)$. The surplus gained in the ripe fruit market is $PSr = (P_4 - ACr)Q_3$. The net gain is the difference between the two.

Very little is known about supply responsiveness and demand responsiveness in the hard-green market in North Vietnam. The expected uptake of this technology is relatively small at about 10–20% of farmers. Moreover the focus is on the getting the planned growth in total fruit hectares to, in part, be based on the new technology. The switch of current total hectares of hard-green fruit is expected to be minimal. Hence no major price impacts on hard-green fruit are predicted. On the other hand, as Vietnam pushes to expand total temperate fruit production with about 10–20% using the low-chill technology associated with the ACIAR projects, there may be price implications in the ripe fruit market. Given the very early nature of the official plans, predicting what this may be would be largely guess work. For the foreseeable future, two considerations are relevant. First, without a major push to increase uptake of the new technology the planned expansion of supply may not occur or at least will be much slower in occurring. Second, the growth in population and real incomes will shift the demand curve for higher-quality fruit out. It will be the balance between these two forces that will determine whether the price premium that currently exists will be eroded or increase over time. In the analysis it is assumed that the current indicative premium will be preserved.

Project outputs necessary to realise low-chill temperate fruit benefits

The outputs listed below are essential for the realisation of benefits from the ACIAR temperate-fruit projects. They include access to protein bait as a necessary condition because protein bait spray is an integral component of the fruit-fly controls required to allow for ripe fruit harvests. The outputs are:

- demonstration areas that show farmers how to plant and manage the new varieties, and the potential yield and fruit quality improvements
- an effective extension package adapted to local conditions to demonstrate the potential returns to individual farmers
- local extension staff with expertise in propagating and raising the new varieties
- a cheap and locally available supply of protein bait spray for use in the orchards

Figure 14 uses an ACIAR pathways template to show how the research undertaken in the various relevant fruit-fly projects with a field control component led to the realisation of field control benefits.

Other necessary conditions to realise low-chill temperate fruit benefits

The ACIAR projects can take the development of low-chill temperate fruit to a small scale of development. To ensure the project leads to ongoing and growing benefits requires a continued commitment to training. Train-the-trainer programs and training farmers are necessary to ensure that the area planted expands. Failure to support the potential development in this way increases the risk that the area planted will not grow much beyond that stimulated by the project and achieved within the project time frame and shortly thereafter. There is a further risk that farmers who have planted the new varieties will 'retreat' to previous management practices.

Potential health and environmental benefits in partner countries

While none of the ACIAR projects had health and environmental benefits as a primary objective, they may eventuate as a by-product if in the future there is widespread uptake of low-cost protein bait sprays to control fruit flies as an alternative to blanket cover sprays. This might reduce pesticide use, with consequent environmental and human health benefits.

The adoption of protein bait sprays has several potential health and environmental benefits. These derive from the reduced use of pesticide per hectare, the reduction in the range of pesticides used and the method of application employed. The benefits include:

- Reduced cover spraying: coarse sprays at low pressure result are potentially hazardous to the spray operator and family members living close by.
- Reduced pesticide residues in crops and the environment. Protein bait sprays are directed onto foliage and away from fruits to minimise fruit residue problems.
- Targeted application. Protein bait sprays are designed to attract fruit flies. They do not attract or therefore harm beneficial insects, such as pollinators and parasites.
- Consistency with IPM programs. Because they do not harm other potentially valuable insects, the use of protein bait sprays is consistent with the use of IPM, which itself is an aid to pesticide use reduction.

The greater the number of farmers in an area switching to protein bait, the greater the potential benefits. In this case, spray drift impacts from surrounding areas will also be reduced.

Project outputs necessary to realise health and environmental benefits

Realising the environmental and health benefits from the protein bait technology depends on the field control technology being taken up by farmers and on its correct use.

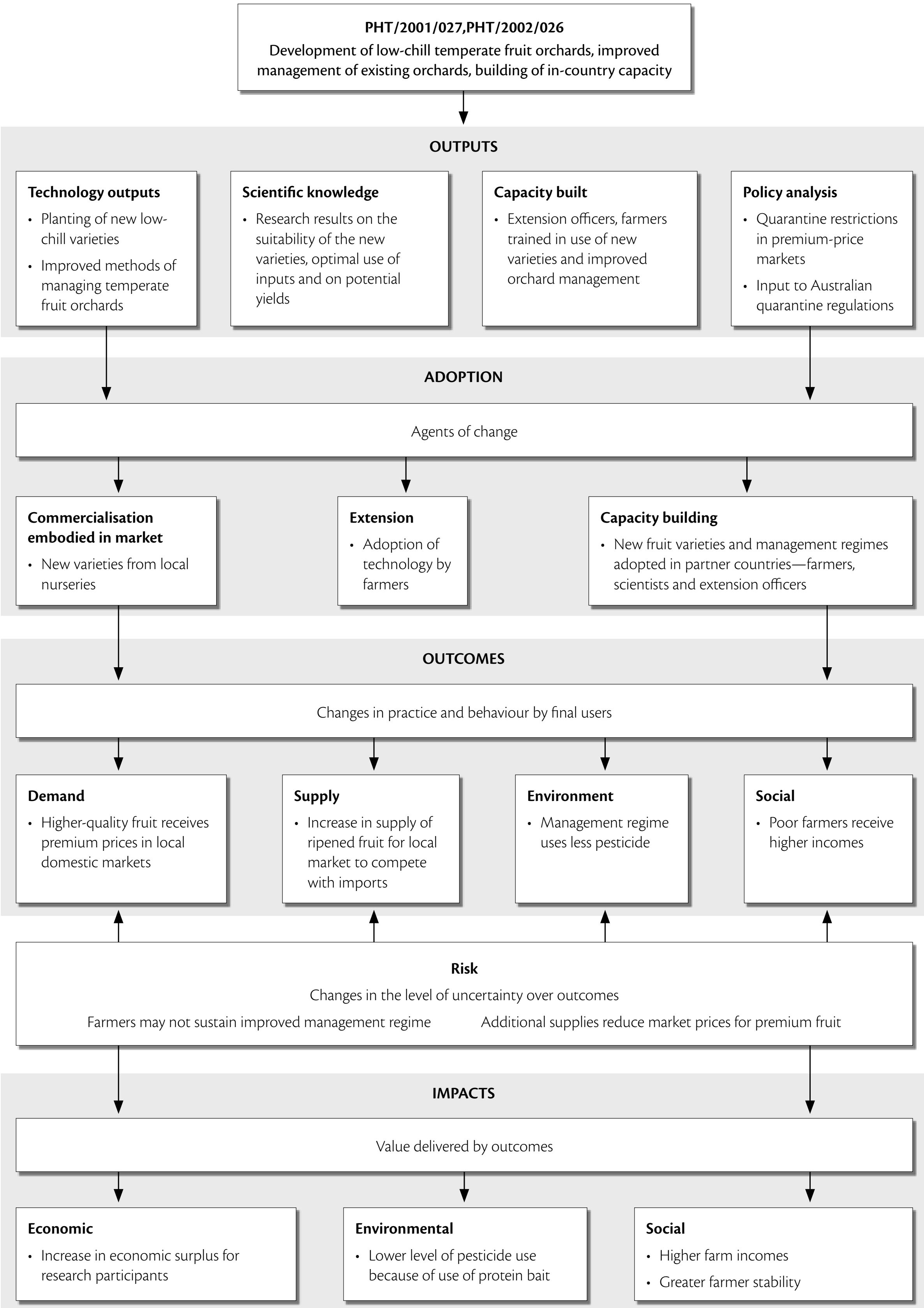


Figure 14. Pathways to benefits from low-chill temperate fruit

Adoption depends primarily on protein bait being sufficiently cheap and easy to apply to make the switch for farmers economical. The health and environmental benefits are a by-product of adoption but will not be the primary reason for adoption. In addition to a ready supply of cheap bait, adoption will depend on having trained staff and extension programs to encourage use of the baits across a contiguous area large enough to secure fruit-fly control benefits.

Other necessary conditions to realise health and environmental benefits

Health and environmental benefits will be achieved through the adoption of the bait. They will be enhanced if the application is best practice using suitable equipment and if a large enough area is treated using the bait.

Protein baits do not eliminate all spraying. Other pests still have to be treated. A necessary condition to maximise the impact of the switch to protein spray is that these sprays are applied optimally and with appropriate equipment and safety precautions.

Potential capacity-building benefits enabled by fruit-fly R&D in partner countries

Very few of the ACIAR projects are final in the sense that all work required for ongoing fruit-fly control is completed within the project. Most projects, but especially the earlier taxonomic projects, were catalyst projects that opened up an area of potentially significant research and control activity in the country concerned. The project benefits can only be fully realised if the agencies within a country have the capacity to carry on the work initialised in the projects.

Most of the ACIAR projects had a specific training objective: training focused on enhancing the capacity to do the original work, to carry on and extend the work, and to apply the results.

Capacity-building benefits accrue through:

- training scientists and others who can carry on the primary research needed for documentation of fruit-fly pests and their distribution—this was a potential benefit of the training components of CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1996/225, CS2/1997/101, CP/1998/005 and CP/2003/036
- training scientists and others who can carry on the work of documenting heat-treatment impacts on fruit flies—this was a potential outcome of PHT/1990/051, PHT/1994/133 and PHT/1993/877
- training scientist, trainers and others in the application of protein baits so they can assist farmers to switch to the baits and apply them correctly
- training extension officers and farmers in improved horticultural practices.

Each area has potentially significant benefits. Scientists trained in taxonomy, surveys and documentation are critical to carrying out the work necessary to optimise quarantine protocols, and to determine critical market-access issues like non-host status. Researchers who are able to undertake heat-treatment analysis are essential to development and documentation of accurate heat-treatment data and these in turn are a necessary condition for market access in many countries.

Without this capacity building, the necessary conditions for the development of quarantine protocols and market access could not be fulfilled.

Training trainers and farmers is essential to ensure that new field control methods such as protein baits are taken up and used correctly.

Necessary conditions to realise potential capacity-building benefits

The following conditions are necessary to realise ongoing benefits from project capacity building:

- project-trained personnel stay in the organisation long enough to influence the range of programs adopted that deal with the various aspects of fruit-fly research
- the project-trained personnel and relevant in-country agencies support ongoing training for a subsequent cohort of qualified people.

3 Estimating realised and prospective benefits

It should be noted that, because the range of fruit-fly species in each country tends to be peculiar to that country, almost all research impacts assessed in this study are highly location-specific. Furthermore, because the sanitary and phytosanitary (SPS) protocols for importing fresh fruit and leafy vegetables are country-specific and idiosyncratic, even the research data on the heat tolerance of pest fruit-fly eggs and larvae to certify commercial quarantine treatments based on high-temperature forced air treatment (HTFA) have to be replicated by each exporting country. Hence, there is virtually no likelihood of direct spillover benefits for any of the fruit-fly projects.

Nevertheless, to paraphrase Sir Isaac Newton, there is no doubt that the achievements of later projects can be attributed in part to 'standing on the shoulders' of earlier projects. This is most evident in the attempts to develop a cheap, locally sourced protein bait from brewery waste, which was first attempted in the original International Centre for the Management of Pest Fruit Flies (ICMPFF)-led ACIAR project in Malaysia, and only now is on the brink of success in Vietnam and Indonesia.

Partner-country market-access benefits based on postharvest disinfestation

For fresh fruit and leafy vegetables that are hosts for endemic pest fruit-fly species, the potential exporting country must negotiate certification of a non-chemical disinfestation treatment in order to gain access to premium-price markets such as Japan, the USA and New Zealand. Postharvest quarantine treatments based on disinfestation with high-temperature forced air (HTFA) were developed by ACIAR projects PHT/1990/051, PHT/1994/133 and PHT/1993/877.

The work under these projects was aimed at overcoming some of the constraints in exporting to premium markets by developing a schedule of treatments for disinfesting tropical fruits of known pests, namely the oriental fruit fly found in parts of South-East Asia and the Queensland fruit fly found in northern parts of Australia. As noted in Monck and Pearce (2007) there had been a considerable amount of heat treatment work prior to the ACIAR research. Many organisations have been and continue to be involved in heat treatment research. Prior to the ACIAR-funded research there was already a diversity of results from heat treatment research.

The main objectives of PHT/1990/051 were: to harmonise heat treatment for quarantine disinfestation procedures across countries; to improve the efficiency of the development of specific disinfestation protocols; and to increase the understanding of the technology requirements for effective heat treatment. PHT/1993/877 aimed to add further value to this work by developing a low-cost heat treatment system.

These projects had the effect of defining schedules of treatments, and providing information on the requirements for suitable heat-treatment equipment. However, once this is achieved, it depends on third parties to implement the results. In the case of heat treatment findings this requires that exporting countries use the information when drafting proposals and submissions for market access, that importing countries recognise the findings and incorporate them into quarantine protocols, and that heat treatment facilities be developed. The latter typically will be based on private firms investing in the required facilities. All elements need to be in place for the ultimate benefits of access and exports to premium markets to be achieved.

The ACIAR projects ended at the research stage. They did not extend to market access negotiations and heat treatment equipment set-up. Nevertheless, as Monck and Pearce (2007b) argue, initially major benefits from these projects could reasonably be attributed to the contribution they made to helping partner countries and Australia gain access to the Japanese mango market. Beyond this, with the passage of time it is harder to ascribe subsequent achievements to the ACIAR research. For example, Thailand has continued to develop findings for use in negotiations, using two VHT machines sourced from Japan. Heat treatment protocols have been approved for mangosteen to Japan and mangoes to Korea. Heat treatment protocols for longan and lychee have been accepted in Australia and a protocol for pomelo has been submitted to Japan. Thailand currently has seven commercial heat treatment facilities. At least in some small part, these successes draw on the original ACIAR projects and on similar work of others. In particular, the methods of researching and documenting heat treatment findings stem back to the training in PHT/1990/051. Moreover, it is argued that acceptance of the initial mango protocol in Japan was the stimulus for the commercial development of heat treatment facilities.

Thailand, the Philippines and Australia were all successful in developing mango exports to the Japanese market. The economic value of these exports and the contribution of ACIAR research to them was analysed in Monck and Pearce (2007). The benefits of mango exports to Japan have been included in this analysis based on their findings. Prior to 2003, Thailand exported frozen mangosteen to Japan. Subsequent to the approval of the heat treatment protocol and negotiation of access, significant fresh mangosteen exports commenced in 2003. In 2004 exports commenced to Australia and New Zealand. Exports to Japan commenced in 2003 with 415 tonnes. In 2006 they were 169 tonnes. Exports to Australia commenced in 2004 and in calendar year 2006 were 74 tonnes, worth around A$270,000. It can be argued that the ACIAR research made a contribution to these access achievements based on the groundwork that these projects established for developing heat treatment protocols.

In the South Pacific, following the banning of chemical fumigants previously used as quarantine treatments for fruit flies, ACIAR projects were only involved indirectly in assisting Pacific island countries to develop alternative quarantine treatments that were environmentally friendly, safe for consumers and relatively inexpensive, in order to regain access to some premium-price markets such as New Zealand and Australia. One of the outputs of project CS2/1989/020 was to establish fruit-fly rearing laboratories in Cook Islands, Fiji, Samoa and Tonga. This necessary step enabled the RMFFP to conduct research on heat treatments using high-temperature forced air (HTFA). Development of HTFA protocols involved determining the heat tolerances of the pest species, and conducting tests to determine the efficacy of the treatment.

As the schedule of postharvest disinfestation treatments has to be certified for each exporting country, the only partner countries where a significant part of market access benefits based on postharvest treatments can be attributed to ACIAR projects are the Philippines and Thailand. These two countries, as well as Australia, have realised benefits from exporting mangoes to Japan, and estimates of these benefits are presented in Table 6. To date, neither Malaysia nor Vietnam has negotiated access to premium-price markets such as Australia, New Zealand, Japan and the USA on the basis of postharvest disinfestation treatments.

In the South Pacific, the RMFFP, often together with the US Department of Agriculture and NZAID, took the leading role in assisting a number of Pacific island countries to gain access to New Zealand for exports of papaya, eggplant, mango and breadfruit, largely based on SPS protocols for postharvest disinfestation using HTFA. More recently, Fiji finally gained access to Australia for papaya exports on the same basis. ACIAR projects made only a minor contribution to these market access benefits by establishing laboratories for breeding colonies of key pest fruit flies, and by developing field control methods as part of an accredited export supply chain pathway.

However, with the notable exception of Fiji, exports of fruits such as papaya, eggplant, mango and breadfruit from Pacific islands countries have declined rather than grown since completion of the ACIAR projects, for reasons explored by McGregor (2007) and already discussed above. More details are provided in the country case studies in the appendixes. Data on recent exports of fruits and vegetables granted market access by New Zealand, Australia and Japan are given in Table 5.

Consequently, market-access benefits for fruit-fly host fruits from Pacific islands countries have been estimated only for Cook Islands, Fiji and Samoa, and the actual values of exports of HTFA-treated mango, eggplant, papaya and breadfruit to New Zealand and Australia from 1994 to 2005, and projected future exports, are plotted in Figure 15.

Realised and prospective benefits

Table 6 summarises the estimated benefits from market-access achievements attributable to ACIAR projects. In this case, realised benefits dominate, due mainly to the early success of achieving export access for mangoes to Japan since 1993–94. The prospective benefits, again dominated by mango exports, are based on continuing access and export growth. The rationale for these growth estimates are set out in Monck and Pearce (2007). For other fruits, projections were based on best available information used to develop realistic estimates of export potential and prices.

Table 5. Recent exports of fruit-fly-host tropical fruits from Pacific islands countries (PIC) to Australia, New Zealand and Japan

	Country of origin			
	Fiji	**Samoa**	**Tonga**	**Cook Islands**
Value of PIC fruit exports to Australia, 2006 (cif A$'000)				
Bananas				
Breadfruit				
Chillies				
Eggplant				
Mango				
Papaya	398			
Vegetables, fresh inc. squash	127		40	
Value of PIC fruit exports to New Zealand 2005 (NZ$ value for duty)				
Bananas		1,732		
Breadfruit	70,123	25,300		
Chillies	163,811			1,305
Eggplant	2,050,290			
Mango	58,650			
Papaya	713,495	20,928		46,200
Vegetables, fresh inc. squash				
Value of PIC fruit exports to Japan 2005 (US$ cif)				
Bananas				
Breadfruit				
Chillies				
Eggplant				
Mango				
Papaya	64,000			
Vegetables, fresh inc. squash			10,088,000	

Source: Andrew McGregor, pers. comm. 2007

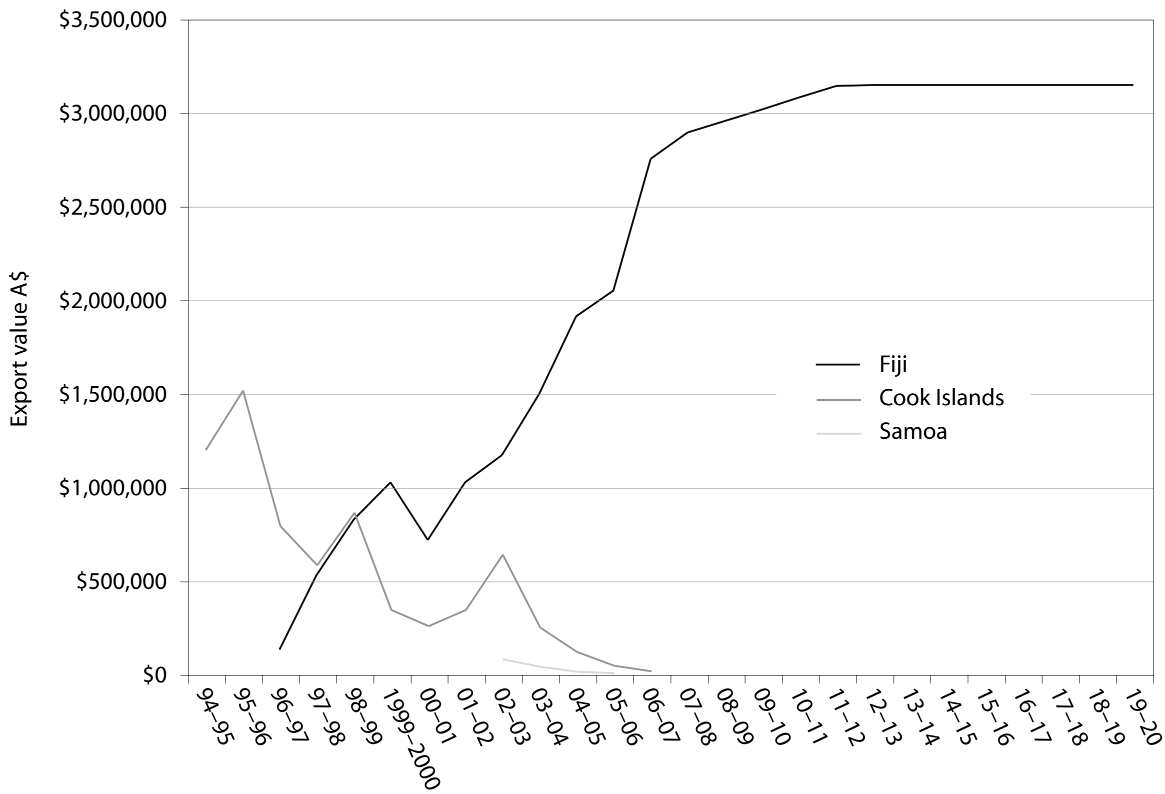


Figure 15. Actual exports of HTFA-treated mango, eggplant, papaya and breadfruit to New Zealand and Australia from 1994 to 2005, and projected future exports. Sources: FAOSTAT (2008), and Economic Research Associates calculations.

Sensitivity analysis

The benefits from obtaining access to new markets based on postharvest treatment vary with price premium received and attribution factor. Figure 16 shows how the estimated benefits attributable to ACIAR are affected by increases and decreases in these key variables when 10% and 20% changes are considered relative to base values.

Partner-country market-access benefits based on establishing non-host status

Facilitating market access for exports of fresh fruit and leafy vegetables on the basis of non-host status was one of the anticipated benefits from most of the large ICMPFF-led ACIAR projects, apart from the two original projects in Malaysia and Thailand. To date, the only outstanding success in realising significant market access benefits from exporting non-host fresh fruit and leafy vegetables has been the export of squash to Japan. Both the ACIAR projects and the RMFFP provided significant assistance to Tonga in projects establishing that squash is not a host for fruit-fly species in Tonga, and that pest fruit flies of squash do not occur in Tonga. They also assisted Tonga to negotiate a non-host status protocol for squash exports to Japan that enabled this export trade.

In addition, New Zealand agreed to harmonise the standards that Pacific island countries had to meet to establish non-host status for some tropical fruits and vegetables. During the life of the RMFFP, Fiji, Cook Islands and Samoa successfully negotiated non-host SPS protocols for the export of chillies and pre-colour break bananas to New Zealand. The ACIAR projects played a key role in this success by participating in fruit-fly trapping and host survey programs that established that these fruits are not hosts for endemic fruit flies in these countries, and that the countries are free of fruit flies that might infest these fruits.

Table 6. Realised and prospective benefits from market-access postharvest projects (present value 2007 A$m).

Host country	Realised	Prospective	Total
Bhutan	0	0	0
Cook Islands	0.063	0	0.063
Fiji	0.073	0.275	0.347
Federated States of Micronesia	0	0	0
Indonesia	0	0	0
Laos	0	0	0
Malaysia	0	0	0
The Philippines	16.284	1.278	17.563
Papua New Guinea	0	0	0
Samoa	0.001	0	0.001
Solomon Islands	0	0	0
Thailand	10.353	3.155	13.508
Tonga	0	0	0
Vanuatu	0	0	0
Vietnam – South	0	0	0
Vietnam – North	0	0	0
Australia	2.3330	0.559	2.892
Total	29.106	5.267	34.374

Legend:

0 = no evidence of uptake/impact.

NI = insufficient information to quantify.

TE = too early to reliably assess.

NT = there was not enough time to quantify in this study.

IE = included in other benefit estimates but not separated out.

Fiji has exported two chilli varieties to New Zealand without the use of postharvest quarantine treatments, although chilli exporters are required to follow an approved quarantine pathway. There has been steady growth in these exports, and they are projected to continue. Initially, Samoa exported quite large volumes of green bananas to New Zealand but in more recent years the value of these exports has been declining and they are not projected to continue in the future. Lastly, Cook Islands has exported small quantities of chillies to New Zealand and, while there have been considerable fluctuations from year to year, these exports are projected to continue, albeit at very modest levels. The values of actual and projected exports of non-host fruits to Japan and New Zealand that have been used to calculate benefits of market access are illustrated in Figure 17.

While other countries have plans to seek non-host status for exports of some fruits to some countries, the realities of negotiating access to premium-price markets are such that these aspirations are most unlikely to be realised for at least two reasons. First, the conditions for gaining market access are becoming more stringent, as well as more standardised, as more and more countries join the World Trade Organization (WTO). Second, because postharvest disinfestation treatment by irradiation is effective for all types of pest, and does not cause fruit

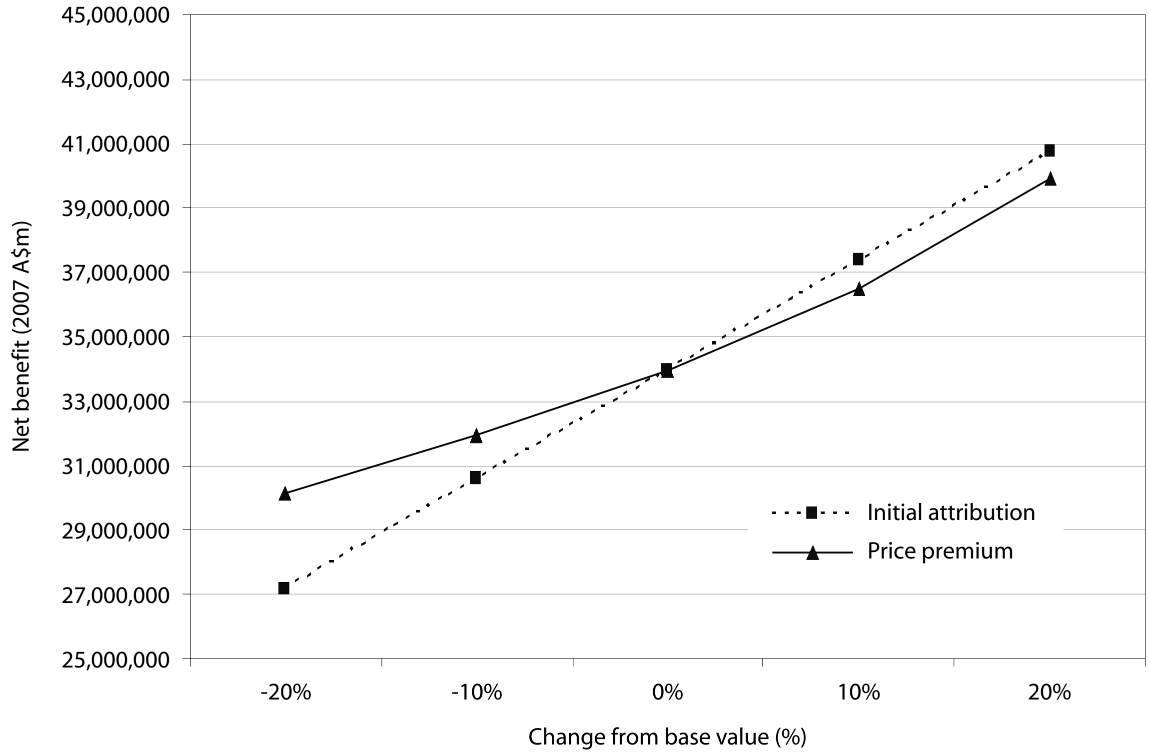


Figure 16. Sensitivity of market access benefits based on postharvest treatment

damage even when applied at high levels, it is gradually being required by more countries as its cost falls relative to the alternative treatments. Hence, no benefits of market access based on non-host status have been estimated for other partner countries.

Realised and prospective benefits

Table 7 shows estimated attributable benefits based on non-host status. Non-host status benefits are confined to situations where non-host status can be considered the sole basis for market access. For reasons discussed above, it is confined to the island economies. For the other countries, market access has in each case required postharvest treatments, even when the exporting country argued non-host status. The significant benefit relates to squash exports from Tonga to Japan.

Sensitivity analysis

The estimated benefits from non-host market access are almost entirely due to Tongan squash exports and these are almost all realised. The key sensitivity is therefore the extent to which the surpluses generated from these exports are attributable to ACIAR research. Figure 18 shows how estimated benefits vary as we move the attribution away from its initial starting value of 0.5.

Partner-country biosecurity benefits

Most, but not all of, the ICMPFF-led ACIAR projects produced outputs that are necessary, albeit not sufficient, for biosecurity benefits in partner countries. However, there were no such projects in Laos and the Philippines, and none of the outputs from the other ACIAR-funded fruit-fly projects enabled potential biosecurity benefits. Hence, the only ACIAR-funded fruit-fly projects that might have generated biosecurity benefits are CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1996/225, CS2/1997/101, CP/1998/005 and CP/2003/036.

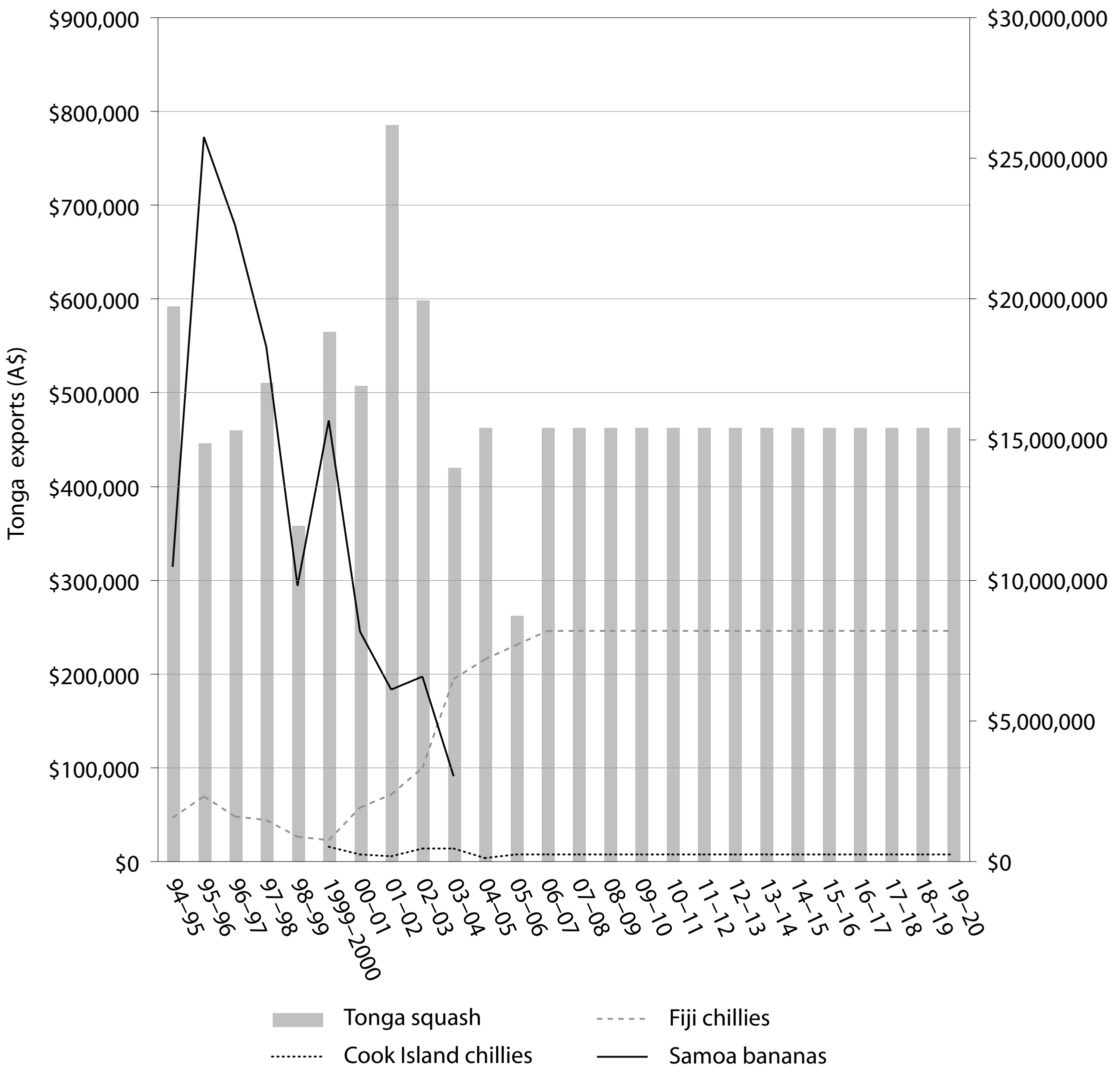


Figure 17. Actual and projected exports of non-host fruits to Japan and New Zealand (A$). Sources: FAOSTAT (2008) and Economic Research Associates calculations

If biosecurity benefits are to be realised, it is vital for a country to have the capacity to minimise the risk of pest fruit-fly incursion, and to respond rapidly and effectively to any incursion that does occur. Lack of shared land borders and geographic isolation provide a degree of natural protection from exotic pest threats for Australia, Pacific island countries (PICs), and some but not all regions in Papua New Guinea, Indonesia and Malaysia. Such natural protection helps to prevent the introduction of harmful exotic fruit-fly pests but, in the absence of a strong quarantine surveillance system, there is still a significant risk of incursions by exotic pest fruit flies due to assisted movement of fruit flies via tourism, imports and exports, and changing transport practices.

Conversely, for countries with extended land borders, the potential for unassisted entry by fruit-fly pests is high. While a sophisticated national quarantine surveillance system might reduce the risk somewhat, the probability of entry and establishment for these countries or regions would still remain high. Other reasons why some developing countries do not maintain effective national quarantine surveillance systems are a lack of resources to do so and/or government breakdown due to civil unrest.

Table 7. Realised and prospective benefits from market access non-host status projects (present value 2007 A$m)

Host Country	Realised	Prospective	Total
Bhutan	0	0	0
Cook Islands	0.003	0.001	0.004
Fiji	0.067	0.031	0.099
Federated States of Micronesia	0	0	0
Indonesia	0	0	0
Laos	0	0	0
Malaysia	0	0	0
The Philippines	0	0	0
Papua New Guinea	0	0	0
Samoa	0.260	0	0.260
Solomon Islands	0	0	0
Thailand	0	0	0
Tonga	14.561	1.930	16.491
Vanuatu	0	0	0
Vietnam – South	0	0	0
Vietnam – North	0	0	0
Australia	0	0	0
Total	14.892	1.962	16.854

Legend:
0 = no evidence of uptake/impact.
NI = insufficient information to quantify.
NT = there was not enough time to quantify in this study.
IE = included in other benefit estimates but not separated out.

As discussed, the enhanced knowledge about pest fruit flies in the partner countries, together with the critical infrastructure and essential skills base created by the training component of the ICMPFF-led ACIAR projects, are all necessary prerequisites for an effective early detection, quarantine surveillance system. Most countries did not have a fruit-fly surveillance system prior to the ACIAR projects, or a prior fruit-fly surveillance system had lapsed (e.g. in Tonga). Moreover, it is debatable whether subsequently a fruit-fly surveillance system would have been established under the counterfactual scenario.

While such capacity building might have occurred eventually, at best the time lag for it to happen most likely would have been many years. Furthermore, although there was considerable concern about fruit flies at the time, and other aid agencies also were funding mainly complementary fruit-fly projects, it is arguable whether any group other than the ICMPFF had the expertise and willingness necessary to mount projects equivalent to the ACIAR activities. The fact that some partner countries subsequently have been unable to access further funding to maintain facilities and operations established during the term of the ACIAR projects suggests there were limits to the investments other aid agencies were prepared to make in fruit-fly biosecurity.

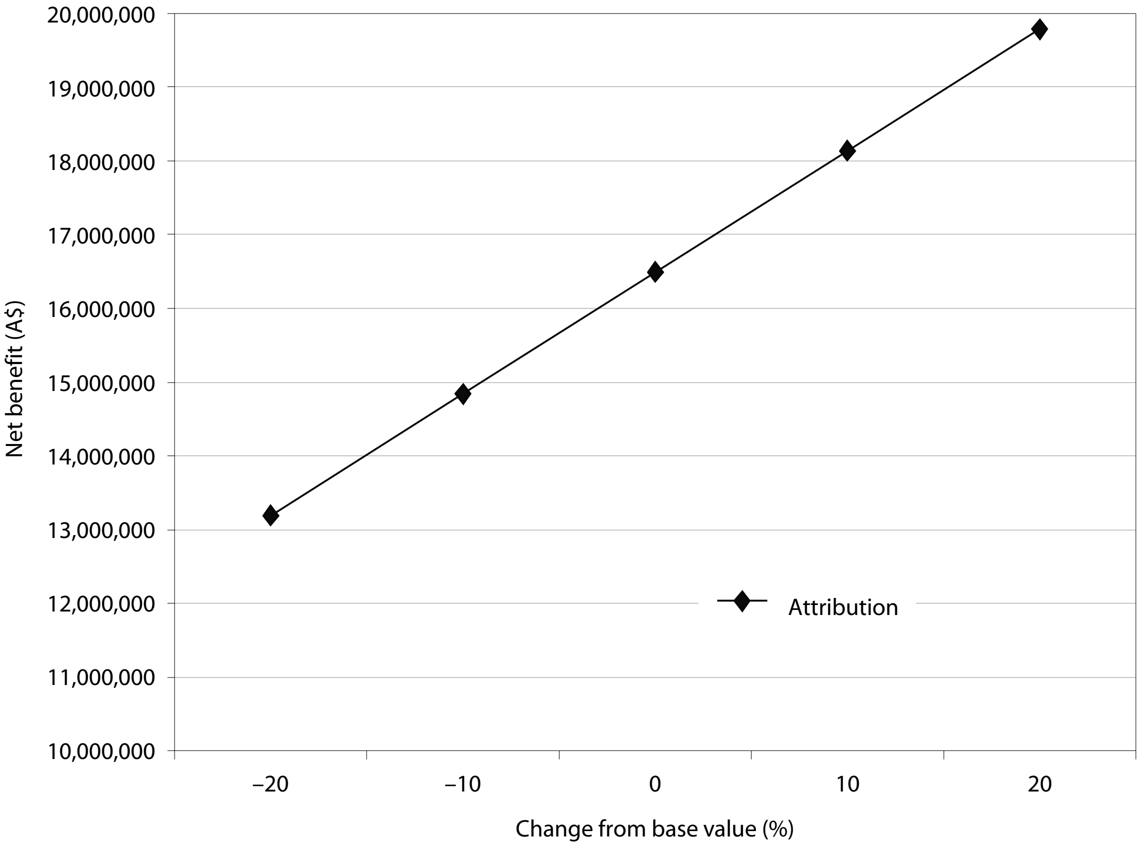


Figure 18. Sensitivity of non-host market access benefits

On balance, the counterfactual scenario is based on the assessment that early-detection-enhanced biosecurity systems would not have been established in the absence of the necessary joint input from ACIAR projects and complementary projects funded by other agencies. However, no biosecurity benefits will be estimated for those countries where such early-detection-enhanced biosecurity systems have not been established or maintained.

Based on widespread consultations about the above considerations, case studies to quantify estimates of biosecurity benefits were carried out for Cook Islands, Fiji, Samoa and Tonga, and there is a more qualitative assessment of prospective biosecurity benefits for Java (but not the rest of Indonesia) in Appendix G.

Biosecurity benefits were not estimated for the other countries that collaborated in one or more ICMPFF-led ACIAR projects. For some countries, the resources to carry out an eradication campaign following detection of an incursion are unlikely to be available. For other countries, even if adequate resources are available, the biosecurity benefit would most likely be small; due either to the low likelihood of a quarantine surveillance system significantly reducing the risk of a pest incursion, or to a poorly maintained quarantine surveillance system, or both. These countries/regions included Bhutan, Federated States of Micronesia, Laos, Indonesia, Malaysia, Papua New Guinea, Solomon Islands, Thailand, Vanuatu and Vietnam.

Analytical framework

The analytical framework used by Biosecurity Australia (2001) provides the basis for the estimation of biosecurity benefits in this study. Pest risk analysis (PRA) is the evaluation of the likelihood of entry, establishment and spread of a pest within a country, and of the associated economic consequences. Relevant economic factors include the costs of containment, eradication or control, and the potential loss of production and domestic sales or exports, in the event of entry, establishment or spread of a pest. In PRA, unrestricted risk is the risk in the absence of specified quarantine surveillance measures to mitigate risk, while restricted risk is the risk where the specified risk management measures are applied.

The first step in PRA is to clearly define the identity of the pest for which the risk assessment is being performed, so that it is not confused with other pests that might pose different risks, and/or require different risk mitigation treatments.

Then, the likelihoods of entry, establishment and spread need to be assessed separately. Biosecurity Australia (2001) defined the different risk level ratings that may be allocated in as shown in Table 8.

While the unrestricted risk of entry per se might be in the medium to high range, the restricted risk of entry can be much reduced by simple quarantine surveillance measures, such as having checkpoints to inspect agricultural produce imports for pests at all major airports, ports and land border entry points, and destroying all fruit that neither has certified non-host status nor certified postharvest disinfestation treatment. Hence, the combined risk of entry and establishment is likely to be somewhere in the low range for the case study countries despite multiple opportunities for both unassisted entry, and assisted entry via inter alia, informal trade and tourism.

The next step, according to Biosecurity Australia (2001), is to assess the likely consequences of an incursion as outlined in Table 9.

Table 8. Factors used to rate the likelihood or potential of a pest incursion

Likelihood or potential	Qualitative ratings	Statistical probability of occurrence
Entry potential, establishment potential and spread potential	High	Range = 0.7 to 1
	Medium	Range = 0.3 to 0.7
	Low	Range = 0.05 to 0.3
	Very low	Range = 0.001 to 0.05
	Extremely low	Range = 10^{-6} to 0.001
	Negligible	Range = 0 to 10^{-6}
	Unknown	NA

Table 9. Categories for rating economic, environmental and social impacts

Impact rating	Definition
Unlikely to be discernible	Not usually distinguishable from normal variation in the criterion
Minor	Not expected to threaten economic viability, but would cause a minor increase in mortality/morbidity or a minor decrease in production. For non-commercial factors, impact not expected to threaten the intrinsic 'value' of the criterion, but the value would be considered as 'disturbed'. These effects would generally be reversible.
Significant	Would threaten economic viability through a moderate increase in mortality/morbidity or moderate decrease in production. For non-commercial factors, the intrinsic 'value' of the criterion would be significantly diminished or threatened. Effects may not be reversible.
Highly significant	Would threaten economic viability through a large increase in mortality/morbidity or a large decrease in production. For non-commercial factors, the intrinsic 'value' of the criterion would be considered as severely or irreversibly damaged.

In the case studies reported below, rather than use these qualitative impact assessments, quantitative estimates are made of the economic impacts. These economic impact estimates are then combined with quantitative estimates of the likelihood of a pest fruit-fly incursion to calculate the expected cost of an incursion under the 'without R&D' scenario of unrestricted risk with the 'with R&D' scenario of restricted risk. The assessed values of these unrestricted and restricted risk scenarios, together with the associated economic impacts, vary on a case-by-case basis and are detailed in the case studies in the appendixes.

In general, the probability of an incursion becoming widely established before it is detected under the 'with R&D' scenario will be significantly lower than that under the 'without R&D' scenario. Then, given that an incursion has become established, there would be a much shorter delay from detection of the incursion to a decision about the relevant course of action to take under the 'with R&D' scenario (vis-à-vis a 'without R&D' scenario).

While it is possible that eradication may become infeasible or uneconomic if the incursion is not detected early enough, to avoid excessive complexity in the analysis below, it was assessed that, even without improved surveillance, an incursion would be detected early enough for eradication to be the optimal response. Hence, the estimated benefit of improved quarantine surveillance includes reduced direct costs of containment, reduced costs of eradication, costs of a temporary ban on any exports of host fruits, and reduced direct costs from the incursion, such as the loss of consumer surplus from the need to substitute a less preferred food supply for a more preferred food supply.

Evidence on incursions and eradication costs

Since 1980 notable outbreaks of major pest species of fruit flies in a number of countries in the Pacific have included:

- *Bactrocera papayae* (Asian papaya fruit fly) into Papua New Guinea and Northern Queensland (Australia) in 1995
- *Bactrocera dorsalis* species complex (oriental fruit fly) into Nauru, Palau and Tahiti; and into Darwin, Australia in 1992
- *Bactrocera cucurbitae* (melon fly) into Nauru and Solomon Islands in 1984–1995, into Torres Strait Islands and Perth in 1996, and reintroduced into Nauru in 2001
- *Bactrocera philippinensis* into Palau in 1996 and into Australia's Northern Territory in 1997
- *Bactrocera papayae* and *Ceratitis capitata* (medfly) into Auckland, New Zealand in 1996
- *Bactrocera xanthodes* (Pacific fruit fly) into French Polynesia in 1999
- *Bactrocera musae* (banana fruit fly) into PNG (East New Britain) in 2000
- *Bactrocera tyroni* (Queensland fruit fly) into Cook Islands (Rarotonga) in 2001(Allwood et al. 1997; PACIFLY website <http://www.spc.int/pacifly/>).

According to Bellas (1996), there has been an incursion of the oriental fruit fly from Hawaii into California, and successful eradication there, on at least 13 occasions. This species also was eradicated from Japan after a campaign that commenced in 1968 but was not completed until 1986, while the melon fly has been eradicated from some southern Japanese islands. Fruit flies also have been eradicated many times in Australia following incursions into one or more states. The Queensland fruit fly, *B. tryoni*, often has infested fruit-growing areas in southern New South Wales, Victoria and South Australia over the years, as well as being responsible for the first-ever infestation in the Perth metropolitan area in 1989–1990. In each of these cases, the incursion was eradicated.

Another instance was the discovery of oriental fruit fly on Tahiti in 1996. A large-scale eradication program was conducted in 1997. However, fruit flies survived in isolated pockets of breeding populations, and multiplied and spread all over Tahiti and Moorea despite six further campaigns in 1997, and another attempt at eradication in 1999. An eradication campaign against Pacific fruit fly (*B. xanthodes*) on Rurutu and Raivavae also was unsuccessful.

B. dorsalis and *B. papayae* are both attracted to the male lure pheromone, methyl eugenol. While no fruit-fly species is easy to eradicate, flies attracted to methyl eugenol are easier to eradicate by male annihilation than other flies because methyl eugenol is such a powerful attractant. Inter alia, male annihilation using methyl eugenol supplemented by protein bait application techniques, has been used to eradicate oriental fruit fly from Okinawa, Rota and Nauru, as well as to eradicate *B. papayae* from North Queensland in Australia.

A campaign conducted in 1998 on Nauru by the RMFFP, with support from an ICMPFF-led ACIAR project, aimed to eradicate melon fly, mango fly, oriental fruit fly and Pacific fruit fly. The campaign used male annihilation, involving blocks impregnated with either methyl eugenol or cuelure, plus the insecticide fipronil, and protein bait application techniques. The campaign succeeded in eradicating oriental fruit fly, Pacific fruit fly and melon fly. In addition to the RMFFP and ACIAR, this eradication program also was supported by funds from the Crawford Fund for International Agriculture Research (Australia) and the Nauru Government. The firms Aventis CropScience and Bronson and Jacobs in Australia provided fipronil and methyl eugenol respectively. According to McGregor (1999), the cost of the campaign was A$280,000. However, this only represented the direct costs incurred, and did not include wages for a large number of people, including some experts. Nor did it include donated supplies. However, melon fly and possibly Pacific fruit fly were reintroduced, due to lack of an active quarantine inspection service.

While many factors influence the cost of an eradication campaign, the geographical extent of the incursion is a key determinant. Bellas (1996) notes that most successful eradication exercises have been conducted on islands or with infestations caught before numbers have increased or flies dispersed very far. Other factors include accessibility of the infested area, the range of host fresh fruit and leafy vegetables, types of eradication techniques that need to be employed, local wage rates, and prices for other necessary supplies. According to Drew and Hooper (1981), the Dacinae can be divided into those species attracted to methyl eugenol, those attracted to cuelure, and those not attracted to either compound. One unusual aspect of the Nauru campaign was the extinction of melon fly (*B. cucurbitae*) using only male annihilation by cuelure impregnated blocks and protein bait application techniques. In this case, eradication apparently was achieved because the melon fly population was at its lowest level following a prolonged drought (Drew 1997). In other cases, melon fly has only been eradicated where the above two techniques are supplemented by the far more costly sterile insect technique (SIT) that involves successive releases over an extended period of sterile male insects to outnumber male wild fruit flies and out-compete the wild population for mates.

Possibly the most expensive fruit-fly eradication campaign was an international program launched in 1997 to eradicate Mediterranean fruit fly from Mexico and Guatemala, and ultimately to eradicate it from Central America. At its peak in 1981, the program cost US$19 million a year, but this was scaled back to about US$10 million per year in later years. The fly was declared eradicated from Mexico in 1982, but the ambitious long-term objective of eradicating the fly from Central America has been postponed indefinitely because it would be too expensive.

In Australia, eradication of the Queensland fruit fly in Perth in 1989–90 used all three eradication methods, namely bait blocks, protein foliage sprays and release of sterile flies to treat an area of about 300 square kilometres. The operation, which had a budget of A$5 million, commenced in February 1989. It was declared successful after December 1990.

The outbreak of *B. papayae* detected in North Queensland in October 1995 provides evidence of how widespread an incursion can become if it is not detected and contained soon after entry. Drew (1997) wrote that:

> … by the time of detection, the fly had become well-established. There were large breeding populations in the urban areas of Cairns, Mareeba and Mossman and a continuous population spread over an area of approximately 2,500 km^2. If all localities are considered where outlying flies have been trapped (or reared from fruit) up to mid-September 1996, an area of approximately 11,000 km^2 is involved.

At its maximum, the eventual size of the pest quarantine area (PQA) established to contain the outbreak of *B. papayae* covered around 78,000 km^2. Eradicating the papaya fruit fly from an area this large was an expensive operation. As can be seen in Table 10, direct costs of the eradication campaign were about A$34 million, but many other costs were incurred by industry and the community. Exports of mangoes and other host fruits to premium markets were suspended until the efficacy of postharvest disinfestation treatments could be proved. There also were restrictions on fruit trade within the

Table 10. Budget (A$'000) for *Bactrocera papayae* eradication campaign in North Queensland

Activity	1995–06	1996–07	1997–08	1998–09
R&D	50,000	586,000	1,006,000	376,000
Monitoring	800,000	2,588,000	3,168,000	1,983,000
Eradication	2,093,000	5,283,000	4,610,000	238,000
Quarantine	2,344,000	3,411,000	4,132,000	1,606,000
Total	5,287,000	11,868,000	12,916,000	4,203,000

Source: QDPI papaya fruit fly—facts at a glance, at: <http://www2.dpi.qld.gov.au/health/4665.html>, accessed 21 November 2007

quarantine area and 'export' of fruit from the area to other parts of Australia required postharvest disinfestation treatment that imposed a significant economic burden on growers, as did the need to use costly field control methods. While no formal estimates were made, Cantrell et al. (2002) claimed that costs to industry were about A$100 million.

In the terminology of PRA, the incursion of *B. papayae* into Queensland provides an illustration of the possible consequences of the unrestricted risk of establishment and spread in the absence of quarantine surveillance measures, because male lure traps that previously provided a sensitive and efficient system to detect an incursion of an exotic pest fruit fly were removed from the Cairns area and other places in northern Queensland in 1988 (Bellas 1996). As a result, the incursion was not detected by the quarantine surveillance system, and it was not until an astute grower noticed that green papaya (pawpaw) growing on his property were being infested at an unusually early stage. After several weeks of observation, he realised something was amiss and reported the problem in early October 1995.

Some experts estimate that the papaya fruit fly had been present in Cairns for at least 1 year and perhaps as long as 2 years (Bellas 1996). Drew (1997) estimated that the fly must have been introduced 2 to 2½ years earlier given the size and distribution of the fly population and the area of land infested at the time of discovery. On the other hand, Cantrell et al. (2002) stated that 'scientific consideration of factors such as the extent of the outbreak when it was discovered and knowledge of papaya fruit fly breeding potential suggests that it may have been here for 12 to 15 months before October 1995. This is equivalent to five generations of papaya fruit fly'.

In this study we follow Waage et al. (2004) and 'assume that once established, the population is naturalised and it spreads by a diffusive process such that the area occupied by the population expands following the function: $A_t = 4D\pi rt^2$.'

In Table 11, the estimated rate of increase in geographic spread of *B. papayae* is shown for various estimates of the number of generations from establishment until it populated the PQA of around 78,000 km^2. The underlying parameter values were used in the country case studies to estimate the extent of geographic spread of a fruit-fly incursion for both the 'with R&D' scenario of restricted risk where an effective quarantine surveillance system is in place, and for the 'without R&D' scenario of unrestricted risk where there is not an effective system to detect entry and establishment.

Table 11. Parameters for global spread of *Bactrocera papayae*

Number of generations	Rate of growth of infested area (km^2) for following parameter values:		
1	1	1	1
2	6	3	2
3	84	17	5
4	2,045	185	32
5	78,000	3,165	304
6		78,000	4,175
7			78,000

It is likely that if monitoring for exotic fruit flies had been in place at Cairns in 1994, the papaya fruit fly would have been detected soon after its arrival and the infestation would have been confined to Cairns so that it could have been eradicated by a relatively minor campaign (Bellas 1996). This opinion is buttressed by subsequent cases of entry after 1995 when more comprehensive quarantine surveillance was implemented.

On 28 July 1999, a quarantine officer found guava fruit-fly (*B. correcta*) maggots in an oriental apple in the baggage of a tourist arriving from Thailand. Destruction of the infested fruit prevented a possible destructive fruit fly outbreak. In early 1996 a trap in a network in suburban Perth established to detect new invasions of Queensland fruit fly after the successful eradication of the species from Western Australia in 1990, caught one male melon fly but the entry did not become established because no further melon flies were detected by more intensive monitoring.

In November 1997 *B. philippinensis* was detected in a trap in the Darwin area. This outbreak caused many difficulties for Northern Territory mango growers. A quarantine zone of a 50 km radius from the outbreak source was established, and both pre- and postharvest treatments were required for all mangoes originating from within this zone. The fly was officially declared eradicated in May 1999 after more than 17 months with no more detections. The direct operating costs of the eradication program were estimated to be about A$4.9 million. In this case, early detection and effective response preparedness and planning reduced the cost of eradication greatly.

Even when an entry does not become established, non-trivial costs often have to be incurred to prove this is the case. For instance, a single specimen of an exotic fruit fly was detected in a surveillance trap in Darwin in late August 2001. The trap was part of the AQIS ports surveillance network designed as an early warning alert or detection system for exotic pest species. There were concerns that the suitable climate and numerous untreated trees in Darwin backyards would provide ideal breeding conditions for this exotic fruit fly (The Litchfield Times, 11 October 2001). As required by the national protocol on detection of exotic pest fruit flies, the Northern Territory undertook intensive additional surveillance work within a 2.5 km radius of the detection site for a period of 9 weeks to ensure the fly was not established in the territory. As a precaution, growers were encouraged to apply pre-harvest fruit-fly control treatments to their mangoes. Because no further flies were detected during the initial intensive trapping surveillance program, nor during a reduced program that was continued for a further 6 months, this detection had no adverse repercussions on international trade. Nevertheless, the Northern Territory government expended more than A$10,000 to comply with the national response arrangements for this fruit-fly detection.

In November 2001 Queensland fruit fly (*B. tryoni*) was detected in Rarotonga. This was the first record of the species in Cook Islands. Its detection prompted a quick emergency response. Action was taken to eradicate the invasive species in Cook Islands. The last few flies were trapped in February 2002. Since then, no Queensland fruit fly has been recorded in Cook Islands. This case is used in the country case studies in the appendixes as the basis for most estimates of eradication costs in partner countries for the 'with R&D' scenario. More details are provided in Cook Islands country case study in Appendix 4.

Key informed judgments

For reasons stated, case studies to estimate biosecurity benefits were carried out for only Cook Islands, Fiji, Samoa and Tonga. These four PICs have all maintained the quarantine surveillance systems that were established jointly by ACIAR projects CS2/1989/020 and CS2/1994/003, and the RMFFP. Since 2001 the SPC has provided support for quarantine surveillance systems in these and other PICs in various ways, including providing assistance to complete emergency response plans, maintaining a central store of materials for use in eradication campaigns, and maintaining the Pacific Fruit Fly Web website PACIFLY <http://www.spc.int/pacifly/>.

Because the above four countries have only a small number of pest fruit-fly species of economic importance, there are a large number of exotic pest fruit flies that potentially could invade and become established. Apart from Tonga, one of the most damaging potential pest threats is an incursion by *B. papayae,* which is a highly polyphagous species. As has been shown in cases of previous incursions described, eradication is possible using a combination of orchard hygiene and fruit destruction, fruit movement control, male annihilation technique (MAT), protein bait application technique (PBAT), and insecticide ground treatment, even when the fly has become established over a large area.

Estimation of the likely cost of large eradication campaigns for Cook Islands, Fiji and Samoa are based on estimates by McGregor (2000) of the cost of a large operation lasting 2 years to eradicate *B. dorsalis* and *B. umbrosa* from Palau, a PIC with a land area of 488 km^2. While these fruit flies are different species than *B. papayae*, all three species are attracted to methyl eugenol, and therefore were judged to be similarly costly to eradicate using, inter alia, a combination of MAT and spot protein bait treatment. The budget calculated by McGregor for the Palau eradication campaign is reproduced in Table 12.

As discussed, one of the determinants of the cost of an eradication campaign is the geographical size of the incursion. For each country, the likely size of an incursion of *B. papayae* that was not detected for at least 12 months was estimated based on the imputed rate of spread of *B. papayae* in North Queensland, as well as the land area and terrain of the country. These estimates are contained in the country case studies in the appendixes and were used to scale up (or down) each cost item in the above budget, based on the likely ratio of fixed to variable costs for each item. For instance, amounts and costs of attractants and chemicals are almost entirely variable, and therefore vary more or less in proportion to the size of the area being treated. Conversely, human resources have a high fixed cost component and will not vary much as the area being treated changes. Actual budgets used for each country are detailed in the appendixes.

For more limited incursions, it is relatively easy and inexpensive to eradicate in a fairly short period of time because *B. papayae* is attracted to methyl eugenol. Consequently, a small incursion that becomes established but is not widely spread when detected, can be eradicated in less than 1 year at a modest cost that also depends on the area in which it has become established. In this case, a budget for a small eradication campaign set out in Table 13 was constructed by the authors based on information about key supplies, such as BactroMAT cuelure bait stations, and resources actually used to eradicate *B. tyroni* from Cook Islands in less than 1 year in 2001–02. Note that cuelure, to which *B. tyroni* is attracted, is a less powerful attractant than methyl eugenol so the cost estimates may overestimate the costs of a fruit fly attracted to methyl eugenol. This in turn

Table 12. Summary cost estimates of the Palau fruit-fly eradication program (US$)

Item	2000	2001	Total
Human resources	224,330	199,800	420,100
Equipment and supplies	101,200	14,400	115,600
Subcontracts	30,000	18,000	48,000
Training	24,000	9,500	33,500
Publications and public relations	49,000	5,000	54,000
Communications	8,000	8,000	16,000
Transport	7,300	5,300	12,600
Utilities	5,000	5,000	10,000
Helicopter	126,200	45,400	171,600
Attractants and chemicals	184,840	61,280	246,120
Contingencies	40,000	40,000	80,000
Total	799,840	411,280	1,211,120

Source: McGregor (2000)

Table 13. Estimated costs of actual campaign to eradicate Queensland fruit fly on Cook Islands (US$)

Item	2001–02
Human resources	48,222
Equipment and supplies	13,480
Subcontracts	3,996
Training	5,720
Publications and public relations	11,105
Communications	1,626
Transport	972
Utilities	1,016
Ultralight aircraft	16,809
Attractants and chemicals	21,211
Contingencies	8,131
Total	132,289

Source: Economic Research Associates calculations using information from McGregor (2000) and information about maximum area treated and materials used in actual Cook Islands eradication campaign in 2001–02.

will tend to underestimate biosecurity benefits. The same estimates of eradication costs for a small incursion were used for all three countries because the size of the area to be treated would be determined primarily by time from entry for an incursion detected soon after it became established.

The biggest biosecurity threat for Tonga is a possible incursion by a damaging pest fruit fly for which squash is a host. This is because of the large exports of squash to Japan by Tonga on the basis of a non-host protocol that relied to a substantial extent on information collected as part of projects CS2/1989/020 and CS2/1994/003 in conjunction with the RMFFP.

One of the most serious agricultural pests in cucurbits is *B. cucurbitae*, which attacks not only fruits but also young seedlings, flowers, roots and stems of hosts. A benefit–cost analysis of the eradication of melon fly from Guam and the Commonwealth of the Northern Mariana Islands (CNMI) was carried out by Andrew McGregor (McGregor and Vargas 2002), and provides most of the required information for estimation of biosecurity benefits for Tonga. In the study, McGregor and Vargas assessed that a major eradication campaign would last 5 years, and require a combination of MAT, spot protein bait treatment and the expensive SIT. The budget for such a major campaign if *B. cucurbitae* became widely established in Tonga, which has an area less than double that of the CNMI, is provided in the Tonga case study. The corresponding budget for eradicating a small incursion for the 'with R&D' scenario also is contained in the Tonga case study. It was derived by the authors using a similar approach to that used to adjust the Palau budget, although the campaign would still need to employ SIT and last for 2.5 years.

Table 14 summarises some of the key parameter values used to calculate biosecurity benefits that vary between countries.

Realised and prospective benefits

Table 15 shows the realised and prospective biosecurity benefits. Again the dominant benefits relate to the island economies. As noted in the previous discussion, biosecurity risks are especially high when trade access is based on non-host status (e.g. Tongan squash exports) and this only applies to the island economies.

Sensitivity analysis

The benefits from biosecurity vary with the probability of a large incursion, the probability of a small incursion when quarantine is in place, the costs of eradication of the large incursion and the attribution factor. Figure 19 shows how the estimated benefits attributable to ACIAR are affected by increases and decreases in these key variables when 10% and 20% changes are considered relative to base values.

Partner-country field control benefits

As noted, one common objective in a number of ICMPFF-led ACIAR projects was to develop a cheap and locally available protein bait spray from brewery yeast waste for large-scale field control of fruit flies, and to test the efficacy of bait-spray formulations for fruit-fly control in fruit and leafy vegetable crops in host countries.

Table 14. Parameter values used to calculate biosecurity benefits

	Cook Islands	Fiji	Samoa	Tonga
Land area (km^2)	237	18,333	2,935	747
Value of domestic fruit production (2007 A$ million/year)	4.964	65.233	8.856	4.726
Pest fruit fly	*B. papayae*	*B. papayae*	*B. papayae*	*B. cucurbitae*
With R&D and small incursion				
Quarantine surveillance costs (2007 A$/year)	–50,000	–150,000	–100,000	–50,000
Risk of small incursion	2.50%	2.50%	2.50%	2.50%
Cost of eradicating small incursion (2007 A$ million/year)	0.300	0.030	0.300	0.300
Loss of domestic production from small incursion	0.0%	0.0%	0.0%	0.0%
Without R&D and large incursion				
Risk of large incursion	4.50%	4.50%	4.50%	4.50%
Cost of eradicating large incursion (2007 A$ million/year)	1.910	8.284	4.963	11.110
Loss of domestic production from large incursion	10.0%	10.0%	10.0%	10.0%
Attribution to ACIAR projects				
Market access non-host parameter 1	0.50	0.50	0.50	0.50
Market access non-host parameter 2	0.40	0.40	0.40	0.40
Market access non-host parameter 3	17.00	17.00	17.00	17.00
Market access heat treatment	5%	5%	5%	5%
Market access quarantine surveillance	50%	50%	50%	50%

Protein bait spray has proved effective in controlling fruit fly in a variety of experimental situations. Significant reductions in fruit damage have been recorded. In some cases, such as temperate fruits in North Vietnam and Barbados cherry in South Vietnam, use of the bait has allowed farmers to harvest ripe fruit where previously they harvested green to avoid fruit-fly losses. In Malaysia it has been effective as an adjunct to bagging on star fruit where the use of the protein bait lengthens the window for applying bags, and this helps save labour costs.

Protein bait research is a necessary but not sufficient condition for success. Commercial success for protein bait will depend on uptake by farmers. As with all such developments, uptake will depend on the farmer being delivered economic gains through using the bait. Bait effectiveness, price, application costs and availability of substitutes including imported bait sprays will all influence uptake. A particular issue that bears upon potential uptake prospects is the need for area-wide spraying to maximise effectiveness.

Protein bait spray technology has been included in quarantine protocols developed with assistance from the RMFFP between New Zealand and Fiji, Samoa, Tonga and Cook Islands for the export of some fruits, and is being used in some of these countries as one component of quality assurance schemes for selected exports. In addition, due to concern about high pesticide levels among tropical fruit producers in South Vietnam, the government may in the future instigate mandated use of protein bait sprays as a way to solve the problem. The Vietnamese government is committed to a pesticide reduction policy.

Table 15. Realised and prospective benefits from biosecurity projects (present value A$million 2007)

Host country	Realised	Prospective	Total
Bhutan	0	0	0
Cook Islands	1.541	0.458	2.000
Fiji	4.157	4.677	8.834
Federated States of Micronesia	NT	NT	NT
Indonesia	0	TE	TE
Laos	0	0	0
Malaysia	0	0	0
The Philippines	0	0	0
Papua New Guinea	0	0	0
Samoa	1.229	1.416	2.645
Solomon Islands	0	0	0
Thailand	0	0	0
Tonga	4.917	6.327	11.244
Vanuatu	NT	NT	NT
Vietnam – South	0	0	0
Vietnam – North	0	0	0
Australia	43.304	0	43.304
Total	55.149	12.878	68.026

Legend:
0 = no evidence of uptake/impact.
NI = insufficient information to quantify.
NT = there was not enough time to quantify in this study.
IE = included in other benefit estimates but not separated out.

The history of attempts to develop a cheap and locally available protein bait spray from brewery yeast waste for large-scale field control of fruit flies as part of a number of ICMPFF-led ACIAR projects is as follows:

- In collaboration with the Malaysian Agricultural Research and Development Institute (MARDI), ACIAR projects CS2/1983/043 and CS2/1989/019 developed a waste yeast autolysate formulation marketed under the name of Promar as a by-product of brewing stout. Australian bait spray technology was adapted to Malaysian conditions using Promar, and proved to be an excellent attractant for fruit flies that very successfully controlled fruit-fly damage in, inter alia, carambola (star fruit) crops. However, the original Malaysian production plant was based around a formula for Promar that was not stable, and it was not fully commercialised. There also was a further problem when the original source of yeast waste (Guinness) merged with Anchor breweries, which caused a change in quality of yeast waste available.
- While use of protein bait sprays was an effective alternative method of controlling fruit-fly infestation to the standard practice used by carambola exporters of bagging individual fruit, fruit bagging also provided other benefits such as better fruit quality. Hence, it is unlikely that protein bait sprays will ever be widely adopted

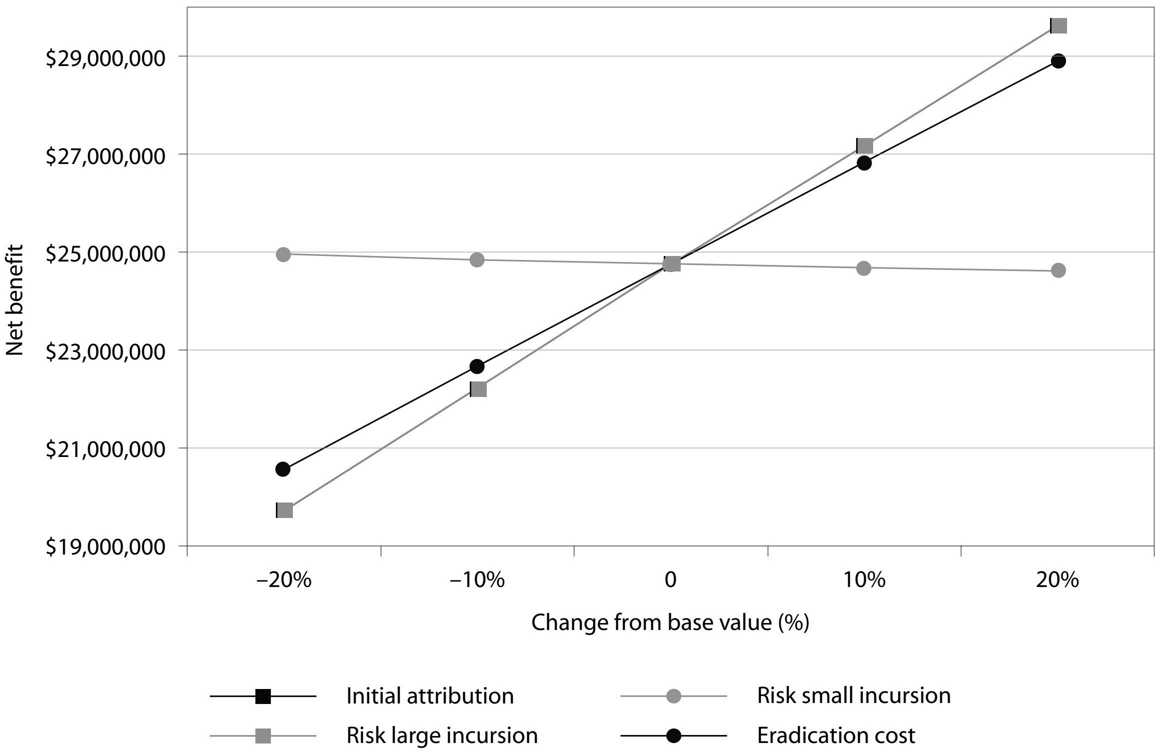


Figure 19. Sensitivity analysis of biosecurity benefits for Pacific islands

by carambola exporters. Protein bait spraying has potential to be used in conjunction with bagging. Bait sprays control fly infestation while bagging is underway and increases the period of time to get fruit bagged. This can reduce labour force requirements.

- In collaboration with the Ministry of Agriculture in Tonga, ACIAR project CS2/1994/115 developed another beer yeast waste protein formulation, and constructed a small prototype yeast protein production plant that demonstrated the feasibility of the concept. This plant was used to prepare and evaluate different formulations for attractiveness. Subsequently, a commercial product, known as Royal Tongalure, was launched in March 1998. Despite only being operational intermittently, the plant did produce some protein bait sprays for Pacific island countries exporting fruit-fly host commodities (Nacanieli Waqa, pers. comm.). However, for various reasons, this plant has delivered very little bait, either to other Pacific island countries for use in quarantine surveillance, or to fruit exporters. One problem has been freight difficulties but arguably the pivotal problem has been the high price ($TOP13.20/kg + $TOP2.64 for freight) charged by the brewery, making Tongalure barely competitive with Mauri Pinnacle Protein Insect Lure imported from Australia ($TOP19.95/kg + $TOP10.42 for freight). As a result, there has been a lack of demand even by farmers in Tonga. Thus from the brewery's point of view, the plant was not a financial proposition. It was not operational when inspected in October 2007.

- A plan to establish a similar plant in Vanuatu, run by Vanuatu Tusker Brewery, was devised in 2001. However, the Tusker Brewery has not continued production because of lack of demand.

- Further development of the protein bait spray technology in Vietnam was undertaken in project CS2/1998/005 when the first fully commercial factory capable of producing 50,000 litres of protein bait per year was built in the Foster's brewery in the Mekong Delta in South Vietnam. The facility produced its first small trial batch in December

2002 and enough bait for about 420 hectares of crop in 2004. Essentially this was a corporate goodwill operation for Foster's, which provided some key inputs at subsidised prices. The protein bait is marketed by the Cantho Pesticide Company in South Vietnam under the commercial name of SOFRI Protein10DD. The application of this protein bait has provided excellent control of fruit flies on farms producing peach, guava, jujube, barbados cherry, luffa and bitter gourd, and uptake rates during the term of the first ICMPFF-led ACIAR project in Vietnam were significant.

However, the initial venture was not fully commercial, and the future of the operation is subject to ongoing discussions. The Foster's brewery has been sold to Singapore Breweries and the protein bait spray plant is not core business for the new brewery owners. This change in ownership control has led to discussion about whether the bait plant should be moved to the Cantho Pesticide Company site. At the time of drafting this report, negotiations were continuing on this issue. Any move is likely to involve costs which may impact on the ability to hold the price of bait at the current level. Any increase in the price charged for the protein bait is likely to affect uptake levels. If each crop requires eight treatments per year, and each treatment requires 1 litre of bait per ha, and if there are at least two crops per ha per year, then the current installed capacity of 50,000 litres/year would only be sufficient to treat about 3,000 ha. This is slightly more than the 1% of a possible 250,000 ha in South Vietnam alone where fruit flies need to be controlled.

While current capacity is 50,000 litres/year, this only uses about 20% of brewery waste yeast, so in theory capacity could be increased to 250,000 litres/year if further investment capital were available. However, as noted, the brewery does not want to expand on site and, if more capacity is not built, prospective benefits from protein bait technology is likely to be limited to less than 2% of tropical fruit production from South Vietnam.

- Following the perceived success of the protein bait plant in South Vietnam, ACIAR funded a small project in North Vietnam to establish a second protein bait plant for the northern region. The partners in project CP/2007/187 were the National Institute of Plant Protection (NIPP) and MDI Vietnam, which is an organisation that develops commercial ventures with a focus on alleviating poverty. This plant is a joint venture between An Thinh brewery, Hoa Binh chemical company and MDI Vietnam that produces a protein bait marketed under the name of ENTO – PRO. It is a fully commercial operation in which the brewery has invested, as a way of diversifying to offset seasonal beer sales in North Vietnam. Officially launched in May 2007, the plant has a capacity of 115,000 litres/year, although planning envisages a second stage expansion to 300,000 litres/year and ultimately to 400,000 litres/year. Initially, the price of ENTO – PRO was 10,000 dong (A$0.67) per litre, but this has increased to 40,000 dong (A$2.70) per litre, similar to the price in the south.

Based on a range of crops being treated with protein bait, application in the north will average 14 litres/ha Planning anticipates that protein bait will be used on around 17,500 ha

- In Malaysia, knowledge gained from earlier ICMPFF-led ACIAR projects was used to refine the formula for Promar to generate a new protein bait spray called Prima Fruit Fly Bait. While Prima is 'endorsed' by the ICMPFF and Griffith University, it is manufactured and marketed as a commercial operation by Pupuk Alam Sdn Bhd with brewery waste from the Carlsberg brewery using technology developed by the ICMPFF. The plant commenced operation in December 2006, and planned capacity for production of Prima is 160,000 litres annually. However, actual production capacity may be lower if there is low uptake of the product by end users. The initial price for Prima protein bait was about RM 35 (A$11.95) per litre but uptake rates were low, even though this price was much less than the price of RM 80 (A$27.32) per litre charged by Dow for another commercially available protein bait spray. Recently, the price of Prima fruit-fly bait has been reduced to about RM 25 (A$8.50) per litre and it remains to be seen whether uptake rates will increase at this lower price.

Again, if each crop requires eight treatments, and there are at least two crops per ha per year, the current installed capacity could only produce enough bait to treat 10,000 ha, while MOA statistics estimate that there are 297,000 ha of fruits and 37,000 ha of vegetables, on much of which fruit flies need to be controlled.

- Recently, a plant has been completed at the Multi Bintang/Heineken brewery in Tangerang, Indonesia, with an initial installed capacity to produce 80,000 litres per year of protein bait spray from brewery yeast. If demand warrants, capacity at the Multi Bintang/Heineken brewery could be expanded to 480,000 litres per year. In the future, there is the possibility of negotiating similar agreements with other breweries that could at least double production of protein bait sprays in Indonesia provided that there is sufficient demand. The final price for the protein bait spray is likely to be around 40,000 Rp. (A$4.68) per litre. As the first batch was only produced after a visit to Indonesia, and presumably will be used by the ongoing ICMPFF-led ACIAR project in Indonesia, it will be some time before the extent of uptake of commercially marketed protein bait spray becomes apparent. Using the same approach as outlined in the previous points, current capacity in Indonesia is only sufficient to treat about 5,000 ha/year. If the pilot is successful, this could increase to 30,000 ha. According to FAO, there are 2,734 km^2 (= 273,400 ha) of mango in Indonesia, so planned capacity is only sufficient to treat approximately 10% of the mango crop and no other crops.

Based on available information, there is no current capacity to produce commercial quantities of protein bait sprays in Bhutan, Cook Islands, Fiji, the Federated States of Micronesia, Laos, Papua New Guinea, the Philippines[3], Samoa, Solomon Islands, Tonga or Vanuatu. The four commercial-scale plants in South and North Vietnam, Malaysia and Indonesia have only recently commenced production, and it is too early to assess their commercial viability. However, the need for the product is demonstrable and none of the businesses is targeting very large market share based on their production capacities and the total hectares of fruit and vegetables that could potentially use the products. For example the bait project in North Vietnam is only targeting around 10% of the actual hectares for most crops, with higher percentages targeted only where there are known to be significant potential for an increase in producer net incomes from using the protein bait.

Any benefits realised to date from development of a cheap, locally available supply of protein bait spray for field control of fruit flies have been small, ephemeral and arguably due in part to the donation of brewery waste and other inputs that have kept prices below commercially sustainable levels. However, as one of the primary constraints to widespread uptake on a non-subsidised basis, namely lack of availability of a commercially produced economical protein bait spray, may be about to change, there is significant potential for prospective benefits from possible future uptake of this technology.

Consequently, prospective benefits have to be predicted, which poses a number of challenges and is a significantly less objective process than measuring realised benefits. Inter alia, a key problem that may have been solved is finding a yeast source based on brewery waste that is secure and cheap. The size of prospective benefits from uptake of protein bait spray technology will be limited by the future capacity of protein bait production facilities, and the critical limit on production capacity is the availability of brewery yeast, which ultimately is determined by demand for brewery products. The South Vietnamese experience indicates that because converting waste yeast into protein bait is not a core business, changes in brewery company ownership and operations can impinge on bait production when the brewery is simply a contract supplier. Another key question is whether there is sufficient demand from fruit growers for protein bait sprays at commercial prices to make further investment in extra plant capacity profitable. So far, there is no clear evidence of commercial viability. Only the Malaysian, North Vietnamese and Indonesian operations appear to have been planned as fully commercial, and all three are very new.

Planned production capacities can meet the needs of only a small percentage of the total hectares of relevant crops. In this study, the assessment is made that all of the breweries where protein bait is being made will continue to be willing to supply as much brewery yeast waste as needed for this purpose. Furthermore, in view of the relatively small area and after discussion with experts and industry, the assessment is that demand for protein bait sprays at commercial prices will grow sufficiently over the period 2020–21 to justify expanding plant capacity at all four current breweries to a level where all brewery yeast waste is fully utilised

3 If there is such a plant in the Philippines, it cannot be attributed to any of the ACIAR projects assessed in this study.

producing protein bait. However, no allowance will be made for the possibility that similar arrangements to utilise brewery yeast waste will be negotiated with other breweries.

In common with extension packages of other field control measures that do not use protein bait spray formulations for fruit-fly control, obtaining objective evidence of past uptake and predicting future uptake of scientifically tested practices for protein bait spraying for field control of fruit fly is crucial to credible estimation of realised benefits and predicting prospective benefits, respectively. As many of the issues affecting uptake of packages of field control methods are crop and/or country specific, they will be discussed on a country-by-country basis.

However, one specific issue that may have an important influence on uptake of protein bait spray technology and consequential benefits is the need for area-wide treatment in some circumstances. Unless all farmers in an area use the bait, field control may be much less effective, which means that achieving coordination of field control methods between farmers in an area can be central to the success of protein bait sprays.

More generally, to date there is no objective evidence of substantial uptake of other adapted field control methods but there is significant potential for prospective benefits from future uptake of such methods. The extent of realisation of such prospective benefits will depend critically on actual future uptake of adapted field control methods.

Realised and prospective benefits

Realised and prospective benefits are shown in Table 16. The availability of economic information for some of the experimental areas in Vietnam allowed a detailed modelling based on data pertaining to increased yield, prices and costs of using bait and additional required labour inputs. Equivalent information does not appear to be available for Malaysia and Indonesia. The benefits are almost all prospective. Of the A$104.3 million in estimated attributable benefits, some A$99.8 million is prospective. The small realised benefits are related to existing use of the bait on Barbados cherry in South Vietnam.

Sensitivity analysis

The benefits from the adoption of field control (protein bait) in North and South Vietnam are greater when the uptake rate and area planted are higher, the price received per kg of fruit is higher and the greater the attribution factor. Figure 20 shows how the estimated benefits attributable to ACIAR are affected by increases and decreases in these key variables when 10% and 20% changes are considered relative to base values.

Partner country low-chill temperate fruit benefits

There are two benefit streams arising from the research in low-chill temperate fruits. Improved management incorporating effective pest control can increase yields and improve returns. If crops are managed so they can be harvested ripe not green, the per-unit prices received by farmers will increase.

Where new varieties are planted a further price benefit arises. The new varieties are ready for harvest and sale later, at a time when markets in Hanoi offer higher prices. Currently Chinese imported fruit dominates this time and receives a significant premium.

As part of this project, four arboreta sites were established in Vietnam with a range of chilling. Over 1,300 stone fruit trees of 25 varieties of peach, plum, nectarine and persimmon have been sent to Vietnam (and Laos). The sites are in Moc Chau, Bac Ha, Sapa and Dalat (100 chill units). Within the ACIAR project, high-quality medium-chill plum cultivars Black Amber, Simca and Fortune were identified as potentially valuable crops. Of the trees sent, 70% have been raised successfully. There is now evidence of considerable nursery raisings of the introduced varieties.

NIPP has published a variety of information on the effects of the new fruits and the improved orchard management on returns in the experimental areas. These data (yields, costs, prices) are the basis for the benefit estimates below.

The stated government aim is to expand the temperate fruit area in the north to 10,000 ha by 2010. Although the target year looks unrealistic we have taken the

Table 16. Realised and prospective benefits from field control with protein bait (present value A$ million 2007)

Host country	Field control		
	Realised	Prospective	Total
Bhutan	0	0	0
Cook Islands	0	0	0
Fiji	0	0	0
Federated States of Micronesia	0	0	0
Indonesia	TE	TE	TE
Laos	0	0	0
Malaysia	NI	NI	NI
The Philippines	0	0	0
Papua New Guinea	0	0	0
Samoa	0	0	0
Solomon Islands	0	0	0
Thailand	0	0	0
Tonga	0	0	0
Vanuatu	0	0	0
Vietnam – South	1.558	54.035	55.594
Vietnam – North	2.924	45.842	48.766
Australia	0	0	0
Total	4.483	99.877	104.360

Legend:
0 = no evidence of uptake.
Neg = negligible.
NI = insufficient information to quantify.
TE = too early to reliably assess.

area itself to be reflective of policy intent. Based on discussion with those involved with the research and those developing the protein bait market, the potential uptake rate for the ACIAR work is estimated to be at most 15–20%. An area of 2,160 ha by 2020–21 has been used in the analysis. This appears an achievable target and will be based primarily on larger, more professional farmers taking up the technologies.

Realised and prospective benefits

The realised and prospective benefits are shown in Table 17. As with protein bait the benefits are prospective. The attributed benefits are estimated to be A$35.2 million.

Sensitivity analysis

The benefits from the adoption of low-chill temperate fruits in North Vietnam are greater when the uptake rate and area planted is higher, the price received per kg of fruit is higher and the greater the attribution factor. Figure 21 shows how the estimated benefits attributable to ACIAR are affected by increases and decreases in these key variables when 10% and 20% changes are considered relative to base values.

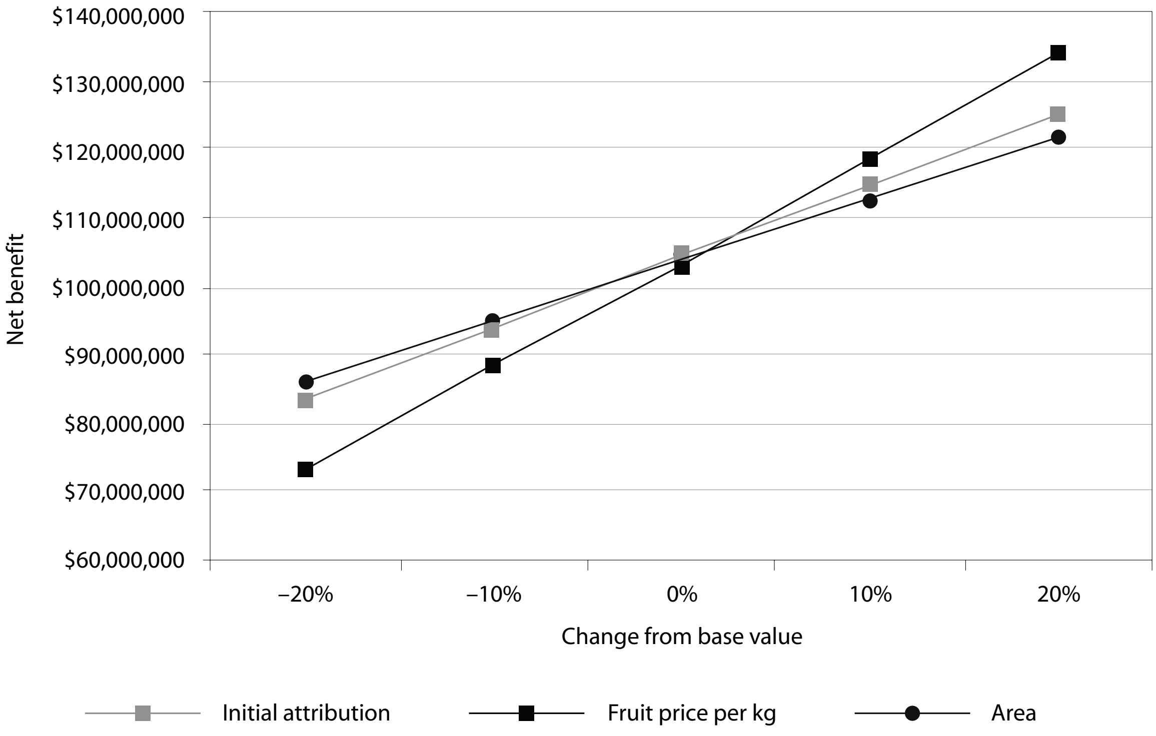


Figure 20. Sensitivity analysis on field control benefits

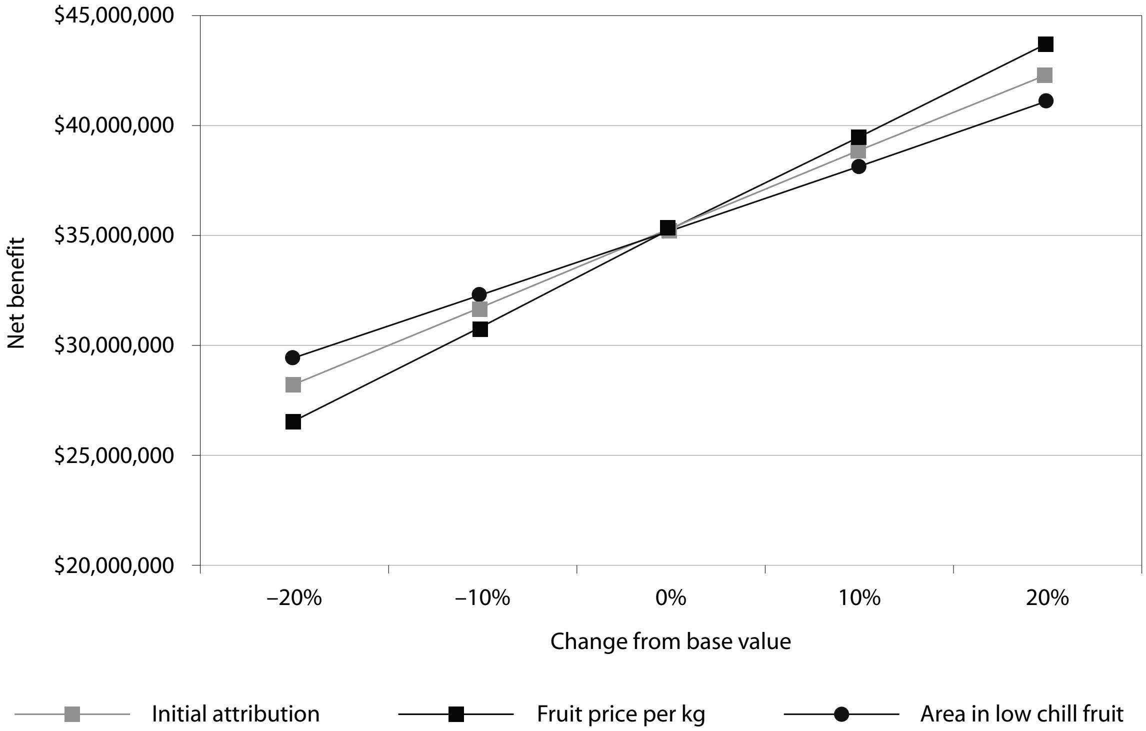


Figure 21. Sensitivity analysis for low-chill temperate fruit benefits

Table 17. Realised and prospective benefits from low-chill temperate fruit projects (present value A$ million 2007)

Host country	Low-chill temperate fruit		
	Realised	Prospective	Total
Bhutan	0	0	0
Cook Islands	0	0	0
Fiji	0	0	0
Federated States of Micronesia	0	0	0
Indonesia	0	0	0
Laos	0	0	0
Malaysia	0	0	0
The Philippines	0	0	0
Papua New Guinea	0	0	0
Samoa	0	0	0
Solomon Islands	0	0	0
Thailand	0	0	0
Tonga	0	0	0
Vanuatu	0	0	0
Vietnam – South	0	0	0
Vietnam – North	0.732	34.487	35.219
Australia	0	0	0
Total	0.732	34.487	35.219

Legend:
0 = no evidence of uptake.
Neg = negligible.
NI = insufficient information to quantify.

Partner-country health and environmental benefits

Improved field control has been a by-product of some projects and a specific objective of others. The two major areas where improved field control is an output are the adoption of protein bait and improved orchard management of temperate fruits. In North Vietnam the latter also incorporates the use of protein baits.

Realising the environmental and health benefits depends on the field control technology being taken up by farmers and on its correct use. As noted, adoption depends primarily on protein bait and orchard management methods being sufficiently cheap and easy to apply to make the switch for farmers profitable. In addition to a ready supply of cheap bait, adoption will depend on having trained staff and extension programs to encourage use of the bait across a contiguous area large enough to secure fruit-fly control benefits.

Health and environmental benefits will potentially be achieved through the adoption of the bait. They will be enhanced if the application is best practice using suitable equipment and if a large enough area is treated using the bait. However, protein bait does not eliminate all spraying. Other pests still have to be treated. A necessary condition to maximise the impact of the switch to protein spray is that these sprays are applied optimally and with appropriate equipment and safety precautions.

The protein benefits and improved orchard management benefits are almost entirely prospective. Hence any health and environmental benefits are also prospective. Currently the data are not available to make a meaningful estimate of these benefits, and more research would be needed on the impact of such changes before such benefits could be valued. Studies have yet to be done on the actual reduction in pesticide use, the required ongoing spray use, the methods of application, and the numbers of workers and farm residents within range of any spray externality.

Partner-country capacity-building benefits

Capacity building is central to securing the estimated benefits from the ACIAR projects included in this assessment. There are two reasons why this is the case.

First, the ACIAR projects included in this report are not final in the sense that all work required for ongoing fruit-fly control, postharvest treatment and field control is completed within the project time frame. The projects were largely catalyst projects that opened up an area of potentially significant research and control activity, postharvest treatment and field control work in the partner country.

Second, even where a flow of ongoing benefits can be attributed, the bulk of these benefits are prospective not realised.

The ACIAR projects had a specific training objective. Training focused on enhancing the capacity to do the original work, to carry on and extend the work, and to apply the results. It can be argued that these project-related capacity-building activities were a necessary requirement to have any chance of securing projected benefits. They are not, however, sufficient.

In each of the key project benefit categories of quarantine surveillance, market access and field control, only if the relevant agencies within a country have the capacity to carry on the work initiated in the projects can the expected benefits be fully realised. Depending on the project, agencies are required to:

- maintain and enhance the basic research activity
- maintain the quarantine systems
- maintain postharvest treatment facilities including research and training
- extend field control activities to a wider number of producers.

Capacity-building activities include the following:

- Training scientists and others who could then carry on the primary research needed for documentation of fruit-fly pests and their distribution. This was the focus of training connected to CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1996/225, CS2/1997/101, CP/1998/005 and CP/2003/036.
- Training scientists and others who could then carry on the work of documenting heat treatment impacts on fruit flies. This was the training focus of PHT/1990/051, PHT/1994/133 and PHT/1993/877.
- Training scientist, trainers and others in the development and application of protein baits. They can then assist farmers to switch to the baits and apply them correctly. This was the training focus of CS2/1998/005.
- Training extension officers and farmers in the application of improved horticultural practices. This was the training focus of PHT/1993/087, CP/2001/027 and CP/2002/086.

These training activities are essential if the project work is to be successfully completed and then extended in time and scope.

Scientists trained in taxonomy, surveys and documentation are critical to carrying out the work necessary to optimise quarantine protocols and to determine critical market access issues like non-host status. Researchers who are able to undertake heat treatment analysis are essential to the development and documentation of accurate heat treatment data and these in turn are a necessary part of negotiations for market access in countries where market access is limited by quarantine controls. Training trainers and farmers is essential to ensure that new field control methods such as protein baits are taken up and used correctly. Without this training/capacity building the necessary conditions for the development of quarantine protocols, market access and the uptake of field control technology would not be met.

Where training occurs during the project phase, it is clearly desirable that project-trained personnel stay in the organisation long enough to influence the range of programs adopted that deal with the various aspects of fruit-fly research, and that those personnel and the relevant in-country agencies support ongoing training for a subsequent cohort of qualified people.

In the case of the projects considered in this study, the estimated benefits are mainly prospective. To realise these benefits requires agencies in partner countries to continue the training and capacity building undertaken during the project phase. Two examples can be used to illustrate this: mango market access to Japan and the development of low-chill temperate fruit orchards in North Vietnam. In both cases there are substantial estimated net benefits. The mango export benefits are partly realised (pre 2006–07) and partly prospective. The low-chill temperate fruit benefits are almost all prospective.

For the temperate fruits, benefit realisation is dependent on increasing the uptake rate of the introduced fruit varieties, extending the area growing the varieties and ensuring that farmers adopt best practice orchard management, including use of protein bait. The research project and associated training terminated at an early stage in this development process. Realisation of the estimated prospective benefits will require continued effort by the various agencies in Vietnam to extend the results and promote uptake through extension (training the trainers), through demonstration farms, and through direct assistance to farmers wishing to adopt the new technology.

In estimating the prospective benefits from temperate fruits, it was assessed that the area of temperate fruit would grow over time to around 2,160 ha over the period to 2020–21, and that the required nursery stock, trained farmers, extension officers and the research capability to deal with any new pest threats would happen to the extent needed to achieve this estimated growth.

Similarly the benefits of mango exports to Japan are significantly prospective. Continued market access will require that the various exporters such as Thailand maintain effective heat treatment research and documentation capacity, and maintain benchmark heat treatment facilities. In Thailand the scientists associated with the original fruit-fly taxonomic research and the later heat treatment research have largely retired or moved to other roles. However, the fly-rearing facility and heat treatment testing facility has been maintained and in fact expanded with a new generation of scientists trained in the area, some in Japan, some in Australia. The facility now uses Japanese-sourced equipment to undertake heat treatment research and documentation. This level of commitment is necessary to maintain their ability to sustain existing market access success and develop new market access initiatives. Therefore while the original ACIAR-funded research and training allowed for the research and documentation necessary to gain market access in Japan, the current scientists working in the area who have responsibility for maintaining the system have little connection to those projects.

This poses some issues when valuing the contribution of the training and capacity building. For most of the projects, the training was an integral part of the generation of project benefits. Arguably, benefits that could be attributed to project training and capacity building have already been capitalised into the estimated project benefits. Indeed the capacity building was in most cases a necessary condition for the project benefits to be achieved, at least initially, and the value of the prospective benefits is estimated on the basis that the capacity building that has taken place will be maintained and enhanced, as required, by the partner country.

Given that the training and capacity-building activities were so integral to most of the projects, the benefits derived from these activities form a significant component of the quantifiable project benefits. However, because both skilled staff and other project outputs are joint necessary conditions for achieving these quantifiable benefits, it was not possible to objectively and reliably separate out the component of these benefits that could be ascribed to capacity building.

The data on the extent of capacity-building activities (courses offered, people trained etc.) is in the country case studies in the appendixes.

Australian biosecurity and market-access benefits

There are at least four benefits to Australia from ACIAR fruit-fly projects. First, there are the actual benefits realised during the eradication program of *B. papayae* in North Queensland following detection of an incursion in 1995. This campaign was more effective than it otherwise would have been due to knowledge gained about the biology and range of *B. papayae* during ICMPFF-led ACIAR projects CS2/1983/043 and CS2/1989/019.

Second, ACIAR project PHT/1990/051 to research the development of postharvest heat disinfestation treatments played an important role in the development of the mango export trade to Japan.

Third, following suspension of tropical fruit exports from the pest quarantine area in Queensland due to the incursion of *B. papayae*, Australia was able to utilise methods just developed in ACIAR project PHT/1994/133 to quickly prove the efficacy of heat treatment protocols for disinfestation of *B. papayae* necessary for prompt resumption of this trade to Japan.

Fourth, there are ongoing avoided losses from enhanced effectiveness of Australia's quarantine surveillance system that are somewhat similar to the host country biosecurity benefits detailed above. Such benefits can be attributed in some part to knowledge about fruit fly biology and movement in Papua New Guinea and the Torres Strait gained during ACIAR project CS2/1996/225, and shared with plant protection and quarantine surveillance staff in Australia.

Market access for heat-treated mango exports to Japan

Key objectives of ACIAR project PHT/1990/051 were the development of harmonised quarantine disinfestation procedures using heat treatment to improve the development of such disinfestation protocols and to increase understanding of the technology. Broad heat-treatment parameters that do not injure fruit but do kill fruit-fly eggs and instars need to be defined in order to aid the development of disinfestation schedules for many fruit and pest combinations. This understanding was used by other organisations to develop efficacious protocols for the disinfestation of Queensland fruit fly in mangoes. Some Australian participants in PHT/1990/051 also were involved, along with other organisations, in negotiating access to the Japanese market for Australian mango exports for the 1994–95 season on the basis of these quarantine disinfestation protocols. Although several other organisations also were involved in gaining access, it is clear that a sizeable part of the benefits from the subsequent mango exports to Japan can be attributed to this ACIAR project.

Monck and Pearce (2007) estimated these benefits on the basis that there would be no supply response by mango growers to Australia gaining access to a new premium-price market. Using the same data and predicted prices, the benefits were re-estimated in this study on the basis that there would be a supply response, which the authors consider a more likely scenario.

Cost saving in eradication of *B. papayae*

According to Drew (1997), fruit flies found in green pawpaw in north Queensland were identified as *B. papayae* on 17 October 1995. This represented the first-ever outbreak of an oriental fruit fly complex pest species in Australia. Details of this incursion, and the cost of eradicating it, were discussed earlier in Section 3.

Collins and Collins (1998) estimated the benefits to Australia that could be attributed to ACIAR projects CS2/1983/043 and CS2/1989/019 as a result of increased effectiveness of the papaya fruit-fly eradication program in Queensland. Specifically, they found that knowledge gained from these two projects saved time, and therefore costs, in undertaking the delimiting survey and thereby allowed eradication of *B. papayae* to be achieved earlier than otherwise would have been the case. In turn, the earlier eradication of the pest accelerated the realisation of eradication benefits. Furthermore, the success of negotiations with Australia's major trading partners in obtaining area freedom concessions for produce sourced outside the quarantine area, and thereby enabling continued access to papaya export markets, was attributed to the extensive trapping program throughout Australia, and to the scientific knowledge of the papaya fruit fly, its host fruits and pest status that came directly from the ACIAR projects. Collins and Collins (1998) estimated that benefits were realised over the 5 years from 1995–96, and totalled A$21.2 million in nominal dollars. Their estimates have been used in this study.

Accelerated market access for mango after eradication of *B. papayae*

Project PHT/1994/133 established a breeding colony of *B. papayae* in Malaysia as well as the scientific methods necessary to generate data needed to establish disinfestation schedules prior to the discovery of the incursion of *B. papayae* into North Queensland. Market access to Japan was withdrawn in October1995 for Australian mango exports sourced inside the quarantine area. Using results from PHT/1994/133, QDPI was able to generate postharvest treatment protocols for *B. papayae* in Australian mangoes much sooner than otherwise would have been possible, and approval to restart exports was granted in December 1996 as a result. This was at least 6 months sooner than would have been possible without this background knowledge. No attempt has been made to separately estimate the size of this benefit because it is included as part of the benefits estimated previously.

Biosecurity due to avoided loss from re-entry of *B. papayae*

McLeod (1998) notes there are potential biosecurity benefits to Australia from better regional control of fruit flies throughout South-East Asia and the Pacific. He argues the likelihood of an incursion of an exotic fruit-fly species will be reduced by:

- more effective quarantine and fruit-fly control programs across the region, which will result in fewer fruit flies being 'exported' to Australia
- correct identification of a wider range of fruit-fly species, which reduces the probability of misidentification of an incursion into Australia, and therefore saves unnecessary expenditure on further surveillance, containment and eradication.

In practice, more effective quarantine and fruit-fly control programs have not been realised to date in South-East Asia or Papua New Guinea, where almost all the major fruit-fly pest threats to Australia exist. Instead, Australia has established the Northern Australia Quarantine Strategy (NAQS) as the primary quarantine surveillance system for protecting Australia from an incursion by an exotic pest fruit fly.

In meetings with representatives from several Australian government agencies with responsibility for quarantine, biosecurity and plant health, there was consensus that due to knowledge from the ACIAR projects about fruit-fly taxonomy, ecology and movement patterns, NAQS was, and continues to be, more effective than it would be otherwise. However, the necessary information to quantify the magnitude of biosecurity benefits has proved to be elusive, so no formal estimates of this biosecurity benefit have been made in this study because of the speculative nature of the information on which it would have to be based. For instance, if the most likely cost of an exotic pest fruit fly becoming established is similar to that actually incurred as a result of the incursion of *B. philippinensis* into the Darwin area in1997, which arguably cost as much as A$20 million, and if risk for the counterfactual scenario is only slightly higher than the current situation, then the annual biosecurity benefit to Australia could be as large as A$333,000 and the PV could be greater than A$6 million. However, plausible arguments could be made for both smaller and larger values, and given the reluctance of knowledgeable persons to make quantitative estimates of key parameters, it was not possible to make a credible estimate.

Realised and prospective benefits

The attributable benefits of A$43.3 million in 2006–07 present values are all realised.

Table 18. Realised Australian biosecurity benefits (A$ million 2007)

Year	Biosecurity benefits realised
1995–96	7.801
1996–97	7.137
1997–98	6.359
1998–99	7.038
1999–2000	0.169
TOTAL	28.504
PV @ 2007	43.304

4 Conclusions

The involvement of ACIAR in fruit-fly research goes back some 25 years to an initial project in Malaysia. Since that time there has been an almost continuous involvement by ACIAR in most areas of fruit-fly control. In this report, the economic impact of some 17 projects dealing with fruit fly has been assessed. The core projects focused on the identification and control of fruit fly in the Pacific islands, Bhutan, PNG, Malaysia, Thailand, Vietnam and Indonesia. The first of these studies commenced in September 1984 and all, apart from ongoing studies in Indonesia and North Vietnam, were completed prior to this impact assessment. In addition, two small projects were funded specifically to further develop a cheap and locally available protein bait spray from brewery yeast waste for field control of fruit flies, although the objective of developing and testing the efficacy of a protein bait spray also was one of the common threads running through several of the larger projects. ACIAR projects were also funded to look at postharvest heat treatment, use of improved temperate fruits and orchard management, supply chain improvement and integrated pest management.

A range of objectives was covered by these projects. In assessing the impacts of these projects, the quantifiable benefits have been categorised as coming from:

- improved biosecurity
- market access based on non-host status
- market access based on postharvest heat treatment
- field control with protein bait
- introduction of low-chill temperate fruit and improved orchard management.

Project objectives did not align neatly with this grouping. As discussed, field control with protein bait was a specific focus of just two projects, although an indirect consideration in a number of others. Yet it has the potential to generate significant ongoing benefits.

Almost all projects had a specific training and capacity-building component. For the projects with significant prospective benefits, it was important that a capacity existed to carry the implementation post-project to ensure potential benefits would be realised. However, as noted, this requires an ongoing commitment from the partner country to having the required scientists, extension officers and equipment. Training was an integral part of the projects so the benefits from capacity building are effectively capitalised into the estimates of project benefits.

The ACIAR investment has been substantial. Over this period 1984 to 2009, ACIAR will have invested A$12.16 million in nominal dollars, or A$15.14 million in constant 2006–07 dollars. The present value (PV) of this expenditure is A$22.86 million. The total investment in these projects by ACIAR and its partners will be A$27.54 million in nominal dollars, or A$33.48 million in constant 2006–07 dollars The PV of this expenditure is A$50.76 million.

A summary of project benefits is shown in Table 19. The estimated benefits in present value terms are A$258.83 million in total or A$212,633 million when only partner-country benefits are taken into account. The estimated benefit:cost ratio is a very respectable 5.1:1 for total benefits and 4.2:1 for partner benefits. The internal rate of return on total benefits is 33%.

The total attributed benefits have been broken down by benefit type and country. The funding for these projects commenced in 1984 and the last project is funded until

Table 19. Summary of project benefits

	2007 A$ million
Total present value (PV) gross benefits[a]	258.83
PV gross benefits to Australia [a]	46.19
PV gross benefits to partner countries [a]	212.63
PV ACIAR investment in research projects	22.87
PV total cost of research projects (includes ACIAR + partner investments)	50.76
NPV total benefits (after deducting total project costs)	208.07
NPV benefits to partner countries (after deducting total project costs)	161.87
Total benefit:cost ratio	5.1:1
Partner countries benefit:cost ratio	4.2:1
Total benefit internal rate of return (IRR)	33%

a Attributed to ACIAR projects

2009. There is therefore a need to assess the balance between realised and prospective benefits. Tables 21 and 22, respectively, indicate the split between realised and prospective benefit for the various benefit categories by country. Prospective benefits are from 2006–07 on.

Looking at quantified attributable total benefits, the pattern of benefits is variable. Australia derives a significant biosecurity benefit. Of the Pacific islands, only Fiji and Tonga have significant benefits. Fiji is estimated to have derived significant biosecurity and postharvest market access benefits. Tonga has derived significant benefits from biosecurity improvements and market access based on non-host status. Indeed this is the only case of significant quantifiable benefits based on non-host status. Vietnam has no quantifiable biosecurity benefits and no quantifiable market access benefits. It is developing a quarantine system consistent with its emerging role in world trade but this is in its early stages. It has no significant fresh fruit exports to countries with high quarantine access standards such as the USA and Japan. It is working toward commercial postharvest treatments and protocol negotiation but has a long way to go. The more immediate challenge for Vietnam is to improve all aspects of its horticultural industry consistent with its desire to expand fruit and vegetable production in future years. The Vietnamese attributable benefits come from improved field control using protein bait and the improved performance of temperate fruit orchards based on the combination of field control, improved management and improved varieties.

Given the time lags, the scope of the projects and countries, and the prospective nature of some benefits, data limitations have meant that identified attributable benefits could not always be quantified. A case in point is field control benefits in Indonesia. The recently completed facility for protein bait production has great potential but it is too early to project benefits as the economics cost and returns data for crops with and without bait use have not been developed. There are some cases where, apart from capacity building, no benefits (realised or prospective) have been found. Papua New Guinea and Solomon Islands are cases in point.

There are significant differences when we consider the breakdown between realised and prospective benefits. Most of the attributable biosecurity and market access benefits have been realised. The field control and temperate fruit project benefits are prospective.

In large part, this reflects the timing of the projects. The early projects in the Pacific islands and South-East Asia were most relevant to biosecurity. Where biosecurity benefits have been identified, they were realised early, as countries moved to incorporate the knowledge into their quarantine systems. Similarly the postharvest heat treatment projects were early in the time span of

Table 20. Total attributed benefits from ACIAR fruit-fly projects (present value A$ million 2007)

Host country	Source	Biosecurity	Market access non-host status	Market access post-harvest	Field control with protein bait	Low-chill temperate fruit	Environmental & human health impacts	Capacity-building impact	Total
Bhutan	Appendix 3	0	0	0	0	TE	0	TE	TE
Cook Islands	Appendix 4	2.000	0.004	0.063	0	0	0	IE/TE	2.067
Fiji	Appendix 5	8.834	0.099	0.347	IE	0	NI	IE/TE	9.279
Federated States of Micronesia	Appendix 6	NT	0	0	0	0	0	NT	NI
Indonesia	Appendix 7	TE	0	0	TE	0	TE	TE	TE
Laos	None	0	0	0	0	0	0	0	0
Malaysia	Appendix 8	0	0	0	TE	0	0	NT	NT
The Philippines	Appendix 9	0	0	17.563	0	0	0	IE/NT	17.563
Papua New Guinea	Appendix 10	0	0	0	0	0	0	TE	TE
Samoa	Appendix 11	2.645	0.260	0.001	0	0	0	IE/TE	2.906
Solomon Islands	Appendix 12	0	0	0	0	0	0	TE	0
Thailand	Appendix 13	0	0	13.505	0	TE	0	IE/TE	13.563
Tonga	Appendix 14	11.244	16.491	0	0	0	0	IE/TE	27.734
Vanuatu	Appendix 15	NT	0	0	0	0	0	TE	TE
Vietnam – South	Appendix 16	0	0	0	55.594	0	TE	IE/TE	55.594
Vietnam – North	Appendix 16	0	0	0	48.766	35.219	TE	IE/TE	83.985
Australia	Appendix 2	43.304	0	2. 903	0	0	0	IE	46.197
Total		68.026	16.854	34.382	104.360	35.219	NI, TE	TE, IE, NT, NI	258.830

Legend:
0 = no evidence of uptake/impact.
NI = insufficient information to quantify.
TE = too early to reliably assess.
NT = there was not enough time to quantify in this study.
IE = included in other benefit estimates but not separated out.

the projects. Where they have been used in negotiating access, such as for mangoes to Japan, significant benefits have already been realised.

The field control with protein bait and temperate fruit project benefits are almost entirely prospective. In the case of the temperate fruit projects, benefits are a function of the expansion of successful plantings and ultimately harvest. These projects are relatively recent and the expansion of plantings beyond experimental areas is only just commencing.

Although field control with protein bait was part of some early projects, major commercial operations are recent in South Vietnam, North Vietnam and most recently Indonesia. Prospective attributable benefits are tied to the future success of these ventures.

There are some caveats to these numbers. First, in-so-far as the bulk of the benefits are prospective, actual realisation will depend on continued uptake of the project technologies. This will in turn depend on it being profitable for farmers to adopt. The

Table 21. Realised attributed benefits from ACIAR fruit-fly projects (present value A$ million 2007)

Host country	Biosecurity	Market access non-host status	Market access post-harvest	Field control with protein bait	Low-chill temperate fruit
Bhutan	0	0	0	0	0
Cook Islands	1.541	0.003	0.063	0	0
Fiji	4.157	0.067	0.073	IE	0
Federated States of Micronesia	0	0	0	0	0
Indonesia	0	0	0	0	0
Laos	0	0	0	0	0
Malaysia	0	0	0	0	0
The Philippines	0	0	16.284	0	0
Papua New Guinea	0	0	0	0	0
Samoa	1.229	0	0.001	0	0
Solomon Islands	0	0	0	0	0
Thailand	0	0	10.353	0	0
Tonga	4.917	14.561	0	0	0
Vanuatu	0	0	0	0	0
Vietnam – South	0	0	0	1.558	0
Vietnam – North	0	0	0	2.924	0.732
Australia	43.304	0	2.333	0	0
Total	55.149	14.892	29.106	4.483	0.732

Legend:

0 = no evidence of uptake/impact.

NI = insufficient information to quantify.

NT = there was not enough time to quantify in this study.

IE = included in other benefit estimates but not separated out.

ongoing commitment of the various commercial and government players will be important, as will the quality and consistency of the relevant policy settings. Uptake rates for protein bait and temperate fruit are based on the assessment that these requirements will be met. This is very much the case for the protein bait plants and the temperate fruit initiatives.

There is the potential for benefits to be larger than those quantified. The success of protein bait in Indonesia is the most obvious example. If the planned capacity is turned into actual sales and buyers experience yield and value improvements as has happened elsewhere, significant net benefits will be realised. However, it is too early in the planning to make a quantitative estimate. This can be contrasted with North Vietnam where a range of experimental results is available on yield improvement and price impacts, and where a detailed production and marketing plan provides data that can form the basis for assessing prospective benefits.

Table 22. Prospective attributed benefits from ACIAR fruit-fly projects (present value A$ million 2007)

Host country	Biosecurity	Market access non-host status	Market access post-harvest	Field control with protein bait	Low-chill temperate fruit
Bhutan	0	0	0	0	TE
Cook Islands	0.458	0.001	0	0	0
Fiji	4.677	0.031	0.275	IE	0
Federated States of Micronesia	0	0	0	0	0
Indonesia	TE	0	0	TE	0
Laos	0	0	0	0	0
Malaysia	0	0	0	TE	0
The Philippines	0	0	1.279	0	0
Papua New Guinea	0	0	0	0	0
Samoa	1.416	0	0	0	0
Solomon Islands	0	0	0	0	0
Thailand	0	0	3.155	0	TE
Tonga	6.327	1.930	0	0	0
Vanuatu	NT	0	0	0	0
Vietnam – South	0	0	0	45.842	0
Vietnam – North	0	0	0	54.035	34.487
Australia	0	0	0.571	0	0
Total	12.878	1.962	5.280	99.877	34.487

Legend:

0 = no evidence of uptake/impact.

NI = insufficient information to quantify.

TE = too early to reliably assess.

NT = there was not enough time to quantify in this study.

IE = included in other benefit estimates but not separated out.

Lessons learnt

Overall the investment by ACIAR and its partners has been very successful, and the total value of benefits generated is impressive. However, the pattern of benefits is variable by type of benefit and by country. Like drilling for oil, the cost of many projects that yield little or no return is more than compensated for by the very large returns from the few projects that pay off handsomely. This is illustrated in Table 23, where an attempt has been made to ascribe benefits to individual projects. In some cases, this was relatively straightforward, but in other cases, such as the prospective benefits from field control using protein bait spray, many projects have contributed to the development of the technology over a period of more than two decades.

The lesson that ex ante, the returns on individual investments in research are very unpredictable, and ex post, are highly variable, is not a new lesson, but it is often forgotten in the enthusiasm of developing plans for new projects. An advantage of a more thematic and wide-ranging impact assessment such as the current study is that it reminds readers of this basic fact about returns to investment in research.

A related lesson is that the high returns to research are often serendipitous. Virtually the only benefit of the early work on fruit fly in Malaysia was the cost savings in Australia in containing the incursion of the papaya fruit fly into northern Queensland, and then eradicating the pest sooner than would otherwise have been possible. It seems that such a benefit was unanticipated when ACIAR decided to invest in the first fruit-fly project.

Notwithstanding the last point, consideration of the pattern of benefits is instructive in providing some guidance for future investment in crop protection research. One of the most important general lessons, also widely known but reinforced by the results from this study, is that while successful research project outcomes may be necessary to enable potential benefits, they rarely are sufficient for benefits to be realised. In particular, potential benefits will only be realised if there is uptake of project outputs. Yet at the time of project formulation, the necessary conditions for adoption of project outputs often seem to receive insufficient attention. Fundamentally, potential adopters, be they growers, government officers or whomever, will only decide to adopt a new practice or product on an ongoing basis if there are net benefits in doing so. At best, failure to address this fact at the outset can delay the realisation of research benefits by many years. At worst, a return on the investment will never be realised.

Notwithstanding some 20 years of research on the development of low-cost protein bait sprays from brewery waste, it still has not been conclusively demonstrated that the use of these sprays is a cost-effective alternative to existing practices in most developing countries. Unlike Australia, where stringent minimum residue requirements often make the use of bait sprays a cost-effective means of controlling fruit flies, in developing countries use of blanket chemical cover sprays by commercial growers has several advantages, including that it also controls other pests, and that its effectiveness does not depend on neighbouring growers also using it. It is even more difficult to determine the relative merits of protein bait sprays vis-à-vis other methods of fruit fly management for poorer subsistence producers, where other supporting structures are not developed. In some cases, an intensive extension program may suffice to persuade growers to adopt the technology, but in other cases such as in Bhutan and Papua New Guinea, and for subsistence farmers in Pacific islands, the net benefits from using protein bait sprays do not appear to be positive, and no amount of extension effort is likely to lead to significant uptake. Where ongoing support beyond the time frame of an ACIAR project is required for potential benefits to be realised, it is a moot point whether this should be the responsibility of ACIAR or other aid agencies, or of the partner-country government.

Another example of the problems of recognition of uptake requirements and time frames is provided by temperate fruits. The experimental evidence for the low-chill temperate fruits is impressive, and significant prospective benefits have been estimated based on the data. However, a significant resource commitment to training and extension is required to ensure uptake. Even then, uptake will initially be by farmers who are adopting a more commercial and professional focus. For the many farmers who are not so focused, and who earn very low incomes, the initial set-up costs may be too high.

Table 23. Estimated benefits attributed to projects (present value A$ million 2007)

Project	Partner countries	Realised benefits in countries	Biosecurity	Market access postharvest	Market access non-host status	Field control with protein bait	Low-chill temperate fruit
CS2/1983/043[a]	Malaysia	Australia	43.304	0	0	IE/TE	0
CS2/1989/019[a]	Thailand Malaysia		0	0	0	IE	0
CS2/1989/020	Fiji Samoa Tonga Cook	Fiji Samoa Tonga	24.722	0.411	16.854	0	0
PHT/1990/051	Philippines Thailand	Philippines	0	33.794	0	0	0
CS2/1994/115[a]	Tonga		0	0	0	IE	0
CS2/1994/003	Vanuatu Solomon FSM		NT	0	0	0	0
PHT/1994/133	Malaysia		0	IE	0	0	0
PHT/1993/877	Vietnam Thailand		0	0	0	0	0
CS2/1996/225	PNG	Australia	0	0	0	0	0
CS2/1997/101	Bhutan		0	0	0	0	0
CP/1997/079	Vietnam Thailand		0	0	0	0	0
CP/1998/005[a]	Vietnam		0	0	0	IE	0
CP/2001/027[a]	Vietnam Thailand Laos	Vietnam	0	0	0	0	35.219
CP/2002/086	Vietnam		0	0	0	0	0
CP/2003/036	Indonesia		TE	0	0	TE	0
CP/2003/042	PNG		0	0	0	0	0
CP/2007/187[a]	Vietnam		0	0	0	IE	0
CP/2007/002	Indonesia		0	0	0	IE	0
[a] Multiple projects		Vietnam	0	0	0	104.360	0

Biosecurity benefits are another example of where potential benefits have not always been realised. While a number of Pacific island countries have obtained significant biosecurity benefits, especially given the small size of their economies, there have been little or no realised biosecurity benefits for a number of other partner countries. With the benefit of hindsight, some of the necessary preconditions for biosecurity benefits to be realised were absent in some of these countries. In particular, for a number of countries in South-East Asia, long land borders make the task of keeping out other exotic pest fruit flies very expensive at best, and impossible at worst. Furthermore, given large numbers of endemic pest fruit-fly species that infest a wide range of economically important crops and cause severe crop losses, the possible benefits of avoiding higher costs of field control from excluding other exotic pest fruit flies are minimal.

For some types of benefits, a necessary condition for potential benefits to be realised is that governments of partner countries have the financial and organisational capacity, and the commitment, to continue necessary ongoing activities. For market access benefits based on postharvest disinfestation treatments in the South Pacific, only Fiji has been able to continue to grow exports of fruit to New Zealand under sanitary and phytosanitary (SPS) protocols negotiated with assistance from the aforementioned projects, and to successfully negotiate a new market access agreement for fruit exports to Australia subsequent to completion of the Regional Management of Fruit Flies in the Pacific (RMFFP) project and complementary ACIAR projects.

Negotiating market access is a complex and difficult area for partner countries. As has been noted in this report, market access requires that the potential exporter make an application, undertake a pest risk analysis and join a long queue of applications. The process can take many years and requires considerable resources. It will be influenced by the importance that each country (exporter and importer) attaches to facilitating the particular trade. Not all countries have the requisite resources (human and financial) to manage their way through this process. The ease with which such benefits would flow, and the requirements to realise them, seem to have been generally underestimated in formulating some research projects. This issue also is a concern in terms of realising future potential benefits from capacity building that has been an impressive outcome from the fruit-fly projects.

Timeliness is another requirement for realisation of potential research benefits. Tonga is the only country that has realised substantial market access benefits based on non-host status. While other countries hope to do so in the future, the realities of negotiating access to premium-price markets are such that these aspirations are most unlikely to be realised, especially as not every importing country accepts the same evidence. Thus, while Thailand has non-host status for mangosteen to Australia, New Zealand and the USA, Taiwan and Korea have not granted non-host status. Even where non-host status might be granted, postharvest treatment usually also will be required to deal with other pests, and different postharvest treatments may be required. Moreover, conditions for gaining market access are becoming more stringent and more standardised as more countries join the WTO and technology developments are overtaking previous requirements. Because postharvest disinfestation treatment by irradiation is effective for all types of pest, and does not cause fruit damage even when applied at high levels, it is gradually being required by more countries as the cost of this treatment falls relative to the alternatives.

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Appendixes

Appendix 1. Project cost details

Table 24. Total ACIAR-only investment in fruit-fly projects (in constant 2006–07 A$)

Project	1983/043	1989/019	1989/020	1990/051	1994/115	1994/003	1994/133	1993/877	1996/225
Year									
83–84	$0	$0	$0	$0	$0	$0	$0	$0	$0
84–85	$209,214	$0	$0	$0	$0	$0	$0	$0	$0
85–86	$155,599	$0	$0	$0	$0	$0	$0	$0	$0
86–87	$210,164	$0	$0	$0	$0	$0	$0	$0	$0
87–88	$161,545	$0	$0	$0	$0	$0	$0	$0	$0
88–89	$47,141	$0	$0	$0	$0	$0	$0	$0	$0
89–90	$0	$0	$0	$0	$0	$0	$0	$0	$0
90–91	$0	$375,200	$0	$0	$0	$0	$0	$0	$0
91–92	$0	$447,655	$361,961	$515,613	$0	$0	$0	$0	$0
92–93	$0	$301,356	$234,265	$359,504	$0	$0	$0	$0	$0
93–94	$0	$263,610	$50,084	$590,105	$71,022	$0	$0	$0	$0
94–95	$0	$14,593	–$14,593	$0	$35,658	$168,730	$0	$0	$0
95–96	$0	$0	$0	$0	$96,427	$245,540	$59,966	$0	$0
96–97	$0	$0	$0	$0	$0	$90,704	$84,613	$0	$0
97–98	$0	$0	$0	$0	$0	$200,645	$0	$416,263	$0
98–99	$0	$0	$0	$0	$0	$118,622	$0	$300,610	$668,935
1999–2000	$0	$0	$0	$0	$0	$0	$0	$325,687	$560,397
00–01	$0	$0	$0	$0	$0	$0	$0	$101,447	$558,576
01–02	$0	$0	$0	$0	$0	$0	$0	$180,644	$523,554
02–03	$0	$0	$0	$0	$0	$0	$0	$0	$0
03–04	$0	$0	$0	$0	$0	$0	$0	$0	$0
04–05	$0	$0	$0	$0	$0	$0	$0	$0	$0
05–06	$0	$0	$0	$0	$0	$0	$0	$0	$0
06–07	$0	$0	$0	$0	$0	$0	$0	$0	$0
07–08	$0	$0	$0	$0	$0	$0	$0	$0	$0
08–09	$0	$0	$0	$0	$0	$0	$0	$0	$0

Table 24. (continued)

Project	1997/079	1997/101	1998/005	2001/027	2002/086	2003/036	2003/042	2007/187	2007/002
Year									
83–84	$0	$0	$0	$0	$0	$0	$0	$0	$0
84–85	$0	$0	$0	$0	$0	$0	$0	$0	$0
85–86	$0	$0	$0	$0	$0	$0	$0	$0	$0
86–87	$0	$0	$0	$0	$0	$0	$0	$0	$0
87–88	$0	$0	$0	$0	$0	$0	$0	$0	$0
88–89	$0	$0	$0	$0	$0	$0	$0	$0	$0
89–90	$0	$0	$0	$0	$0	$0	$0	$0	$0
90–91	$0	$0	$0	$0	$0	$0	$0	$0	$0
91–92	$0	$0	$0	$0	$0	$0	$0	$0	$0
92–93	$0	$0	$0	$0	$0	$0	$0	$0	$0
93–94	$0	$0	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$0	$0	$0	$0	$0	$0	$0
95–96	$0	$0	$0	$0	$0	$0	$0	$0	$0
96–97	$0	$0	$0	$0	$0	$0	$0	$0	$0
97–98	$0	$0	$0	$0	$0	$0	$0	$0	$0
98–99	$0	$0	$0	$0	$0	$0	$0	$0	$0
1999–2000	$0	$106,128	$0	$0	$0	$0	$0	$0	$0
00–01	$25,267	$64,257	$0	$0	$0	$0	$0	$0	$0
01–02	$262,891	$81,417	$188,074	$199,565	$0	$0	$0	$0	$0
02–03	$228,726	$51,932	$179,943	$137,505	$0	$0	$0	$0	$0
03–04	$253,968	$34,289	$168,549	$121,682	$0	$0	$0	$0	$0
04–05	$52,679	$21,951	$161,833	$123,958	$268,903	$337,526	$0	$0	$0
05–06	$0	$0	$51,785	$103,327	$234,090	$358,470	$86,952	$0	$0
06–07	$0	$0	$148,240	$86,773	$212,926	$277,412	$254,529	$80,000	$46,910
07–08	$0	$0	$50,689	$0	$125,674	$255,917	$227,895	$38,835	$2,913
08–09	$0	$0	$0	$0	$89,645	$85,926	$158,071	$0	$0

Table 25. Total investment by ACIAR and its partners in fruit-fly projects (in constant 2006–2007 A$)

Project	1983/043	1989/019	1989/020	1990/051	1994/115	1994/003	1994/133	1993/877	1996/225
Year									
82–83	$0	$0	$0	$0	$0	$0	$0	$0	$0
83–84	$0	$0	$0	$0	$0	$0	$0	$0	$0
84–85	$209,214	$0	$0	$0	$0	$0	$0	$0	$0
85–86	$155,599	$0	$0	$0	$0	$0	$0	$0	$0
86–87	$210,164	$0	$0	$0	$0	$0	$0	$0	$0
87–88	$161,545	$0	$0	$0	$0	$0	$0	$0	$0
88–89	$47,141	$0	$0	$0	$0	$0	$0	$0	$0
89–90	$0	$0	$0	$0	$0	$0	$0	$0	$0
90–91	$0	$522,314	$520,104	$0	$0	$0	$0	$0	$0
91–92	$0	$591,908	$956,337	$1,387,532	$0	$0	$0	$0	$0
92–93	$0	$413,381	$821,303	$996,465	$0	$0	$0	$0	$0
93–94	$0	$263,610	$101,978	$1,207,352	$71,022	$0	$0	$0	$0
94–95	$0	$14,593	–$14,593	$0	$35,658	$235,044	$0	$0	$0
95–96	$0	$0	$0	$0	$96,427	$374,875	$59,966	$0	$0
96–97	$0	$0	$0	$0	$0	$154,455	$84,613	$0	$0
97–98	$0	$0	$0	$0	$0	$200,645	$0	$778,470	$0
98–99	$0	$0	$0	$0	$0	$118,622	$0	$846,567	$1,096,648
1999–2000	$0	$0	$0	$0	$0	$0	$0	$843,178	$978,547
00–01	$0	$0	$0	$0	$0	$0	$0	$305,197	$956,932
01–02	$0	$0	$0	$0	$0	$0	$0	$180,644	$910,908
02–03	$0	$0	$0	$0	$0	$0	$0	$0	$0
03–04	$0	$0	$0	$0	$0	$0	$0	$0	$0
04–05	$0	$0	$0	$0	$0	$0	$0	$0	$0
05–06	$0	$0	$0	$0	$0	$0	$0	$0	$0
06–07	$0	$0	$0	$0	$0	$0	$0	$0	$0
07–08	$0	$0	$0	$0	$0	$0	$0	$0	$0
08–09	$0	$0	$0	$0	$0	$0	$0	$0	$0

Table 25. (continued)

Project	1997/079	1997/101	1998/005	2001/027	2002/086	2003/036	2003/042	2007/187	2007/002
Year									
82–83	$0	$0	$0	$0	$0	$0	$0	$0	$0
83–84	$0	$0	$0	$0	$0	$0	$0	$0	$0
84–85	$0	$0	$0	$0	$0	$0	$0	$0	$0
85–86	$0	$0	$0	$0	$0	$0	$0	$0	$0
86–87	$0	$0	$0	$0	$0	$0	$0	$0	$0
87–88	$0	$0	$0	$0	$0	$0	$0	$0	$0
88–89	$0	$0	$0	$0	$0	$0	$0	$0	$0
89–90	$0	$0	$0	$0	$0	$0	$0	$0	$0
90–91	$0	$0	$0	$0	$0	$0	$0	$0	$0
91–92	$0	$0	$0	$0	$0	$0	$0	$0	$0
92–93	$0	$0	$0	$0	$0	$0	$0	$0	$0
93–94	$0	$0	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$0	$0	$0	$0	$0	$0	$0
95–96	$0	$0	$0	$0	$0	$0	$0	$0	$0
96–97	$0	$0	$0	$0	$0	$0	$0	$0	$0
97–98	$0	$0	$0	$0	$0	$0	$0	$0	$0
98–99	$0	$30,598	$0	$0	$0	$0	$0	$0	$0
1999–2000	$0	$165,957	$0	$0	$0	$0	$0	$0	$0
00–01	$25,267	$92,756	$0	$0	$0	$0	$0	$0	$0
01–02	$405,211	$81,417	$1,043,078	$900,842	$0	$0	$0	$0	$0
02–03	$373,177	$51,932	$873,604	$822,235	$0	$0	$0	$0	$0
03–04	$398,740	$34,289	$556,937	$786,976	$0	$0	$0	$0	$0
04–05	$52,679	$21,951	$534,750	$235,212	$409,364	$1,310,920	$0	$0	$0
05–06	$0	$0	$164,808	$209,464	$368,090	$1,285,957	$111,294	$0	$0
06–07	$0	$0	$364,140	$188,145	$340,908	$1,163,264	$302,027	$161,000	$54,160
07–08	$0	$0	$155,495	$0	$218,644	$1,115,967	$274,011	$107,767	$2,913
08–09	$0	$0	$0	$0	$149,175	$461,010	$180,457	$0	$0

Appendix 2. Australia case study

Market access for heat treated mango exports to Japan

The benefits attributable to ACIAR project PHT/1990/051 from providing necessary inputs for Australia to negotiate access for exports of Australian mango to the premium priced Japanese market have been estimated previously by Monck and Pearce (2007) in their assessment of ACIAR project PHT/1990/051. Table 26 shows the data on exports to Japan, exports to the rest of the world, and prices in Japan and the rest of the world for mango exports from Australia taken from Monck and Pearce (2007). The estimation of benefits is based on this data and the price premiums, shown in the tables, derived them. The benefits estimates are modified slightly from Monck and Pearce and are based on the logic of Figure 5: Producer gains from achieving market access to a restricted market.

Estimated benefits

The benefits derived are based on the price premium achievable in the Japanese market and are shown in Table 27. Benefits are estimated by applying the estimated price premium to the existing and projected exports to Japan.

The project was neither a necessary nor sufficient condition for market access. The project essentially ended at the research stage having provided heat treatment findings. It did not extend to the process of getting treatment schedules accepted in Japan for quarantine purposes for Thailand and the Philippines. Neither did it get involved in setting up commercial treatment equipment.

According to Monck and Pearce (2007), there was involvement in negotiating market access for Australian mangoes into Japan. This makes a higher attribution justified. Attribution starts at 80%. Following Monck and Pearce (2007) attribution is declining and modelled using the formula, $\Omega=0.8-0.8/(1+EXP(0.4*(17-t)))$ where *EXP* is the natural exponent and t is indexed from one to 28. Attributable benefits in 2006–07 values are A$62,754 in 1993–94 and decline to A$2,072 in 2019–20.

Cost saving in eradication of *B. papayae*

For the details of the estimation of these benefits, see above and McLeod (1998).

Accelerated market access based on postharvest disinfestation of mango after eradication of *B. papayae*

Project PHT/1994/133 commenced in Malaysia in January 1995 and in the first year established a breeding colony of *B. papayae* in Malaysia, and the scientific methods necessary to generate data needed to establish disinfestation schedules. Following the discovery of the incursion of *B. papayae* into North Queensland, market access to Japan was withdrawn in October1995 for Australian mango exports sourced inside the quarantine area. Due to the prior work by ACIAR project PHT/1994/133 in Malaysia, Queensland's Department of Primary Industries was able to generate postharvest treatment protocols for *B. papayae* in Australian mangoes and other tropical fruit in a much shorter

Table 26. Export volume and price premium for mango export from Australia to Japan

Australia to Japan						
Year	**Domestic sales (tonnes)**	**Exports to other markets (tonnes)**	**Exports to Japan (tonnes)**	**Price for other markets ($ per tonne)**	**Price for sales to Japan ($ per tonne)**	**Price Premium**
1994	21,475	2,623	115	$2,404	$3,038	$634
1995	34,562	3,064	91	$2,414	$3,051	$637
1996	24,691	2,952	75	$2,654	$3,355	$701
1997	27,797	4,398	207	$2,120	$2,680	$560
1998	32,772	3,602	193	$2,179	$2,754	$575
1999	23,586	2,640	146	$2,485	$3,141	$656
2000	34,646	3,124	301	$2,073	$2,620	$547
2001	33,726	3,354	318	$2,420	$3,059	$639
2002	36,906	3,737	330	$2,356	$2,979	$623
2003	35,889	2,711	370	$2,087	$2,638	$551
2004	34,405	2,289	475	$2,270	$2,869	$599
2005	35,859	2,325	483	$2,207	$2,805	$598
2006	37,372	2,362	490	$2,145	$2,722	$577
2007	38,947	2,400	498	$2,086	$2,641	$555
2008	40,587	2,438	506	$2,028	$2,562	$534
2009	42,294	2,477	514	$1,971	$2,484	$513
2010	44,071	2,516	522	$1,917	$2,409	$492
2011	45,920	2,556	531	$1,863	$2,334	$471
2012	47,845	2,597	539	$1,811	$2,261	$450
2013	49,850	2,638	548	$1,761	$2,189	$428
2014	51,936	2,680	556	$1,712	$2,116	$404
2015	54,107	2,723	565	$1,665	$2,043	$378
2016	56,367	2,766	574	$1,618	$1,969	$351
2017	58,719	2,810	583	$1,573	$1,894	$321
2018	61,168	2,855	593	$1,529	$1,817	$288
2019	63,716	2,901	602	$1,487	$1,740	$253
2020	66,369	2,947	612	$1,446	$1,665	$219
2021	69,129	2,994	621	$1,405	$1,593	$188
2022	72,003	3,041	631	$1,366	$1,527	$161
2023	74,993	3,090	641	$1,328	$1,467	$139
2024	78,105	3,139	651	$1,291	$1,414	$123

Table 27. Attributable net benefits from Australian mango exports to Japan

Year	With R&D Australian mango exports to Japan		
	Net surplus	**Attribution to ACIAR Projects**	**Attributed to ACIAR projects**
93–94	$78,348	0.80	$62,574
94–95	$62,291	0.80	$49,709
95–96	$56,496	0.80	$45,031
96–97	$124,566	0.80	$99,106
97–98	$119,252	0.79	$94,623
98–99	$102,920	0.79	$81,337
1999–2000	$176,927	0.79	$138,996
00–01	$218,358	0.78	$170,040
01–02	$220,924	0.77	$169,817
02–03	$219,076	0.75	$165,214
03–04	$305,746	0.73	$224,253
04–05	$310,377	0.70	$218,703
05–06	$303,818	0.67	$202,225
06–07	$297,005	0.61	$182,604
07–08	$290,357	0.55	$160,271
08–09	$283,349	0.48	$135,710
09–10	$275,979	0.40	$110,392
10–11	$268,755	0.32	$86,284
11–12	$260,641	0.25	$64,644
12–13	$252,038	0.19	$46,672
13–14	$241,378	0.13	$32,438
14–15	$229,499	0.10	$21,886
15–16	$216,501	0.07	$14,406
16–17	$201,101	0.05	$9,222
17–18	$183,522	0.03	$5,750
18–19	$163,666	0.02	$3,482
19–20	$144,025	0.01	$2,072
20–21	$2,509,114	0.01	$24,345
Present value			
Total	**$6,490,934**		**$2,903,250**
Realised	**$3,141,105**		**$2,332,710**
Prospective	**$3,349,828**		**$570,540**

Note that the value for 2020–21 is the capitalised value for all future benefits as recommended in the ACIAR impact assessment guidelines by Gordon and Davis (2007).

time than normally required. As a result, approval to restart exports was granted in December 1996, which the scientists involved estimated was at least six months sooner than would have been possible without this background knowledge. In 1997 Australia exported 207 tonnes of mangoes to Japan with a cost, insurance and freight (CIF) value of A$1.366 million. Presumably, if ACIAR had not funded PHT/1994/133, fewer mangoes would have been exported to Japan in 1997. No attempt has been made to separately estimate the size of this benefit because it is included as part of the benefits estimated in Section 3 of this report.

Biosecurity due to avoided loss from re-entry of *B. papayae*

Australia now has a highly conservative approach to quarantine risk management that entails applying such quarantine surveillance measures as are necessary to reduce the restricted risk of entry of exotic pest fruit fly to very low levels. After the debacle of the incursion of papaya fruit fly in 1995, Australia established the North Australian Quarantine Surveillance (NAQS) program as the primary quarantine surveillance system for protecting Australia from an incursion by an exotic pest fruit fly.

This program focuses on pests and diseases with the potential to enter Australia via the Australian northern border by assisted or unassisted natural or non-conventional pathways. Fruit flies are included on the NAQS target lists of exotic insect pests that are considered serious threats to Australia's agricultural productivity, export markets or the environment. For inclusion on these targeted pest lists, pests are considered to have a substantial probability of entry in northern Australia, a significant probability of establishment, a considerable likelihood of spread after establishment, into and beyond northern Australia, and the potential to cause significant adverse impact to agriculture, the environment, and/or the Australian public. There are 18 fruit-fly species on the NAQS targeted pest lists. In the National Tropical Fruit Industry Biosecurity Plan, Plant Health Australia (2006) identifies the following fruit flies are as being high-priority threats to the industry:

- Carambola fruit fly *Bactrocera carambolae*
- Melon fly *Bactrocera cucurbitae*
- Oriental fruit fly *Bactrocera dorsalis*
- *Bactrocera occipitalis*
- Papaya fruit fly *Bactrocera papayae*
- Fiji fruit fly *Bactrocera passiflorae*
- Philippine fruit fly *Bactrocera philippinensis*
- New Guinea fruit fly *Bactrocera trivialis*
- Guava fruit fly, peach fruit fly *Bactrocera zonata*

For all except *B. passiflorae* and *B. zonata*, the potential unrestricted risk of entry has been assessed as high, and all have been assessed as having a high establishment potential, high spread potential, and high potential economic impact. It is clear from several recorded instances of fruit-fly entry into Australia that even with all the current quarantine surveillance measures, and with the benefit of greater knowledge about fruit-fly biology and movement in Papua New Guinea and the Torres Strait generated in particular by the International Centre for Management of Pest Fruit Flies-led ACIAR project CS2/1996/225, the restricted risk of entry is low to very low rather than extremely low or negligible.

In meetings with representatives from several Australian government agencies with responsibility for quarantine, biosecurity and plant health, there was consensus that due to knowledge from the ACIAR projects about fruit-fly taxonomy, ecology and movement patterns, NAQS was, and continues to be, more effective than it would be otherwise. However, it was only possible to elicit qualitative rather than quantitative estimates of the reduction in risk that could be attributed to such knowledge. A range of other experts were consulted, but it proved impossible to obtain any quantitative estimates of risk reduction, so no formal estimates of this biosecurity benefit have been made in this study because of the speculative nature of the information on which it would have had to be based.

Nevertheless, the following reasoning suggests that it could be significant. Since the incursion of papaya fruit fly into Queensland in 1995, Australia's quarantine surveillance system has been strengthened, and it is not plausible to suggest that any future entry of an exotic pest fruit fly would ever again go undetected for such a long period of time. A more likely scenario would be an incursion equivalent to the entry of *B. philippinensis* into the Darwin area in1997, which cost A$5 million in direct costs to eradicate, and possibly as much as A$20 million in total after fully accounting for all costs to growers and the general population. Even with the much enhanced quarantine surveillance system now in place, the risk of such an incursion in future years is arguably of the order of one in 30 given the record of entries in recent years. If the risk is higher for the counterfactual scenario, say one in 20, then the annual biosecurity benefit to Australia could be as large as A$333,000, and the PV could be greater than A$6 million. However, plausible arguments could be made for both smaller and larger values, and given the reluctance of knowledgeable persons to make quantitative estimates of key parameters, it was not possible to make a credible estimate.

Estimated benefits

The estimated benefits are shown in Table 28. They are all realised benefits.

Table 28. Attributable Australian biosecurity net benefits (A$ 2007)

Year	Attributed to ACIAR
95–96	$7,801,176
96–97	$7,137,410
97–98	$6,359,161
98–99	$7,037,649
1999–2000	$169,081

Appendix 3. Bhutan

Bhutan does not have an effective quarantine surveillance system, so no biosecurity benefits were estimated. Project outputs also did not enable Bhutan to gain access to new markets, so no market access benefits were estimated. Potentially there may be field control in mandarin production in Bhutan but, because attempts to find tangible evidence of uptake of project outputs were not successful, no attempt was made to estimate any benefits. However, there is some follow-up work on field control embedded in a subsequent ACIAR project that might result in uptake of outputs from project CS2/1997/101.

There have been some capacity-building activities associated with CS2/1997/101. Within the project, staff in Bhutan and Australia have been trained in the identification of *B. minax*. This fruit fly is a devastating pest in the mandarin industry. As a result of the project there are staff in Bhutan who are now able to advise growers on control programs for *B. minax*.

Appendix 4. Cook Islands case study

The only two pest species of economic importance in Cook Islands are *B. melanotus* and *B. xanthodes*. Host fruits prone to infestation include papaya and avocado but damage levels are only moderate (e.g. papaya—12.4% when ripe, and avocado—< 2% at mature green stage); while cucurbits are free from fruit-fly infestation.

No tangible evidence was found of uptake of project outputs to enable field control of fruit flies in Cook Islands, so no attempt was made to estimate any field control benefits.

Market access

Cook Islands negotiated a bilateral quarantine arrangement (BQA) with New Zealand based on high temperature forced air (HTFA) protocols for export of papaya and mango, and for 'birds eye' chilli, smooth cayenne pineapples and zucchini based on non-host protocols.

The only fruit exports based on HTFA postharvest treatment from Cook Islands to New Zealand of any significance have been papayas. Cook Islands commenced postharvest disinfestation treatment of papaya exports to New Zealand using HTFA in 1994. As can be seen from Figure 22, by the latest year of available data in 2005 these exports had declined to levels where future viability would be very marginal.

Hence, no projections of continued papaya exports beyond 2006–07 have been made. While Cook Islands has exported small amounts of mangoes since 1997, and eggplants since 1999, these exports have not been sustained for more than a few years, and were not estimated as part of the market access benefits.

Between 2000 and 2005, small and fluctuating volumes of green chillies and peppers also were exported from Cook Islands on the basis of non-host sanitary and phytosanitary (SPS) protocols with New Zealand. Realised benefits for actual exports over this period have been estimated, and prospective benefits from predicted small volumes of future exports also were estimated.

Biosecurity benefits—actual cost savings of eradicating *B. tyroni* in 2001–02

From 1998 the early-warning quarantine surveillance system set up as part of project CS2/1989/020 consisted of 15 cuelure and 15 methyl eugenol traps in regularly monitored trapping sites supplemented by regular host fruit surveys that sampled breadfruit, guava, mango and papaya. The trapping sites were located in high-risk locations such as tourist resorts, urban areas, educational institutions for overseas students, markets, farming areas, diplomatic missions and ports of entry. Trapping and host fruit survey data were compiled on Microsoft Excel spreadsheets.

The biosecurity value of this early-warning quarantine surveillance system was demonstrated in November 2001 when Queensland fruit fly (QFF) (*Bactrocera tryoni*) was detected in Cook Islands. *B. tryoni* is a polyphagous pest species that can infest all commercial crops of fresh fruit and leafy vegetables hosts. Furthermore, because it also infests many 'wild' fruits, it can be difficult to eradicate. Furthermore, if eradication of this incursion were unsuccessful *B. tryoni* would become endemic in Cook Islands, and provide an easier doorway for its introduction to the other Pacific island countries.

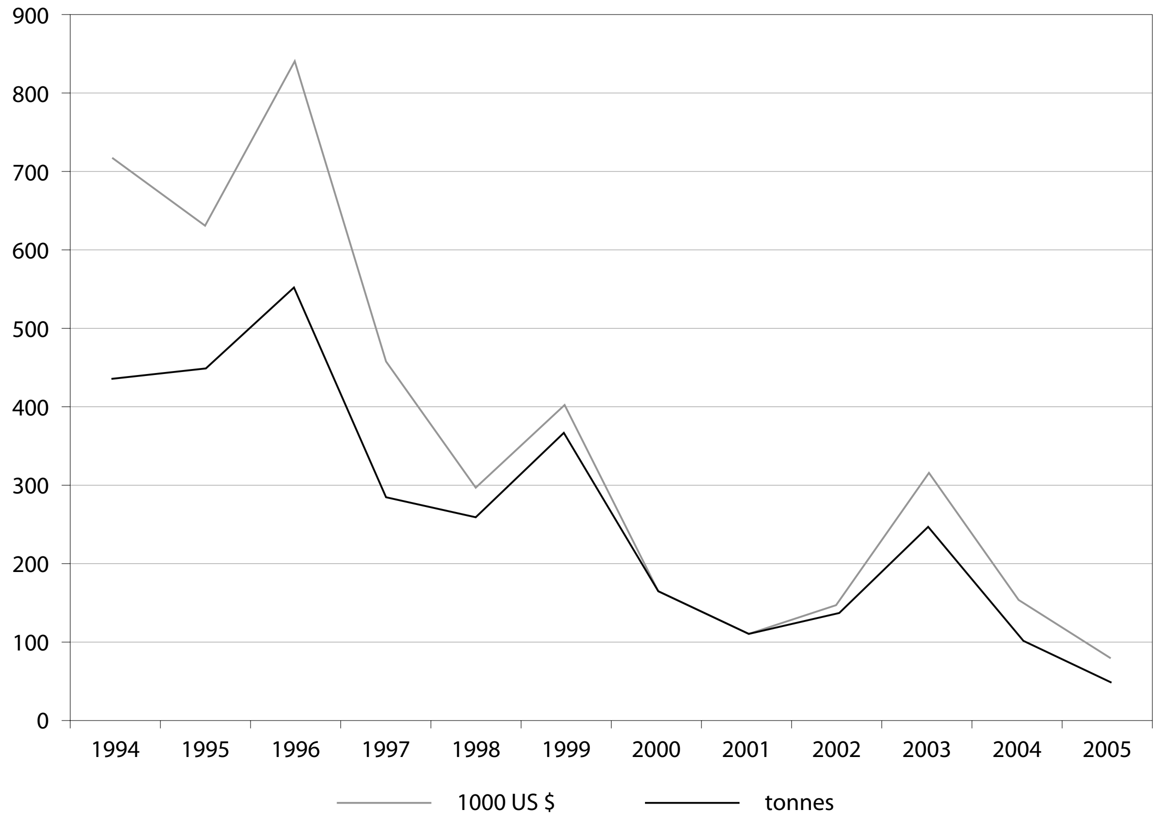

Figure 22. Papaya exports to New Zealand. Source: Food and Agriculture Organization of the United Nations (FAOSTAT) 2008.

This detection of *B. tryoni* was the first record of the species in Cook Islands, and prompted a rapid emergency response, including inter alia, new technologies such as the distribution of fruit-fly stations (BactroMAT/ Amulet C-L fruit fly stations) from a microlight aircraft over a mountain area of approximately 1.8 km^2. The last fly was trapped in February 2002, but trapping and suppression measures were continued until October, although at a scaled back level for the last six months. The fruit-fly eradication program was declared a success in late 2002. This outcome would not have been possible without training in eradication techniques provided to staff as part of the ACIAR/ Regional Management of Fruit Flies in the Pacific (RMFFP) projects, and prior development of an ERP by those staff (<http://www.spc.int/pacifly/Country_profiles/Cook_Is.htm>. Accessed 10 January 2008).

Other costs, such as loss of domestic fruit production, were negligible.

Prospective biosecurity benefits—entry of *B. papayae*

As of November 2006 the early-warning quarantine surveillance system set up as part of project CS2/1989/020 still consisted of 21 regularly monitored trapping sites, supplemented by regular host fruit surveys that sampled breadfruit, guava, mango, papaya and Syzygium apples. Because Cook Islands has only two pest fruit-fly species of economic importance, there are a large number of exotic pest fruit flies that potentially could invade and become established.

'With R&D' scenario

This scenario is based on the following facts or informed judgments:

- Realised market access benefits to the economy of Cook Islands from export of papaya to New Zealand from 1994 to 2005 inclusive was estimated to be 10% of the gross value of these exports. Extrapolating from the trend of recent years, even smaller volumes of HTFA-treated fruit were projected to be exported in 2005–06 and 2006–07, and then to cease from then on.
- Realised market access benefits to the economy of Cook Islands from export of chillies to New Zealand from 1999 to 2005 inclusive was estimated to be 10% of the gross value of these exports. Chillies do not require HTFA treatment because New Zealand accepts that they are not a fruit-fly host in Cook Islands. Small volumes of chillies were projected to continue indefinitely at an annual value of 2007 A$6,200.
- The incursion of *B. tryoni* in 2001 was detected by the effective quarantine surveillance system shortly after entry to Cook Islands, and before it had the opportunity to become established.
- An emergency response plan for containment and eradication of the QFF, including male annihilation, spot protein bait treatment, waste fruit destruction, fruit movement control and a public awareness campaign, was implemented shortly after detection of the entry.
- The maximum area treated was 8 km^2, and a total of less than 7,500 BactroMAT C-L bait stations were applied in four campaigns, plus about 28 protein bait application treatments done weekly used about 2,500 litres of bait. These are less than 0.5% of estimated requirements for Palau eradication.
- Based on Economic Research Associates' calculations using information from McGregor (2000), total estimated costs in 2007 A$ were $349,823, comprising $299,823 for the eradication campaign, and A$50,000 for quarantine surveillance in 2001.
- Fruit exports were not suspended because of evidence from trapping records that a breeding population did not become established.
- There was no measurable loss of production for domestic consumption because the incursion did not become established.
- Benefits were attributed 50:50 between ACIAR and RMFFP.
- Cook Islands maintained an effective quarantine surveillance system after cessation of the RMFFP project in 2000 at an annual cost of 2007 A$50,000 pa.
- While there is a 5% probability of entry by *B. papayae* without immediate detection and destruction in any future year, due to effective quarantine surveillance, the conditional probability that the entry will become established and go undetected by quarantine surveillance trapping until completion of the third generation of the breeding population is 50%. By this time, the incursion is predicted to occupy about 5 km^2. Hence, there is a joint probability of 2.5% of the need for a 'small' eradication program lasting less than 1 year.
- An emergency response plan involving a minor eradication campaign as described in the scenario above would be implemented immediately.
- The basis for estimating costs of this campaign is the same as for the actual campaign in 2001–2002. Total estimated costs in 2007 A$ were $299,823.
- At worst, exports of chillies to New Zealand would be suspended for only a few months. However, it was assessed that there would be no loss of exports.
- There would be an almost negligible loss of production for domestic consumption because the incursion would occupy less than 1 % of the area of Cook Islands. Hence, it was assessed to be less than 0.05% of the value of subsistence and commercial fresh fruit and leafy vegetables production for only the first year of the incursion.

- It is possible for further incursions to occur after a successful eradication campaign, in which case a further cycle of eradication costs and export and production losses would follow.

Table 29 sets out the annual estimates[1] for the 'with R&D' scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a small eradication program plus annual quarantine surveillance costs.

'Without R&D' scenario

This scenario is based on the following facts or informed judgments:

- The market access benefits to Cook Islands from fruit exports to New Zealand would not have happened without the ACIAR projects.
- Cook Islands did not have staff trained to identify exotic pest fruit flies, nor an emergency response plan, nor necessary expertise in fruit-fly eradication to mount an effective campaign at short notice.
- As a result, the entry of *B. tryoni* in 2001 was not detected until it was widely established on several islands. Further delays in training staff, etc., meant that the incursion occupied half of the total land area of Cook Islands by the time the eradication campaign started.
- A large eradication campaign lasting 2 years was carried out using a combination of male annihilation (MA) and spot protein bait treatment. The budget for this eradication campaign in Table 30 is based on estimates by McGregor (2000) of the cost to eradicate Oriental fruit fly (*B. dorsalis*) and breadfruit fly (*B. umbrosa*) from the Republic of Palau, which has a land area about double that of Cook Islands
- Total estimated costs in 2007 A$ would have been $1,909,643 comprising $1,213,842 for the first year, and $695,801 for the second year.
- All exports of papaya were suspended for the 2-year duration of the eradication campaign. In 2007 A$, lost sales were $251,574 in 2001–02, and $299,742 in 2002–03. Most of this would be lost value added because fixed costs would have been incurred, and land and labour have a low opportunity cost in Cook Islands. Nevertheless, because of the lack of objective information on actual values, it was conservatively estimated that only 10% of lost export value was lost value added.
- The overall value of subsistence and commercial fresh fruit and leafy vegetables production in Cook Islands was estimated to be A$4.96 million in constant 2007 dollars. This estimate was derived from a study by McGregor (1999) who calculated that domestic fruit production in the Fiji was then valued at about US$33 million. By 2006–07, this value was calculated to have increased to $65.2 million in constant 2007 Australian dollars due to growth in population and income per head, or about A$78.28 per head. Given the similarities in culture and climate, this latter value was multiplied by the population of Cook Islands to obtain the above estimate.
- Once widely established, the fruit-fly infestation incursion would have caused considerable damage. However, people would gradually learn to mitigate the value of losses, so it was assessed that only 10% of the overall value of subsistence and commercial fresh fruit and leafy vegetables production would be lost for the first year of the eradication campaign, but would be negligible in earlier years as the incursion became established, as well as afterwards because the eradication program would suppress the fruit-fly population.
- Without an efficient early-warning quarantine surveillance system, there is a 4.5% probability that an entry of *B. papayae* would not be detected for more than 12 months after entry, by which time it would be widely established throughout Cook Islands and occupy half of the total land area of Cook Islands by the time an eradication campaign started.

[1] Note that the value for 2020–21 is the capitalised value for all future benefits as recommended in the ACIAR impact assessment guidelines by Gordon and Davis (2007).

Table 29. Benefits for Cook Islands 'with R&D' scenario

Year	Fruit exports				Small incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$147,412	−$3,685	$0	$0	$0	$0	$0
94–95	$119,790	−$2,995	$0	$0	−$0	−$7,496	−$50,000
95–96	$151,588	−$3,790	$0	$0	−$0	−$7,496	−$50,000
96–97	$79,332	−$1,983	$0	$0	−$0	−$7,496	−$50,000
97–98	$58,319	−$1,458	$0	$0	−$0	−$7,496	−$50,000
98–99	$86,463	−$2,162	$0	$0	−$0	−$7,496	−$50,000
1999–2000	$34,542	−$864	$1,486	−$37	−$0	−$7,496	−$50,000
00–01	$25,874	−$647	$625	−$16	−$0	−$7,496	−$50,000
01–02	$34,456	−$861	$411	−$10	−$0	−$299,823	−$50,000
02–03	$63,941	−$1,599	$1,249	−$31	−$0	−$7,496	−$50,000
03–04	$25,135	−$628	$1,287	−$32	−$0	−$7,496	−$50,000
04–05	$12,073	−$302	$260	−$7	−$0	−$7,496	−$50,000
05–06	$4,620	−$116	$620	−$16	−$0	−$7,496	−$50,000
06–07	$1,620	−$41	$620	−$16	−$0	−$7,496	−$50,000
07–08	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
08–09	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
09–10	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
10–11	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
11–12	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
12–13	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
13–14	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
14–15	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
15–16	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
16–17	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
17–18	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
18–19	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
19–20	$0	$0	$620	−$16	−$0	−$7,496	−$50,000
20–21	$0	$0	$12,400	−$310	−$0	−$149,912	−$1,000,000

Table 30. Cost estimates of large eradication program on Cook Islands in US$

Item	yr1	yr2	total
Human resource	198,852	177,108	375,959
Equipment and supplies	62,887	8,948	71,835
Sub-contracts	18,642	11,185	29,828
Training	23,091	9,140	32,232
Publications and public relations	45,290	4,621	49,911
Communications	6,789	6,789	13,577
Transport	4,536	3,293	7,830
Utilities	4,243	4,243	8,486
Helicopter	78,422	28,212	106,635
Attractants and chemicals	58,880	19,520	78,400
Contingencies	33,943	33,943	67,885
Total	535,575	307,003	842,578
AUD:USD	0.532	0.532	0.532
Deflator 2001–02 to 2006–07	0.830	0.830	0.830
Total costs (2007 AU$)	1,213,842	695,801	1,909,643

Source. Economic Research Associates' calculations using information from McGregor (2000) on budgeted cost for fruit-fly eradication program on Palau.

- As described above, total estimated costs in 2007 A$ of a large eradication campaign would be $1,909,643 comprising $1,213,842 for the first year, and $695,801 for the second year.
- It was assessed that the lost value of subsistence and commercial fruit production would be 10% of the overall value of A$4.96 million in constant 2007 Australian dollars in only 1 year.
- It is possible for further incursions to occur after a campaign has successfully eradicated *B. papayae* from Cook Islands, in which case a further cycle of eradication costs and production losses would follow.

Table 31 sets out annual estimates for the 'without R&D' scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a large eradication program plus annual quarantine surveillance costs.

Estimated benefits

Estimates of the annual value of total benefits of the ACIAR and related fruit-fly projects together with the proportion of these calculated values that could reasonably attributed to the ACIAR projects are shown in Table 32. The values of benefits actually attributed to the ACIAR fruit-fly projects are shown in Table 33.

Many of the core building blocks for the quarantine surveillance systems established in Cook Islands, and elsewhere in the South Pacific, were outputs from ACIAR projects CS2/1989/020 and CS2/1994/003. For instance, some of the key outputs from the ACIAR projects were the necessary knowledge to establish effective border quarantine surveillance procedures for early detection of entry of exotic pest fruit flies, and training partner-country personnel in fruit-fly identification, and trapping and survey methods. These were critical, necessary inputs to enable potential biosecurity

Table 31. Benefits for Cook Islands 'without R&D' scenario

Year	Fruit exports				Large incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$0	$0	–$22,340	–$54,623	$0
95–96	$0	$0	$0	$0	–$22,340	–$84,525	$0
96–97	$0	$0	$0	$0	–$22,340	–$84,525	$0
97–98	$0	$0	$0	$0	–$22,340	–$84,525	$0
98–99	$0	$0	$0	$0	–$22,340	–$84,525	$0
1999–2000	$0	$0	$0	$0	–$22,340	–$84,525	$0
00–01	$0	$0	$0	$0	–$22,340	–$84,525	$0
01–02	$0	$0	$0	$0	–$496,443	–$1,213,842	$0
02–03	$0	$0	$0	$0	–$22,340	–$695,801	$0
03–04	$0	$0	$0	$0	–$22,340	–$84,525	$0
04–05	$0	$0	$0	$0	–$22,340	–$84,525	$0
05–06	$0	$0	$0	$0	–$22,340	–$84,525	$0
06–07	$0	$0	$0	$0	–$22,340	–$84,525	$0
07–08	$0	$0	$0	$0	–$22,340	–$84,525	$0
08–09	$0	$0	$0	$0	–$22,340	–$84,525	$0
09–10	$0	$0	$0	$0	–$22,340	–$84,525	$0
10–11	$0	$0	$0	$0	–$22,340	–$84,525	$0
11–12	$0	$0	$0	$0	–$22,340	–$84,525	$0
12–13	$0	$0	$0	$0	–$22,340	–$84,525	$0
13–14	$0	$0	$0	$0	–$22,340	–$84,525	$0
14–15	$0	$0	$0	$0	–$22,340	–$84,525	$0
15–16	$0	$0	$0	$0	–$22,340	–$84,525	$0
16–17	$0	$0	$0	$0	–$22,340	–$84,525	$0
17–18	$0	$0	$0	$0	–$22,340	–$84,525	$0
18–19	$0	$0	$0	$0	–$22,340	–$84,525	$0
19–20	$0	$0	$0	$0	–$22,340	–$84,525	$0
20–21	$0	$0	$0	$0	–$446,799	–$1,690,498	$0

Table 32. Annual value of total net benefits for Cook Islands and attribution ratios

Year	Market access benefits				Biosecurity benefits		Total benefit
	HTFA exports	Attribution to ACIAR projects	Non-host exports	Attribution to ACIAR projects	Biosecurity benefit	Attribution to ACIAR projects	Attributed to ACIAR projects
93–94	$143,727	0.05	$0	0.50	$0	0.50	$7,186
94–95	$116,795	0.05	$0	0.50	$19,467	0.50	$15,573
95–96	$147,798	0.05	$0	0.50	$49,369	0.50	$32,075
96–97	$77,348	0.05	$0	0.50	$49,369	0.50	$28,552
97–98	$56,861	0.05	$0	0.50	$49,369	0.50	$27,528
98–99	$84,302	0.05	$0	0.49	$49,369	0.50	$28,900
1999–2000	$33,679	0.05	$1,449	0.49	$49,369	0.50	$27,080
00–01	$25,227	0.05	$609	0.49	$49,369	0.50	$26,242
01–02	$33,594	0.05	$401	0.48	$1,360,462	0.50	$682,103
02–03	$62,343	0.05	$1,218	0.47	$660,645	0.50	$334,014
03–04	$24,507	0.05	$1,255	0.46	$49,369	0.50	$26,485
04–05	$11,771	0.05	$254	0.44	$49,369	0.50	$25,385
05–06	$4,505	0.05	$605	0.42	$49,369	0.50	$25,161
06–07	$1,580	0.05	$605	0.38	$49,369	0.50	$24,996
07–08	$0	0.05	$605	0.34	$49,369	0.50	$24,893
08–09	$0	0.05	$605	0.30	$49,369	0.50	$24,866
09–10	$0	0.05	$605	0.25	$49,369	0.50	$24,836
10–11	$0	0.05	$605	0.20	$49,369	0.50	$24,806
11–12	$0	0.05	$605	0.16	$49,369	0.50	$24,778
12–13	$0	0.05	$605	0.12	$49,369	0.50	$24,755
13–14	$0	0.05	$605	0.08	$49,369	0.50	$24,735
14–15	$0	0.05	$605	0.06	$49,369	0.50	$24,721
15–16	$0	0.05	$605	0.04	$49,369	0.50	$24,710
16–17	$0	0.05	$605	0.03	$49,369	0.50	$24,702
17–18	$0	0.05	$605	0.02	$49,369	0.50	$24,696
18–19	$0	0.05	$605	0.01	$49,369	0.50	$24,693
19–20	$0	0.05	$605	0.01	$49,369	0.50	$24,690
20–21	$0	0.05	$12,090	0.01	$987,386	0.50	$493,766

Note that the value for 2020–21 is the capitalised value for all future benefits as recommended in the ACIAR impact assessment guidelines by Gordon and Davis (2007).

Table 33. Attributed net benefits for Cook Islands

Year	Attributed to ACIAR projects			
	HTFA exports	Non-host exports	Biosecurity benefits	Total benefit
93–94	$7,186	$0	$0	$7,186
94–95	$5,840	$0	$9,734	$15,573
95–96	$7,390	$0	$24,685	$32,075
96–97	$3,867	$0	$24,685	$28,552
97–98	$2,843	$0	$24,685	$27,528
98–99	$4,215	$0	$24,685	$28,900
1999–2000	$1,684	$711	$24,685	$27,080
00–01	$1,261	$296	$24,685	$26,242
01–02	$1,680	$193	$680,231	$682,103
02–03	$3,117	$574	$330,323	$334,014
03–04	$1,225	$575	$24,685	$26,485
04–05	$589	$112	$24,685	$25,385
05–06	$225	$251	$24,685	$25,161
06–07	$79	$232	$24,685	$24,996
07–08	$0	$209	$24,685	$24,893
08–09	$0	$181	$24,685	$24,866
09–10	$0	$151	$24,685	$24,836
10–11	$0	$121	$24,685	$24,806
11–12	$0	$94	$24,685	$24,778
12–13	$0	$70	$24,685	$24,755
13–14	$0	$51	$24,685	$24,735
14–15	$0	$36	$24,685	$24,721
15–16	$0	$25	$24,685	$24,710
16–17	$0	$17	$24,685	$24,702
17–18	$0	$12	$24,685	$24,696
18–19	$0	$8	$24,685	$24,693
19–20	$0	$5	$24,685	$24,690
20–21	$0	$73	$493,693	$493,766
Net present value				
Total	$62,848	$4,271	$1,999,791	$2,066,910
Realised	$62,848	$3,454	$1,541,481	$1,607,784
Prospective	$0	$817	$458,310	$459,126

benefits in any given host country. However, the RMFFP also made significant contributions from a much larger budget, and the Secretariat of the Pacific Community (SPC) has provided support for quarantine surveillance systems in various ways, including providing assistance to complete emergency response plans, maintaining a central store of materials for use in eradication campaigns, and maintaining the website PACIFLY < http://www.spc.int/pacifly/> since 2001. The relative importance of the contributions from these main sources was discussed with many of the staff involved in the projects and, not surprisingly, there were some differences in the opinions expressed. Based on this anecdotal evidence and the above facts, it was assessed that 50% of total biosecurity benefits could be attributed to the ACIAR projects.

Benefits from non-host exports that can be attributed to the ACIAR/RMFFP projects were assessed to be 50% initially because research conducted as part of the ACIAR projects provided crucially necessary data to establish the non-host status of some fruits. However, due to the possibility that Pacific island countries would have acquired the necessary enabling data from other sources in subsequent years, the proportion of benefits, Ω, attributed to the ACIAR projects then gradually declined over time according to the formula:

$$\Omega=0\ 5-1/(1+ EXP(0.4*(17-t)))$$

where *EXP* is the natural exponent and t is number of years indexed from one to 28. Biosecurity benefits were attributed 50:50 between ACIAR and RMFFP.

Expertise and funding for the development of HTFA treatment was contributed by New Zealand through the Horticulture and Food Research Institute of New Zealand. USAID provided the small scale HTFA plant. Other key enabling contributions for this bilateral quarantine agreement were outputs from the RMFFP project. ACIAR projects made only a small contribution to gaining market access to premium price New Zealand market. However, the ACIAR projects did provide some necessary inputs, such as setting up fruit-fly rearing laboratories to provide a supply of flies to be used in testing the efficacy of different postharvest disinfestation treatments. Hence, while any market access benefits that could reasonably be attributed to the ACIAR projects are minor, given all the facts, a figure of 5% was chosen as a reasonable proportion of total estimated benefits to attributable to the ACIAR projects.

Capacity building

Like the other Pacific islands countries, capacity building in Cook Islands was primarily undertaken within the framework of the RMFFP. ACIAR cooperated with that project and ACIAR projects CS2/1994/003 and CS2/1996/225 worked cooperatively with the RMFFP project. Through this major project, staff from Cook Islands received a variety of training on fruit fly management. As noted, the benefits accruing to biosecurity outcomes for Cook Islands would not have been possible without training in eradication techniques provided to staff as part of the ACIAR/RMFFP projects, and prior development of an ERP by those staff.

Appendix 5. Fiji case study

Although there are seven species of fruit fly endemic to Fiji, most either have a restricted host and/or geographic range, or do not cause significant damage. The main exception is the Pacific fruit fly (*B. xanthodes*).

Apart from the use of protein bait sprays by growers of tropical fruits for exports to premium-price markets, no tangible evidence was found of uptake of project outputs to enable field control of fruit flies in Fiji. Hence, no attempt was made to separately estimate any field control benefits because any benefits from use of protein bait sprays by export growers will be incorporated in the estimated market access benefits.

Market access

Papaya and other tropical fruits were exported from Fiji to Australia and other premium-price markets using an ethylene dibromide fumigation treatment regime for fruit flies up until the early 1990s. However, the withdrawal of ethylene dibromide as an acceptable postharvest disinfestation treatment in the mid 1990s stopped these exports in the absence of an alternative and equivalent fruit-fly treatment. This prompted a drive to gain acceptance by Australia, New Zealand and Japan of High Temperature Forced Air (HTFA) disinfestation treatment of fruit flies in certain tropical fruits.

The Regional Management of Fruit Flies in the Pacific (RMFFP) project, in conjunction with the ACIAR projects, generated data on the heat tolerances of fruit-fly eggs and instars, and had data accepted by New Zealand for imports of mango, papaya, eggplant and breadfruit. Fiji was the first Pacific island country (PIC) to undertake commercial-scale confirmatory tests for export of papaya, eggplant, mangoes and breadfruit using forced hot air, and to submit research reports to New Zealand Ministry of Agriculture and Forestry (MAF) for approval of the treatment. This assisted Fiji Quarantine to negotiate a bilateral quarantine arrangement (BQA) with New Zealand based on HTFA protocols for export of papaya, mango, eggplant and breadfruit, to develop quarantine pathways for export of commodities to New Zealand. The Fiji also was the first PIC to gain market access on basis of postharvest disinfestation treatments for exports of mango, papaya, eggplant and breadfruit.

The RMFFP with contributions from the ACIAR project also undertook confirmatory tests for papaya for export to Australia, and submitted the results to Australia. As a result, Fiji is the only PIC to have gained market access to the Australia market for heat-treated papaya.

It also used laboratory and field tests developed by the ACIAR projects, the RMFFP, and the New Zealand Ministry of Agriculture and Forestry (MAF) Regulatory Authority to determine non-host status for certain fruits and vegetables, and to negotiate non-host protocols for two types of chilli. Inter alia, it proved that cucumber, bitter gourd, squash/pumpkin and other gourds are not susceptible to fruit flies in Fiji.

Unlike all other Pacific island countries Fiji has a thriving, albeit still modest, export trade of tropical fruits that are fruit-fly hosts and require postharvest disinfestation treatment. Fiji also continues to export significant amounts of selected chilli varieties under a non-host status quarantine treatment. This can be seen from Figure 23. Both of these types of fruit exports are projected to grow modestly for one or more years and then stabilise.

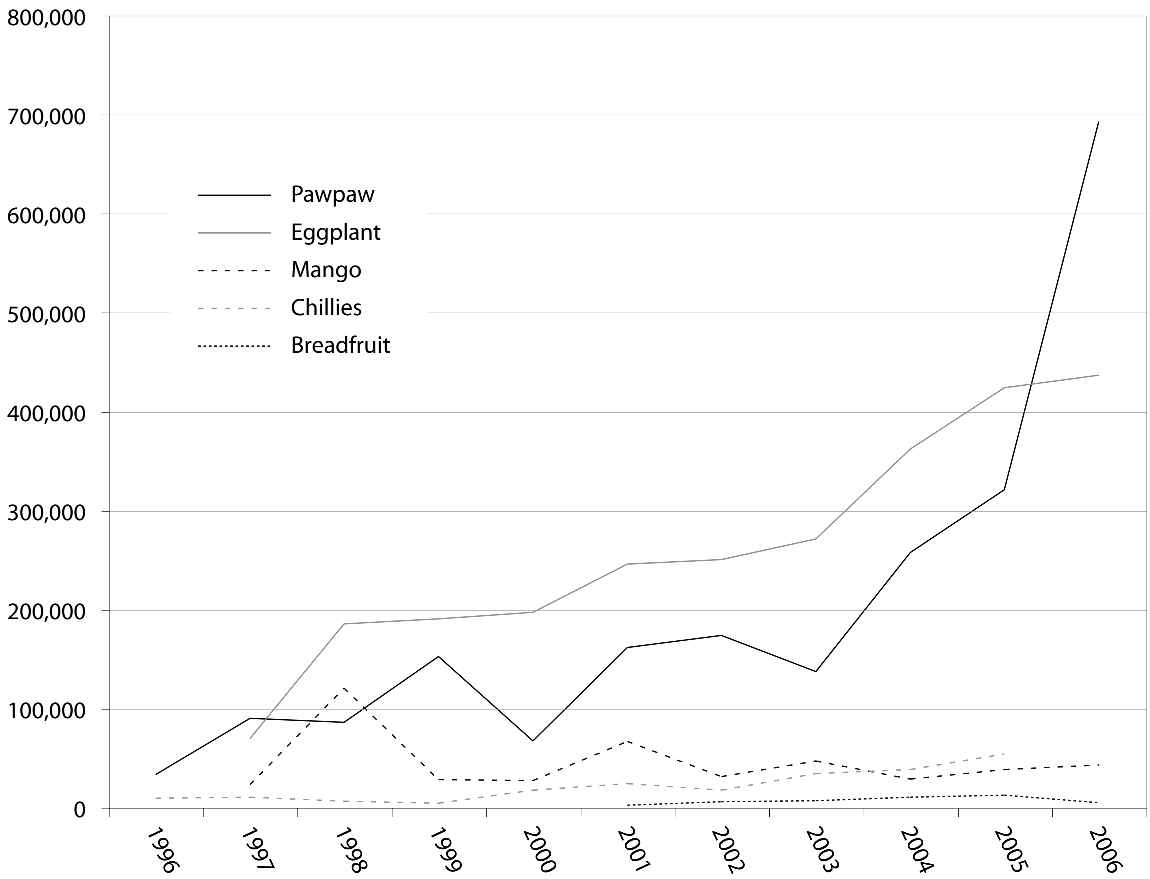

Figure 23. Exports from Fiji to New Zealand of host and non-host tropical fruits. Source: FAOSTAT 2008 and data from Natures Way Cooperative.

Reduced pesticide use for fruit exports

The RMFFP program developed a package for field control of fruit flies based on sound crop hygiene, early harvesting of fruit, bagging of fruit and protein bait sprays. As a result, use of protein bait sprays to control fruit flies is now a required field control measure for the quality assurance export pathway to obtain a phytosanitary certificate for export of mango, eggplant and breadfruit to New Zealand (See Fresh Produce Export System Training Modules, Secretariat of the Pacific Community, Land Resources Division).

A possible side benefit of reduced pesticide use is that workers in export fruit orchards may have reduced exposure to insecticides, which would have health and possibly environmental benefits. However, there is no available evidence on pesticide levels in fruit export orchards relative to orchards producing for the domestic market, and insufficient information on the relationship between pesticide levels and human and environmental health was available to quantify any such benefits.

Biosecurity benefits—entry of *B. papayae*

The biosecurity benefits for Fiji are essentially the same as for the Cook Islands case study, except for appropriate adjustments for area of land mass, population size, living standards, volume of production of vulnerable fresh fruit and leafy vegetables hosts, and value of 'at-risk' exports of fresh fruit and leafy vegetables.

'With R&D' scenario

This scenario is essentially the same as for the Cook Islands case study, except for the following facts and informed judgments:

- Market access benefits to the economy from HTFA-treated fruit exports to New Zealand were estimated to be 10% of the gross value of these exports.
- The overall value of subsistence and commercial fresh fruit and leafy vegetables production in Fiji was estimated by McGregor (1999) to be A$ $65.233 million in constant 2007 dollars.
- No incursion of an exotic pest fruit fly has been detected in Fiji.
- Ongoing quarantine surveillance costs are $150,000 in 2007A$/year.

Table 34 sets out annual estimates for the 'with R&D' scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a small eradication program plus annual quarantine surveillance costs.

'Without R&D' scenario

This scenario is essentially the same as for the Cook Islands case study, except for the following facts and informed judgments:

- The overall value of subsistence and commercial fresh fruit and leafy vegetables production in Fiji was estimated by McGregor (1999) to be A$ $65.233 million in constant 2007 dollars.
- The estimated budget for a large fruit-fly eradication campaign on Fiji is set out in Table 35.
- In total, cost of eradicating a large incursion is $8.283 million in 2007A$.

Annual estimates for the 'without R&D' scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a large eradication program plus annual quarantine surveillance costs are set out in Table 36.

Estimated benefits

Estimates of the annual value of total benefits of the ACIAR and related fruit-fly projects, together with the proportion of these calculated values that could reasonably attributed to the ACIAR projects, are shown in Table 37, and the values of benefits actually attributed to the ACIAR fruit-fly projects are shown in Table 38. Attribution of benefits to the ACIAR projects is the same as for Cook Islands.

Capacity building

Fiji also benefited from capacity-building activities under the RMFFP project. Fiji quarantine staff received training in the preparation of emergency response plans and emergency response simulations were conducted. Other staff received training in fruit-fly eradication techniques, bagging and protein bait control.

Table 34. Benefits for Fiji 'with R&D' scenario

Year	Fruit exports				Small incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$4,529	−$226	−$0	−$7,496	−$150,000
95–96	$0	$0	$6,823	−$341	−$0	−$7,496	−$150,000
96–97	$12,840	−$642	$4,664	−$233	−$0	−$7,496	−$150,000
97–98	$52,373	−$2,619	$4,321	−$216	−$0	−$7,496	−$150,000
98–99	$82,233	−$4,112	$2,553	−$128	−$0	−$7,496	−$150,000
1999–2000	$102,152	−$5,108	$2,130	−$106	−$0	−$7,496	−$150,000
00–01	$71,302	−$3,565	$5,618	−$281	−$0	−$7,496	−$150,000
01–02	$102,054	−$5,103	$6,993	−$350	−$0	−$7,496	−$150,000
02–03	$116,720	−$5,836	$9,877	−$494	−$0	−$7,496	−$150,000
03–04	$149,298	−$7,465	$19,382	−$969	−$0	−$7,496	−$150,000
04–05	$190,833	−$9,542	$21,453	−$1,073	−$0	−$7,496	−$150,000
05–06	$204,595	−$10,230	$22,982	−$1,149	−$0	−$7,496	−$150,000
06–07	$274,958	−$13,748	$24,500	−$1,225	−$0	−$7,496	−$150,000
07–08	$288,873	−$14,444	$24,500	−$1,225	−$0	−$7,496	−$150,000
08–09	$295,230	−$14,761	$24,500	−$1,225	−$0	−$7,496	−$150,000
09–10	$301,388	−$15,069	$24,500	−$1,225	−$0	−$7,496	−$150,000
10–11	$307,745	−$15,387	$24,500	−$1,225	−$0	−$7,496	−$150,000
11–12	$313,903	−$15,695	$24,500	−$1,225	−$0	−$7,496	−$150,000
12–13	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
13–14	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
14–15	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
15–16	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
16–17	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
17–18	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
18–19	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
19–20	$314,300	−$15,715	$24,500	−$1,225	−$0	−$7,496	−$150,000
20–21	$6,286,000	−$314,300	$490,000	−$24,500	−$0	−$149,912	−$3,000,000

Table 35. Budget for fruit-fly eradication campaign in Fiji

Item	yr1	yr2	Total
Human resources	393,060	350,080	743,140
Equipment and supplies	354,926	50,503	405,429
Subcontracts	105,215	63,129	168,344
Training	30,017	11,882	41,899
Publications and public relations	73,570	7,507	81,077
Communications	16,023	16,023	32,046
Transport	25,602	18,588	44,190
Utilities	10,014	10,014	20,029
Helicopter	442,605	159,226	601,831
Attractants and chemicals	1,019,006	337,831	1,356,837
Contingencies	80,115	80,115	160,230
Total	**2,550,154**	**1,104,898**	**3,655,052**
A$:US$	**0.532**	**0.532**	**0.532**
Deflator 2001–02 to 2006–07	**0.830**	**0.830**	**0.830**
Total costs (2007 A$)	**5,779,742**	**2,504,172**	**8,283,913**

Table 36. Benefits for Fiji 'without R&D' scenario

Year	Fruit exports				Large incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$0	$0	−$293,549	−$260,088	$0
95–96	$0	$0	$0	$0	−$293,549	−$367,705	$0
96–97	$0	$0	$0	$0	−$293,549	−$367,705	$0
97–98	$0	$0	$0	$0	−$293,549	−$367,705	$0
98–99	$0	$0	$0	$0	−$293,549	−$367,705	$0
1999–2000	$0	$0	$0	$0	−$293,549	−$367,705	$0
00–01	$0	$0	$0	$0	−$293,549	−$367,705	$0
01–02	$0	$0	$0	$0	−$293,549	−$367,705	$0
02–03	$0	$0	$0	$0	−$293,549	−$367,705	$0
03–04	$0	$0	$0	$0	−$293,549	−$367,705	$0
04–05	$0	$0	$0	$0	−$293,549	−$367,705	$0
05–06	$0	$0	$0	$0	−$293,549	−$367,705	$0
06–07	$0	$0	$0	$0	−$293,549	−$367,705	$0
07–08	$0	$0	$0	$0	−$293,549	−$367,705	$0
08–09	$0	$0	$0	$0	−$293,549	−$367,705	$0
09–10	$0	$0	$0	$0	−$293,549	−$367,705	$0
10–11	$0	$0	$0	$0	−$293,549	−$367,705	$0
11–12	$0	$0	$0	$0	−$293,549	−$367,705	$0
12–13	$0	$0	$0	$0	−$293,549	−$367,705	$0
13–14	$0	$0	$0	$0	−$293,549	−$367,705	$0
14–15	$0	$0	$0	$0	−$293,549	−$367,705	$0
15–16	$0	$0	$0	$0	−$293,549	−$367,705	$0
16–17	$0	$0	$0	$0	−$293,549	−$367,705	$0
17–18	$0	$0	$0	$0	−$293,549	−$367,705	$0
18–19	$0	$0	$0	$0	−$293,549	−$367,705	$0
19–20	$0	$0	$0	$0	−$293,549	−$367,705	$0
20–21	$0	$0	$0	$0	−$5,870,990	−$7,354,103	$0

Table 37. Annual value of total net benefits for Fiji and attribution ratios

Year	Market-access benefits				Biosecurity benefits		Total benefit
	HTFA exports	Attribution to ACIAR projects	Non-host exports	Attribution to ACIAR projects	Biosecurity benefit	Attribution to ACIAR projects	Attributed to ACIAR projects
93–94	$0	0.05	$0	0.50	$0	0.50	$0
94–95	$0	0.05	$4,303	0.50	$396,142	0.50	$200,217
95–96	$0	0.05	$6,482	0.50	$503,759	0.50	$255,109
96–97	$12,198	0.05	$4,431	0.50	$503,759	0.50	$254,693
97–98	$49,754	0.05	$4,105	0.50	$503,759	0.50	$256,403
98–99	$78,121	0.05	$2,425	0.49	$503,759	0.50	$256,983
1999–2000	$97,044	0.05	$2,023	0.49	$503,759	0.50	$257,725
00–01	$67,737	0.05	$5,337	0.49	$503,759	0.50	$257,864
01–02	$96,951	0.05	$6,643	0.48	$503,759	0.50	$259,919
02–03	$110,884	0.05	$9,383	0.47	$503,759	0.50	$261,846
03–04	$141,833	0.05	$18,413	0.46	$503,759	0.50	$267,412
04–05	$181,291	0.05	$20,380	0.44	$503,759	0.50	$269,919
05–06	$194,365	0.05	$21,833	0.42	$503,759	0.50	$270,680
06–07	$261,210	0.05	$23,275	0.38	$503,759	0.50	$273,884
07–08	$274,429	0.05	$23,275	0.34	$503,759	0.50	$273,631
08–09	$280,468	0.05	$23,275	0.30	$503,759	0.50	$272,870
09–10	$286,318	0.05	$23,275	0.25	$503,759	0.50	$272,014
10–11	$292,357	0.05	$23,275	0.20	$503,759	0.50	$271,168
11–12	$298,208	0.05	$23,275	0.16	$503,759	0.50	$270,398
12–13	$298,585	0.05	$23,275	0.12	$503,759	0.50	$269,503
13–14	$298,585	0.05	$23,275	0.08	$503,759	0.50	$268,764
14–15	$298,585	0.05	$23,275	0.06	$503,759	0.50	$268,196
15–16	$298,585	0.05	$23,275	0.04	$503,759	0.50	$267,777
16–17	$298,585	0.05	$23,275	0.03	$503,759	0.50	$267,476
17–18	$298,585	0.05	$23,275	0.02	$503,759	0.50	$267,265
18–19	$298,585	0.05	$23,275	0.01	$503,759	0.50	$267,118
19–20	$298,585	0.05	$23,275	0.01	$503,759	0.50	$267,018
20–21	$5,971,700	0.05	$465,500	0.01	$10,075,181	0.50	$5,338,999

Table 38. Attributed net benefits for Fiji

Year	Attributed to ACIAR projects			
	HTFA exports	Non host exports	Biosecurity benefits	Total benefit
93–94	$0	$0	$0	$0
94–95	$0	$2,146	$198,071	$200,217
95–96	$0	$3,229	$251,880	$255,109
96–97	$610	$2,203	$251,880	$254,693
97–98	$2,488	$2,036	$251,880	$256,403
98–99	$3,906	$1,198	$251,880	$256,983
1999–2000	$4,852	$993	$251,880	$257,725
00–01	$3,387	$2,598	$251,880	$257,864
01–02	$4,848	$3,192	$251,880	$259,919
02–03	$5,544	$4,423	$251,880	$261,846
03–04	$7,092	$8,441	$251,880	$267,412
04–05	$9,065	$8,975	$251,880	$269,919
05–06	$9,718	$9,083	$251,880	$270,680
06–07	$13,061	$8,944	$251,880	$273,884
07–08	$13,721	$8,030	$251,880	$273,631
08–09	$14,023	$6,967	$251,880	$272,870
09–10	$14,316	$5,819	$251,880	$272,014
10–11	$14,618	$4,670	$251,880	$271,168
11–12	$14,910	$3,608	$251,880	$270,398
12–13	$14,929	$2,694	$251,880	$269,503
13–14	$14,929	$1,955	$251,880	$268,764
14–15	$14,929	$1,387	$251,880	$268,196
15–16	$14,929	$968	$251,880	$267,777
16–17	$14,929	$667	$251,880	$267,476
17–18	$14,929	$456	$251,880	$267,265
18–19	$14,929	$310	$251,880	$267,118
19–20	$14,929	$209	$251,880	$267,018
20–21	$298,585	$2,823	$5,037,591	$5,338,999
Net present value				
Total	$347,291	$98,456	$8,833,600	$9,279,347
Realised	$72,746	$67,018	$4,157,053	$4,296,818
Prospective	$274,545	$31,438	$4,676,547	$4,982,530

Appendix 6. Federated States of Micronesia

The Federated States of Micronesia (FSM) still has regular fruit-fly surveillance that involves quarantine officers clearing and checking strategically located traps, and it also has quarantine import requirements to protect the countries from new fruit-fly species. However, there was insufficient information available to quantify biosecurity benefits for FSM. There is no export trade of fruit-fly host commodities from FSM countries, so no market access benefits were estimated. No tangible evidence was found of uptake of project outputs to enable field control of fruit flies in FSM, so no attempt was made to estimate any field control benefits.

FSM have benefited from fruit-fly management and eradication training under the RMFFP. Staff received emergency response training.

Appendix 7. Indonesia case study

Market access on basis of non-host status

Indonesia is planning to try to negotiate an SPS protocol for export of mangosteen to Australia based on non-host status. Based on consultation with knowledgeable officials, it seems that the expected present value (PV) of any realised benefits would be negligible. Not only is the probability of a successful outcome from such negotiations very low, but the time lag before any benefits would be realised is likely to be measured in decades rather than years.

Mangosteen is a very difficult fruit to disinfest. The only consent granted to import mangosteen into Australia (from Thailand) requires, inter alia, that the fruit be fumigated, so it is unimaginable that Australia would agree to an import condition based solely on non-host status. Furthermore, Biosecurity Australia only conducts a small number of Import Risk Analyses, and a long queue is prioritised from Australia's perspective. Given that the market for mangosteen in Australia is small, that some mangosteen is already being imported, that Indonesia has many higher-priority items for trade negotiations with Australia, and that Indonesia is yet to formally apply, there will be a very long delay before any such application is even considered. For these reasons, the judgment was made that Indonesia would not realise any market access to Australia on basis of non-host status.

For similar reasons, Indonesia's aspiration to negotiate an SPS protocol for export of other tropical fruits such as mangosteen, banana, fresh snake skin fruit, rambutan, papaya before colour break and durian to China on the basis of non-host fruit status was judged to have negligible chances of success. Now that China has joined the World Trade Organization (WTO), such plans will face similar difficulties to those above with respect to export of mangosteen to Australia and/or the US, where postharvest disinfestation by irradiation is required for market access.

Biosecurity benefits—entry of *B. musae* into Java

A decision was made not to include estimates of biosecurity benefits for Indonesia in either the realised or prospective benefits categories used to measure the return to ACIAR's investment in fruit-fly research. Some of the information on which such estimates would need to have been based was simply too subjective for quantitative estimates of biosecurity benefits to be credible. A key issue is the effectiveness of the quarantine surveillance system for detecting entry of exotic pest fruit flies into various provinces of Indonesia and, in particular, the probability of early detection at multiple points of entry with and without the research; and with or without significant upgrading of the quarantine surveillance system by the Indonesian government. Instead, the following discussion of one possible scenario, the possible entry of *B. musae* into Java, includes some indicative values for the possible size of potential and prospective benefits.

B. musae is already widely established in parts of Australia and PNG but not on Java. While it does infest a limited range of other fruits occasionally, the majority of host records are from bananas. Furthermore, it is the main and almost only common fruit fly that infests green bananas, which can be heavily damaged before they ripen. If it became widely established on Java, heavy losses to the value of banana production would be likely unless growers resorted to the costly and time-consuming practice of bagging all bunches. In 2005

5,177,608 tonnes of bananas were produced in Indonesia (http://faostat.fao.org/site/535/DesktopDefault.aspx?PageID=535. Accessed 22 April 2008.).

Of this, perhaps 2,600,000 or more would have been grown on Java. If this production is valued conservatively, multiplying by 50% of the export price, and converted to 2007 A$, the gross value of Java banana production would exceed A$660 million. Banana growers in the East New Britain province of Papua New Guinea (PNG) are reportedly incurring heavy losses from infestation by *B. musae* (John Moxon, pers. comm., 2008), so while 10% losses on Java of A$66 million per annum might be a conservative estimate, field control measures would almost certainly be a much less costly option. Whether a major eradication campaign would be economic is problematic. *B. musae* is attracted to methyl eugenol, so scaling up the estimated costs of the proposed eradication campaign on Palau in way to allow for fixed and variable components suggests that the cost of eradicating *B. musae* from all of Java could be of the order of A$250 million.

There are multiple possible pathways for entry of *B. musae* into Java, including across land borders between PNG and Irian Jaya, and then by boat/plane/other provinces, tourist travel between PNG and Java, and inter-island boat travel. Project CP/2003/036 is producing some key outputs that would be necessary inputs to the establishment of an effective border quarantine surveillance and detection system for fruit flies that might greatly increase the chance of detecting an entry of *B. musae* into Java before it became established and widely dispersed.

Currently, the only form of border quarantine surveillance is a system of annual surveys that consists of temporary trapping (i.e. less than one week in duration) at a rotating series of sites (Budiman pers. comm. 2008). Hence, at best the chance of detecting entry of *B. musae* before it could become established is less than 2% of the chance of detection if a fully effective system of permanent traps and regular host surveys was in place at ports, airports and other high-risk points of entry. A more likely scenario is that an incursion would only be detected more than one year after entry, and after it had spread to main production areas where it would be discovered by a backup system of trapping and identification coordinated by 32 units of Food and Horticulture Crop Protection Centres and 84 field Laboratories for Pest and Disease Investigation for Food and Horticulture Crops. However, while this system of pest detection is more elaborate, it is poorly resourced and has only limited expertise to identify those fruit flies that are collected from traps. As there can be more than 5,000 fruit flies in a single trap, the magnitude of the task is daunting. In practice, most flies caught in traps are only counted, with little attempt made to identify individual fruit flies due to the overwhelming numbers involved (Cahyaniati, pers. comm., 2008).

Consequently, an incursion is most likely to be detected only after it has become so widely established that unusual damage to infested fruit comes to the attention of the system of 5,000 pest observers. Note however that these pest observers have various assignments, including monitoring a wide range of pests on numerous food crops and horticultural crops, as well as providing training and extension advice to farmers, so monitoring fruit-fly damage in tropical fruits comprises only a small part of their duties. Hence, it is likely that by the time an incursion is detected, eradication is unlikely to be an economic proposition.

Protein bait spray for exports of mango

The ongoing project CP/2003/036 has made considerable progress in working with a commercial partner to create the capacity to produce protein bait from brewery waste. The first stage of this production facility has been commissioned, and Indonesian regulatory approval is now being sought so that protein bait can be used by export mango growers in the Cirebon district. It is expected they will purchase 80,000 litre of protein bait in 2008–2009 at a price of 40,000 Rp. (A$4.68) per litre to protect 5,000 ha. Whether this level of uptake is actually achieved will not become evident until regulatory approval is granted. Further research also needs to be completed to determine the best crop-protection package involving protein bait for mango growers to use. Over the next 5 years, it is hoped that uptake of protein bait sprays will rise steadily to a ceiling level of 30,000 ha in 2012–2013. These plans depend on the commercial partner investing in further plant at the Multi Bintang/Heineken brewery outside Jakarta to increase protein bait production capacity from 80,000 litres per year to the maximum of 480,000 litres per year. Uptake will be capped by the available supply of protein bait, so field control benefits are likely to be limited to an area of 24,000 ha (=480,000/20). However, until such time as evidence becomes available about actual uptake, it would be too speculative to attempt to calculate quantitative estimates of the benefits that might be generated.

Capacity building

Training is an integral part of CP/2003/036 and, while the project is still running, a number of capacity building initiatives have been completed. In part these are a necessary condition of undertaking the project as the staff in Indonesia have to be trained appropriately and have to be able to train local staff appropriately so that the core project research work of trapping and identification is done properly. Nevertheless this is part of the wider capacity building that is invariably needed if project results are going to be turned into realised benefits. The training so far includes:

- A training workshop on Fruit Flies of Indonesia: Their Identification and Pest Status was held in Darwin at the Australian Quarantine and Inspection Service (AQIS) Training Facility in March 2006. The workshop was attended by 17 Indonesian field staff. Four staff from the Northern Australian Quarantine Strategy (NAQS), AQIS also attended.
- A training workshop on fruit-fly surveillance techniques for project field staff was held in Bali in 2006. Thirty two project field staff from Bali, Sulawesi and Sumatera attended.
- Indonesian staff attached to the project held a training workshop on fruit-fly surveillance techniques for staff involved in May, 2007 in Mataram, West Nusa Tenggara. Thirteen staff from the Food Crops and Horticulture Protection Centre attended.
- The Indonesian Ministry of Agriculture funded a related workshop on Identification of Fruit Flies in Indonesia, held in Java. Ten technical staff from the Food Crops and Horticulture Protection Centre attended.
- In June 2007 a workshop on Fruit-Fly Pest Free Areas was conducted in Jakarta for 44 senior Indonesian scientists and quarantine staff from various agencies.

Appendix 8. Malaysia case study

Malaysia has completed a thorough nation-wide survey of fruit fly. Control programs are based on the use of methyl eugenol, insecticide sprays, poisoned protein hydrolysate bait and the bagging of fruit. The two major production crops are papaya and starfruit. *B. papayae* and *B. carambolae* are the major pests for these crops.

Market access

Malaysia is not a major exporter of fresh fruit and vegetables. Historically, it has exported fruits to countries such as China and Singapore that had lesser quarantine restrictions. To date, it has not achieved access to countries such as Australia, New Zealand, Japan and the USA. China is a major market and has required some upgrading of Malaysian postharvest treatments.

In early December 2003 more than 7 tonnes of the exotica papaya from Malaysia were refused entry by the Shenzhen Entry-Exit Inspection and Quarantine Bureau of China. Inspections revealed the presence of larva of the papaya fruit fly, *Bactrocera papaya*. In 2005 China banned Malaysian papayas because of fruit-fly risks and more recently required postharvest disinfestation with hot water treatment for exports of papaya to China. This a different method of postharvest disinfestation treatment to the high-temperature forced air (HTFA) treatment that was researched by ACIAR project PHT/1994/133, so no market access benefits have been quantified for Malaysia.

Field control

Both CS2/1983/043 and CS2/1989/019 had improved field control as a supplementary objective with a focus on protein bait, but commercial use of Prima protein bait is limited so current benefit is minimal. Potentially, benefits are more significant if protein bait is adopted on a scale consistent with capacity of plant, which currently is 160,000 litres annually with a projected capacity of 480,000 litres. At 1 litre per ha, 8 sprays per crop and 2 crops per year, the potential is to treat at least 10,000 hectares, and up to 30,000 ha. In 2007 Ministry of Agriculture statistics estimated there were 297,000 ha of fruits and 37,000 ha of vegetables.

The following appear to be some of the main reasons why protein bait is not being adopted more rapidly:

- Price—although cheaper than alternative baits, PRIMA has been selling for around MYR35 per litre. It is hoped that a reduced price of MYR20–MYR25 will increase market penetration.
- Protein bait sprays, as opposed to cover spraying, have to be applied correctly once a week. Many farmers are not geared up to do this. A change in understanding and practice by farmers is required.
- Small farm size—Malaysian farmers are smallholders, and many are part-time farmers. Organising area-wide participation is difficult, yet this is a necessary condition for maximum success with protein bait.

Field control benefits have not been estimated because, based on the available data on economic returns to farmers, it was assessed that there would be negligible uptake of protein bait spays to control fruit fly in Malaysia.

Appendix 9. Papua New Guinea

Apart from capacity-building benefits, which have been impressive, no grounds could be found for estimating benefits from the fruit-fly projects in Papua New Guinea. Some of the reasons are summarised below.

Market access

Papua New Guinea (PNG) has the largest number of endemic pest fruit flies of any country, including several especially polyphagous species. Hence, almost all fresh fruit and leafy vegetables that PNG might export will be hosts for at least one endemic fruit-fly species, so there is virtually no prospect of PNG being able to negotiate a sanitary and phytosanitary (SPS) protocol with possible importing countries based on non-host status.

Therefore, for there to be any prospect of trade facilitation benefits in PNG, some form of postharvest treatment to kill any flies infesting the fruit would need to be developed, and used as the basis to negotiate SPS trade protocols with possible importing countries. At best, this would be a long, drawn-out process but without any guarantee of ultimate success. As the experience of several other Pacific Island countries (PICs) shows, while SPS trade protocols might be necessary to enable fruit exports, they are not sufficient. In a review of prospects for fruit exports from PICs, McGregor (2007) reviews a number of other challenges that need to be surmounted for a fruit export trade to develop. Most of the factors that have defeated efforts in several other PICs also apply to PNG, so it would seem unrealistic to project trade facilitation benefits in the foreseeable future.

Biosecurity

Leblanc et al. (2001) claim that 'Papua New Guinea (PNG) has the greatest diversity of tropical fruit-fly species (Diptera: Tephritidae: Dacinae) in the world. One hundred and eighty-eight species have been described; and fifty to sixty new species awaiting description have been discovered in recent years'.

Moreover, at least 18 species are known to infest commercial or edible fruits and vegetables, including four of the most damaging species: Asian papaya fruit fly (*Bactrocera papayae*), melon fly (*B. cucurbitae*), mango fly (*B. frauenfeldi*) and banana fly (*B. musae*).

In particular, the mango fly is an especially polyphagous species with more than 72 recorded host plant species, most of which are commercial or edible fruits. According to Leblanc et al. (2001), it has been bred from 33 species of commercial/edible hosts in PNG. Moreover, the mango fly is well established in all PNG provinces, so either controlling fruit fly or accepting fly damage is a fact of life for virtually all types of production of fruit and vegetable hosts. In these circumstances, it is difficult to envisage what further economic damage would be caused by an incursion of another exotic fruit-fly pest.

Even in the unlikely event that an incursion of an exotic fruit-fly pest might result in further losses, there is currently almost no chance of avoiding such losses by early detection due to enhanced quarantine surveillance. The national system of fruit-fly traps and host surveys established during the time of the ACIAR project and RMFFP are no longer functional because the National Agriculture Quarantine & Inspection Authority (NAQIA) lacks the necessary financial resources to maintain the system, and it assigns a higher priority to managing other pests such as cocoa pod borer. Also, it currently does not have any staff in PNG who could identify trapped flies, and the National Agricultural Research Institute (NARI) entomology facilities that previously housed breeding colonies of fruit flies has been vandalised. At the moment, the only quarantine surveillance for fruit flies in PNG is a joint NAQIA and North Australian Quarantine Strategy (NAQS) annual survey conducted at selected sites along the border with Irian Jaya that is funded by Australia.

Field control

In general, none of the available methods of field control of fruit fly are being practised in PNG. Traditional fruits and vegetables for subsistence consumption are grown in village gardens in which several different crops intermingle, and often in proximity to forest or other likely refuges for fruit fly. Hence, field control methods that kill those flies infesting a crop (e.g. cover sprays, bait sprays) will provide only transient protection, because reinfestation will occur rapidly. In highly commercialised fruit growing areas, such as Hawai'i, area-wide fruit-fly management programs have been effective in overcoming this reinfestation problem, but such highly coordinated programs would not be feasible in controlling fruit fly in traditional village gardens in PNG. Further impediments to uptake of such technologies are the current lack of supply of insecticides in PNG, and the high cost of materials if supply constraints could be overcome.

The only possible field control method that might be used is bagging fruit, because it works by denying the fly access to the fruit, and therefore is immune to problems of reinfestation. However, bagging is unsuitable for most fruits, the principle exception in traditional PNG agriculture being bananas.

The situation is much the same in the commercial sector. A recent survey of growers of capsicum for sale in domestic markets found that growers were not aware of fruit fly, and attributed crop damage and loss to other causes. Needless to say, awareness that fruit fly is a pest is a prerequisite for practice of field control methods.

Capacity building

Capacity building is the real success story for PNG. Through the RMFFP and PNG ACIAR projects a considerable investment has been made in raising the ability of scientists and managers in PNG to deal with a variety of fruit-fly issues.

Two PNG staff were involved in a training course on identification, biology and surveillance of fruit flies in Solomon Islands, Vanuatu and Papua New Guinea, which was jointly funded and delivered by RMFFP and ACIAR. In 1999 a training workshop funded by ACIAR was held at Lae for 21 staff on fruit-fly biology, monitoring, control and identification. Participants were scientists and technicians from NARI, NAQIA quarantine officers, Provincial Departments of Primary Industries extension officers, and staff from the Coffee Industry Corporation (CIC) and Fresh Produce Development Company (FPDC). Three staff were involved in RMFFP in a course on generation of heat tolerance data for immature stages of fruit flies held in Port Vila in 1999.

A pair of junior scientific officers was given four months of intensive practical training on fruit-fly management in 1998.

Appendix 10. The Philippines case study

The benefits attributable to ACIAR project PHT/1990/051 from providing necessary inputs for Australia to negotiate access for exports of Australian mango to the premium-priced Japanese market have been estimated previously by Monck and Pearce (2007). Modified estimates for this study have been calculated using the same basic data, but with some minor variations to the underlying analytical framework on which the calculations were based. The benefits derived are based on the price premium achievable in the Japanese market.

Market access—mango exports to Japan

The project was neither a necessary nor sufficient condition for market access for the Philippines. As noted in Monck and Pearce (2007), the Philippines maintained its trade with Japan throughout the period of the ACIAR research. In addition it began vapour heat treatment (VHT) of mangoes before the ACIAR research commenced. On this basis only a minor percentage (5%) is attributed by Monck and Pearce to the ACIAR-funded project.

Table 39 shows the data on exports to Japan, exports to the rest of the world, and prices in Japan and the rest of the world for mango exports from the Philippines taken from Monck and Pearce (2007). The estimation of benefits is based on this data and the price premiums, shown in the tables, derived them. The benefits estimates are modified slightly from those in Monck and Pearce and are based on the logic of Figure 5.

Following Monck and Pearce (2007), attribution is declining and modelled using the formula $\Omega=0.05-0.05/(1+EXP(0.7*(15-t)))$ where *EXP* is the natural exponent and t is indexed from one to 28.

Attributable benefits in 2006–07 values are A$738,011 in 1993–94 and fall to A$158 in 2019–20.

Estimated benefits

Estimated benefits are shown in Table 40.

Table 39. Export volume and price premium for mango exports from the Philippines to Japan

Year	Domestic sales (tonnes)	Exports to other markets (tonnes)	Exports to Japan (tonnes)	Price for other markets ($ per tonne)	Price for sales to Japan ($ per tonne)	Price premium
1994	479,040	23,596	5,464	772	3,286	2,514
1995	549,561	36,817	7,122	757	3,220	2,463
1996	857,449	34,814	5,437	803	3,418	2,615
1997	959,760	40,109	4,831	757	3,220	2,463
1998	892,581	46,388	6,191	850	3,615	2,765
1999	831,086	29,080	6,022	1,066	4,535	3,469
2000	808,301	34,409	5,618	811	3,450	2,639
2001	843,449	32,854	5,397	772	3,286	2,514
2002	919,838	30,594	5,601	819	3,483	2,664
2003	967,930	31,504	6,746	780	3,319	2,539
2004	931,868	28,364	7,303	950	4,042	3,092
2005	984,858	28,383	7,308	950	4,122	3,172
2006	1,040,752	28,402	7,313	950	4,096	3,146
2007	1,099,710	28,421	7,318	950	4,063	3,113
2008	1,161,900	28,439	7,322	950	4,031	3,081
2009	1,227,499	28,458	7,327	949	3,995	3,046
2010	1,296,693	28,477	7,332	949	3,955	3,006
2011	1,369,680	28,496	7,337	949	3,908	2,959
2012	1,446,668	28,515	7,342	949	3,854	2,905
2013	1,527,875	28,534	7,347	949	3,789	2,840
2014	1,613,532	28,553	7,352	949	3,709	2,760
2015	1,703,885	28,572	7,357	949	3,609	2,660
2016	1,799,189	28,591	7,361	949	3,486	2,537
2017	1,899,717	28,610	7,366	949	3,333	2,384
2018	2,005,754	28,629	7,371	948	3,149	2,201
2019	2,117,602	28,648	7,376	948	2,940	1,992
2020	2,235,580	28,667	7,381	948	2,720	1,772
2021	2,360,024	28,686	7,386	948	2,508	1,560
2022	2,491,287	28,705	7,391	948	2,321	1,373
2023	2,629,744	28,724	7,396	948	2,170	1,222
2024	2,775,789	28,744	7,401	948	2,055	1,107

Table 40. Attributable net benefits from the Philippines mango exports to Japan

Year	Net surplus	Attribution to ACIAR projects	Attributed to ACIAR projects
93–94	$14,761,041	0.05	$738,011
94–95	$18,849,829	0.05	$942,386
95–96	$15,278,195	0.05	$763,738
96–97	$12,786,229	0.05	$639,022
97–98	$18,394,880	0.05	$918,906
98–99	$22,448,436	0.05	$1,120,364
1999–2000	$15,931,701	0.05	$793,650
00–01	$14,580,040	0.05	$723,614
01–02	$16,033,961	0.05	$789,854
02–03	$18,405,604	0.05	$893,305
03–04	$24,265,085	0.05	$1,143,705
04–05	$24,909,944	0.04	$1,109,617
05–06	$24,722,667	0.04	$991,606
06–07	$24,480,064	0.03	$817,864
07–08	$24,241,665	0.03	$606,042
08–09	$23,982,647	0.02	$397,887
09–10	$23,683,859	0.01	$234,252
10–11	$23,329,451	0.01	$127,258
11–12	$22,919,310	0.00	$65,692
12–13	$22,421,745	0.00	$32,862
13–14	$21,804,976	0.00	$16,107
14–15	$21,029,233	0.00	$7,772
15–16	$20,067,733	0.00	$3,697
16–17	$18,870,308	0.00	$1,729
17–18	$17,433,616	0.00	$794
18–19	$15,788,878	0.00	$357
19–20	$14,054,647	0.00	$158
20–21	$247,630,952	0.00	$1,382
Present value			
Total	$653,402,106		$17,563,277
Realised	$343,934,460		$16,284,496
Prospective	$309,467,646		$1,278,781

Appendix 11. Samoa case study

No tangible evidence was found of uptake of project outputs to enable field control of fruit flies in Samoa, so no attempt was made to estimate any field control benefits.

Market access

Samoa negotiated a quarantine protocol with New Zealand to export all bananas of the genus *Musa* after demonstrating that pre-colour break bananas are not a host for any of the fruit-fly species endemic to Samoa. The host status surveys conducted by the International Centre for Management of Pest Fruit Flies (ICMPFF)-led ACIAR project in conjunction with the Regional Management of Fruit Flies in the Pacific program provided the base data used to negotiate this protocol. Modest quantities of bananas were exported to New Zealand for a few years, but recently collapsed due to a combination of low prices and some sanitary and phytosanitary (SPS) issues.

Samoa also negotiated a bilateral quarantine arrangement (BQA) with New Zealand based on HTFA protocols for export of papaya, eggplant and breadfruit. Treatment and export of papaya and breadfruit started in 2004, but only breadfruit was still being treated and exported in 2007, and the estimated value was less than US$10,000. Small volumes of eggplant were exported (i.e. less than 1 tonne) for FY 2006–07.

Again, the main contributions of expertise and funding for the development of HTFA treatment, and negotiation of the SPS protocols, came from a combination of New Zealand, USAID and the RMFFP project. ACIAR projects made only a marginal contribution by setting up fruit-fly breeding colonies.

Biosecurity— entry of *B. papayae*

The ACIAR/RMFFP projects established an early-warning quarantine surveillance system of trapping sites on high-risk locations on Samoa. Unlike Cook Islands, no incursions of exotic pest fruit flies have been detected, so there are no realised savings in eradication costs to estimate. In common with the Tonga case study, expected costs avoided start earlier after completion of project CS2/1989/020 at the end of 1993.

‘With R&D’ scenario

This scenario is essentially the same as for the Fiji case study, except for the following facts and informed judgments:

- The overall value of subsistence and commercial fresh fruit and leafy vegetables production in Samoa of A$8.856 million in constant 2007 dollars was derived from an estimate by McGregor (1999) for fruit production in Fiji.
- Ongoing quarantine surveillance costs are $100,000 in 2007A$/year.

Table 41 sets out annual estimates for the ‘with R&D’ scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a small eradication program plus annual quarantine surveillance costs.

'Without R&D' scenario

This scenario is essentially the same as for the Fiji case study, except for the following facts and informed judgments:

- As noted above, the overall value of subsistence and commercial fresh fruit and leafy vegetables production in Samoa was estimated to be A$8.856 million in constant 2007 Australian dollars.
- The estimated budget for a large fruit-fly eradication campaign in Samoa is as follows in Table 42.
- Total estimated costs in 2007 Australian dollars are $3,400,740 for the first year, and $1,561,944 for the second year.

Table 43 sets out the annual estimates for the 'without R&D' scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a large eradication program plus annual quarantine surveillance costs.

Estimated benefits

Estimates of the annual value of total benefits of the ACIAR and related fruit-fly projects, together with the proportion of these calculated values that could reasonably attributed to the ACIAR projects, are shown in Table 44. The values of benefits actually attributed to the ACIAR fruit-fly projects are shown in Table 45. Attribution of benefits to the ACIAR projects is the same as for Cook Islands.

Capacity building

Samoa has benefited from the capacity-building activities of the RMFFP in conjunction with ACIAR. Twenty six staff received training in 2000 through the RMFFP course on fruit fly management that covered: biology of fruit flies, importance of quarantine surveillance, field control methods, quarantine treatments, emergency response planning, and an ERP simulation exercise using the Samoa ERP. Staff have been trained in preparing emergency response plans and simulations of emergencies have been carried out in Samoa under the RMFFP.

Table 41. Benefits for Samoa 'with R&D' scenario

Year	Fruit exports				Small incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$31,293	–$1,565	–$0	–$7,496	–$100,000
95–96	$0	$0	$77,184	–$3,859	–$0	–$7,496	–$100,000
96–97	$0	$0	$67,735	–$3,387	–$0	–$7,496	–$100,000
97–98	$0	$0	$54,758	–$2,738	–$0	–$7,496	–$100,000
98–99	$0	$0	$29,305	–$1,465	–$0	–$7,496	–$100,000
1999–2000	$0	$0	$46,927	–$2,346	–$0	–$7,496	–$100,000
00–01	$0	$0	$24,443	–$1,222	–$0	–$7,496	–$100,000
01–02	$0	$0	$18,237	–$912	–$0	–$7,496	–$100,000
02–03	$8,013	–$401	$19,603	–$980	–$0	–$7,496	–$100,000
03–04	$4,082	–$204	$8,992	–$450	–$0	–$7,496	–$100,000
04–05	$1,415	–$71	$0	$0	–$0	–$7,496	–$100,000
05–06	$766	–$38	$0	$0	–$0	–$7,496	–$100,000
06–07	$0	$0	$0	$0	–$0	–$7,496	–$100,000
07–08	$0	$0	$0	$0	–$0	–$7,496	–$100,000
08–09	$0	$0	$0	$0	–$0	–$7,496	–$100,000
09–10	$0	$0	$0	$0	–$0	–$7,496	–$100,000
10–11	$0	$0	$0	$0	–$0	–$7,496	–$100,000
11–12	$0	$0	$0	$0	–$0	–$7,496	–$100,000
12–13	$0	$0	$0	$0	–$0	–$7,496	–$100,000
13–14	$0	$0	$0	$0	–$0	–$7,496	–$100,000
14–15	$0	$0	$0	$0	–$0	–$7,496	–$100,000
15–16	$0	$0	$0	$0	–$0	–$7,496	–$100,000
16–17	$0	$0	$0	$0	–$0	–$7,496	–$100,000
17–18	$0	$0	$0	$0	–$0	–$7,496	–$100,000
18–19	$0	$0	$0	$0	–$0	–$7,496	–$100,000
19–20	$0	$0	$0	$0	–$0	–$7,496	–$100,000
20–21	$0	$0	$0	$0	–$0	–$149,912	–$2,000,000

Table 42. Budget for fruit-fly eradication campaign in Samoa

Item	yr1	yr2	total
Human resources	291,870	259,955	551,825
Equipment and supplies	202,763	28,852	231,615
Subcontracts	60,108	36,065	96,172
Training	26,409	10,453	36,862
Publications and public relations	58,835	6,004	64,839
Communications	11,211	11,211	22,423
Transport	14,626	10,619	25,245
Utilities	7,007	7,007	14,014
Helicopter	252,853	90,963	343,815
Attractants and chemicals	518,745	171,980	690,725
Contingencies	56,057	56,057	112,115
Total	1,500,484	689,166	2,189,650
A$:US$	0.532	0.532	0.532
Deflator 2001–02 to 2006–07	0.830	0.830	0.830
Total costs (2007 A$)	3,400,740	1,561,944	4,962,684

Table 43. Benefits for Samoa 'without R&D' scenario

Year	Fruit exports				Large incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$0	$0	–$39,854	–$153,033	$0
95–96	$0	$0	$0	$0	–$39,854	–$220,158	$0
96–97	$0	$0	$0	$0	–$39,854	–$220,158	$0
97–98	$0	$0	$0	$0	–$39,854	–$220,158	$0
98–99	$0	$0	$0	$0	–$39,854	–$220,158	$0
1999–2000	$0	$0	$0	$0	–$39,854	–$220,158	$0
00–01	$0	$0	$0	$0	–$39,854	–$220,158	$0
01–02	$0	$0	$0	$0	–$39,854	–$220,158	$0
02–03	$0	$0	$0	$0	–$39,854	–$220,158	$0
03–04	$0	$0	$0	$0	–$39,854	–$220,158	$0
04–05	$0	$0	$0	$0	–$39,854	–$220,158	$0
05–06	$0	$0	$0	$0	–$39,854	–$220,158	$0
06–07	$0	$0	$0	$0	–$39,854	–$220,158	$0
07–08	$0	$0	$0	$0	–$39,854	–$220,158	$0
08–09	$0	$0	$0	$0	–$39,854	–$220,158	$0
09–10	$0	$0	$0	$0	–$39,854	–$220,158	$0
10–11	$0	$0	$0	$0	–$39,854	–$220,158	$0
11–12	$0	$0	$0	$0	–$39,854	–$220,158	$0
12–13	$0	$0	$0	$0	–$39,854	–$220,158	$0
13–14	$0	$0	$0	$0	–$39,854	–$220,158	$0
14–15	$0	$0	$0	$0	–$39,854	–$220,158	$0
15–16	$0	$0	$0	$0	–$39,854	–$220,158	$0
16–17	$0	$0	$0	$0	–$39,854	–$220,158	$0
17–18	$0	$0	$0	$0	–$39,854	–$220,158	$0
18–19	$0	$0	$0	$0	–$39,854	–$220,158	$0
19–20	$0	$0	$0	$0	–$39,854	–$220,158	$0
20–21	$0	$0	$0	$0	–$797,081	–$4,403,157	$0

Table 44. Annual value of total net benefits for Samoa and attribution ratios

Year	Market-access benefits				Biosecurity benefits		Total benefit
	HTFA exports	Attribution to ACIAR projects	Non-host exports	Attribution to ACIAR projects	Biosecurity benefit	Attribution to ACIAR projects	Attributed to ACIAR projects
93–94	$0	0.05	$0	0.50	$0	0.50	$0
94–95	$0	0.05	$29,728	0.50	$85,392	0.50	$57,523
95–96	$0	0.05	$73,325	0.50	$152,516	0.50	$112,786
96–97	$0	0.05	$64,348	0.50	$152,516	0.50	$108,256
97–98	$0	0.05	$52,020	0.50	$152,516	0.50	$102,056
98–99	$0	0.05	$27,839	0.49	$152,516	0.50	$90,009
1999–2000	$0	0.05	$44,581	0.49	$152,516	0.50	$98,148
00–01	$0	0.05	$23,221	0.49	$152,516	0.50	$87,560
01–02	$0	0.05	$17,325	0.48	$152,516	0.50	$84,581
02–03	$7,612	0.05	$18,623	0.47	$152,516	0.50	$85,417
03–04	$3,878	0.05	$8,542	0.46	$152,516	0.50	$80,368
04–05	$1,345	0.05	$0	0.44	$152,516	0.50	$76,325
05–06	$727	0.05	$0	0.42	$152,516	0.50	$76,295
06–07	$0	0.05	$0	0.38	$152,516	0.50	$76,258
07–08	$0	0.05	$0	0.34	$152,516	0.50	$76,258
08–09	$0	0.05	$0	0.30	$152,516	0.50	$76,258
09–10	$0	0.05	$0	0.25	$152,516	0.50	$76,258
10–11	$0	0.05	$0	0.20	$152,516	0.50	$76,258
11–12	$0	0.05	$0	0.16	$152,516	0.50	$76,258
12–13	$0	0.05	$0	0.12	$152,516	0.50	$76,258
13–14	$0	0.05	$0	0.08	$152,516	0.50	$76,258
14–15	$0	0.05	$0	0.06	$152,516	0.50	$76,258
15–16	$0	0.05	$0	0.04	$152,516	0.50	$76,258
16–17	$0	0.05	$0	0.03	$152,516	0.50	$76,258
17–18	$0	0.05	$0	0.02	$152,516	0.50	$76,258
18–19	$0	0.05	$0	0.01	$152,516	0.50	$76,258
19–20	$0	0.05	$0	0.01	$152,516	0.50	$76,258
20–21	$0	0.05	$0	0.01	$3,050,327	0.50	$1,525,163

Table 45. Attributed net benefits for Samoa

Year	Attributed to ACIAR projects			
	HTFA exports	**Non-host exports**	**Biosecurity benefits**	**Total benefit**
93–94	$0	$0	$0	$0
94–95	$0	$14,827	$42,696	$57,523
95–96	$0	$36,527	$76,258	$112,786
96–97	$0	$31,997	$76,258	$108,256
97–98	$0	$25,798	$76,258	$102,056
98–99	$0	$13,751	$76,258	$90,009
1999–2000	$0	$21,890	$76,258	$98,148
00–01	$0	$11,302	$76,258	$87,560
01–02	$0	$8,323	$76,258	$84,581
02–03	$381	$8,778	$76,258	$85,417
03–04	$194	$3,916	$76,258	$80,368
04–05	$67	$0	$76,258	$76,325
05–06	$36	$0	$76,258	$76,295
06–07	$0	$0	$76,258	$76,258
07–08	$0	$0	$76,258	$76,258
08–09	$0	$0	$76,258	$76,258
09–10	$0	$0	$76,258	$76,258
10–11	$0	$0	$76,258	$76,258
11–12	$0	$0	$76,258	$76,258
12–13	$0	$0	$76,258	$76,258
13–14	$0	$0	$76,258	$76,258
14–15	$0	$0	$76,258	$76,258
15–16	$0	$0	$76,258	$76,258
16–17	$0	$0	$76,258	$76,258
17–18	$0	$0	$76,258	$76,258
18–19	$0	$0	$76,258	$76,258
19–20	$0	$0	$76,258	$76,258
20–21	$0	$0	$1,525,163	$1,525,163
Net present value				
Total	$761	$260,315	$2,644,890	$2,905,966
Realised	$761	$260,315	$1,229,035	$1,490,111
Prospective	$0	$0	$1,415,855	$1,415,855

Appendix 12. Solomon Islands

Solomon Islands does not have an effective quarantine surveillance system, so no biosecurity benefits were estimated. There have been no exports of fruit from Solomon Islands since completion of the project, so no market access benefits were estimated. No tangible evidence was been reported of uptake of project outputs to enable field control of fruit flies in Solomon Islands, so no attempt was made to estimate any field control benefits.

Solomon Islands has benefited along with other island nations from the training and capacity-building activities under the Regional Management of Fruit Flies in the Pacific (RMFFP) program. Two Solomon Islands staff attended a workshop on the generation of heat tolerance data for immature stages of fruit flies in Port Vila. Two staff attended the training course on identification, biology and surveillance of fruit flies in Solomon Islands, Vanuatu and Papua New Guinea, which was jointly funded and delivered by RMFFP and ACIAR. An in-country fruit-fly identification workshop in Solomon Islands was funded by ACIAR, with RMFFP involvement, in 1998.

Appendix 13. Thailand case study

The main pest fruit flies in Thailand are *Bractocera dorsalis* (oriental fruit fly). The major species are endemic. There is no permanent trapping. Thailand has fruit inspections at borders but the extensive land borders are permeable with the same species on both sides. Until recently fruit imports were not prohibited.

Thailand is moving to strengthen its approach to quarantine. In April 2007 a quarantine list was developed with a range of pests identified, including a number of pest fruit flies. All approved imports must have a postharvest treatment certificate and any detection causes the shipment to be quarantined. The training requirement for inspectors who can effectively implement this regime is recognised as a major constraint to development of the system. Given the open borders, the very recent development of a quarantine pest list and the endemic nature of the major fruit-fly pests, no biosecurity benefits have been estimated.

Thailand does not have a protein bait spray plant so no attempt was made to estimate any field control benefits. Discussions with officers from the Pest Research Development Office within the Department of Agriculture indicate that there has been and still is general support for the concept of low-cost protein bait. However, the current production of yeast waste from breweries in Thailand is too valuable as an input into animal feed production to allow production of low-cost bait at this stage.

Market access: mango exports to Japan

The benefits attributable to ACIAR project PHT/1990/051 from providing necessary inputs for Australia to negotiate access for exports of Australian mango to the premium priced Japanese market have been estimated previously by Monck and Pearce (2007). As explained above, modified estimates for this study have been calculated using the same basic data.

Table 46 shows the data on exports to Japan, exports to the rest of the world, and prices in Japan and the rest of the world for mango exports from Australia taken from Monck and Pearce (2007). The estimation of benefits is based on this data and the price premiums, shown in the tables, derived them. The benefits estimates are modified slightly from the Monck and Pearce and are based on the logic of Figure 5.

The benefits derived are based on the price premium achievable in the Japanese market. The benefits are estimated by applying the estimated price premium to the existing and projected exports to Japan.

The project was neither a necessary nor sufficient condition for market access. The project was research-focused and ended at the research stage having provided heat-treatment findings. It did not extend to the process of getting treatment schedules accepted in Japan for quarantine purposes for Thailand and the Philippines. Neither did it get involved in setting up commercial treatment equipment.

Table 46. Export volume and price premium for mango export from Thailand to Japan

Year	Domestic sales (tonnes)	Exports to other markets (tonnes)	Exports to Japan (tonnes)	Price for other markets ($ per tonne)	Price for sales to Japan ($ per tonne)	Price premium ($ per tonne)
1994	1,196,582	3,306	112	$1,424	$3,991	$2,567
1995	1,196,344	3,545	111	$1,411	$3,955	$2,544
1996	1,172,711	8,100	150	$1,398	$3,919	$2,521
1997	1,189,889	8,353	185	$1,385	$3,884	$2,499
1998	1,077,566	10,072	138	$1,373	$3,849	$2,476
1999	1,451,300	10,292	181	$1,360	$3,814	$2,454
2000	1,624,725	8,560	194	$1,348	$3,780	$2,432
2001	1,689,173	10,367	460	$1,336	$3,745	$2,409
2002	1,691,264	8,249	487	$1,324	$3,712	$2,388
2003	1,691,902	7,096	1,002	$1,312	$3,678	$2,366
2004	1,691,939	6,855	1,206	$1,300	$3,645	$2,345
2005	1,782,317	7,522	1,323	$1,288	$3,672	$2,384
2006	1,877,507	8,254	1,452	$1,277	$3,620	$2,343
2007	1,977,765	9,057	1,593	$1,265	$3,564	$2,299
2008	2,083,357	9,938	1,748	$1,254	$3,508	$2,254
2009	2,194,567	10,905	1,919	$1,242	$3,451	$2,209
2010	2,311,690	11,966	2,105	$1,231	$3,391	$2,160
2011	2,435,040	13,130	2,310	$1,220	$3,328	$2,108
2012	2,564,944	14,408	2,535	$1,209	$3,259	$2,050
2013	2,701,749	15,810	2,781	$1,198	$3,185	$1,987
2014	2,845,818	17,348	3,052	$1,187	$3,101	$1,914
2015	2,997,534	19,036	3,349	$1,176	$3,005	$1,829
2016	3,157,299	20,888	3,675	$1,166	$2,894	$1,728
2017	3,325,537	22,920	4,032	$1,155	$2,764	$1,609
2018	3,502,691	25,150	4,425	$1,145	$2,617	$1,472
2019	3,689,231	27,597	4,855	$1,135	$2,455	$1,320
2020	3,885,649	30,283	5,328	$1,124	$2,289	$1,165
2021	4,092,461	33,229	5,846	$1,114	$2,130	$1,016
2022	4,310,213	36,462	6,415	$1,104	$1,991	$887
2023	4,539,475	40,010	7,039	$1,094	$1,876	$782
2024	4,780,849	43,902	7,724	$1,084	$1,786	$702

The ACIAR project left both human and machine capital in Thailand that could work on future postharvest heat-treatment research. However, the stock of this capital declines over time. Staff trained within the project more on to new roles and some retire. Equipment is replaced. It appears that at the present time there is a relatively small component left although the organisational capacity is arguably permanently enhanced. Moreover, ongoing work is needed to ensure that access based on a heat-treatment protocol can be maintained. Our assessment is that, following Monck and Pearce (2007), an initial attribution of 40% is appropriate. Based on the decline in the stock of human and machine capital and the ongoing work required, the assessment is that the benefits directly attributable to the original projects have declined substantially to the present time. A small residual contribution remains. The declining attribution is modelled using the formula, $\Omega=0.4-0.4/(1+EXP(0.4*(15-t)))$ where *EXP* is the natural exponent and *t* is indexed from one to 28. Attributable benefits in 2006–07 values are A$123,572in 1993–94 and decline to A$600 in 2019–20.

Estimated benefits

Table 47 shows estimated benefits.

Market access mangosteen exports to Japan

Thailand was given non-host status for mangosteen by Australia in 2004. It has achieved non-host status for mangosteen in USA and New Zealand. However, the USA also requires irradiation to deal with other pests.

Exports to Japan commenced in 2003 with 415 tonnes. In 2006 they were 169 tonnes. Exports to Australia commenced in 2004 and in calendar year 2006 were 74 tonnes worth around A$270,000.

Estimated benefits

Table 48 shows estimated benefits.

Capacity building

Insofar as capacity building is concerned, Thailand has a major commitment to agricultural exports generally and fruit exports in particular. Given the lags, many of the scientists trained in the original ACIAR projects have moved on or retired. However, on the basis of the original work and the ongoing commitment, a new generation of scientists is in place, trained at a variety of national and international locations. The fruit-fly rearing facilities are modern and well supported. Two heat-treatment plants are in place for doing the required work on postharvest disinfestation. Although the current scientists were not specifically trained in ACIAR projects the current director acknowledges the training groundwork laid down in the original projects. In particular, materials produced under the original project (CS/1998/005) are still in use as reference documents for fruit-fly identification.

The projects on postharvest heat treatment and low-cost disinfestation (PHT/1990/051 and PHT/1993/877) had a major capacity building element. Department of Agriculture personnel achieved upgraded facilities and capability for the delivery of disinfestation research in the ASEAN region. The objective was to build a base that would provide ongoing opportunities after the completion of the ACIAR projects. Again, the benefits of the original training are to a large extent embedded in the estimates made above of mango exports to Japan. The commencement of these exports followed the completion of PHT/1990/051 and that work was the basis for the development of the postharvest treatment data on mangoes. Again, while some of the original scientists have moved on and the current installed heat treatment equipment was sourced from Japan, the director acknowledges the critical role that the ACIAR research played in developing postharvest capability.

The work on low-chill temperate fruits (CP/2001/027) is much more recent and capacity-building activities are still occurring. The capacity building here is fundamentally about training extension officers and, through them, farmers. The project-based training has been extensive. Table 49 shows the courses undertaken as part of the project.

Table 47. Attributable net benefits for Thailand mango exports to Japan

Year	Net surplus	Attribution to ACIAR projects	Attributed to ACIAR projects
93–94	$308,948	0.40	$123,572
94–95	$303,446	0.40	$121,365
95–96	$406,355	0.40	$162,505
96–97	$496,797	0.40	$198,629
97–98	$367,173	0.40	$146,735
98–99	$477,303	0.40	$190,571
1999–2000	$506,998	0.40	$202,052
00–01	$1,190,791	0.40	$472,796
01–02	$1,249,696	0.39	$492,493
02–03	$2,547,555	0.39	$989,152
03–04	$3,039,003	0.38	$1,145,918
04–05	$3,389,277	0.36	$1,207,807
05–06	$3,655,779	0.32	$1,173,043
06–07	$3,935,462	0.27	$1,051,851
07–08	$4,233,859	0.20	$846,772
08–09	$4,555,245	0.13	$604,594
09–10	$4,885,926	0.08	$386,606
10–11	$5,232,673	0.04	$228,347
11–12	$5,584,353	0.02	$128,047
12–13	$5,937,996	0.01	$69,622
13–14	$6,277,222	0.01	$37,096
14–15	$6,582,182	0.00	$19,461
15–16	$6,824,049	0.00	$10,057
16–17	$6,971,361	0.00	$5,111
17–18	$6,999,421	0.00	$2,551
18–19	$6,886,590	0.00	$1,247
19–20	$6,670,082	0.00	$600
20–21	$127,650,801	0.00	$5,701
Present value			
Total	**$138,060,613**		**$10,795,815**
Realised	**$24,700,938**		**$8,811,547**
Prospective	**$113,359,675**		**$1,984,268**

Table 48. Attributable net benefits for mangosteen exports to Japan

Year	Net surplus	Attribution to ACIAR projects	Attributed to ACIAR projects
02–03	$1,070,323	0.40	$428,128
03–04	$861,782	0.40	$344,711
04–05	$799,946	0.40	$319,975
05–06	$422,860	0.40	$169,139
06–07	$421,581	0.40	$168,620
07–08	$420,306	0.40	$168,091
08–09	$419,034	0.40	$167,533
09–10	$417,767	0.40	$166,898
10–11	$416,503	0.40	$166,065
11–12	$415,243	0.40	$164,721
12–13	$413,987	0.39	$162,095
13–14	$412,735	0.38	$156,373
14–15	$411,486	0.35	$143,897
15–16	$410,241	0.29	$119,815
16–17	$409,000	0.21	$84,238
17–18	$407,763	0.12	$48,393
18–19	$406,530	0.06	$23,580
19–20	$405,300	0.03	$10,329
20–21	$8,081,476	0.00	$4,241
Present value			
Total	**$11,441,046**		**$2,712,198**
Realised	**$3,853,456**		**$1,541,360**
Prospective	**$7,587,590**		**$1,170,838**

Table 49. Extension officer and farmer training in Thailand on orchard management

Date	Site	Number of trainees	Type of training group	
			Technicians and extension officers	Farmers
18/7/2001	Khun Wang	60	55	5
9–10/4/02	Chiang mai, Khun Wang	10	10	0
29/4/03	Ban Pang Kon, Chiang rai	30	5	25
27/4/2004	Ban Pang Kon, Chiang rai	20	5	15

There have been no prospective benefits estimated for low-chill temperate fruits for Thailand. In part this is based on lack of meaningful data on expected uptake and hectares. It is also based on the assessment by participants that without a major commitment to ongoing training and demonstration, uptake will be very slow and sporadic.

The Royal Project Foundation has taken up the case for low-chill temperate fruits in northern Thailand. It has some 36 research and extension centres in the Highlands of northern Thailand, which can undertake the required extension activities. A related issue is that development of temperate fruits does not appear to be a high priority for the Thai Government. It is not incorporated into any formal agriculture plan as it is in Vietnam. Thailand has enormous export potential across a range of tropical fruits and policy emphasis is on these.

Appendix 14. Tonga case study

Market access for exports of squash to Japan on basis of non-host status

The export of fresh 'Kabocha' squash to Japan, and more recently to South Korea, has been described as the mainstay of the Tongan economy (McGregor 1999). The volume and value of these exports since inception of the trade are depicted in Figure 24.

Data on host ranges for all species from ACIAR/ Regional Management of Fruit Flies in the Pacific (RMFFP) fruit collection surveys was used to establish that fruit flies do not attack squash in Tonga. Freedom from exotic fruit flies of particular concern to Japan also was confirmed from trapping trials and host surveys. These findings were used as the basis for negotiations on quarantine protocols for export of squash to Japan. Therefore, outputs from the ACIAR/RMFFP projects were a necessary input to the establishment and maintenance of the Japanese squash market. Furthermore, a significant part of the value from these exports is value added to the Tongan economy because two of the main inputs, namely land and labour, have a low opportunity cost in Tonga.

Biosecurity—entry of *B. cucurbitae*

There are six species of fruit flies in Tonga (Tephritidae: Dacinae), but only three species that are of economic importance on Tongatapu – *B. facialis, B. kirki* and *B. xanthodes*. Host surveys have shown that damage from fruit flies can be as high as 90% in guava, 89–97% in chilli, and 97–100% in capsicum. Fleshy vegetables are virtually free from fruit-fly infestation.

The ACIAR/RMFFP projects established an early-warning quarantine surveillance system of trapping sites on high-risk locations on six islands of Tonga.

The three endemic species of economic importance on Tonga have a limited host range. Guava, chilli and capsicum are the main hosts that incur significant damage, so an incursion of pest fruit-fly species that infest other fresh fruit and leafy vegetables would have severe consequences for domestic consumption of these foods. However, the biggest threat is to the multi-million dollar squash industry. This industry is the largest in Tonga, and almost all of the exports go to Japan, which would promptly shut down imports from Tonga if there was an incursion by any one of several exotic pest fruit flies.

Hence, fruit-fly quarantine surveillance is critical to keep Tonga free of such destructive fruit-fly species as *B. cucurbitae* (melon fly, pumpkin fly), *B. atrisetosa, B. strigifinis, D. solomonensis, B. papayae*, and *B. dorsalis*. This case study analyses the biosecurity benefits from quarantine surveillance to protect against a possible incursion by *B. cucurbitae*, in part because the species arguably poses the most serious threat to the squash industry. Melon fly is native to Tropical Asia, but has spread to parts of the Indian Ocean and Africa. Also of special importance for the Tonga squash exports, it is now endemic to Hawaii and some Pacific island countries (PICs) including Guam, the Commonwealth of the Northern Mariana Islands (CNMI), Papua New Guinea, Nauru and Solomon Islands. Also, detailed information on costs of eradicating it from CNMI was available from a feasibility study by McGregor and Vargas (2002).

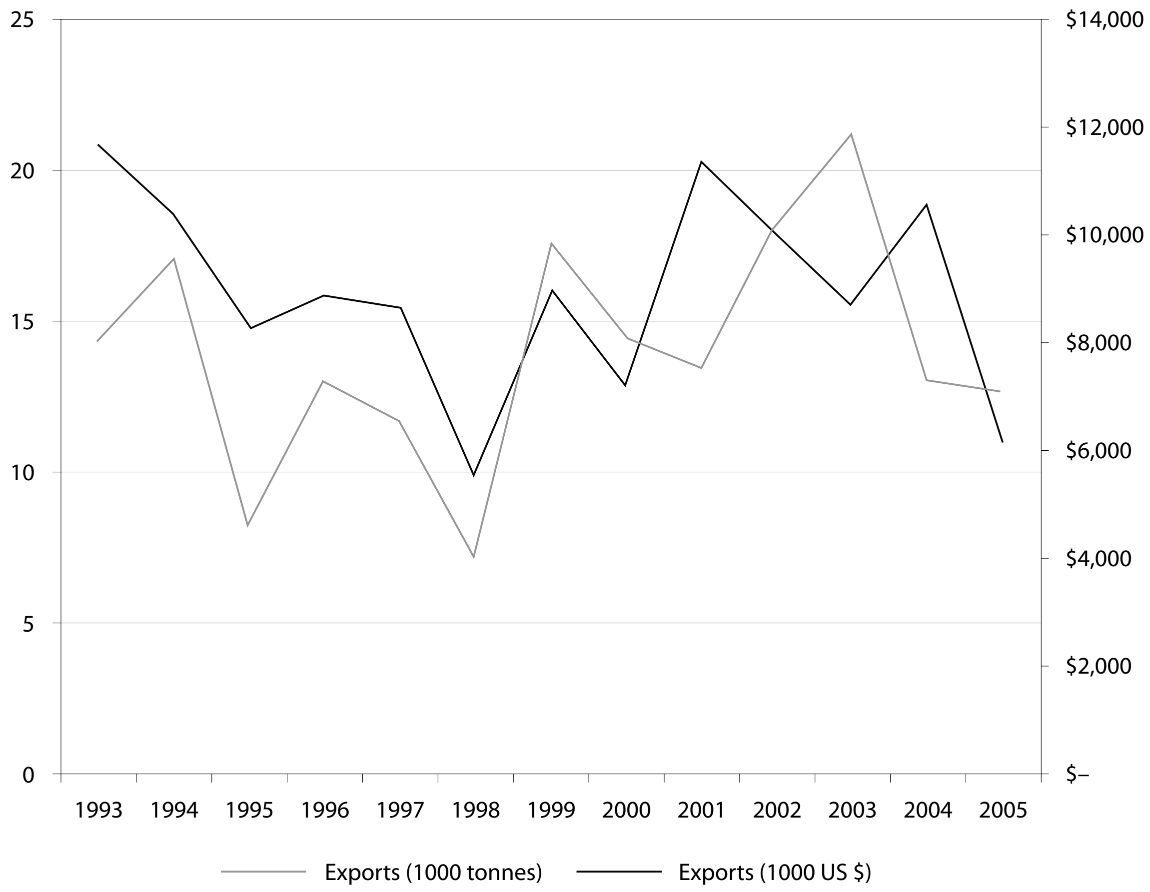

Figure 24. Tongan squash exports to Japan. Source: FAOSTAT 2008

'With R&D' scenario

This scenario is based on the following facts and informed judgments:

- Tonga negotiated a bilateral quarantine agreement (BQA) with Japan based on a non-host protocol for the export of fresh 'Kabocha' squash to Japan.
- Outputs from the ACIAR/RMFFP projects were necessary enabling inputs for this BQA and the start of the export trade in 1993.
- Value added from squash exports was assessed to be 10% of export values.
- Tonga maintained an effective quarantine surveillance system after cessation of the RMFFP project in 2000 at an annual cost of A$50,000 in 2007 dollars.
- There is a 5% probability of entry by *B. cucurbitae* without immediate detection and destruction in any given year. There is a conditional probability of 50% that the entry will become established and go undetected by quarantine surveillance trapping until completion of the third generation of the breeding population, by which time the incursion will occupy about 5 km^2. Thus, there is a joint probability of 2.5% of the need for a 'small' eradication program lasting 2.5 years.
- An emergency response plan involving a minor eradication campaign will be implemented immediately. A combination of male annihilation (MA), spot protein bait treatment, and the expensive sterile insect technique (SIT) will still be needed, and the budget in Table 50 was derived by adjusting estimates made by McGregor (2002) of the cost to eradicate melon fly from the CNMI.

Table 50. Estimated costs of a minor campaign to eradicate melon fly (US$,000)

Year	1	2	3	3 yr sum
Establishing and maintaining a population monitoring and surveillance system				
materials and equipment	6.7	6.7	3.3	16.7
vehicles operating expenses	0.4	.0.4	.0.2	1.1
Population suppressing measures				
ivy gourd eradication	0.3			0.3
male annihilation and bait spraying	100			100
Sterile fly purchases		130.8		130.8
Sterile fly distribution				
helicopter hire		45.8		45.8
vehicle operating costs		1.1		1.1
Project management and staff				
project manager remuneration	10.0	10.0	5.0	25.0
other management and staff costs	17.0	17.0	8.5	42.5
Capital equipment				
vehicles	25.0			25.0
computers and ancillary office equipment	3.0			3.0
laboratory equipment	2.0			2.0
Total costs (2002 US$,000)	164	212	17	393
A$:US$	**0.59**	**0.71**	**0.75**	
Deflator 2001–02 to 2006–07	**0.83**	**0.83**	**0.83**	
Total costs (2007 A$)	**$336,331**	**$357,501**	**$27,225**	**$634,859**

- Exports of squash to Japan would be suspended for 3 years until the incursion was eradicated.
- There would be a negligible loss of production for domestic consumption because the incursion would occupy less than 1 % of the area of Tonga. It was assessed to be less than 0.5% of the value of subsistence and commercial fresh fruit and leafy vegetables production for only the first year of the incursion.
- The overall value of subsistence and commercial fresh fruit and leafy vegetables production in Tonga was estimated to be A$5.3 million in constant 2007 dollars. This figure was derived from an estimate by McGregor (1999) that domestic fruit production in Fiji was about US$33 million by adjusting for differences in population and income levels between Tonga and Fiji.
- It is possible for further incursions to occur after a campaign has successfully eradicated melon fly from Tonga, in which case a further cycle of eradication costs and export and production losses would follow.

Annual estimates for the 'with R&D' scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a small eradication program plus annual quarantine surveillance costs are set out in Table 51.

Table 51. Benefits for Tonga 'with R&D' scenario

Year	Fruit exports				Small incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$0	$0	$2,401,115	−$60,028	$0	$0	$0
94–95	$0	$0	$1,974,269	−$97,480	−$0	−$8,408	−$50,000
95–96	$0	$0	$1,485,767	−$108,670	−$0	−$17,122	−$50,000
96–97	$0	$0	$1,532,990	−$112,124	−$0	−$17,769	−$50,000
97–98	$0	$0	$1,702,192	−$124,499	−$0	−$17,769	−$50,000
98–99	$0	$0	$1,194,119	−$87,339	−$0	−$17,769	−$50,000
1999–2000	$0	$0	$1,882,246	−$137,669	−$0	−$17,769	−$50,000
00–01	$0	$0	$1,690,170	−$123,620	−$0	−$17,769	−$50,000
01–02	$0	$0	$2,619,236	−$191,573	−$0	−$17,769	−$50,000
02–03	$0	$0	$1,995,134	−$145,925	−$0	−$17,769	−$50,000
03–04	$0	$0	$1,399,261	−$102,343	−$0	−$17,769	−$50,000
04–05	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
05–06	$0	$0	$872,442	−$63,811	−$0	−$17,769	−$50,000
06–07	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
07–08	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
08–09	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
09–10	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
10–11	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
11–12	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
12–13	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
13–14	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
14–15	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
15–16	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
16–17	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
17–18	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
18–19	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
19–20	$0	$0	$1,541,290	−$112,731	−$0	−$17,769	−$50,000
20–21	$0	$0	$30,825,792	−$2,254,618	−$0	−$355,388	−$1,000,000

'Without R&D' scenario

In this scenario:

- The possibility that Tonga would acquire the necessary data to enable squash export from other sources in subsequent years was assessed to be equal to $1/(1+ EXP(0.4*(17–t)))$ where *EXP* is the natural exponent and *t* is indexed from one to 44.
- In any given year, there is a 4.5% probability that an incursion of *B. cucurbitae* will remain undetected until it is widely established on several islands, and occupies about half of the total land area of Tonga. Hence, the probability that Tonga will remain free of such an incursion for *t* consecutive years is given by $(1\text{-}\alpha)^{\wedge t}$, where $\alpha = 0.045$ is the probability of an incursion in any given year.
- Whenever such an incursion occurs, a major eradication campaign lasting 5 years will be carried out using a combination of male annihilation (MA), spot protein bait treatment, and the expensive sterile insect technique (SIT). The budget in Table 52 is based on estimates by McGregor (2002) of the cost to eradicate melon fly from the CNMI, which has a land area of about 50% of that of Tonga.
- All exports of squash cease for the 5-year duration of the eradication campaign.
- In the first year of the incursion, melon fly infestation of host plants will cause considerable damage. However, because the melon fly has a relatively restricted host range, and other non-host foods could be grown that would be at least partial substitutes for host foods, the loss in overall value of subsistence and commercial fresh fruit and leafy vegetables production is assessed to be only 5% for only the first year of the incursion.

Annual estimates for the 'without R&D' scenario of calculated value added from exports enabled by postharvest disinfestation treatment or by non-host protocols, expected loss of these values, the expected loss of the value of domestic subsistence and commercial fruit production due to the possibility of an incursion, and the expected cost of a large eradication program plus annual quarantine surveillance costs are set out in Table 53.

Estimated benefits

Estimates of the annual value of total benefits of the ACIAR and related fruit-fly projects, together with the proportion of these calculated values that could reasonably attributed to the ACIAR projects, are shown in Table 54. The values of benefits actually attributed to the ACIAR fruit-fly projects are shown in Table 55.

The share of value added from squash exports that can be attributed to the ACIAR projects was assessed to be 50% initially, and then to decline gradually over time according to the formula below for Ω that reflects the possibility that Tonga would have acquired the necessary enabling data from other sources in subsequent years.

$$\Omega = 1–1/(1+ EXP(0.4*(17–t)))$$

where *EXP* is the natural exponent and *t* is indexed from one to 45. Attribution of other benefits to the ACIAR projects is the same as for Cook Islands.

Capacity building

Tongan scientists and managers have benefited along with other island nations from the training and capacity-building activities under the RMFFP. The RMFFP has conducted three courses in Tonga on fruit-fly management. Staff have been trained in preparing emergency response plans. In 2000 the RMFFP conducted an update course on fruit-fly management including: biology of fruit flies, importance of quarantine surveillance, field control methods, quarantine treatments, emergency response planning and ERP. One Tongan official attended. As noted above, outputs from the ACIAR/RMFFP projects were necessary to enabling inputs for the Tongan BQA with Japan that allowed squash exports based on non-host status.

Table 52. Melon fly eradication costs in the CNMI (US$,000)

Year	1	2	3	4	5	5 yr sum
Establishing and maintaining a population monitoring and surveillance system						
materials and equipment	200	200	200	200	200	1,000
vehicles operating expenses	13	13	13	13	13	65
Population suppressing measures						
ivy gourd eradication	15					15
male annihilation and bait spraying		3,000				3,000
Sterile fly purchases		1,570	1,570			3,140
Sterile fly distribution						
helicopter hire		550	550			1,100
vehicle operating costs		13	13			26
Project management and staff						
project manager remuneration	100	100	100	100	100	500
other management and staff costs	170	170	170	170	170	850
Capital equipment						
vehicles	250			250		500
computers and ancillary office equipment	30			20		50
laboratory equipment	20			10		30
Total costs (2002 US$,000)	**798**	**5,616**	**2,616**	**763**	**483**	**10,276**
A$:US$	**0.59**	**0.71**	**0.75**	**0.75**	**0.79**	
Deflator 2001–02 to 2006–07	**0.83**	**0.83**	**0.83**	**0.83**	**0.83**	
Total costs (2007 A$)	$1,633,052	$9,477,115	$4,177,207	$1,231,780	$735,926	17,255,080

Table 53. Benefits for Tonga 'without R&D' scenario

Year	Fruit exports				Large incursion		
	Market access by HTFA protocol		Market access by non-host protocol		Domestic production	Eradication	Quarantine surveillance
	Value added by exports	Expected loss from incursion	Value added by exports	Expected loss from incursion	Expected loss from incursion	Expected cost of campaign	Extra operating cost
93–94	$0	$0	$0	$0	$0	$0	$0
94–95	$0	$0	$0	$0	−$21,267	−$73,487	$0
95–96	$0	$0	$0	$0	−$21,267	−$480,766	$0
96–97	$0	$0	$0	$0	−$21,267	−$652,204	$0
97–98	$0	$0	$0	$0	−$21,267	−$700,482	$0
98–99	$0	$0	$0	$0	−$21,267	−$728,028	$0
1999–2000	$0	$0	$0	$0	−$21,267	−$728,028	$0
00–01	$0	$0	$0	$0	−$21,267	−$728,028	$0
01–02	$0	$0	$0	$0	−$21,267	−$728,028	$0
02–03	$0	$0	$0	$0	−$21,267	−$728,028	$0
03–04	$0	$0	$0	$0	−$21,267	−$728,028	$0
04–05	$0	$0	$0	$0	−$21,267	−$728,028	$0
05–06	$0	$0	$0	$0	−$21,267	−$728,028	$0
06–07	$0	$0	$0	$0	−$21,267	−$728,028	$0
07–08	$0	$0	$0	$0	−$21,267	−$728,028	$0
08–09	$0	$0	$0	$0	−$21,267	−$728,028	$0
09–10	$0	$0	$0	$0	−$21,267	−$728,028	$0
10–11	$0	$0	$0	$0	−$21,267	−$728,028	$0
11–12	$0	$0	$0	$0	−$21,267	−$728,028	$0
12–13	$0	$0	$0	$0	−$21,267	−$728,028	$0
13–14	$0	$0	$0	$0	−$21,267	−$728,028	$0
14–15	$0	$0	$0	$0	−$21,267	−$728,028	$0
15–16	$0	$0	$0	$0	−$21,267	−$728,028	$0
16–17	$0	$0	$0	$0	−$21,267	−$728,028	$0
17–18	$0	$0	$0	$0	−$21,267	−$728,028	$0
18–19	$0	$0	$0	$0	−$21,267	−$728,028	$0
19–20	$0	$0	$0	$0	−$21,267	−$728,028	$0
20–21	$0	$0	$0	$0	−$425,332	−$14,560,569	$0

Table 54. Annual value of total net benefits for Tonga and attribution ratios

Year	Market-access benefits				Biosecurity benefits		Total benefit
	HTFA exports	Attribution to ACIAR projects	Non-host exports	Attribution to ACIAR projects	Biosecurity benefit	Attribution to ACIAR projects	Attributed to ACIAR projects
93–94	$0	0.05	$2,341,087	0.50	$0	0.50	$1,168,602
94–95	$0	0.05	$1,876,789	0.50	$36,346	0.50	$954,247
95–96	$0	0.05	$1,377,097	0.50	$434,911	0.50	$903,467
96–97	$0	0.05	$1,420,866	0.50	$605,701	0.50	$1,009,386
97–98	$0	0.05	$1,577,692	0.50	$653,980	0.50	$1,109,397
98–99	$0	0.05	$1,106,780	0.49	$681,526	0.50	$887,441
1999–2000	$0	0.05	$1,744,577	0.49	$681,526	0.50	$1,197,362
00–01	$0	0.05	$1,566,550	0.49	$681,526	0.50	$1,103,205
01–02	$0	0.05	$2,427,663	0.48	$681,526	0.50	$1,507,054
02–03	$0	0.05	$1,849,209	0.47	$681,526	0.50	$1,212,365
03–04	$0	0.05	$1,296,918	0.46	$681,526	0.50	$935,288
04–05	$0	0.05	$1,428,559	0.44	$681,526	0.50	$969,898
05–06	$0	0.05	$808,631	0.42	$681,526	0.50	$677,161
06–07	$0	0.05	$1,428,559	0.38	$681,526	0.50	$889,704
07–08	$0	0.05	$1,428,559	0.34	$681,526	0.50	$833,597
08–09	$0	0.05	$1,428,559	0.30	$681,526	0.50	$768,393
09–10	$0	0.05	$1,428,559	0.25	$681,526	0.50	$697,903
10–11	$0	0.05	$1,428,559	0.20	$681,526	0.50	$627,412
11–12	$0	0.05	$1,428,559	0.16	$681,526	0.50	$562,208
12–13	$0	0.05	$1,428,559	0.12	$681,526	0.50	$506,101
13–14	$0	0.05	$1,428,559	0.08	$681,526	0.50	$460,749
14–15	$0	0.05	$1,428,559	0.06	$681,526	0.50	$425,907
15–16	$0	0.05	$1,428,559	0.04	$681,526	0.50	$400,171
16–17	$0	0.05	$1,428,559	0.03	$681,526	0.50	$381,708
17–18	$0	0.05	$1,428,559	0.02	$681,526	0.50	$368,738
18–19	$0	0.05	$1,428,559	0.01	$681,526	0.50	$359,761
19–20	$0	0.05	$1,428,559	0.01	$681,526	0.50	$353,610
20–21	$0	0.05	$28,571,174	0.01	$13,630,513	0.50	$6,988,518

Table 55. Attributed net benefits for Tonga

Year	Attributed to ACIAR projects			
	HTFA exports	**Non-host exports**	**Biosecurity benefits**	**Total benefit**
93–94	$0	$1,168,602	$0	$1,168,602
94–95	$0	$936,074	$18,173	$954,247
95–96	$0	$686,012	$217,455	$903,467
96–97	$0	$706,535	$302,850	$1,009,386
97–98	$0	$782,407	$326,990	$1,109,397
98–99	$0	$546,678	$340,763	$887,441
1999–2000	$0	$856,599	$340,763	$1,197,362
00–01	$0	$762,442	$340,763	$1,103,205
01–02	$0	$1,166,291	$340,763	$1,507,054
02–03	$0	$871,602	$340,763	$1,212,365
03–04	$0	$594,525	$340,763	$935,288
04–05	$0	$629,135	$340,763	$969,898
05–06	$0	$336,398	$340,763	$677,161
06–07	$0	$548,941	$340,763	$889,704
07–08	$0	$492,835	$340,763	$833,597
08–09	$0	$427,630	$340,763	$768,393
09–10	$0	$357,140	$340,763	$697,903
10–11	$0	$286,649	$340,763	$627,412
11–12	$0	$221,445	$340,763	$562,208
12–13	$0	$165,338	$340,763	$506,101
13–14	$0	$119,986	$340,763	$460,749
14–15	$0	$85,144	$340,763	$425,907
15–16	$0	$59,409	$340,763	$400,171
16–17	$0	$40,945	$340,763	$381,708
17–18	$0	$27,975	$340,763	$368,738
18–19	$0	$18,998	$340,763	$359,761
19–20	$0	$12,847	$340,763	$353,610
20–21	$0	$173,262	$6,815,257	$6,988,518
Net present value				
Total	**$0**	**$16,490,825**	**$11,243,552**	**$27,734,377**
Realised	**$0**	**$14,561,251**	**$4,916,744**	**$19,477,995**
Prospective	**$0**	**$1,929,574**	**$6,326,808**	**$8,256,382**

Appendix 15. Vanuatu

The effectiveness of the quarantine surveillance system in Vanuatu could not be verified, so no biosecurity benefits were estimated. Projected growth in fruit exports have not materialised since completion of the project in Vanuatu, so no market access benefits were estimated. Potentially, there could have been field control benefits in Vanuatu from use of protein bait spray, but the Tusker Brewery ceased production because of lack of demand. Hence, no attempt was made to estimate any field control benefits.

Vanuatu has benefitted from the capacity-building activities of the Regional Management of Fruit Flies in the Pacific (RMFF) program in conjunction with ACIAR. Seven staff were involved in a training course on identification, biology and surveillance of fruit flies in Solomon Islands, Vanuatu and Papua New Guinea, which was jointly funded and delivered by RMFFP and ACIAR. An in-country identification workshop was funded by ACIAR and held in Vanuatu in 1999. Two staff were trained in a course on the generation of heat tolerance data for immature stages of fruit flies, which was held in Port Vila in 1999.

Appendix 16. Vietnam case study

Production of fruit crops in Vietnam is estimated to be around 6.5 million tonnes. Major crops are: banana, citrus (orange, mandarin orange and grapefruit) and lychee. The north has around 300,000 ha of fruit crops, while the Mekong Delta has around 231,000 ha.

Vietnam has increased its production of fruit crops markedly in recent years. Between 1990 and 2006, the area of fruit production increased from 281,000 hectares to 774,000 hectares. Current planning calls for fruit production areas to be increased to 1 million ha by 2010. Recent trends in production area and value are shown in Table 56.

Vietnam has been steadily developing fruit exports, with around 10% of total production of fresh fruit being exported. Major fruit exports are longan, thanh long (blue dragon fruit) and lychee. China and Taiwan have been the main export markets.

Table 57 shows recent export data and country of destination.

Fruit flies, which affect a wide variety of fruit and vegetable crops grown for fresh food markets, are Vietnam's most significant fruit and vegetable pest. Without control, infestation levels can reach 100% of the fruit in areas of high fruit-fly populations.

The original ACIAR work in CS2/1998/005—managing pest fruit flies to increase production of fruit and vegetable crops in Vietnam—documented the extent of pest fruit flies. Table 58 shows the estimated fruit-fly impacts by crop.

The prevalence of fruit-fly pests across such as large range of crops is a major issue. Vietnam has policies that focus on improving the performance of its domestic and export fruit industries, and bringing major pests such as fruit fly under control is a necessary condition to achieve this objective. This focus is reflected in the pattern of benefits estimated below for the various ACIAR projects.

With respect to biosecurity, Vietnam has not developed an effective quarantine surveillance system. Hence no biosecurity benefits were estimated.

Table 56. Recent trends in Vietnam fruit production

Year	Total area (ha)	Area growth (%)	Output value (billion VND)	Value growth (%)
2000	565,000	10.2	6105.9	-0.4
2001	609,600	7.9	6402.3	4.8
2002	677,500	11.1	6894.9	7.6
2003	724,500	6.9	7017.3	1.7
2004	747,800	3.2	7439.9	6.0

Source: GSO Yearbook 2004

Table 57. Fruit exports from Vietnam by major destination

Vietnam's fruit exports (million US$)						
Market	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
China	10.454	35.686	120.351	142.800	121.529	67.068
Taiwan	6.055	11.895	20.841	23.319	20.897	21.584
Japan	6.570	9.365	11.729	14.520	14.527	16.710
Korea	4.088	10.075	13.691	20.194	7.783	9.660
Russia	1.248	2.095	4.654	5.030	8.506	8.293
US	2.559	3.209	2.178	1.971	5.318	8.073
Netherlands	1.260	1.589	2.160	2.381	3.870	5.899
Singapore	2.322	2.076	1.226	1.300	3.401	4.454
Hong Kong	5.094	3.222	3.316	1.334	4.581	3.699
Total	53.392	104.992	213.100	329.972	201.156	152.470

Source: Ministry of Agriculture and Rural Development, Vietnam

Table 58. Fruit-fly losses in Vietnamese fruit crops

	Fruit	**Sampling period**	**Location**	**Losses (%)**			**Fruit flies**
				Early crop	**Main crop**	**End crop**	
1	Cherry	3-6/02	Go Cong	70	56	62	*B.correcta, B.dorsalis*
2	Dragon fruit	3-7/04	Cho Gao	2	12	5	
3	Guava	4-8/04	Cai Be	25	80	85	
4	Luffa	2-5/05	Cho Gao	26	100	100	
5	Bitter gourd	3-6/02	Cai Be	1	67	78	
6	Mango	1-7/04	Cai Be	2	8	5	*B.dorsalis*
7	Longan	1-7/04	Vinh Kim	2	8	5	
8	Sapodilla	10/04-3/05	Chau Thanh	35	80	98	
9	Melon	10/04-3/05	Tan My Chanh	12	52	75	*B.cucurbitae, B.tau*
10	Peach	5-7/04	Moc Chau	0	33	100	*B.dorsalis, B.pyrifoliae*
11	Jujube	10/03	Thuy Nguyen	5	28	40	*B.dorsalis*
12	Tangerine	11-12/04	Bac Son	22	20	0	*B.dorsalis, B.pyrifoliae*
13	Persimmon	8-10/04	Da Bac	3	75	9	*B.dorsalis*
14	Bitter gourd	4-6/02	Tu Liem	3	75	100	*B.cucurbitae*
15	Bitter gourd	8-9/02	Me Linh	2	4	16	
16	Lychee	6-7/02	Luc Ngan	0	0	10	*B.dorsalis*

Source: National Institute for Plant Protection, Vietnam

To date Vietnam exports have gone primarily to countries without strict quarantine requirements. The largest markets have been China and Taiwan. There is no evidence of postharvest treatment protocols being submitted based on ACIAR work. No exports of fresh fruit and leafy vegetables from Vietnam can be attributed to any of the ACIAR projects, so no market access benefits were estimated.

There are significant prospective benefits attributable to ACIAR-funded projects CS2/1998/005 on field control (protein bait) and CP/2001/027 on the adaptation of low-chill temperate fruits. The two projects are related in that the latter includes the use of protein bait as part of the field control.

As noted, the prevalence of pest fruit flies is a major threat to fruit production and as such is a threat to achieving the stated government objective of expanding fruit production and fruit exports. The adoption of low-cost protein bait has the potential to make a major contribution to controlling fruit fly, and improving fruit quality and farm performance.

The significant development of the protein bait spray technology in Vietnam arose in project CS2/1998/005. The developed technology resulted in the first fully commercial factory capable of producing 50,000 litres of protein bait per year being built in the Foster's Brewery in the Mekong Delta in South Vietnam. The facility produced its first small trial batch in December 2002 and enough bait for about 420 ha of crop in 2004. ACIAR researchers were an integral part of planning for this facility. The protein bait is marketed by the Cantho Pesticide Company in South Vietnam under the commercial name of SOFRI Protein 10DD. The application of this protein bait has provided excellent control of fruit flies on farms producing peach, guava, jujube, barbados cherry, luffa and bitter gourd, and uptake rates during the term of the first International Centre for Management of Pest Fruit Flies (ICMPFF)-led ACIAR project in Vietnam were significant.

At the time of drafting this report, the prospect exists for the plant to be relocated from the brewery to the pesticide company. This has potential cost implications that could influence the price of bait at the current level. Any increase in the price charged for the protein bait would further inhibit uptake even though the area of potential application is well in excess of projected plant capacity.

The potential benefits depend on the area treated, which in turn depends on production capacity and the application regime. If each crop requires eight treatments per year, and each treatment requires 1 litre of bait per ha and if there are at least two crops per ha per year, then the current installed capacity of 50,000 litres/year would only be sufficient to treat about 3,000 ha. This is slightly more than the 1% of the estimated 250,000 ha in South Vietnam alone where fruit flies need to be controlled. Current capacity is 50,000 litres/year, which is about 20% of brewery waste yeast. In theory, capacity could be increased to 250,000 litres/year if further investment capital were available. Using the above indicative application rates, this equates to only 15,000 ha. This represents a small market penetration target and the potential yield and income improvements, if they can be replicated in commercial operations, offer a significant incentive to farmers. Moreover, as with the planning for the plant in the north, the relatively small area targeted means that marketing can be focused on larger commercial farm operators. Prices are 40,000 dong (A$2.70) per litre.

Following the perceived success of the protein bait plant in South Vietnam, ACIAR funded a small project in North Vietnam to establish a second protein bait plant for the northern region of Vietnam. The partners in project CP/2007/187 were National Institute of Plant Protection (NIPP) and MDI Vietnam. MDI is an organisation that develops commercial ventures with a focus on alleviating poverty. This plant is a joint venture between An Thinh brewery, Hoa Binh chemical company and MDI Vietnam that produces protein bait marketed under the name of ENTO – PRO. It is a fully commercial operation in which the brewery has invested as a way of diversifying to offset seasonal beer sales in North Vietnam. Officially launched in May 2007 the plant has a capacity of 115,000 litres/year, although planning envisages a second-stage expansion to 300,000 litres/year and ultimately to 400,000 litres/year. Initially, the price of ENTO – PRO was 10,000 dong (A$0.67) per litre, but this has increased now to 40,000 dong (A$2.70) per litre, similar to the price in the south.

Based on a range of crops being treated with protein bait, application in the north will average 14 litres/ha. Planning anticipates that protein bait will be used on around 17,500 ha. As with the projected demand in the south, this is a small part of the projected total hectares of fruit production. In the north, there are official targets to expand fruit production. By 2010 area planted is projected to grow to 424,000 ha. North Vietnamese fruit production has suffered from poor management and poor varieties, in addition to the fruit-fly pests. The primary focus in CP/2001/027 was the introduction from Australia and Thailand of a range of varieties of plum, peach, nectarine, pear and persimmon to upland regions of both Laos and Vietnam to replace poor-quality, locally grown cultivars, and to overcome constraints to high-value production that included, but was not limited to, fruit damage from fruit-fly infestation. CP/2002/086 was an adjunct to CP/2001/027 and had similar aims, except that the focus was on post-farm-gate fruit handling throughout the Vietnamese supply chain rather than on on-farm production problems.

As part of this project, four arboreta sites were established in Vietnam with a range of chilling. Over 1,300 stone fruit trees of 25 varieties of peach, plum, nectarine and persimmon have been sent to Vietnam (and Laos). The sites are in: Moc Chau, Bac Ha, Sapa and Dalat (100 chill units). Within the ACIAR project, high-quality, medium-chill plum cultivars black amber, simca and fortune were identified as potentially valuable crops.

Beyond the identification and planting of improved varieties, the major challenge in temperate fruit production in Vietnam is to improve orchard practices. The project identified a range of improved management practices that would benefit farmers. Low input practices such as deficit irrigation, mulching, new orchard hygiene systems (e.g. spot spraying), new tree training and management systems (e.g. postharvest topping and use of exclusion netting and fruit bagging) to eliminate fruit fly have all been trialled. Although manuals have been produced, the key to uptake will be the results from demonstration areas, and the promotion of these varieties and techniques by extension officers and committed farmers. People spoken to as part of this study were under no illusion about the magnitude of this challenge. The areas concerned are very poor farming areas with a high proportion of poorly educated farmers. They have a long history of managing in a certain way (e.g. harvesting hard green to avoid fruit-fly losses) (Nissen 2006b). Adjustment and uptake will be slow. In Vietnam, bait programs were integrated into the management regime and have proved to be highly successful in controlling fruit fly in the experimental areas.

Low-chill temperate fruit production in North Vietnam

The prospective temperate fruit development benefits fit within the stated government aim of expanding the area in the north to 10,000 ha of temperate fruits by 2010. Although the target year looks unrealistic, we have taken the area to be reflective of intent. Based on discussion with those involved with the research, the potential uptake rate for the ACIAR work is estimated to be at most 15–20%. An area of 2,160 ha by 2020–21 has been used in the analysis.

There are two benefit streams arising from the research. Improved management incorporating effective pest control can increase yields and improve returns. If crops are managed so they can be harvested ripe rather than green then the unit prices received by farmers will increase. Where new varieties are planted, a further price benefit arises. The new varieties are ready for harvest and sale at a later time when markets in Hanoi offer higher prices and when Chinese imported fruit currently dominates.

With and without R&D—temperate fruit North Vietnam

Under the 'without R&D' scenario, there would be no field control (i.e. no protein bait use). Based on information from NIPP's experimental work, average prices of A$0.80/kg have been used. Since fruit is harvested hard green, there is no need for replacement pesticides and yields (18kg) are high. Operating costs have been set at 80% of revenue.

For the 'with R&D' scenario, price is assessed to be A$2/kg. A variety of prices have been presented in the literature. The highest are around A$3/kg but A$2–$2.50/kg seems to be generally accepted (Nissen et al 2006; Nissen 2006). Basic operating costs have been assessed to be the same as for the 'without R&D' scenario. The additional costs of improved management (labour, protein bait, supplementary pesticides) have been added to this basic cost to get the estimated total operating cost. A$2000/ha has been used as the cost of establishing the new varieties. Yields are set at 14kg. The results are shown in Table 59. Without the R&D, net benefits grow from around $345,600 in 2006–07 to around $3.5 million by 2019–20. With the R&D, benefits grow from $2.3 million to $22.6 million over the same period.

Table 59. Benefits for 'with' and 'without R&D' scenario low-chill temperate fruit in Vietnam

Year	Vietnam low-chill temperate fruits	
	Without R&D	With R&D
06–07	$345,600	$2,266,346
07–08	$587,520	$3,572,788
08–09	$829,440	$5,159,230
09–10	$1,071,360	$6,745,673
10–11	$1,313,280	$8,332,115
11–12	$1,555,200	$9,918,557
12–13	$1,797,120	$11,504,999
13–14	$2,039,040	$13,091,441
14–15	$2,280,960	$14,677,884
15–16	$2,522,880	$16,264,326
16–17	$2,764,800	$17,850,768
17–18	$3,006,720	$19,437,210
18–19	$3,248,640	$21,023,652
19–20	$3,490,560	$22,610,095
20–21	$74,649,600	$483,930,736

Estimated benefits—North Vietnam

As already noted the uptake rate for the low-chill temperate and improved management practices will be slow. While the ACIAR research set the groundwork, significant further work will be required to ensure a consistent uptake of the new technology over time. Most important will be commitment to ongoing education and extension. For the new varieties, commercial nursery investment will be needed to propagate the trees. As protein bait is an integral part of the improved management regime, the efforts of the commercial bait company, and its distribution and sales forces will be potentially critical. Attribution has been set a 40% declining to 10% over the period to 2020–21. On this basis attributable net benefits are A$768,298 in 2006–07 rising to A$1.9 million in 2019–20.

Protein bait spray in North Vietnam

As noted, the planning for the protein bait facility in North Vietnam envisages a total market of around 17,000 ha based on an average usage rate of 14 litres/ha/year. This will cover a range of crops. To date the reduced damage and fruit-loss consequences of using the bait have only been documented for a subset of these. The economic consequences have been documented for only a couple of crops, most notably peaches.

For the assessment of prospective benefits, we took the balance of the projected potential protein bait hectares after deducting that needed for temperate fruit expansion as the basis for estimating the growth in demand for protein bait over the period to 2020–21. The reference crop is peaches, taken as representative of the targeted stone fruit crops.

The analysis is based on existing varieties harvested at current times. Price benefits accrue only because application of bait allows ripe harvesting.

With and without R&D—North Vietnam

The 'with R&D' scenario uses a price of $0.29/kg. Costs are modelled as for the temperate fruit case study, as the application rates of bait spray are the same. There is no set-up cost for trees. Without the R&D, fruit will be harvested hard green for a price of only $0.09/kg. The costs of protein bait are saved.

These prices are based on indicative price data from the Hanoi markets and are reported by NIPP in various publications. The results are shown in Table 61. Without the R&D, benefits are A$420,000 in 2006–07 and grow to around A$1.2 million by 2019–20. With the use of the bait spray benefits grow from A$10.6 million in 2006–07 to A$30.1 million in 2019–20.

Table 60. Attributable net benefits from low-chill fruit in Vietnam

Year	Vietnam low-chill temperate fruit		
	Net surplus	**Attribution to ACIAR projects**	**Attributed to ACIAR projects**
06–07	$1,920,746	0.4	$768,298
07–08	$2,985,268	0.4	$1,074,697
08–09	$4,329,790	0.3	$1,402,852
09–10	$5,674,313	0.3	$1,654,630
10–11	$7,018,835	0.3	$1,842,023
11–12	$8,363,357	0.2	$1,975,391
12–13	$9,707,879	0.2	$2,063,666
13–14	$11,052,401	0.2	$2,114,532
14–15	$12,396,924	0.2	$2,134,588
15–16	$13,741,446	0.2	$2,129,487
16–17	$15,085,968	0.1	$2,104,061
17–18	$16,430,490	0.1	$2,062,425
18–19	$17,775,012	0.1	$2,008,075
19–20	$19,119,535	0.1	$1,943,972
20–21	$409,281,136	0.1	$37,452,158
Present value			
Total	**$289,416,875**		**$35,218,569**
Realised	**$1,829,282**		**$731,713**
Prospective	**$287,587,593**		**$34,486,856**

Estimated benefits—North Vietnam

Protein bait is a sufficient condition for improved yields and ripe fruit harvesting. It is not necessary. Alternatives exist, however they are unlikely to be economically viable for most farmers. The ongoing efforts of training and extension are central to long run uptake. The efforts of the commercial bait company, its distribution and sales forces will be critical. The researchers have no major role to play beyond the end of the project. Attribution has been set at 30% declining to 10% over the period to 2020–21. On this basis, net benefits are $3.1 million in 2006–07 declining to $2.2 million in 2019–20.

Protein bait spray on barbados cherries to Japan and other crops in South Vietnam

As discussed, the protein bait facility in South Vietnam is operational with a capacity of 50,000 litres per annum. It can be expanded to 250,000 litres per annum. Currently the production goes almost exclusively to barbados cherry in Tien Giang and Co Gong. The best estimate is that this accounts for around 1,200 ha. Cherries can be harvested three to five times per year. The estimates of benefits are based on four crops per year. Barbados cherry is a niche market and little expansion can be expected.

Table 61. Benefits for with and without R&D scenario protein bait in North Vietnam

Year	Vietnam protein bait	
	Without R&D	With R&D
06–07	$420,000	$10,654,800
07–08	$479,016	$12,151,952
08–09	$538,032	$13,649,103
09–10	$597,048	$15,146,255
10–11	$656,064	$16,643,407
11–12	$715,080	$18,140,558
12–13	$774,096	$19,637,710
13–14	$833,112	$21,134,861
14–15	$892,128	$22,632,013
15–16	$951,144	$24,129,165
16–17	$1,010,160	$25,626,316
17–18	$1,069,176	$27,123,468
18–19	$1,128,192	$28,620,620
19–20	$1,187,208	$30,117,771
20–21	$24,924,480	$632,298,456

The barbados cherry is the only crop for which reasonable economic data (prices, input costs) is available. Other crops that could use bait in the south include dragonfruit, guava, sapota, mango and star apple.

For the assessment of prospective benefits, we take the balance of the potential protein bait hectares after allowing for barbados cherry, and model benefits based on similar yield improvements and price improvements that barbados cherry has received. More accurate modelling will only be possible when economic returns and cost data is collected for other crops.

With and without R&D—South Vietnam

The 'with R&D' scenario uses a price of, in Australian dollars, $0.18/kg. Costs are modelled based on data collected for the treated areas and reported by the Southern Fruit Research Insitute (SOFRI). Application rates are 32 litres per year based on four crops per year. Without the R&D, fruit will be harvested hard green for a price of only $0.11/kg. The costs of protein bait are saved. These prices are based on indicative price data from the current harvests and reported by SOFRI in various publications. The results are shown in Table 63.

Without the R&D, benefits are $556,000 in 2006–07 and grow to around $4.17 million by 2019–20. With the use of the bait spray, benefits grow from $6 million in 2006–07 to $42.7 million in 2019–20.

Estimated benefits – South Vietnam

As in North Vietnam, protein bait is a sufficient condition for improved yields and ripe fruit harvesting, however it is not essential. Alternatives exist, however they are not likely to be economically viable for most farmers. The ongoing efforts of training and extension are central to long run uptake. The efforts of the commercial bait company, its distribution and sales forces will be critical. The researchers have no major role to play beyond the end of the project. Attribution has been set at 30% declining to 10% over the period to 2020–21. On this basis net benefits are A$1.6 million in 2006–07 growing to A$2.9 million in 2019–20.

Capacity building

Capacity building was an important aspect of the significant Vietnam projects. The bulk of the capacity-building activities relate to field control, although capacity also was built in postharvest treatment, orchard management and the growing of low-chill temperate fruit.

Table 62. Attributable benefits for protein bait in North Vietnam

Year	Vietnam protein bait		
	Net surplus	**Attribution to ACIAR projects**	**Attributed to ACIAR projects**
06–07	$10,234,800	0.3	$3,070,440
07–08	$11,672,936	0.3	$3,151,693
08–09	$13,111,071	0.2	$3,185,990
09–10	$14,549,207	0.2	$3,181,912
10–11	$15,987,343	0.2	$3,146,789
11–12	$17,425,478	0.2	$3,086,871
12–13	$18,863,614	0.2	$3,007,469
13–14	$20,301,749	0.1	$2,913,079
14–15	$21,739,885	0.1	$2,807,492
15–16	$23,178,021	0.1	$2,693,892
16–17	$24,616,156	0.1	$2,574,937
17–18	$26,054,292	0.1	$2,452,834
18–19	$27,492,428	0.1	$2,329,402
19–20	$28,930,563	0.1	$2,206,128
20–21	$607,373,976	0.1	$41,684,305
Present value			
Total	**$474,799,901**		**$48,766,285**
Realised	**$9,747,429**		**$2,924,229**
Prospective	**$465,052,473**		**$45,842,056**

With respect to the low-chill temperate fruit (CP/2001/027), the focus was on ensuring a capacity to extend the knowledge of the introduced fruit varieties and of the cultivation and orchard management techniques needed for both the new varieties and for improved yields with existing varieties. Some eight training courses were organised from 2001–2004 for local technicians, extension officers and farmers. The courses were delivered by Dr Alan George and Mr Bob Nissen from Queensland's Department of Primary Industries and Mr Uthai Noppakoonwong and Mr Pichit SriPinta from the Department of Agriculture in Thailand. Trainees learned cultivation techniques and orchard management techniques for low-chill temperate fruit trees including crop protection management. They undertook hands-on practical training in pruning, thinning, tree planting, pest and disease identification, etc. Some 152 extension and technical officers were trained, and 210 farmers.

Table 65 summarises the training course data.

The use of protein bait is an integral part of the management regime for the new low-chill temperate fruit and for improved temperate fruit management generally in North Vietnam. The evidence to date is that the bait is effective in reducing losses to acceptable levels. Protein baits has also been shown to be effective in reducing fruit losses across a variety of crops in South Vietnam. In both cases realisation of the estimated benefits depends on the techniques being taken up by farmers continuously after the projects have finished.

Table 63. Benefits for 'with R&D' and 'without R&D' scenario protein bait in South Vietnam

Year	Vietnam protein bait	
	Without R&D	With R&D
06–07	$556,074	$6,010,740
07–08	$834,111	$8,836,249
08–09	$1,112,149	$11,661,759
09–10	$1,390,186	$14,487,268
10–11	$1,668,223	$17,312,777
11–12	$1,946,260	$20,138,287
12–13	$2,224,297	$22,963,796
13–14	$2,502,334	$25,789,305
14–15	$2,780,371	$28,614,814
15–16	$3,058,408	$31,440,324
16–17	$3,336,446	$34,265,833
17–18	$3,614,483	$37,091,342
18–19	$3,892,520	$39,916,851
19–20	$4,170,557	$42,742,361
20–21	$88,971,880	$911,357,399

Under CP/1998/005 a large number of Plant Protection Department staff were trained in courses held in North Vietnam at the National Institute of Plant Protection (NIPP) and in South Vietnam at the Southern Fruit Research Institute (SOFRI). The programs included scientists, plant protection officers and farmers.

Workshops for research and technical staff focused on providing the biological and ecological information necessary for fruit-fly control using the protein bait technology. Some 177 extension staff were trained in preparation to deliver farmer training courses. In total these extension staff offered courses to some 4,575 farmers in the new technology.

In is significant that in Vietnam senior researchers at SOFRI (Dr Nguyen Minh Chau) and at NIPP (Dr Le Duc Khanh) are still taking leading roles in promoting fruit-fly research and in promoting the field control methods.

Low-cost disinfestation was the focus of PHT/1993/877. The Vietnamese component of this project was primarily a capacity-building exercise. The project provided heat treatment equipment, funded laboratory renovations and provided general and specific training. Some of the training was conducted at the DOA Thailand both to achieve an efficient training outcome and to encourage cross-country interaction. The pilot scale heat treatment unit was installed at the Research Institute of Fruit and Vegetables in December 2003. Staff were trained in the use of the equipment.

Discussion with staff at the Provincial Plant Protection Department in Hanoi confirmed that the legacy of this project and related efforts by other agencies is an ability to undertake professional disinfestation research. Also, there is now ability to undertake the associated postharvest physiology studies needed for the development and documentation of product treatments that are required to begin negotiations for market access to quarantine controlled markets. However, there is some concern that actual market access to such countries has not come as quickly as expected, although this is not a function of the training. The project established the platform on which future postharvest disinfestation work could be carried out. However, it has required ongoing commitment from government and some significant additional funding from other sources to ensure that the established base was indeed built upon and enhanced.

Research Institute of Fruits and Vegetables (RIFAV) research leader Dr Chu Doan Thanh was the recipient of an ACIAR John Dillon Fellowship (the first awarded to a Vietnamese) to undertake research management training in Australia.

Maintaining the capacity-building effort into the future is critical to the success of the major projects in North Vietnam. The relatively low uptake rate ascribed to low-chill fruit and improved orchard management is in part based on some doubts expressed by participants as to whether this will be the case.

Table 64. Attributable net benefits for protein bait in South Vietnam

Year	Vietnam protein bait		
	Net surplus	Attribution to ACIAR projects	Attributed to ACIAR projects
06–07	$5,454,666	0.3	$1,636,400
07–08	$8,002,138	0.3	$2,160,577
08–09	$10,549,610	0.2	$2,563,555
09–10	$13,097,082	0.2	$2,864,332
10–11	$15,644,554	0.2	$3,079,318
11–12	$18,192,027	0.2	$3,222,663
12–13	$20,739,499	0.2	$3,306,546
13–14	$23,286,971	0.1	$3,341,426
14–15	$25,834,443	0.1	$3,336,264
15–16	$28,381,915	0.1	$3,298,721
16–17	$30,929,387	0.1	$3,235,323
17–18	$33,476,859	0.1	$3,151,618
18–19	$36,024,332	0.1	$3,052,301
19–20	$38,571,804	0.1	$2,941,330
20–21	$822,385,518	0.1	$56,440,628
Present value			
Total	**$593,644,485**		**$55,593,666**
Realised	**$5,194,920**		**$1,558,476**
Prospective	**$588,449,565**		**$54,035,190**

Table 65. Extension officer and farmer training in orchard management

Date	Site	Number of trainees	Type of training group	
			Technicians and extension officers	Farmers
23/7/2001	Hanoi, NIPP, RIFAV	60	60	0
10/4/02	Chiang mai, Khun Wang	2	2	0
16/4/2002	Moc Chau–Son La	50	15	35
19/4/2002	Sapa–Lao Cai	50	15	35
23/7/2002	Moc Chau–Son La	50	15	35
26/7/2002	Sapa–Lao Cai	50	15	35
4/7/2003	Bac ha–Lao Cai	50	15	35
6/ 9/2003	Moc Chau–Son La	50	15	35

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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

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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	
36	Lindner, R. (2005)	Impacts of mud crab hatchery technology in Vietnam	FIS/1992/017 and FIS/1999/076
37	McLeod, R. (2005)	Management of fruit flies in the Pacific	CS2/1989/020, CS2/1994/003, CS2/1994/115 and CS2/1996/225
38	ACIAR (2006)	Future directions for ACIAR's animal health research	
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56	Lindner, B. and McLeod, P. (2008)	A review and impact assessment of ACIAR's fruit-fly research partnerships, 1984–2007	CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225, CS2/1997/101, CS2/1998/005, CS2/2003/036, CP/2007/002, CP/2007/187, PHT/1990/051, PHT/1994/133, PHT/1993/87, CP/1997/079, CP/2001/027 and CP/2002/086

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