MANAGEMENT OF FRUIT FLIES IN THE PACIFIC

ACIAR Projects CS2/1989/020, CS2/1994/003, CS2/1994/115 and CS2/1996/225

Ross McLeod
eSYS Development

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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, policy makers, quarantine officers and other intended beneficiaries.

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Foreword

Fruit and vegetables are a significant component of the diet of people of Pacific nations and are also becoming increasingly important in these countries for generating export income. Fruit flies impose a huge economic drain on these countries. In the Pacific region, crop losses ranging from 15 to 100% have been reported. Most fruit is exported to New Zealand, Australia and Japan — countries that regard fruit flies as a major threat.

To help overcome the fruit fly problem in the Pacific, ACIAR began supporting regional fruit fly management projects in the early 1990s. This research aimed to provide improved fruit fly management tools for growers and Pacific governments, and to improve prospects for entering export markets.

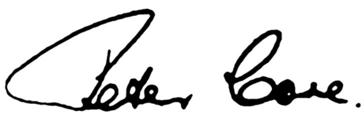
The various projects provided information on taxonomy, wild and commercial fruit hosts, levels of infestation, and geographic distribution and seasonal abundance of species. They also developed a cheap and effective field control system using protein bait sprays. Project activities also included training people from partner countries in the region to carry out host fruit surveys and identify both flies and host plants.

As a result of the projects, some Pacific countries now have the capacity to export fruit and vegetables to markets which would otherwise have been closed.

Economic analysis of project benefits and costs suggests that the total investment in fruit fly research will deliver considerable benefits, mainly to Fiji, but also to Tonga, Samoa, the Cook Islands and Vanuatu.

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

This report is Number 37 in ACIAR's Impact Assessment Series and is also available for free download at <www.aciar.gov.au>.



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Details of projects evaluated

ACIAR project CS2/1996/225	Identification, biology, management and quarantine systems for fruit flies in Papua New Guinea
Collaborating organisations	Australia: Griffith University (GU), Australian Quarantine & Inspection Service (Northern Australian Quarantine Strategy) (AQIS), Queensland Department of Primary Industries (QDPI). Papua New Guinea: National Agricultural Research Institute (NARI); Department of Agriculture and Livestock (DAL); Forest Research Institute, Lae (FRI); Livestock Development Corporation, Port Moresby; Fresh Produce Development Company, Lae; Provincial Departments of Primary Industry
Project leaders	Australia: Dr Dick Drew (GU) Papua New Guinea: Sim Sar, Dr Mark Johnston (NARI)
Linked project(s)	CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003
Duration of project	1 July 1998–30 June 2002
Total ACIAR funding	$1,819,042
Project objectives	• to describe the fruit fly species in Papua New Guinea • to conduct risk assessment studies on the described species • to develop environmentally sensitive pre-harvest field control strategies • to develop quarantine procedures • to conduct training workshops in the local community.
Location of project activities	Papua New Guinea

ACIAR project CS2/1994/115	Development of economical protein bait sprays from brewery yeast waste for fruit fly control
Collaborating organisations	Australia: Queensland Department of Primary Industries (QDPI) Tonga: Ministry of Agriculture and Forestry (MAF)
Project leaders	Australia: Dr Dick Drew (QDPI) Tonga: ‘Ofa Fakalta (MAF)
Linked project(s)	CS2/1989/019, CS2/1989/020, CS2/1994/003
Duration of project	1 July 1998–30 June 2002
Total ACIAR funding	$145,720
Project objectives	• to develop a method of treating and autolysing brewery yeast waste from the Royal Brewery in Tonga in order to formulate a protein bait spray for fruit fly control • to develop a treatment that will ensure a reasonable shelf-life for the yeast autolysate formulation • to test the attractancy of chosen yeast autolysate formulations developed from brewery yeast waste • to establish a model plant in Tonga for brewery yeast waste treatment, as a basis for a commercial unit • to carry out an economic assessment of the model plant operation, to determine the viability of such plants throughout the Pacific and elsewhere.
Location of project activities	Tonga

ACIAR project CS2/1994/003	Identification of pest fruit flies in Vanuatu, Solomon Islands and Federated States of Micronesia
Collaborating organisations	Australia: Griffith University (GU) Federated States of Micronesia (FSM): Department of Resources and Development (DRD) Solomon Islands: Ministry of Agriculture and Fisheries (MAF) Vanuatu: Department of Agriculture and Horticulture (DAH)
Project leaders	Australia: Dr Dick Drew (GU) Fiji: Dr Allan Allwood FSM: Salias Henry (DRD) Solomon Islands: R. Liloqula (MAF) Vanuatu: Dr A. Whitwell (DAH)
Linked project(s)	CS2/1989/019, CS2/1989/020
Principal researchers	Solomon Islands: Ezekiel Walaodo (MAF) Vanuatu: Benuel Tarilongi (DAH)
Duration of project	1 July 1998–30 June 2002
Total ACIAR funding	$606,838
Project objectives	• to train host country personnel in operation of the existing database and in field survey techniques for fruit fly collection and identification • to ascertain the complete host fruit range of each fruit fly species (including wild hosts such as forest trees and plants, and weeds) • to facilitate host country workers to carry out field control trials on fruit flies, using protein bait spray formulations • to develop and maintain a computer database to store the data accumulated during the field survey work, for the use of the individual countries and SPC.
Location of project activities	FSM, Solomon Islands, Vanuatu

ACIAR project CS2/1989/020	Identification and control of pest fruit flies of the South Pacific
Collaborating organisations	Australia: Queensland Department of Primary Industries (QDPI); Department of Entomology, University of Queensland (UQ) Cook Islands: Ministry of Agriculture and Fisheries (MAF CI) Fiji: Ministry of Primary Industries (MPI) Tonga: Ministry of Agriculture and Forestry (MAF); Western Samoa: Ministry of Agriculture, Forests, Fisheries and Meteorology (MAFFM)
Project leaders	Dr Dick Drew (QDPI), Parei Joseph (MAF CI), Jai Nand Kumar (MPI), Semisit Semisi (MAFFM), 'Ofa Fakalata (MAF).
Linked project(s)	CS2/1983/043, CS2/1989/019
Principal researchers	Australia: Dr D.L. Hancock (QDPI), Dr G.H. Walter (UQ) Fiji: Sada Nawd Lal (MPI) Tonga: Mr Sione Foliaki, Mr Tu'ipulotu Langi (MAF) Western Samoa: Mr Albert Peters (MAFFM)
Duration of project	1 July 1998 – 30 June 2002
Total ACIAR funding	$436,787
Project objectives	• to collect and identify all species of fruit fly breeding in commercially significant fruits and vegetables in Cook Islands, Fiji, Tonga and Western Samoa • to ascertain the complete host fruit range of each fruit fly species (including wild hosts such as forest trees and plants, and weeds) • to gather information on the seasonality, abundance and damage levels of each fruit fly species • to investigate the parasite fauna attacking fruit flies in each of the four countries, and to evaluate their significance as natural enemies • to identify and test locally available materials in each country that could be used as protein baits to attract fruit flies for orchard control by bait spraying.
Location of project activities	Cook Islands, Fiji, Tonga and Western Samoa

Summary

Fruit flies of the family Tephritidae are considered to be the most important insect pest species of fruits worldwide. Losses of soft fruit and vegetables as a result of fruit fly infestation occur across all Pacific island countries and their presence inhibits the export of horticultural produce. Production losses of up to 100% have been reported by Allwood and LeBlanc (1997) in vegetable and fruit crops as a result of fruit fly damage.

To help overcome the fruit fly problem in the Pacific, ACIAR commenced support of regional fruit fly management projects in the early 1990s, in conjunction with the Regional Management of Fruit Fly Project (RMFFP) funded by the United Nations Development Programme, the Food and Agriculture Organization of the United Nations and the Australian Agency for International Development. Both the ACIAR-funded and RMFFP activities aimed to provide improved fruit fly management tools for growers and Pacific governments, and to improve prospects for entering export markets. The ACIAR-funded projects had a technical orientation, focusing on identifying fruit flies of the region, and fruit fly host crops, and developing protein bait sprays and export protocols, while the RMFFP focused of extending best practice.

As a result of the projects, some Pacific countries including Fiji, Samoa, Vanuatu and Tonga now have the capacity to export commodities such as papaya, eggplant, mango and breadfruit, primarily to New Zealand and Australia. In the absence of these projects, along with earlier United States Agency for International Development projects to develop heat-treatment facilities for disinfesting fruit, these markets would have been closed when the quarantine fumigant ethylene dibromide was withdrawn from use in 1985. Adoption of improved fruit fly management and quarantine protocols developed within the projects has been most pronounced in Fiji. Currently, over 500 tonnes of mainly eggplant and papaya are exported, and sales are forecast to increase with the recent opening of new markets for Fijian produce. Export sales of these commodities could become significant for Samoa, Vanuatu, the Cook Islands and Tonga, generating economic benefits through the higher prices received for horticultural produce on international markets.

Economic analysis of project benefits and costs suggests that the total investment in fruit fly research will deliver considerable benefits, principally to Fiji, but also to Tonga, Samoa, the Cook Islands and Vanuatu. It is estimated that the net present value of the projects is currently

A$0.1 million and the internal rate of return on funds invested 6%. If exports are projected over a 30-year period, the project is estimated to generate a net present value of A$15.7 million using a similar discount rate.

The quarantine protocols and capacity developed by the projects could be extended to a wider range of produce, including gourds, citrus and other tropical fruits. Additionally, cultural practices could be extended to subsistence farmers to improve food security, thereby further increasing the project impacts quantified in this report. Given that these farming systems are typically non-commercial, adoption is likely to be limited. Some adoption of these practices has, however, occurred in Papua New Guinea largely due to the substantial production losses fruit fly pests inflict in that country.

1 Introduction

During the late 1980s, ACIAR financed a series of fruit fly projects in Southeast Asia, which led to improved management of these pests in that region. Previously conducted economic analyses, such as those by Collins and Collins (1998) and Tobin (1990), indicated that the funds invested were likely to generate considerable economic benefits for recipient communities and for partner governments in Asia and Australia. Collins and Collins (1998), for example, calculated that ACIAR-supported research had been used to expedite the control of fruit fly outbreaks in northern Queensland during the mid-1990s, leading to considerable economic benefits through faster access to markets for horticultural produce that would otherwise have been closed.

Fruit flies of the family Tephritidae are also serious pests of fruit and vegetables grown in the Pacific. Farmers in this region suffer devastating crop losses, and export trade is inhibited due to fruit flies. Field research for selected studies summarised by Allwood and Leblanc (1997) indicated that fruit damage can result in crop losses of as high as 70% in breadfruit, 40–90% in guava, 60% in cumquat, 20–25% in mango and 12–60% in papaya. Alleviating the impact of these pests would lead to enhanced food security and greater quantities of fruit and vegetables for international trade.

Given the scientific success of its earlier research in Asia and the need to better manage fruit flies in the Pacific, ACIAR began support of improved fruit fly management in Samoa, Tonga, Fiji and the Cook Islands in 1991 under project CS2/1989/03. The project was undertaken in conjunction with the Regional Management of Fruit Fly Project (RMFFP) funded by the United Nations Development Programme (UNDP), the Food and Agriculture Organization of the United Nations (FAO) and the Australian Agency for International Development (AusAID). This project had the objective of developing improved fruit fly management practices for growers, to support horticultural exports. Key outputs targeted by the RMFFP were the development of pre-harvest control methods (bait spraying) and postharvest control through the refinement of forced hot-air disinfestation procedures (ACIAR 1989, project proposal: CS2/1989/003).

The ACIAR-funded investment in fruit-fly control in the Pacific region was designed to provide specialist backup to the RMFFP, particularly in the field of taxonomy, host studies and the design of bait-spray trials. An integral part of the initial ACIAR-funded project was on training in fruit fly identification, host plant recording, monitoring of species geographic distributions and commercial fruit host status testing (ACIAR 1989, project proposal: CS2/1989/003). The projects funded by ACIAR were:

- Identification and control of pest fruit flies of the South Pacific (CS2/1989/020)
- Identification and control of pest fruit flies in Vanuatu, Solomon Islands and the Federated States of Micronesia (CS2/1994/003)
- Development of economical protein sprays from brewery yeast waste for fruit fly control (CS2/1994/115)
- Identification biology, management and quarantine systems for fruit flies in Papua New Guinea (CS2/1996/226).

In total, A$8.5m (nominal terms) has been invested by ACIAR, partner governments and other donors (UNDP, FAO and AusAID) across the life of the projects. As a result of these initiatives, protocols for safe export of horticultural produce have been developed, although implementation has been largely limited to Fiji, bait sprays have been commercialised and are used by growers, primarily in Fiji, and the body of knowledge about fruit fly species and ecology throughout the Pacific has been greatly enhanced.

This adoption and impact study focuses on the nature of these outcomes, paying particular attention to the current and potential future levels of project output adoption, and reasons why the technology has or has not been adopted. Where adoption has been shown to have an impact, economic benefits are quantified using benefit–cost analysis. The report begins with a review of the project outputs, followed by an overview of the adoption of improved fruit fly control and, finally, an assessment and quantification of economic impacts.

2 The ACIAR projects and their outputs

The four ACIAR-funded projects evaluated in this report commenced in the 1991 financial year with project CS2/1989/020 – Identification and control of pest fruit flies of the South Pacific. The outputs of this and subsequent projects are described in this section.

2.1 Identification and control of pest fruit flies of the South Pacific (CS2/1989/020)

During the late 1980s, ACIAR financed research in Malaysia and Thailand on fruit fly taxonomy, hosts and levels of infestation, and on the abundance of fruit flies in those countries. Given the large endemic populations of tephritid fruit flies in the South Pacific, and the large economic loss their presence inflicts on farmers and exporters, project CS2/1989/020 was undertaken in the Cook Islands, Fiji, Tonga and Samoa. The project involved researchers from the Queensland Department of Primary Industries (QDPI; now the Department of Primary Industries and Fisheries) and the University of Queensland, working with scientists from national ministries of agriculture in each of the partner countries.

The RMFFP, funded by UNDP, FAO and AusAID, was also initiated at about the same time (in 1990) to tackle the regional fruit fly problem. This project aimed to develop improved management tools for growers and better prospects for exports. The project had a focus on the development of pre-harvest control methods (bait spraying) and postharvest control (heat treatment for disinfestation). The ACIAR-funded project provided specialist input to the RMFFP, most notably in taxonomy, fruit fly ecology and the design of bait-spray trials. Specific objectives of the ACIAR-funded project included:

- identifying the economic fruit fly species in the Cook Islands, Fiji, Tonga and Samoa
- identifying the parasites of fruit fly species in each of the four countries
- developing a computer database to compile host records and geographical distributions of the fruit fly species and parasite records
- testing bait-spray formulations for fruit fly control in fruit and vegetable crops in Fiji and Tonga

- conducting a training workshop for officers throughout the Pacific region, to disseminate data obtained during the project.

A key component of the research was the systematic collection of cultivated and wild fruits, and the rearing of fruit flies and their parasites. As part of the effort, fly species were identified on the basis of adult and larval morphology and male pheromones, the geographic distributions of species were mapped, levels of parasitism recorded and fruit fly damage levels in commercial fruit and vegetables assessed.

The ACIAR-funded and RMFF projects were jointly reviewed in 1993, with the review team concluding that the standards of technical investigation and project management were very high throughout the course of the projects. Laboratory colonies of major pest species had been established using local diets, laboratory systems for biological studies were established, and host testing and disinfection had also been developed and implemented. Lure trapping and host fruit collecting programs were successfully undertaken, although collection at a number of sites in Samoa was hindered by cyclone damage in December 1991.

Attractancy testing of baits was conducted in three of the four countries, and it was shown that economic species in each of these countries were attracted to the baits. Following the recommendation of the review, field trials were accelerated during the final 6 months of the project.

Progress was also made in the development of postharvest disinfection treatment. Postharvest studies required the development of viable insect colonies for induced oviposition studies and commodity treatment research. Under the project, artificial diets were developed and colonies of major species established and maintained in Fiji, Cook Islands and Samoa. There were four species in culture in Tonga. Using New Zealand National Agricultural Service (NASS) standards, commodities were determined as being ‘hosts’ or ‘non-hosts’ to various fruit fly species. Additionally, heat tolerance testing for key stages of major economic species had begun in Tonga, Cook Islands and Fiji by 1993.

2.2 Identification and control of pest fruit flies in Vanuatu, Solomon Islands and the Federated States of Micronesia (CS2/1994/003)

The earlier ACIAR project CS2/1989/020, on the identification and control of pest fruit flies in the Cook Islands, Fiji, Tonga and Samoa, generated considerable data about the pest species of fruit flies, distributions, seasonal and geographic abundance and pest status for the four participating countries. When Vanuatu, Solomon Islands and the Federated States of Micronesia were added to the RMFFP, ACIAR-funded project CS2/1994/003 was implemented to provide technical support for these new participants. The major focus of the project was taxonomic assistance to support improved fruit fly management and the quarantine protocol development aspects of the RMFFP. The objectives of this follow-on ACIAR-funded project were to:

- train personnel from the Federated States of Micronesia, Solomon Islands and Vanuatu to undertake host fruit field surveys, preserve fruit fly and plant specimens, and participate in the fruit fly and plant identification program
- find technical solutions to difficult taxonomic problems, and incorporate fruit fly/host plant information into a database for the use of the countries
- supplying protein bait sprays and advice on experimental design of field control trials in orchards.

As in the previous ACIAR-funded activity, the research undertaken in this project involved the collection of cultivated and wild fruits (and the rearing of fruit flies from these samples), identification of fly species, mapping the geographic distribution of fruit fly species, and assessment of fruit fly damage levels in fruit and vegetables. Results of the identification research were stored in a computer database held at Griffith University, Brisbane. Several workshops were conducted to train officers from Solomon Islands, Vanuatu and Papua New Guinea in fruit fly monitoring and identification. Protein bait spray applications for fruit fly control were tested. Trial design and execution advice was provided through the ACIAR project.

All of the planned outputs of the project were achieved in the three countries (Vanuatu, Solomon Islands and Federated States of Micronesia). For example, by July 1998, the Vanuatu collection contained 30 species of fruit flies, of which 14 were indigenous. The Solomon Islands collection contains 52 species, of which 40 are native to Solomon Islands. National staff can now identify major fruit fly species and undertake survey work to determine fruit fly distribution. The five training workshops conducted during the project, led to a total of 50 national plant protection staff being trained in fruit fly identification.

Two problems led to delays in the project. First, a 9-month delay in the start up of the Solomon Islands component was due to contractual issues, and second, the outbreak of exotic papaya fruit fly in northern Queensland. The delays caused some implementation problems (linking to the RMFFP timetable), but all planned project outputs were achieved.

2.3 Development of economical protein sprays from brewery yeast waste for fruit fly control (CS2/1994/115)

A small ACIAR-funded project was undertaken in Tonga to develop protein bait sprays from brewery yeast. By mixing insecticides with protein baits, the amount of insecticides needed to control fruit flies is likely to be reduced, as adult flies are attracted to the mixture (females consume protein for egg production) and blanket spraying of chemicals can be avoided. Any decrease in insecticide use reduces the potential for residue problems, avoids the non-target mortality of beneficial insects that are natural predators of fruit flies, and could possibly reduce farmers' production costs.

Breweries in Australia, Fiji, Tonga and Samoa produce large quantities of live yeast that could be used in yeast autolysate baits. For brewery wastes to be used as protein baits, a cost-effective autolysis (self-digestion and disintegration of yeast cells) technique had to be developed and the attractancy of the resulting baits to fruit flies tested.

The project involved collaboration between QDPI, the Ministry of Agriculture and Forestry and the Royal Brewery in Tonga, and the RMFFP. The objectives of the project were:

- to develop a method of treating and autolysing brewery yeast waste from the Royal Brewery in Tonga in order to formulate a protein bait spray for fruit fly control
- to develop a treatment that will ensure a reasonable shelf life for the yeast autolysate formulation
- to test the attractancy of selected yeast autolysate formulations developed from brewery yeast waste
- to establish a model plant in Tonga for brewery waste treatment, as a basis for a commercial unit.

The infrastructure at the brewery was established and different formulations were prepared and tested for attractiveness. Although the bait production facility has been operational since the completion of the project, three fruit exporters have expressed concern about the delays experienced in obtaining baits. During this project evaluation, the principal researcher stressed that the key objective of the project was to demonstrate that a commercial unit could be established, and that commercial production itself was not the targeted output.

2.4 Identification, biology, management and quarantine systems for fruit flies in Papua New Guinea (CS2/1996/226)

The ACIAR-funded project CS2/1996/226 began in 1998 following requests to ACIAR by the Department of Agriculture and Livestock of Papua New Guinea that it extend the fruit fly research into that country. The following were among the key objectives of the project:

- to identify fruit fly species in Papua New Guinea and determine which are the pest species
- to undertake field control trials to determine protein bait-spray efficacy under tropical conditions
- to conduct pest risk assessment studies to determine the chances of spread of different pest fruit fly species within and from Papua New Guinea
- to develop fruit fly quarantine procedures in Papua New Guinea.

Some 180 species of fruit fly were recorded, with 12 species of economic importance identified. Damage assessment studies were conducted at Laloki, Bubia and Keravat, although the project final report indicates that the seasonal abundance for most economic species still requires determination. The Papua New Guinea Fruit Fly Emergency Response Plan was finalised by the time the project was completed. The plan is based on the distribution of key pest species in each province. Data were also collected on whether or not fruit carried by airline passengers contributes to the spread of fruit flies.

Protein bait-spray trials were undertaken and the spray used showed a degree of efficacy against fruit flies. Field trials at Karavia, Tavui and Malapau demonstrated village-level fruit control strategies for fruit flies in banana. Techniques demonstrated included fruit bagging, protein bait spraying and male annihilation.

In the final report, it was concluded that a key achievement of the project has been the development of scientific capacity within Papua New Guinea institutions. Training programs included three workshops before the project and seven during the implementation phase. Workshops covered fruit fly biology and identification, rainforest biodiversity studies, postharvest and heat tolerance investigations, field eradication experience in Australia and Nauru, informal training achieved through visiting Australia institutions and academic training for Junior Scientific Officers.

2.5 Key project achievements and impacts

Before the ACIAR-funded prject and the RMFFP there had been limited systematic assessment of fruit fly taxonomy, distribution and abundance and of the fruit fly 'host' status of commodities. Development of scientific capacity in fruit fly trapping, rearing and laboratory techniques had also been limited throughout the Pacific. The ACIAR-supported projects have resulted in the generation of a great deal of technical information in relation to host surveys, fruit fly trapping and species identification, protein bait development and the training of scientists. The RMFFP helped to package and extend this information into improved management practices at the farm and industry level

Fruit fly technical information

The major achievement of the ACIAR-funded projects has been the enhancement of the body of scientific knowledge on fruit flies in the Pacific. The substantial contribution the ACIAR-funded projects have made is outlined in ACIAR Proceedings No. 76 (Allwood and Drew 1997). Research bearing on host fruit surveys, fruit fly trapping and the training of scientists in fruit fly laboratory and identification techniques was conducted successfully in Fiji, Tonga, Samoa, Papua New Guinea, Vanuatu and the Cook Islands. Key information provided by these activities included:

- definition of the pest species in a country
- determination of the geographic distributions of pest species
- identification of the host plants of pest species.

It should be also noted that much of this information has been used to provide a sound base on which to establish long-term quarantine surveys for the early detection of new incursions into a country. Table 1 indicates key research and farm-level achievements of the projects. This estimate of impact is derived from McGregor (2000) and information from ACIAR review teams and consultations undertaken as part of this evaluation study.

The projects have led to the establishment of permanent quarantine early-warning field surveys and the writing of emergency response plans in all 22 Pacific island countries. Although ACIAR projects officially covered only 8 countries, officers from all 22 countries attended ACIAR-supported training workshops.

Table 1. Key research and farm-level achievements, by country, of ACIAR fruit fly projects CS2/1989/200, CS2/1994/003, CS2/1994/115 and CS2/1996/225. Dots indicate significant research and farm-level impact.

Outputs and outcomes	Fiji	Tonga	Samoa	Cook Islands	Papua New Guinea	Federated States of Micronesia	Vanuatu
Host fruit surveys	●	●	●	●	●	●	●
Fruit fly trapping	●	●	●	●	●	●	●
Training of scientists	●	●	●	●	●	●	●
Packaged commercial IPM practices	●						
Protein bait development		●					
Extend practices to farmers	●						

Additionally, extensive in-field training was carried out with officers from most countries through the Nauru fruit fly eradication program. This, together with the workshops and in-field training within the countries, provided intensive training and instruction in quarantine and emergency response systems. The quarantine surveys are vital to the sustainability of Pacific island horticulture by preventing the establishment of new invasive species such as the Southeast Asian papaya fruit fly (*Bactrocera papayae*) now in Papua New Guinea. Also, these surveys are highly important to Australia, as the establishment of major pest species in countries like Vanuatu will, in turn, threaten Australia (R. Drewe, pers. comm.).

Farm-level adoption

There has been significant farm-level adoption of protein bait spraying and other fruit fly management practices in Fiji that were packaged following research in the ACIAR-supported projects. Adoption in Fiji is widespread due to the expansion of horticultural exports and the need to manage fruit flies within all parts of the supply chain.

There are currently 284 producers in Fiji who have adopted improved fruit fly management practices (Fiji Quarantine Service Data 2004), with eggplant producers being the major group to take up the techniques. This is due to the export orientation of this cropping system. It is difficult to ascertain what proportion of total crop production the number of registered growers represents. All registered eggplant growers are from Sigatoka Valley, with only few from elsewhere. They may represent only about 15–20% of all eggplant producers across Fiji (S. Lal, pers. comm.). In the case of mango and papaya, most producers are registered, and may represent over 60–70% of all growers. Nevertheless, there are many growers with a few to many mango and papaya trees who sell in local markets or grow for their own consumption

In contrast, there are only a very small numbers of registered export growers in Samoa, Tonga and other Pacific nations, and production using these techniques has largely been on an experimental or small-scale trial basis. The numbers of producers adopting the methods are likely to grow in the medium term according to staff from the various agriculture ministries.

Key factors leading to increased adoption of improved fruit fly management practices within the commercial sector include the higher production resulting from the adoption of protein baits. and the increased revenue farmers gain following attainment of access to export markets that pay premium prices. Factors impeding adoption include supply problems associated with procuring protein baits for growers in some areas, higher production costs—particularly labour—associated with more intensive pest control, and increased commercial risks as export markets may close and freight may prove difficult in some countries due to limited air transport capacity.

Subsistence agriculture

Outside the commercial sector there has been only limited adoption in most Pacific countries of fruit fly control practices such as ‘bagging’ to protect fruit from fly infestation. The labour intensiveness of manually covering fruit precludes adoption, as does the lack of inputs, such as newspaper for wrapping fruit on the tree, in outer islands and more remote countries.

The exception is Papua New Guinea, where ‘bagging’ is used as a field control method. Banana bunches, for example, are wrapped with banana leaves to protect them from the banana fruit fly. Other fruits bagged are guava and carambola. This adoption was, in part, a result of ACIAR-supported extension that included posters displayed at schools, leaflet distributions and radio broadcasts in pidgin English (R. Drewe, pers. comm.).

Bait production and development

Bait production capacity was successfully established in Tonga and the bait shown to be attractive to the key economic fruit fly species of the region. The small scale of production and marginal economic attractiveness of this enterprise have limited the volume of bait produced from the Tongan facility. A number of exporters are again sourcing bait from Australia and production capacity has been established in Vanuatu due to problems of procuring from the facility in Tonga. Baiting is of lower risk to people and the environment than is the use of conventional insecticides.

It should be noted that the Tongan project was set up as an experiment to prove that the protein could be manufactured from brewery yeast waste and was never meant to be a commercial-scale activity (R. Drewe, pers. comm.). Nevertheless, a major economic impact has come from a recent ACIAR project in Vietnam where, as a result of the Tongan experiment, a plant capable of producing 3000 litres of protein per week has been built. This protein is now registered for use and has led to major increases in crop production for Vietnamese farmers. Given this assessment is focusing on the Pacific, these benefits are not quantified in this report.

Postharvest and export protocols

A major achievement of the projects was the establishment of insect colonies and techniques to test for heat tolerance of fruit fly life stages and develop export protocols in all the countries listed in Table 2. Using these data, operating procedures for high-temperature forced air (HTFA) units that were transferred to the Cook Islands, Fiji, New Caledonia and Tonga in the early 1990s as part of a United States Agency for International Development (USAID) project have been refined.

Table 2. Key postharvest achievements, by country, of ACIAR fruit fly projects CS2/1989/200, CS2/1994/003, CS2/1994/115 and CS2/1996/225. Dots indicate significant impacts

Outputs and outcomes	Fiji	Tonga	Samoa	Cook Islands	Papua New Guinea	Federated States of Micronesia	Vanuatu
Heat tolerance research	●	●	●	●			
Significant volumes exported using heat treatment	●						
Market access maintained through research		●					

The HTFA process entails heating the fruit to about 47.2˚C for 5–6 hours so that fruit fly larvae and eggs are killed. McGregor (2001) noted that the process increases the shelf life of fruit and, correspondingly, improves marketability. A large amount of technical data was collected for this purpose and used to gain import approvals for eggplant, mango, papaya and breadfruit shipments into New Zealand from Fiji (McGregor 2000). Australia has recently accepted some of these protocols, and further development could be expected for new produce (e.g. gourds and citrus) and for other countries (McGregor 2000).

Export approvals and volumes

Fiji is the principal country which has successfully negotiated export licences for fruit and vegetables: it is exporting significant volumes of produce into New Zealand and Australia. Reasons for this outcome include technical capacity in this country, access to airfreight, marketing know-how and links into key markets, and strong commercial and public-sector partnerships. These exports generate economic benefits through the higher prices attained for horticultural products on the international market.

These benefits are quantified in the next section, following a brief description of fruit and vegetable production and fruit flies in the Pacific. Before the development of heat treatment and associated export protocols, exporters relied on ethylene dibromide to fumigate produce, but this compound was withdrawn from the market due to concerns about its safety.

A major benefit from the project was the demonstration that some areas were free of specific fruit fly species. This finding had particular importance for the export of high-value squash from Tonga to Japan. Typically, this crop is targeted by fruit flies, but research conducted in the ACIAR projects demonstrated that key species were not present in Tonga and the market to Japan remained open. In the absence of field surveys, host trapping and a better understanding of local fruit fly ecology the ACIAR-supported research generated, this export trade would most likely have ceased.

Staff capacity development

Numerous workshops and training course were conducted, and enhanced capacity of staff was a major outcome of the project. Within the first project, CS2/1989/020 – Identification and control of pest fruit flies of the South Pacific, staff were trained in insect rearing, identification, trapping and other entomological techniques, largely to improve fruit fly quarantine and enlarge the body of information relating to fruit ecology and biology within the region.

As part of the second project, CS2/1994/003 – Identification and control of pest fruit flies in Vanuatu, Solomon Islands and the Federated States of Micronesia, these techniques were also transferred, and development of the scientific knowledge base relating to each country was further extended. As already mentioned, a further 50 national plant protection staff were trained in fruit fly identification and related techniques. The transfer of these skills has improved the technical capacity of these countries to prevent exotic fruit fly incursion.

Corresponding with project activities in the initial ACIAR-supported Pacific projects, the project CS2/1996/226 developed scientific capacity within Papua New Guinea. Numerous training programs, including workshops on fruit fly biology and identification, eradication and postharvest management practices were conducted, and training was also provided through during visits to Australia by Papua New Guinea scientific officers.

3 Realised and potential project outcomes

The annual economic cost of fruit flies to Australia alone is estimated at A$125m (Vickers 1994). Worldwide losses due to fruit flies are likely to be many times this, given the value of global horticultural production. There is also a significant amount of fruit production in subsistence-based agricultural production systems, which are subject to fruit fly infestation and hence losses. Because of the potential losses from fruit fly infestations, considerable funds are invested worldwide in quarantine programs to reduce the probability of fruit fly incursion.

A wide range of fruit and vegetables is consumed across the countries of the Pacific (Figure 1), typically as part of small, traditional, subsistence production systems. Crops such as breadfruit, taro, banana and yam are staples in the diets of many Pacific peoples. Soft fruits and vegetables, which typically host fruit flies, are grown as non-staples, but provide an important source of nutrition. Non-staples such as papaya, mango, guava and other tropical fruits tend to be sweet but low in calories. They are typically eaten as snacks and provide dietary fibre and vitamin C (McGregor 2000).

With greater integration of the population into the cash economy and the development of semi-commercial subsistence agriculture involving tropical fruits and vegetables, fruit fly damage is inflicting greater financial costs. Production-loss costs are particularly acute in crops which have the potential to generate income, increase export earnings and improve food security at the household level. The presence of fruit flies leads to reduced production, lower fruit quality and impedes international trade.

Before quantifying the economic benefits from the ACIAR and RMFFP investments in reducing the magnitude of this impediment, a background to fruit and vegetable production in the Pacific is provided.

3.1 Fruit and vegetable production in the Pacific

Many types of root crops, coconuts, pulses, leafy vegetables and fruits are grown in the Pacific. Breadfruit and banana are staples in the diets of most people in the region, and areas planted to these crops are increasing with growing demand for food as populations increase. Figure 2 and Appendix 1 provide data (FAO 2004) on production levels of staple and non-staple fruit and vegetable crops in the Pacific islands over the period 1990–2004.

It is evident that volumes of staple food crop production (cassava, banana, taro) are much greater than those of non-staple fruits in all countries. Given the subsistence nature of production in these countries, it is difficult to collect accurate data on actual production, and values should therefore be interpreted with caution. It is evident, however, that root crop production is the most substantial form of cropping and is increasing in most cases, the exceptions being cassava and taro in Tonga. Crops such as cassava and taro are grown widely due to their high energy content: their energy contents are, respectively, 131 kcal (548 kJ)/100 g and 82 kcal (343 kJ)/100 g boiled (SPC 1994), compared to ripe papaya with 50 kcal (209 kJ)/100 g. McGregor (2000) and SPC (1994) review nutritional issues.

Of the countries in which the fruit fly projects were implemented, Papua New Guinea has the highest crop production. Its land area is significantly greater than that of any of the other countries involved.

Figure 1. Map showing Pacific island countries. Source: SPC (2004)

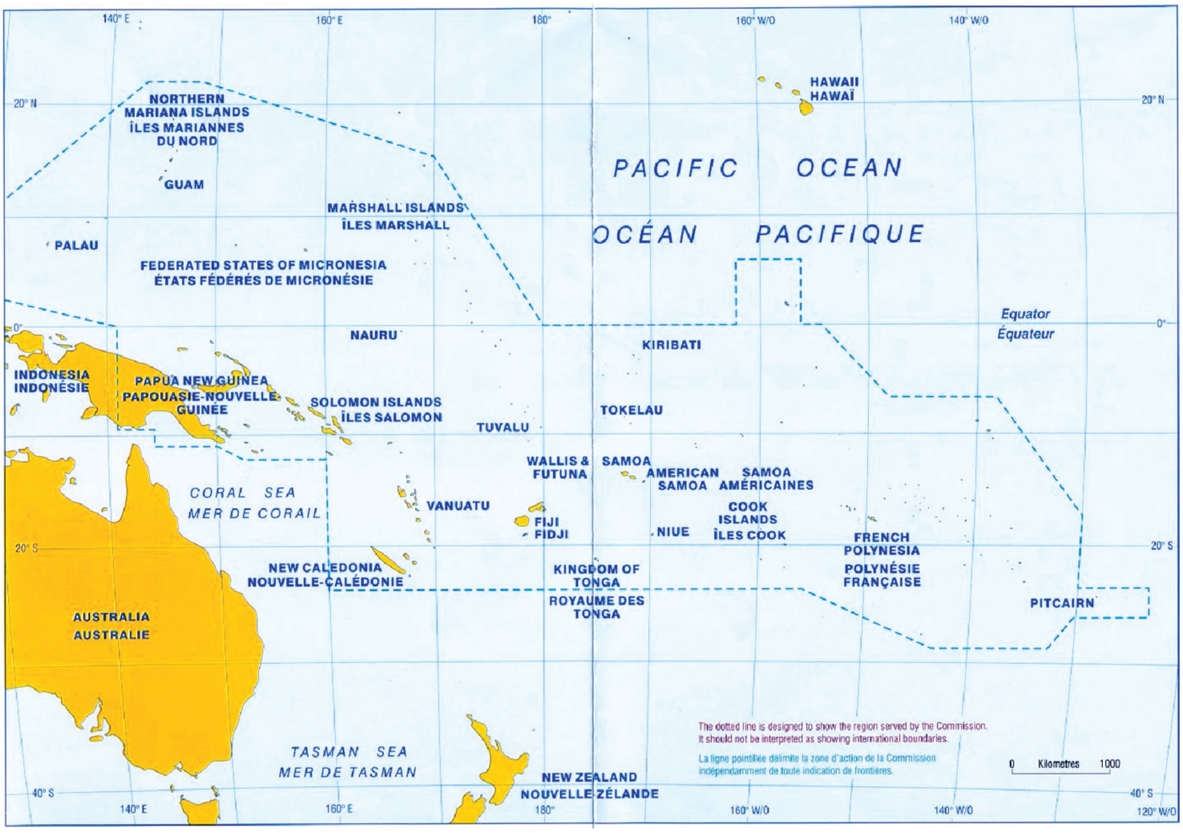


Figure 2. Fruit and vegetable production in Pacific island countries, 1990–2004. Source: FAO (2004)

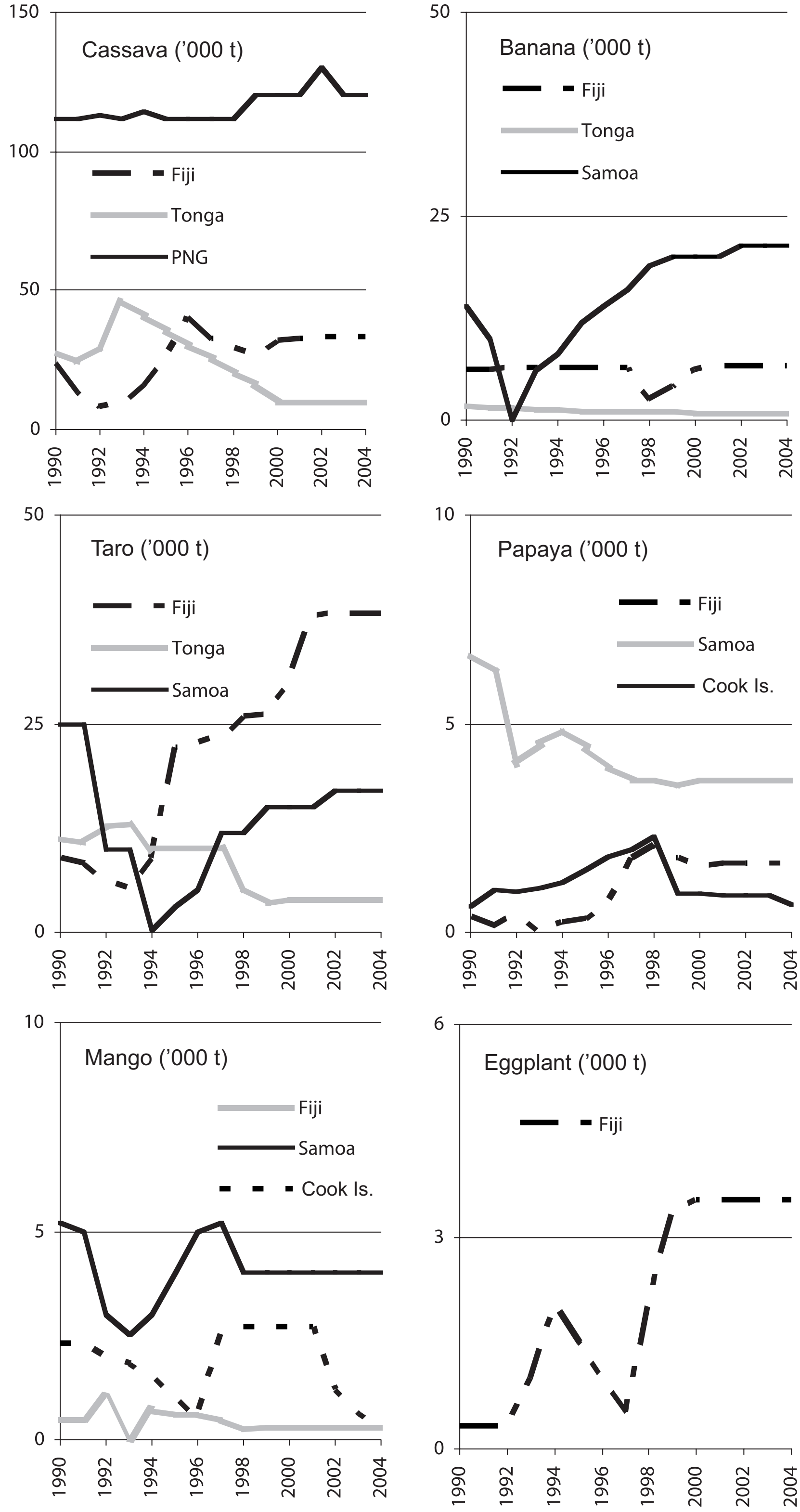


Figure 2 shows that, for the staple crops, increases in banana production in Samoa and taro in Fiji since about 1992 are the most striking trends. Background information about crop production in Fiji can be found in ADB (1985, 1996). In the case of taro, the increase in Fijian production may have been due largely to the outbreaks of disease in other traditional taro-producing countries in the region.

Production levels of non-staple crops such as mango, papaya and eggplant are much less than those of the abovementioned crops. Production of cassava in Fiji, for example, is about 30,000 tonnes (t)/year, whereas eggplant is around 3,000 t (FAO, 2004). For some non-staples, the level of production is falling. Papaya production in Samoa has fallen since 1990, possibly due to export restrictions following the banning of ethylene dibromide fumigant in 1985.

Despite being of lesser importance to the overall food security of Pacific countries when compared to widely produced high-energy staples, many of the fruits and vegetables that are fruit fly hosts could be cultivated to provide much needed cash to poor households. Additionally, some traditional commodity sectors—such as sugar and copra in Fiji—are facing serious economic difficulties, and there is a strong need to realise the potential of horticultural export crops (ADB 1985, 1996, 2002). Partly as a result of export protocol development stemming from the ACIAR and regional fruit fly project investments, the small farmer horticultural industry is the fastest growing part of the Fijian agricultural sector.

3.2 Impact of fruit flies

Fruit flies of the family Tephritidae are thought to be the most severe pests of horticultural production. In addition to crop damage, the presence of fruit flies impedes trade by triggering quarantine restrictions and requiring costly produce-treatment procedures. There are numerous fruit fly species endemic to the Pacific, although only a limited number cause major economic impacts. The fruit fly species of economic importance in each of the ACIAR project partner countries are listed in Table 3.

Pacific fruit fly (*Bactrocera xanthodes*) is found in the ACIAR project countries of Fiji, Tonga and the Cook Islands. It infests 40 host-plant species and damage assessments indicate that this species can cause major economic losses where it is present. In Samoa, for example, it has been recorded as infesting 4–31% of papaya of the ‘Sunset’ variety (SPC 2004).

Bactrocera passiflorae is a key pest in Fiji. In this country, damage levels (i.e. percentages of fruit infested) of 60% have been observed on cumquats, 40–90% on guavas and 20–25% on mangoes.

Table 3. Key fruit fly species of economic importance in ACIAR fruit fly project partner countries in the Pacific. A dot indicates the species is of major economic importance.

Species	Fiji	Tonga	Samoa	Cook Islands	Papua New Guinea	Federated States of Micronesia	Solomon Islands
Bactrocera xanthodes	●	●	●	●			
B. passiflorae	●						
B. kirki	●	●	●				
B. frauenfeldi					●	●	●
B. papayae					●		

The species *Bactrocera kirki* is endemic to Tonga, Samoa and the Fiji islands (on Rotuma only). This species has been recorded as infesting 45–99% of guavas in Samoa (SPC 2004).

Mango fly (*Bactrocera frauenfeldi*) is found in Papua New Guinea, Solomon Islands and the Federated States of Micronesia. Assessments made in Papua New Guinea indicated that 17–98% of guava were damaged, 1–98% of carambola, 6–66% of cashew, 0.5 % of mandarin, 18% of yellow mangosteen, 15% of ripe papaya and 0.5% of ripe banana (SPC 2004).

Bactrocera papayae, the most severe of all pest fruit fly species, is now well established in Papua New Guinea where it was introduced in 1993. It now causes major crop losses there and continually threatens to invade northern Australia

The biggest economic cost associated with fruit flies may result from the obstacle to horticultural exports they represent. Trade in horticultural exports was halted as a result of the banning, in early 1985, of ethylene dibromide fumigation of horticultural produce. Alternative techniques needed to be developed to treat fruit and vegetables and ensure they were free of fruit flies. Additionally, the horticultural products which could be shipped internationally as non fruit fly 'hosts' needed to be determined. The ACIAR-funded projects played a key role in developing export treatment protocols and assisting with unimpeded export of fruit and vegetables from Pacific nations.

3.3 Benefits associated with improved fruit fly management

The key economic benefit from the ACIAR investment has been the ability of South Pacific countries to export fruit and vegetables that otherwise would have been banned by importing countries due to concerns about fruit flies. To date, Fiji has been the only country capable of developing a sustainable export industry based on the ACIAR-supported fruit fly management technology (heat treatment) or, in the case of Tonga, benefiting from establishing host ranges for certain species.

A largely prospective economic study by McGregor (2000) estimated that the increase in regional trade facilitated by the RMFFP in the South Pacific is likely to have generated a return on investment of 19%, as measured by the economic internal rate of return. These projections are explored again here, some 5 years since the abovementioned analysis. Forecast growth in key commodity markets for fruit fly 'host' produce is described, along with less tangible benefits generated by scientific capacity building. Potential benefits accruing to Australia as a result of the projects are outlined in the concluding part of this section.

Horticultural exports

Horticultural exports for Pacific countries largely stopped when ethylene dibromide fumigation was banned as a quarantine treatment in 1985. Facing the closure of international markets, Tonga, the Cook Islands and Fiji, with assistance from USAID, acquired HTFA quarantine treatment technology from the United States Department of Agriculture (USDA). Within Fiji, the Nature's Way Co-operative was established to operate the HTFA, beginning in 1996. At present, the Fijian HFTA facility treats over 500 t of produce (papaya, mango, eggplant and breadfruit) annually. The characteristics of the markets for these commodities are outlined in Table 4.

Papaya

Market analysis undertaken by McGregor (2001) suggested that papaya sales of 1,000 t/year were achievable in New Zealand, provided there was good quality fruit and continuity of supply. McGregor noted: 'It is difficult to assess what the overall size of the New Zealand market for papaya might be'. The Cook Islands was a pioneer exporter into the New Zealand market. In 1986, 555 t were exported from the Cook Islands, but the volume then declined, with only 371 t being exported in 1999. McGregor (2001) noted that by 2001 papaya exports from the Cook Islands had all but finished.

Table 4. Export market characteristics for key horticultural commodities from Pacific countries

Market factor	Fruit type				
	Eggplant	Papaya	Mango	Breadfruit	Other
Key target markets	• New Zealand and Australia	• New Zealand and Australia	• New Zealand and Australia	• New Zealand (expatriates)	• Hot rod chillies in New Zealand and Australia markets • Tongan squash at current production
Current volume	• 250 t from Fiji in 2002	• Current sales of about 150 t/year from Fiji	• 120 t from Fiji 1998 to current average of 47 t	• Small volumes	• 40 t of chillies are exported from Fiji annually
Potential for increased volume	• New Zealand market 1,000 t/year • Australian market possibly the same size	• New Zealand market 800 t/year • Australian market only recently opened (quarantine approvals very slow) • Market could be twice the New Zealand volume (1,600 t/year)	• Limited due to competition from Latin and Central American product	• Suitability for HTFA treatment • Large production base in Samoa • New Zealand accepts breadfruit from Tonga and Fiji • New Zealand market possibly 500–600 t/year • Australian market could be half that of New Zealand	• An annual volume of 100 t into Australia and New Zealand
Constraints	• Product quality (mite damage)	• Cook Islands have Queensland fruit fly • Lack of freight capacity in Samoa • Tonga HTFA not operating	• Competition as above • Samoa, Vanuatu and Tonga have airfreight constraints	• Samoa, Vanuatu and Tonga have airfreight constraints	• Development of protocols

For this benefit–cost study, the overall market size for Fijian papaya in New Zealand and Australian markets in 2005 is estimated to be 250 t, but to be growing by 60 t/year. It is estimated that papaya exports will principally grow from Fiji as the HTFA facility is working effectively, and Fiji has less costly and greater freight capacity. Nadi Airport, Fiji is a Pacific hub for international air traffic, and wide-bodied aircraft (e.g. Boeing 747s) provide freight capacity. ADB (2003) noted that the horticultural export industry has been built around the freight capacity afforded by tourism. Any future market opportunities for horticultural exports therefore depend on the development and success of the tourism industry.

Eggplant

Eggplant is the major horticultural export from Fiji. The market for Fijian eggplant has largely been the Auckland winter market. Exports are now year-round to New Zealand and Australia. HTFA treatment of eggplant destined for the New Zealand market commenced in 1997 and 250 t were treated in 2002 (Nature's Way Co-operative, pers. comm. 2004). An annual growth of 10 t in Fijian eggplant shipments is projected over the forecast period.

Mango

Mango exports from Fiji have been variable. In 1997, 23 t were shipped, while in 1998 exports amounted to around 120 t. McGregor (2002) noted that the average annual throughput over the 7 years of operation has been 47 t. Weather conditions are largely responsible for the wide fluctuations in export volumes. No growth in mango exports is projected for the next 5 years, due to increasing competition from Latin American and Australian mangoes in the New Zealand market.

Chillies

Around 40 t of chillies are exported annually from Fiji (Nature's Way Co-operative, pers. comm. 2004). The two varieties 'hot rod' and 'red fire' can be imported into New Zealand in green form under a non-host protocol, the main demand being during winter (April–June). More recently, approval has been given for importation of red 'birds eye' chillies. An export growth of 10 t/year from Fiji is projected.

Breadfruit

Breadfruit is exported from Fiji and a protocol has been established for Tongan production. McGregor (2002) estimated the New Zealand market for breadfruit to be around 500–600 t/year. Samoa has a strategic advantage in this market, with strong links to Samoan expatriates, although low airfreight capacity will impede any increases in export volume. An annual export of 800 t might be possible. McGregor (2001) noted that 'There would probably be room for Samoa to supply around 500 tonnes of breadfruit to New Zealand, without depressing prices to an uneconomical level, particularly if these exports were focused in the November to March period'. For the forecast, it is estimated that breadfruit exports are principally from Fiji due to its already developed export network. It is estimated that exports will be 25 t in 2005, growing by 25 t/year over the evaluation period.

Squash

Squash production in Tonga is highly attractive to farmers due to squash's short growing cycle of 3 months and high returns. In 1987 there were at least 2,000 growers, but numbers fell to 800 by 1999 (Felemi 2001) and 550 by 2003 (ACIAR 2004). It was reported in ACIAR (2004) that the industry was worth $10.8m in 2002, but that pest and disease control had become more problematic and pesticide resistance was developing. Tongan export squash production is forecast to stabilise at 16,500 t/year. A proportion of the benefits from trade in this commodity can be attributed to the ACIAR investment in fruit fly research, which confirmed the non-host status of this crop and thereby helped sustain market assess. Pumpkin squash is typically a major fruit fly host in most parts of the world. The ACIAR research proved through survey work that no cucurbit-infesting fruit fly species were present in Tonga and, on the basis of this area freedom, Japan accepted imports of Tongan squash.

In many countries of Southeast Asia, in Australia and in some South Pacific nations, fruit fly species whose host plants are in the family Cucurbitaceae (melons, pumpkins, squashes, gourds etc.) are present. For Tonga, it was proved beyond doubt that no such species occurs. If the melon fruit fly, for example, now present in Papua New Guinea and Solomon Islands, were introduced into Tonga, the pumpkin squash trade would be lost immediately

Scientific capacity development

A key achievement of the ACIAR-funded projects has been the provision of training for counterpart plant protection staff, for extension and quarantine staff, and for farmers and exporters in each country. For example, during the Papua New Guinea project, workshops were conducted to provide training in fruit fly biology and identification, rainforest biodiversity studies, postharvest handling and heat tolerance investigations, field eradication techniques, informal training through study tours and academic training for junior scientific officers.

In addition to workshops, a great deal of information has been disseminated through publications and presentations. The Proceedings of the Symposium on the Management of Fruit Flies (Allwood and Drew 1997) contained 51 technical papers on fruit flies in the Pacific. In addition, the Secretariat of the Pacific Community publishes pest advisory leaflets on fruit flies and an Infofly Newsletter in Papua New Guinea.

Technicians, extension officers and quarantine officers are all benefiting from skills acquired within the ACIAR-supported projects. In the case of technicians, insect rearing techniques developed during the project continue to be used to maintain insect colonies, and fruit fly identification techniques have been extended to quarantine officers in all Pacific countries, leading to improved quarantine practice and a reduced chance of incursion through points staffed by quarantine officers.

Benefits to Australia

The benefits to Australia from ACIAR investment in fruit fly research were explored by Collins and Collins (1998). The major impact quantified in that study was a reduction in the time taken to eradicate papaya fruit fly near Cairns in late 1995. Without the body of knowledge generated by the ACIAR projects, it would have taken longer to design and undertake delimiting surveys, and correspondingly longer to achieve eradication of the fruit fly. Collins and Collins (1998) noted that delimiting surveys can take up to 2 months in some cases.

By reducing the time to conduct surveys and eradicate the pest, producers of fruit and vegetables susceptible to fruit flies lost market access for a shorter times and economic losses were minimised. ABARE (1995) estimated that the eradication program generated around $893m in economic gains. Of those benefits, Collins and Collins (1998) estimated that ACIAR-supported research generated a net present value of about $10m (in 1996 dollars), or a return of over $9 for every $1 invested. Given that benefits to Australia from ACIAR-supported fruit fly research have already been attributed to previous ACIAR investments, to avoid double counting, only benefits to South Pacific countries are included in this assessment.

4 Benefit–cost analysis of the projects

In this section, project costs are first outlined, followed by a description of the assumptions made in estimating project benefits. The section concludes with a presentation of the results of the benefit–cost analysis and sensitivity analyses.

4.1 Evaluation framework

Benefits and costs are discounted using a 5% discount rate for project benefits that have already been realised and for a 30-year projection. Net present value, internal rate of return and benefit–cost ratio investment criteria are presented. A benefit–cost ratio of greater than one and a positive net present value indicate that project benefits are greater than project costs.

4.2 Project costs

ACIAR, partner governments and RMFFP donors have supported improved fruit fly management in the Pacific. McGregor (2000) estimated the total cost of donor and Pacific island country support of improved fruit fly management over the 1990–2002 period to be about A$9m (US$6.1m).

Table 5. Annual costs of Pacific fruit fly projects, 1991–2002

Year	ACIAR project costs (A$ nominal)	Partner costs (A$ nominal)	Other costs (A$ nominal)	Total project costs (A$ nominal)
1991	91,392	47,230	232,378	371,000
1992	152,563	94,460	253,977	501,000
1993	153,080	94,460	411,460	659,000
1994	129,050	47,230	486,720	663,000
1995	169,942	43,500	515,558	729,000
1996	201,357	87,000	350,643	639,000
1997	219,421	87,000	515,579	822,000
1998	197,152	43,500	684,348	925,000
1999	591,984	321,500	0	913,484
2000	430,869	321,500	0	752,369
2001	434,809	321,500	0	756,309
2002	434,545	321,500	0	756,045
Total	3,206,164	1,830,380	3,450,663	8,487,207

Source: ACIAR project documents and McGregor (2000).

Costs associated with ACIAR-funded project activities and partner governments throughout the Pacific for the period 1991–2002 are presented in Table 5, drawing on information in ACIAR project documents and McGregor (2000). In addition to ACIAR and partner government costs, a number other donors, including those involved in the

RMFFP (UNDP, FAO and AusAID), the New Zealand Agency for International Development (NZAID), and USAID were active in the support of fruit fly control. These costs were derived as the difference between total donor support outlined by McGregor (2000) and funds provided by ACIAR and partners.

The total costs of these activities over the 1991–2002 period were approximately A$8.5m in nominal terms. ACIAR has supported about a third of project activities, at a total cost A$3.2m over the period. Adjustment factors for inflation are used to translate these costs into 2005 dollar terms. When adjusted for inflation, the total cost of the projects for all donors is about A$10m.

4.3 Project benefits and adoption

In this section, the assumptions underpinning the calculation of project benefits are provided. Key economic impacts that are quantified include the net economic benefits of increasing the regional trade in produce that is susceptible to fruit fly infestation, and also continuity in the export of vegetables that the research demonstrated were not hosts to fruit fly. To quantify these benefits, the exporter margins for horticultural produce are outlined, the volume of produce being exported as a result of the acceptance of export protocols (fruit fly treatments for host and non-host materials) quantified and potential increases in the export trade over the medium term are estimated.

Exporter benefits

Horticultural export markets closed when ethylene dibromide fumigation was banned as a quarantine treatment in the early 1990s. To fill the gap, HTFA units, quarantine treatment protocols and farmer fruit fly control strategies were adopted to facilitate the export of soft fruits and vegetables from Pacific countries, although so far Fiji is the only country from which large volumes of product are being exported. Exports from countries such as Samoa and Tonga have remained low.

At the exporter level, fruit and vegetables require treatment using HTFA units, which is very expensive. The costs of treating fruit and vegetables to eliminate fruit flies, relative to other exporter costs and returns for eggplant, are outlined in Table 6 using budgets provided by McGregor (2002). The net benefit to Pacific countries from horticultural export is estimated to be 34% of export price, given the cost structures for export operations outlined in Table 6.

Exporters are required to supply farmers with protein baits and to pay for HTFA treatment. As a percentage of overall costs, heat treatment and bait costs amount to 16% of total exporter costs, or around $0.38/kg exported.

Table 6. The costs and returns (in Australian dollars) of exporting eggplant from Fiji to New Zealand by air in September 2002

Costs	**A$/kg exported**
Eggplant purchased (1.2 t @ $0.85/kg)	1.02
Purchase of bait spray for grower ($170/32 kg of bait)	0.01
Cleaning and checking (3 people for 5 hours)	0.04
Cartage to packing shed (Sigatoka–Nadi)	0.13
Checking at packing shed	0.08
Cartons and tape (@ $1.32 each, VAT inclusive, plus 5c)	0.13
Cartage to heat-treated forced air facility	0.02
Quarantine treatment (@37c VAT inclusive/kg)	0.37
Telecommunications ($425/month spread over 15 t)	0.02
Electricity ($238 spread over 15 t)	0.02
Rental ($136/month spread over 15 t)	0.01
Fixed labour costs ($467/month spread over 15 t)	0.46
Total free-on-board (FOB) cost	2.32
Exporters gross margin	0.77
Gross margin as a percentage of FOB cost	34%

Taken from McGregor (2002). Assumes A$1 = F$1.18.

Exporter adoption

Since HTFA facilities were first certified for export in the mid 1990s a range of produce (papaya, mango, eggplant and breadfruit) has been treated and exported, mainly to New Zealand. Australia was slow to approve treatment facilities, although significant quantities of papaya and eggplant are now being shipped from Fiji to Australia. The volumes and values of horticultural produce treated and shipped from Fiji and Tonga are given in Table 7.

During 1994–2002, Vanuatu, Samoa and the Cook Islands exported only limited quantities of horticultural produce using outputs from the ACIAR projects and RMFFP. Much of this volume has subsequently stopped, and this benefit–cost study focuses on production in Tonga and Fiji. McGregor (2000) summarised these export revenues, and the exporter profit margin (34% of revenue) has been included in benefits over the 1994–2002 period under 'other export' benefits in the discounted net benefits table (see Table 14). They comprise a very small portion of overall project benefits.

Table 7. Fruit and vegetable exports from Fiji and Tonga, 1996–2003, and benefits to those countries and to Samoa and the Cook Islands attributable to the fruit fly projects

Country/commodity	Year							
	1996	1997	1998	1999	2000	2001	2002	2003
Fiji[a]								
Chillies (t)	20	20	20	20	30	40	40	40
Papaya (t)	33	90	86	152	67	161	173	137
Mango (t)		23	120	28	27	66	31	47
Eggplant (t)		70	185	190	197	246	250	270
Breadfruit (t)						2	5	7
Total (t)	53	203	411	390	321	515	499	501
FOB value (A$m)[b]	0.09	0.27	0.52	0.49	0.42	0.67	0.65	0.66
Attributed benefit (A$m)[c]	0.03	0.08	0.15	0.14	0.12	0.19	0.18	0.18
Tonga								
Squash (t)	12,254	12,284	7,248	15,305	12,535	12,535	18,162	22,657
Papaya (t)			11	46	19	12,535		
Total (t)	12,254	12,284	7,259	15,351	12,554	0.69	18,162	22,657
Attributed benefit (A$m)[c]	0.64	0.64	0.39	0.83	0.69		0.95	1.19
Samoa								
Attributed benefit (A$m)[c]	0.02	0.16	0.05	0.05	0.00	0.00	0.00	0.00
Cook Islands	0.04	0.01	0.12	0.18	0.04	0.05	0.05	0.00
Attributed benefit (A$m)[c]								
Total	0.74	0.90	0.71	1.20	0.85	0.93	1.19	1.37

[a] Fruit treated by Nature's Way Co-operative, Nadi.
[b] Border or free-on-board (FOB) prices (A$/t). FOB price equivalents per tonne (A$) of 2,500, 1,200, 1,200, 1600, 1,200 and 500/t of chillies, eggplant, papaya, breadfruit, mango and squash, respectively. These FOB price estimates were derived from estimates for the years 2005 and 2008 in ADB (2003). Squash prices were taken from ACIAR (2004).
[c] Assumes 35% of FOB value captured by Pacific countries as gross benefit (i.e. exporter margin) [derived from McGregor (2002)] and 80% of benefit attributable to research investment for Fiji exports and 30% for Tongan squash exports.

Tonnages, gross value of export (FOB) and net benefits

Tonnages shipped during 1996–2002 indicate that Fijian eggplant exports and Tongan squash comprise the major share of exports that the ACIAR-funded and RMFFP (UNDP, FAO and AusAID) research has facilitated. It is forecast that papaya exports will increase and that countries such as Samoa and possibly Tonga and Vanuatu will also increase the volume of their exports to Australia and New Zealand over the medium term. The potential increases in export volumes were described in the market characteristics section. The following are key assumptions in the estimation of benefits:

- exports of mango from Fiji of around 47 t/year will remain constant due to competition from Latin America and Australian production

- papaya exports from Fiji will grow by 60 t/year
- eggplant exports of 250 t/year from Fiji will grow by 10 t/year
- Fiji will be the sole exporter of eggplant
- Tongan squash exports will stabilise at 16,500 t/year
- the New Zealand and Australian breadfruit markets will total about 750 t/year
- breadfruit exports from Fiji will be 25 t in 2005, growing by 25 t/year
- Fiji's exports of chillies will grow by 10 t/year from the current base of 40 t/year.

In addition to export volumes and values, Table 7 gives the estimated net benefits to Fiji, Tonga, Samoa, Cook Islands and other Pacific countries from exports of soft fruits and vegetables. Forecast export volumes and attributed economic benefits are provided in the appendixes. Note that Fiji and Tonga have been the major beneficiaries of the research so far. In the case of Fiji, the export industry has commercialised treatment facilities and established export/import protocols with countries including New Zealand and Australia. Other countries—such as Samoa, Vanuatu and the Cook Islands—have the technical capacity to export, but need to establish supply chains into importing countries. For the purposes of the evaluation, is it forecast that this will occur on a limited basis over the evaluation time frame.

Attribution of benefits

In addition to produce that is host to fruit flies, such as papaya and eggplant, various commodities were shown during testing within the ACIAR-supported research projects not to be fruit fly hosts. Given the demonstration of non-host status, produce such as squash could be shipped to Asian, Australian and New Zealand markets. For produce such as banana, papaya, eggplant and mango, the fruit fly research has been integral to sustaining market access.

Additionally, a range of other projects outside the ACIAR and RMFFP (UNDP, FAO and AusAID) supported research and technology development investments have led to the establishment of export treatment capacity for soft fruits and vegetables. USAID, for example, supported the original development of the treatment units. Consequently, only 80% of the benefits from international trade in these commodities are attributed to the research investments by ACIAR and the RMFFP.

Other commodities are less susceptible to the effects of fruit fly infestation and the research has been only partly responsible for the continuation in their trade. Exports of squash, for example, are affected by the sensitivity of the Japanese market to the presence of fruit flies, even though squash is not a fruit fly host. Thus, only one-third of the benefits of increased squash exports are attributed to the research investments. This proportion was derived from consultation with the principal researcher and information in McGregor (2000).

Farmer benefits

Farmers benefit from the increased price received for export-quality produce. For growers to sell to international buyers in Fiji, they must become registered and follow prescribed spray regimes and other farm hygiene protocols. The economics of targeting international markets, as opposed to local sale of produce, have not received a great deal of attention within the ACIAR projects.

McGregor (2002) estimated gross margins for eggplant farmers in the Sigatoka Valley of Fiji (Table 8). It is evident that the cash cost of fruit fly control using malathion insecticide is less than 1% of overall production costs. For export registration, farmers must regularly apply bait sprays, entailing significant labour use. During interviews, some farmers indicated that they did not know the economic implications of export production, particularly as prices vary across seasons.

Table 8. Costs and margins for growing 1 acre (0.4 ha) of eggplant in Sigatoka Valley, Fiji

Costs	Details	A$
Seed bed preparation	Cloth, wire, labour	68
Land preparation	Herbicide and labour	268
Planting	Labour	43
Cultivation	Hoeing, scarifying with horse, bullock plough to cover plants	245
Fertiliser application	Use of urea, NPK, Lush, Borox	267
Irrigation	Hand watering	1,555
Disease and pest control	Includes control of thrips, rust, mites and fruit flies. Malathion insecticide for weekly fruit fly control costs $1. Total cost A$14/acre.	1,907
Harvesting, grading and removing calyx (weekly)	Yields vary depending on whether 1st, 2nd or 3rd pick (200–600 kg/week)	2,074
Total cost		**A$6,399**
Gross margin/acre	**Revenues of about A$8,007/acre**	**A$1,608**
Gross margin as a percentage of costs		25%

Source: McGregor (2002)

Farmer adoption

In Fiji, where the ACIAR-funded projects have had most impact, farmer adoption of fruit fly management practices devised during the projects is widespread. Table 9 gives 2004 adoption levels for export commodities. For farmers to sell to international traders, they must be certified by government quarantine officers. Given the composition of horticultural exports from Fiji, it is not surprising that eggplant producers represent the majority of registered producers in 2004.

Table 9. Numbers of Fijian farmers adopting improved fruit fly management techniques (as indicated by export registration) in 2004

Commodity	Eggplant	Mango	Breadfruit	Chillies	Papaya	Total
Month						
January	–	–	13	4	4	21
February	5	–	–	–	14	19
March	17	–	–	2	3	22
April	4	–	2	2	2	10
May	8	–	6	9	5	28
June	6	–	–	–	2	8
July	11	–	–	5	5	21
August	13	11	–	7	10	41
September	8	–	–	5	3	16
October	14	22	5	12	19	72
November	6	5	–	1	4	16
December	1	6	–	1	–	8
Total	93	44	26	48	73	284
District						
Sigatoka	94	–	7	33	70	204
Nadi	15	–	–	5	2	22
Lautoka	–	31	19	–	–	50
Ba	1	7	–	12	–	20
Tavua	–	6	–	–	1	7
Total	**110**	**44**	**26**	**50**	**73**	**303**

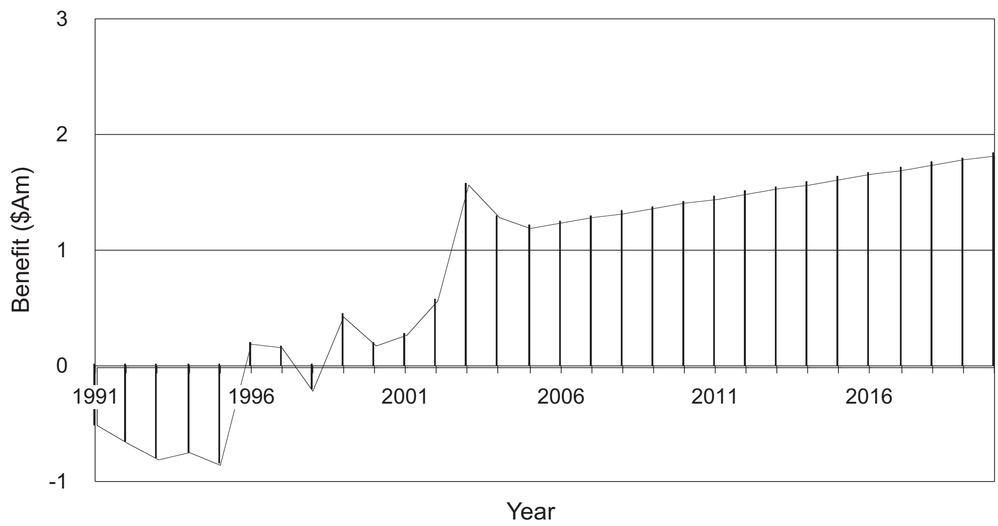
Source: Fiji Quarantine

Eggplant producers ($n = 93$) accounted for about 33% of all registered growers. Papaya growers ($n = 73$) were the next largest group of registered farmers. Some farmers may have dual registration, which explains why the numbers of registered farmers in Table 9 do not exactly correspond for regional and commodity-based classifications. On a regional basis, most registered farmers are in the Sigatoka Valley. This valley is the most productive horticultural cropping area in Fiji and a large proportion of the country's horticultural produce is sourced from it. Samoa, Tonga and other Pacific nations have only very small numbers of registered export growers. According to staff in the various ministries of agriculture, the numbers of producers are likely to grow in the medium term.

4.4 Results

The net present value of improved fruit fly management in the Pacific is forecast to be A$15.6 million expressed in 2005 dollar terms and at a discount rate of 5%. The corresponding benefit–cost ratio was estimated to be 2:1 and the internal rate of return 15%. A benefit–cost ratio of this magnitude suggests that for each dollar allocated to the projects two dollars of project benefits will be generated. The net benefits flows generating these economic returns are presented, by country, in Table 14. Appendix 2 gives projected export volumes. Figure 3 plots project net benefits against time.

Figure 3. Estimated fruit fly management project net benefits through time



The net present value of benefits realised to date and of benefits projected to 2020 are given in Table 10. If only benefits to date are accounted for, then the ACIAR-supported (also regional fruit fly project donors) fruit fly projects are calculated to generate a present value of benefits of A$15m. In contrast, if all benefits are incorporated in the projection, then a present value of benefits of A$30.6m would accrue to the projects.

Given the success of export operations in Fiji, and research leading to continued squash export in Tonga, the majority of project benefits are estimated to be captured by the horticultural industries of those two countries. Of total project benefits accruing to the fruit fly management projects so far, benefits to Tonga are estimated to have accounted for 79%. If benefits are projected forward, then Fiji is forecast to capture 25% of all project benefits.

Table 11 gives the estimated benefit–cost ratio, net present value and internal rate of return for all countries in the region and for all funds invested (ACIAR, partner governments and other donors). When benefits and costs are projected over a 30-year period, the net present value of the project is estimated to be A$15.6m, the internal rate of return 15% and the benefit–cost ratio 2.0:1. If, on the other hand, only benefits to date are considered, then the project has a net present value of $0.1m. Given the long period over which the projects have been implemented, and their substantial cost, the investment payback time is significant.

Table 10. Present value (A$m) of benefits of ACIAR-supported fruit fly projects

Source of benefits	Present value of benefits (A$m)	Proportion of present value of benefits (%)
Benefits (1991–2005)		
Fiji	2.1	14
Tonga	11.8	79
Other	1.1	8
Total	15.0	100
Benefits (projected forward to 2020)		
Fiji	7.7	25
Tonga	21.7	71
Other	1.1	4
Total	30.6	100

Project benefits are also constrained by the financial and technical capacity of Pacific horticultural industries to invest in expensive export-treatment technology. To date, Fiji and Tonga have been the only countries able to generate considerable export earnings from the ACIAR investment.

Table 11. Estimated benefits of ACIAR-supported fruit fly management projects

Period of benefits	Benefit–cost ratio (BCR)	Net present value (A$m)	Internal rate of return (%)
To present (1991–2005)	1.0	0.1	6
Thirty-year projection (1991– 2020)	2.0	15.6	15

4.5 Sensitivity analysis

A number of assumptions and estimates have been made in calculating the economic impacts of the fruit fly projects. While they have been based on the best available information, they remain uncertain. Sensitivity analysis is undertaken in this section to determine which parameters have a significant effect on the estimated economic returns of the projects.

Discount rate

A 5% discount rate was used in the analysis for baseline economic return calculations. Since different investors use varying discount rates, the economic attractiveness of the project is calculated using 0, 5 and 10% discount rates (Table 12).

Table 12. Sensitivity of investment criteria for ACIAR-supported fruit fly management projects to the discount rate used

Benefits (1991–2020)	Discount rate		
	0%	5%	10%
Net present value (A$m) Benefit–cost ratio	25.2 3.4	15.7 2.0	7.3 1.3

Higher benefit–cost ratios and net present values are calculated at lower discount rates. The difference between net present values at 0 and 5% discount rates for the projection is calculated to be A$9.6m.

Potential future exports

A significant proportion of the economic benefits assessed in this benefit–cost analysis are forecast benefits. The projection of future export growth was based on forecasts of market sizes in New Zealand and Australia, as discussed in a previous section. To gain an appreciation for how sensitive investment criteria are to changes in projected export growth, export forecasts for papaya and eggplant (the leading commodities) are varied by 50%. Table 13 gives the results of this sensitivity analysis, which indicates that a 50% increase in the levels of papaya and eggplant exports forecast would generate an extra A$1.2m in net present value.

Table 13. Sensitivity of investment criteria for ACIAR-supported fruit fly management projects to changes in papaya and eggplant export volumes

Investment criterion	Case		
	Export volume falls by 50%	Base case	Export volume rises by 50%
Net present value (A$m) Benefit–cost ratio	14.5 1.9:1	15.7 2.0:1	16.8 2.6:1

Table 14. Benefit–cost analysis of ACIAR-supported fruit fly management projects

Period							Benefits		
Year no.	Year	Fiji export (A$m)	Tonga export (A$m)	Other export (A$m)	Adjustment factor	Gross benefits (A$m)	Total costs (A$m 2005)	Net benefits (A$m 2005)	Net present value (A$m 2005)
1	1991	0.00	0.00	0.00	1.37	0.00	0.51	–0.51	–1.00
2	1992	0.00	0.00	0.00	1.31	0.00	0.66	–0.66	–1.24
3	1993	0.00	0.00	0.04	1.30	0.06	0.85	–0.80	–1.43
4	1994	0.00	0.00	0.08	1.29	0.11	0.85	–0.74	–1.27
5	1995	0.01	0.00	0.06	1.27	0.08	0.92	–0.84	–1.37
6	1996	0.03	0.71	0.06	1.24	0.99	0.79	0.20	0.31
7	1997	0.08	0.71	0.18	1.19	1.15	0.98	0.16	0.24
8	1998	0.15	0.43	0.18	1.18	0.89	1.09	–0.20	–0.29
9	1999	0.14	0.91	0.23	1.18	1.51	1.08	0.44	0.58
10	2000	0.12	0.75	0.04	1.17	1.07	0.88	0.19	0.24
11	2001	0.19	0.76	0.05	1.14	1.14	0.87	0.27	0.33
12	2002	0.18	1.05	0.05	1.08	1.39	0.82	0.57	0.66
13	2003	0.18	1.31	0.00	1.06	1.57	0.00	1.57	1.73
14	2004	0.21	0.95	0.00	1.11	1.29	0.00	1.29	1.35
15	2005	0.25	0.95	0.00	1.00	1.21	0.00	1.21	1.21
16	2006	0.29	0.95	0.00	1.00	1.25	0.00	1.25	1.19
17	2007	0.34	0.95	0.00	1.00	1.29	0.00	1.29	1.17
18	2008	0.38	0.95	0.00	1.00	1.33	0.00	1.33	1.15
19	2009	0.42	0.95	0.00	1.00	1.37	0.00	1.37	1.13
20	2010	0.46	0.95	0.00	1.00	1.41	0.00	1.41	1.11
21	2011	0.50	0.95	0.00	1.00	1.46	0.00	1.46	1.09
22	2012	0.54	0.95	0.00	1.00	1.50	0.00	1.50	1.06
23	2013	0.59	0.95	0.00	1.00	1.54	0.00	1.54	1.04
24	2014	0.63	0.95	0.00	1.00	1.58	0.00	1.58	1.02
25	2015	0.67	0.95	0.00	1.00	1.62	0.00	1.62	1.00
26	2016	0.71	0.95	0.00	1.00	1.66	0.00	1.66	0.97
27	2017	0.75	0.95	0.00	1.00	1.71	0.00	1.71	0.95
28	2018	0.80	0.95	0.00	1.00	1.75	0.00	1.75	0.93
29	2019	0.84	0.95	0.00	1.00	1.79	0.00	1.79	0.90
30	2020	0.88	0.95	0.00	1.00	1.83	0.00	1.83	0.88
Total		10.33	22.82	0.98		35.54	10.30	25.24	15.65

5 Conclusions

The investment in improved fruit fly management in the Pacific by ACIAR and associated donors has generated economic benefits. The overall economic attractiveness of the projects, as estimated using net present value and internal rate of return investment criteria, is considerable. It is estimated that the project will generate A$15.7m of benefits (net present value) over a 30-year period at a 5% discount rate, giving an internal rate of return of 15%.

Research undertaken in the projects led to an improved understanding of fruit fly distribution and the susceptibility of different fruits and vegetables to fruit fly infestation. Protein bait sprays and heat-treatment protocols were also developed. As a result, bilateral quarantine agreements and other export protocols were established that allowed the export of horticultural produce to international markets, leading to the generation of significant economic benefits.

The success of the projects is most evident in Fiji, where the Nature's Way Cooperative was established in 1996 to operate the heat-treatment facility on behalf of growers and exporters. This facility now treats more than 500 t of produce a year, and exports, particularly of papaya, are forecast to increase further. Farmers in Fiji have also adopted bait spraying and other improved fruit fly control measures required for produce to attain export standard. In 2004, 284 farmers—producing mainly eggplant and papaya—were registered by government quarantine officers to supply export markets.

At the farm level, some growers expressed concern that control regimes may be too stringent for some of the produce that is being exported and that the economics of supplying the export market are not clear. There are several gross margins studies examining farm level economics that could be readily extended to farmers and provide benchmarks for production. Similarly, field trials could be undertaken to further refine optimal control strategies for different commodities and production areas.

Much of the information generated during the projects has been used to assist commercial and semi-commercial farmers supplying export markets, although extension to non-commercial producers was a feature project work in Papua New Guinea. Given the substantial production losses inflicted by fruit fly (e.g. on bananas in Papua New Guinea) locally adapted fruit fly control techniques, such as the manual bagging of fruit, could be extended to a wider range of farmers, boosting food security.

Additional benefits could also be generated by extending the range of produce accepted by the New Zealand and Australian governments for import. A number of crops, such as gourds, citrus and other exotic fruits, have export potential but their status as fruit fly hosts and requisite export protocols need to be established. The capacity to conduct this type of research (insect-rearing techniques, host testing etc.) was established during the period of the ACIAR-funded projects and RMFFP and could be built on further.

Perhaps most importantly, the series of traps and monitoring systems established under the projects needs to be maintained so any exotic fruit fly incursions can be cost-effectively dealt with. New fruit fly introductions could result in closed export markets, eroding the hard-fought gains and successes of these projects.

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Appendixes

1 Crop production in the Pacific

Crop production across Pacific countries are provided in the following sets of tables. The data are derived from the database at <www.fao.org>.

Cassava ('000 t/year)

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Fiji	16	26	40	33	29	27	32	33	33	33	33
Tonga	40	35	30	25	20	16	9	9	9	9	9
Samoa	0.25	0.25	0.25	0.25	0.25	0.3	0.3	0.3	0.3	0.3	0.3
Cook Islands	4	3	3	3	3	3	3	3	3	1	1
Papua New Guinea	114	112	112	112	112	120	120	120	130	120	120
Federated States of Micronesia	0	12	12	12	12	12	12	12	12	12	12

Banana ('000 t/year)

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Fiji	6	6	6	6	2	4	6	7	7	7	7
Tonga	1	1	1	1	1	1	1	1	1	1	1
Samoa	8	12	14	16	19	20	20	20	22	22	22
Cook Islands	0	0	0	0	0	0	0	0	0	0	0
Papua New Guinea	689	710	738	755	769	790	810	832	860	870	870
Federated States of Micronesia	0	2	2	2	2	2	2	2	2	2	2
Vanuatu	13	13	13	13	13	13	13	13	14	14	14

Taro ('000 t/year)

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Fiji	9	22	23	23	26	26	30	38	38	38	38
Tonga	10	10	10	10	5	3	4	4	4	4	4
Samoa	0.3	3	5	12	12	15	15	15	17	17	17

Papaya ('000 t/year)

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Fiji	0.199	0.33	0.692	2	2	2	2	2	2	2	2
Samoa	5	4	4	4	4	4	4	4	4	4	4
Cook Islands	1	2	2	2	2	0.908	0.908	0.9	0.9	0.875	0.65

Mango ('000 t/year)

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Fiji	0.719	0.6	0.6	0.5	0.246	0.3	0.3	0.3	0.3	0.3	0.3
Tonga	0	0	0	0	0	0	0	0	0	0	0
Samoa	3	4	5	5	4	4	4	4	4	4	4
Cook Islands	2	1	0.5	3	3	3	3	3	1	0.6	0.25

Eggplant (000 t/year)

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Fiji	2	2	1	0.51	2	3	4	4	4	4	4

2 Projected exports of soft fruits and vegetables from Fiji and Tonga

The export volumes of key commodities impacted by the research projects, along with export production to date, are tabulated for Fiji and Tonga below. Chillies and eggplant exports are forecast to rise by 10 t/year, papaya by 60 t/year and breadfruit 25 t/year. These estimates are those of the consultant, derived from ADB (2003). Tongan squash and Fiji mango export production are estimated to remain constant.

Period		Fiji export production (t)					Tonga (t)
Year no.	Year	Chillies	Eggplant	Papaya	Breadfruit	Mango	Squash
1	1991	0	0	0	0	0	0
2	1992	0	0	0	0	0	0
3	1993	0	0	0	0	0	0
4	1994	4	2	0	0	0	0
5	1995	9	3	0	0	0	0
6	1996	20	25	33	0	0	12,254
7	1997	20	70	90	0	23	12,284
8	1998	20	185	86	0	120	7,248
9	1999	20	190	152	0	28	15,305
10	2000	30	197	67	0	27	12,535
11	2001	40	246	161	0	66	12,535
12	2002	40	250	173	0	31	18,162
13	2003	40	270	137	0	47	22,657
14	2004	50	280	197	0	47	16,500
15	2005	60	290	257	25	47	16,500
16	2006	70	300	317	50	47	16,500
17	2007	80	310	377	75	47	16,500
18	2008	90	320	437	100	47	16,500
19	2009	100	330	497	125	47	16,500
20	2010	110	340	557	150	47	16,500
21	2011	120	350	617	175	47	16,500
22	2012	130	360	677	200	47	16,500
23	2013	140	370	737	225	47	16,500
24	2014	150	380	797	250	47	16,500
25	2015	160	390	857	275	47	16,500
26	2016	170	400	917	300	47	16,500
27	2017	180	410	977	325	47	16,500
28	2018	190	420	1,037	350	47	16,500
29	2019	200	430	1,097	375	47	16,500
30	2020	210	440	1,157	400	47	16,500

3 Economic benefits to Fiji and Tonga attributable to the ACIAR-supported fruit fly management projects

The economic benefits flowing to Fiji and Tonga from export development or sustained market access are tabulated below. The cash flows assume free-on-board price equivalents in Australian dollars of 2,500, 1,200, 1,200, 1600, 1,200 and 500/t for chillies, eggplant, papaya, breadfruit, mango and squash, respectively. In the case of Fiji, an exporter margin of 35% is assumed and 80% of export benefits are attributed to the research investment. For Tonga, on the other hand, only 33% of export benefits are attributed to the research projects as squash is typically not a host plant for fruit flies.

Period		Nominal benefits (A$m)							
		Fiji						Tonga	
Year no.	Year	Chillies	Eggplant	Papaya	Breadfruit	Mango	Total	Squash	Other
1	1991	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	1993	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	1994	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1995	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00
6	1996	0.01	0.01	0.01	0.00	0.00	0.03	0.71	0.00
7	1997	0.01	0.02	0.03	0.00	0.01	0.08	0.71	0.00
8	1998	0.01	0.06	0.03	0.00	0.04	0.15	0.42	0.01
9	1999	0.01	0.06	0.05	0.00	0.01	0.14	0.88	0.03
10	2000	0.02	0.07	0.02	0.00	0.01	0.12	0.72	0.03
11	2001	0.03	0.08	0.05	0.00	0.02	0.19	0.72	0.03
12	2002	0.03	0.08	0.06	0.00	0.01	0.18	1.05	0.00
13	2003	0.03	0.09	0.05	0.00	0.02	0.18	1.31	0.00
14	2004	0.04	0.09	0.07	0.00	0.02	0.21	0.95	0.00
15	2005	0.04	0.10	0.09	0.01	0.02	0.25	0.95	0.00
16	2006	0.05	0.10	0.11	0.02	0.02	0.29	0.95	0.00
17	2007	0.06	0.10	0.13	0.03	0.02	0.34	0.95	0.00
18	2008	0.06	0.11	0.15	0.04	0.02	0.38	0.95	0.00
19	2009	0.07	0.11	0.17	0.06	0.02	0.42	0.95	0.00
20	2010	0.08	0.11	0.19	0.07	0.02	0.46	0.95	0.00
21	2011	0.08	0.12	0.21	0.08	0.02	0.50	0.95	0.00
22	2012	0.09	0.12	0.23	0.09	0.02	0.54	0.95	0.00
23	2013	0.10	0.12	0.25	0.10	0.02	0.59	0.95	0.00
24	2014	0.11	0.13	0.27	0.11	0.02	0.63	0.95	0.00
25	2015	0.11	0.13	0.29	0.12	0.02	0.67	0.95	0.00
26	2016	0.12	0.13	0.31	0.13	0.02	0.71	0.95	0.00
27	2017	0.13	0.14	0.33	0.15	0.02	0.75	0.95	0.00
28	2018	0.13	0.14	0.35	0.16	0.02	0.80	0.95	0.00
29	2019	0.14	0.14	0.37	0.17	0.02	0.84	0.95	0.00
30	2020	0.15	0.15	0.39	0.18	0.02	0.88	0.95	0.00
Total		1.72	2.54	4.17	1.52	0.38	10.33	22.72	0.10

IMPACT ASSESSMENT SERIES

No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics (1998)	Control of Newcastle disease in village chickens	8334, 8717 and 93/222
2	George, P.S. (1998)	Increased efficiency of straw utilisation by cattle and buffalo	8203, 8601 and 8817
3	Centre for International Economics (1998)	Establishment of a protected area in Vanuatu	9020
4	Watson, A.S. (1998)	Raw wool production and marketing in China	8811
5	Collins, D.J. and Collins, B.A. (1998)	Fruit fly in Malaysia and Thailand 1985–1993	8343 and 8919
6	Ryan, J.G. (1998)	Pigeon pea improvement	8201 and 8567
7	Centre for International Economics (1998)	Reducing fish losses due to epizootic ulcerative syndrome—an ex ante evaluation	9130
8	McKenney, D.W. (1998)	Australian tree species selection in China	8457 and 8848
9	ACIL Consulting (1998)	Sulfur test KCL–40 and growth of the Australian canola industry	8328 and 8804
10	AACM International (1998)	Conservation tillage and controlled traffic	9209
11	Chudleigh, P. (1998)	Post-harvest R&D concerning tropical fruits	8356 and 8844
12	Waterhouse, D., Dillon, B. and Vincent, D. (1999)	Biological control of the banana skipper in Papua New Guinea	8802-C
13	Chudleigh, P. (1999)	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039
14	McLeod, R., Isvilanonda, S. and Wattanutchariya, S. (1999)	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008 and PHT/1990/008
15	Chudleigh, P. (1999)	Use and management of grain protectants in China and Australia	PHT/1990/035
16	McLeod, R. (2001)	Control of footrot in small ruminants of Nepal	AS2/1991/017 and AS2/1996/021
17	Tisdell, C. and Wilson, C. (2001)	Breeding and feeding pigs in Australia and Vietnam	AS2/1994/023
18	Vincent, D. and Quirke, D. (2002)	Controlling *Phalaris minor* in the Indian rice–wheat belt	CS1/1996/013
19	Pearce, D. (2002)	Measuring the poverty impact of ACIAR projects—a broad framework	
20	Warner, R. and Bauer, M. (2002)	*Mama Lus Frut* scheme: an assessment of poverty reduction	ASEM/1999/084
21	McLeod, R. (2003)	Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in Southeast Asia	AS1/1983/067, AS1/1988/035, AS1/1992/004 and AS1/1994/038
22	Bauer, M., Pearce, D. and Vincent, D. (2003)	Saving a staple crop: impact of biological control of the banana skipper on poverty reduction in Papua New Guinea	CS2/1988/002-C
23	McLeod, R. (2003)	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011 and AS2/1993/001
24	Palis, F.G., Sumalde, Z.M. and Hossain, M. (2004)	Assessment of the rodent control projects in Vietnam funded by ACIAR and AUSAID: adoption and impact	AS1/1998/036
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

IMPACT ASSESSMENT SERIES

No.	Author(s) and year of publication	Title	ACIAR project numbers
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

ECONOMIC ASSESSMENT SERIES (DISCONTINUED)

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