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AN ECONOMIC EVALUATION OF REALISED AND POTENTIAL IMPACTS OF 15* OF ACIAR'S BIOLOGICAL CONTROL PROJECTS (1983–1996)†

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* The 15 projects are:
Salvinia (PN8340 and PN8340—extension into Africa and Southeast Asia;
Mimosa pigra (PN8339, PN8722, and PN9319);
Fruit piercing moths (PN8802-A and PN9308);
Banana skipper (PN8802-C);
Bread fruit mealybug (PN9111);
Banana aphids (PN8802-E and CS2-92828);
Leucaena psyllid (PN8802-D);
Mimosa invisa (PN8569);
Passion fruit white scale (PN8718);
Banana weevil (PN8802-B).

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CONTENTS

1. INTRODUCTION

Over the 10-year period from 1983, ACIAR invested significantly in biological control research. This paper estimates the welfare benefits from 15 biological control projects funded by ACIAR over this period. Biological controls have attracted increased interest in the recent past because of the inadequacies associated with chemical control, for example:

- pests sooner or later become resistant to pesticides and new chemicals must thus be developed to maintain control;
- chemical controls affect non-target and target species—in some cases predator populations have been reduced, thereby leading to a reduction in elements of natural control, though the newer chemical controls are more selective;
- even when resistant predators survive, they face a reduced food supply;
- residues from some pesticides, particularly insecticides, have spilled over into the environment, leading to degradation in land and water quality;
- residues in food and feedstuffs have also led to human, livestock, and wildlife health problems; and
- there has been a tendency to overuse chemicals—especially in cases where chemicals are applied according to regular schedules.

There are two additional considerations which have been important to ACIAR in investing in biological control research. First, while chemical control often require outlays of funds for an adopting farmer, this is not necessary for most biological controls. For many farmers in ACIAR's mandate regions, the requirement for cash outlay is a hindrance to the adoption of even the best chemical controls. Thus, the cashless nature of the biological control methods developed in ACIAR projects was a particularly attractive attribute of the technology.

Second, while many technologies require conscious decisions by farmers to adopt or reject them, most of the biological control technologies developed under the ACIAR projects do not require a farmer to decide *to adopt* or *not to adopt* a technology. In many cases, once a biological control agent is established in a region, the impacts follow automatically to producers and consumers of the affected commodities.

This evaluation relies on economic surplus techniques to estimate the benefits to producers and consumers due to the biological control of the various pests (see Davis et al. 1987; Alston et al. 1995; Auld et al. 1987.

The rest of the paper is organised as follows. Section 2 presents a brief description of the research projects—their objectives and achievements, and the associated research costs.

Section 3 discusses the approach taken in estimating the benefits from research, the sources of data for key parameters required in the economic evaluation of the projects, and presents a summary of the results on the realised and potential economic impacts of 15 completed ACIAR-funded biological control research activities.

These results represent the base case or the most likely scenario. The estimates are based on a number of assumptions about key economic variables. Section 4 undertakes a series of sensitivity analyses to indicate how the estimates would change if values of selected economic variables changed.

2 DESCRIPTION OF 15 ACIAR-SUPPORTED RESEARCH PROJECTS ON BIOLOGICAL CONTROL

To date ACIAR-funded research on biological control has covered the following six main areas:

- Salvinia*[1] (PN8340 and PN8340—extension into Africa and Southeast Asia);
- *Mimosa pigra* * (PN8339, PN8722 and PN9319);
- Biological control of pests and weeds in Papua New Guinea and the South Pacific
  - fruit piercing moths* (PN8802-A and PN9308);
  - banana skipper* (PN8802-C);
  - breadfruit mealybug* (PN9111);
  - banana aphids* (PN8802–E and CS2–92–828);
  - Leucaena psyllid* (PN8802–D)
  - *Mimosa invisa* * (PN8569);
  - passion fruit white scale* (PN8718);
  - banana weevil* (PN8802–B);
  - green vegetable bug in Papua New Guinea (PN9307)
- Water hyacinth (PN8918 and PN9320);
- Siam weed—*Chromolaena odorata* (PN9110, CS2-96-91) and
- Use of naturally occurring fungi to control grassy weed in Vietnam (CS2-9402)

This paper estimates benefits from 15 completed projects. Projects which are completed, but which still have ACIAR-supported, related projects active in other partner countries, are not evaluated in this paper. These projects will be evaluated at a later stage when all related activities are completed. This decision was made for efficiency reasons. It is more efficient to evaluate related projects as a package rather than as separate research activities. The rest of the paper deals with the 15 completed activities indicated above.

Table 1 summarises key aspects of the selected projects. In Table 1 the start date refers to the date ACIAR began financial support for biological control of a given weed or pest. Where there is more than one project, the completion date refers to the last in the suite of projects. The row for estimated benefits in Table 1 provides a summary of the benefits estimated in this paper. The benefits are estimated assuming a 30-year time horizon and an 8 percent discount rate.

Research expenditure includes ACIAR's invested funds, plus the financial contributions of the Australian research organisation commissioned to undertake the research, plus the financial contribution of ACIAR's overseas partner countries collaborating in the research project.

The row for the number of projects shows a count of discrete funded activities, where each activity is identified by a separate project number in the first row of Table 1.

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[1] An asterisk (*) denotes a project whose benefits are estimated in this paper

Table 1. A summary of the research projects.

	ACIAR PROJECT NUMBER									
	PN8340; PN8340 extension	**PN8339; PN8722; PN9319**	**PN8802–A; PN9308**	**PN8802–C**	**PN9111**	**PN8802–D**	**PN8802–E; CS2-92828**	**PN8569**	**PN8718**	**PN8802–B**
	Control target									
	S. molesta	*M. pigra*	Fruit percing moth	Banana skipper	Breadfruit mealybug	*Leucaena psyllid*	Banana aphids	*Mimosa invisa*	Passion fruit scale	Banana weevil
Date started	1984	1983	1988	1988	1992	1988	1988	April 1986	June 1987	1988
Date completed	1992	PN9319 was still active in 1996	1996	1992	PN9911 was still active in 1996	1992	1994	October 1986	July 1988	1992
Estimated benefits over a period of 30 years ($Am, 1990)	27.72	23.06	0.66	22.50	2.57	Project led to a decision not to introduce two biological controls which would have led to negative impacts	Parasite tested did not work on banana aphids but seemed to work on taro and melons	0	0	0
Research expenditure ($A'000, 1990)	0.70	1.30	0.67	0.27	0.63	0.06	0.059	0.03	0.08	0.07
Net benefit ($A m, 1990)	27.02	21.77	–0.01	22.23	1.94	Not estimated	Not estimated	–0.03	–0.08	–0.07
Estimated rate of return (per cent)	77%	26%	7.9%	81%	26%	Not estimated	Not estimated	Negative	Negative	Negative
No of projects (Total projects = 15)	2	3	2	1	1	1	2	1	1	1
Countries involved in the research project	Australia, Sri Lanka, Philippines, Malaysia, Africa	Australia, Thailand Indonesia, Malaysia, Vietnam	Australia, Fiji, Western Samoa, Tonga	Australia and Papua New Guinea	Australia, Kiribati and FSM; Marshall Islands, Palau	Australia	Australia, Tonga	Australia, Western Samoa	Australia, Western Samoa	Australia, Tonga

2.1 Biological control of *S. molesta* (PN8340 and its extensions to Africa and Southeast Asia)

Salvinia *(Salvinia molesta)* is a floating fern. Thick mats of salvinia halt the movement of boats, block irrigation channels, stop rice from growing, prevent fishing and kill submerged plants and animals by cutting off light and oxygen. Salvinia comes originally from south-eastern Brazil, where specially adapted insects keep its growth in check. Because it grows so quickly, doubling its mass in less than 3 days under ideal conditions, control with herbicides or by physical removal requires indefinite, frequent and expensive repetition, leaving biological control as the only viable method. This project introduced the Brazilian weevil, *Cyrtobagous silviniae*. to Sri Lanka, Malaysia, the Philippines, and Africa (Kenya and Zambia).

2.2 *Mimosa pigra* (PN8339, PN8722 and PN9319)

Mimosa pigra, or giant sensitive plant, is believed to be of Central American origin. It is a tall, prickly, woody, perennial shrub that forms impenetrable thickets in paddyfields, and along watercourses. Mechanical control is totally ineffective; herbicidal methods can achieve partial control for part of the year, but are ineffective overall. The most promising solution appears to be biological control, combined with herbicide applications to increase pressure on the plant.

The aim of these three projects was to assist in the development of a long-term sustainable integrated weed management system involving biological control agents for Australia and ACIAR’s partner countries (Thailand, Malaysia, Indonesia and Vietnam).

The two projects, PN8339 and PN8722 identified and released eight control agents of *M. pigra* in Australia and Thailand. The aim of Project PN9319 is to identify an appropriate subset of these controls for release in Malaysia, Indonesia and Vietnam.

2.3 Fruit piercing moths in the South Pacific (PN8802A and PN9308)

Fruit-piercing moths (FPM) have been recorded as attacking over 40 fruits worldwide. They are serious pests of most tropical and subtropical fruit in the Pacific region. Citrus varieties, mango, papaya, lychee, stone fruit, carambola, kiwi fruit, capsicum and tomatoes are all particularly susceptible. Moths (male and female) attack both unripe and ripe fruits, but most damage is caused at the ripening stage by moths puncturing the fruit and sucking the juice. Rots caused by fungi and bacteria quickly enter and destroy the whole fruit. A single moth can cause severe damage, while several moths can devastate a whole crop.

ACIAR project 8802A sought a biological control of the moth in Western Samoa, releasing two egg parasites from Papua New Guinea (where FPM is not a problem to fruit growers). Project PN9308 continued the research of Project 8802A in three Pacific countries—Western Samoa, Tonga and Fiji.

2.4 Banana skipper (PN8802C)

Banana skipper (*Erionota thrax*) butterflies originated in the Indo-Malayan region and feed on the foliage of banana plants; severe infestations may strip the plant, and subsequently affect yield depending on the extent of defoliation (Soon and Hill, 1992). In the early 1980s, the butterfly was accidentally introduced into Papua New Guinea, and in two years spread from the north coast to near Port Moresby, from where it threatened to spread across Torres Strait to Australia where a banana industry worth about $A150m per annum was at risk. In conjunction with the PNG Department of Agriculture and Livestock, the research team tested the suitability of known natural enemies of the banana skipper for use in PNG, and also Australia as a precautionary measure. The program ensured that the natural enemies of banana skipper do not also attack the particularly rich fauna of non-pest skipper butterflies present in Papua New Guinea and Australia.

2.5 Breadfruit mealybug in the south Pacific (PN9111)

Breadfruit (*Artocarpus* spp.) is a staple food in smaller Pacific nations and one of the few crops that grow well on island atolls. It has a greater nutritional value than imported food substitutes such as rice and wheat flour. The breadfruit tree is also a valuable source of timber, being the only alternative to coconut on atolls and is used for boat-building in particular. However, supplies were jeopardised by the introduced mealybug, *Icerya aegyptiaca*. Heavy infestations of the pest, which kills young leaves and stems, reduce fruit yields by 50% or more, and may kill mature trees.

During the first phase of PN9111, a predacious beetle (*Rodolia limbata* Blackburn) which attacks only the mealybug, and which bred easily and was suitable as a biological control agent, was introduced, first to the Federated States of Micronesia, and then to Kiribati. In the second phase of the project (which is still under way), the project team will introduce the biological control agent for breadfruit mealybug into other South Pacific Islands.

2.6 Banana aphids (PN8802E and CS292828)

Subproject PN8802E aimed at controlling the banana aphid (*Pentalonia nigronervosa*) in Tonga. This aphid not only causes damage by feeding on banana palm, but also is the vector for banana bunchy top, a serious virus disease. The team used the aphid's known parasites from Australia to reduce its numbers in Tonga.

The objectives of CS292828 were to monitor the establishment of the aphid parasitoid, *Aphidius colemani*, in the Kingdom of Tonga.

2.7 Leucaena psyllid (PN8802D)

This project dealt aimed at controlling *Heteropsylla cubana*, a psyllid which feeds by sucking the sap from the soft, growing tips of *Leucaena leucocephala* (a multi-purpose tree legume), by introducing natural enemies from the psyllid's native range in Central America.

In the early 1980s, Leucaena psyllid had spread to a number of Pacific islands and to Australia. In some places Leucaena is used as a fodder and in others as a shade for cocoa and other plants, and its destruction had serious consequences. Under this subproject, scientists sought baseline information on psyllid population dynamics and seasonal fluctuations in all regions and on the impact of natural enemies, and assessed ways to ameliorate the problem.

2.8 *Mimosa invisa* in Western Samoa (PN8569)

The purpose of this project was to enable the Queensland Lands Department to continue for six months to October 1986, a program seeking natural enemies of the weed *Mimosa invisa* in South America, particularly Brazil. *M. invisa* is among the worst weeds in Western Samoa, Vanuatu, Solomon Islands, Papua New Guinea, New Caledonia and French Polynesia. It also occurs on several other Pacific islands and in various countries in Southeast Asia.

Under this project two biological control agents were released in Western Samoa, but they did not establish (Dr Paul Ferrar, ACIAR, pers. comm., January 1997).

2.9 Passion fruit white scale in western Samoa (PN8718)

Until 1984, passion fruit pulp ranked as the third most important agricultural export for Western Samoa. In late 1984, the passion fruit industry suddenly collapsed. Vines throughout the Island were engulfed and destroyed by white scale insects (*Pseudaulacaspis pentagona*). This project, led by Dr D. Sands, a CSIRO scientist, identified a suitable natural enemy, and arranged for its importation into Western Samoa. It multiplied rapidly after their release in mid-1986, and 18 months later the population of scale insects showed a major decline.

The biological control agent is a minute parasitic wasp, *Encarsia diaspidicola*, which can live only on the passionfruit scales. The female wasp lays her eggs inside the scale insect. When they hatch, the wasp larvae feed on the scale, killing it. The larvae develop into adult wasps, which in turn seek out scale insects for egg laying. This process continues, keeping the pest under control. The biological control agent cannot live on any other insect, animal, plant or human being.

2.10 Banana weevil (PN8802B)

Banana weevil borer causes considerable trouble as a major pest of bananas in Tonga and elsewhere in the tropics. It tunnels into the corm, producing physical damage and promoting fungal and bacterial rots. Damaged banana plants also blow over readily during storms. Chemical control is difficult, unsatisfactory and expensive, and no natural enemies are known. However, CSIRO and NSW Department of Agriculture and Fisheries field trials have shown that entomopathogenic nematodes (roundworms) attack and kill banana weevils very effectively. This subproject conducted parallel trials in Tonga, adapting techniques for the deeper-planted bananas grown in the Pacific.

3. ESTIMATION OF THE RESEARCH IMPACTS OF ACIAR PROJECTS ON BIOLOGICAL CONTROL

This section discusses the estimation of the research impacts of, and welfare benefits from, the projects discussed in Section 2. The following assumptions apply: the base year is 1990; the time horizon is 30 years for all the projects; and the discount factor is set at 8 per cent per annum, as recommended in Department of Finance (1991).

A first step in the estimation of the impact of agricultural research is to identify the commodities or qualities likely to be affected by research. Table 2 shows the agricultural commodities likely to be affected by the 15 ACIAR-supported research activities on biological control. In a number of cases — due to scarcity of data — it was not possible to include all commodities likely to be affected.

3.1 Biological control of salvinia (PN8340 and PN8340 extension to Africa and Southeast Asia)

The control of salvinia affected four main commodities: rice, fish, waterways, and human life (Table 2). Not all these commodities were affected to the same extent in all ACIAR's mandate countries. The impact of the control of salvinia on each of these commodities is discussed in turn.

3.1.1 Rice

Rice production affected by S. molesta

Doeleman (1990) notes that among agricultural crops, only rice production appears to have suffered from salvinia. The problem arises in the paddies and is commonly introduced by salvinia-infested irrigation water. Rainfed paddies may also be affected by salvinia but only in wet periods.

When salvinia gets into the paddy, it impedes production by competing with rice for space and nutrients and by interfering with drainage. The presence of salvinia in a paddy thus increases production costs per hectare of paddy rice and lowers yields of rice per hectare. Better control of salvinia reduces total production costs while simultaneously increasing yields of rice per hectare.

In this analysis, salvinia has an effect on rice production only in Sri Lanka and the Philippines. The key parameters describing this impact on rice are summarised in Table 3. The data on production of rice in the different countries is from FAO (1994a,b). The data on the proportion of rice affected by salvinia is from Doeleman (1990) for Sri Lanka, from Pablico et al. (1986) and Department of Agriculture, Philippines (1993). Yields before research were for 1990 (the base year) and were obtained from IRRI (1995) for the relevant countries. Doeleman (1990) estimated that control of salvinia would reduce paddy rice losses by 2–3 percent. This result is used in estimating the yields of paddy rice after research.

Table 2. The country where project was based, the pest or weed tackled, and the commodity affected.

	PN8340 and extensions to Africa and Southeast Asia Control target	**PN8339 - PN8722 - PN9319**	**PN8802-A PN9308**	**PN8802-C**	**PN9111**	**PN8802-D**	**PN8802-E CS2-92828**	**PN8569**	**PN8718**	**PN8802-B**
	Salvinia molesta	*Mimosa pigra*	Fruit piercing moth	Banana skipper	Breadfruit mealybug	Leucaena psyllid	Banana aphids	*Mimosa invisa*	Passion fruit scale	Banana weevil
Fish	•									
Rice	•	•								
Palm oil		•						•		
Beef		•				•		•		
Cocoa						•		•		
Coconut								•		
Banana				•			•	•		•
Taro							•			
Breadfruit					•				•	
Passion fruit									•	
Orange			•							
Papaya			•							
Pineapple			•							
Pepper			•							
Capsicum			•							
Tomato			•							
Human health	•									
Waterways	•	•								
Tourism		•								
					Countries affected by research					
	Australia, Sri Lanka, Philippines, and Africa	Australia, Thailand Indonesia, Malaysia, Vietnam	Australia, Fiji, Western Samoa, Tonga	Australia and Papua New Guinea	Australia, Kiribati and FSM	Australia	Australia, Tonga	Australia, Western Samoa	Australia, Western Samoa	Australia, Tonga

Cost of production before research— rice

A detailed cost analysis for the production of irrigated rice by the Bureau of Agricultural Statistics was obtained from Dr John Bennett (IRRI, Manila, pers. comm., July 1996). These data were used as a basis for estimating unit costs of rice production—before research—in the Philippines. The costs of production of rice before research in Sri Lanka are based on estimates in IRRI (1995). Unit costs of production ($A/t) were estimated by dividing the total cost per hectare by the yield of rice per tonne.

The research impact of the project with respect to rice

A major research impact of PN8340 is the reduction in the cost of clearing salvinia. The cost of clearing salvinia in Sri Lanka was estimated from Doeleman (1990) who indicated that:

> The Department of Agriculture, Sri Lanka, estimates that 23 hours of labour (at a 1987 agricultural wage per hour of 7.5 rupees) on average per month per hectare is all the affected farmer needs to keep irrigation and drainage channels free and pumps protected.

This cost estimate in Sri Lankan rupees is converted to an estimate in $A (1990) by allowing for inflation at 11.2 percent per annum (Far Eastern Economic Review, 1994) and an exchange rate of 46 Sri Lankan rupees to an Australian dollar. In the Philippines, Pablico et al. (1986) quoted a figure of 800–1200 pesos per hectare for the annual removal of *S. molesta* before planting. The successful control of salvinia in two of these three countries led to a reduction in the cost of producing rice as indicated in Table 3. At present there is no widespread control of salvinia in Malaysia (Mic Julien, CSIRO Division of Entomology, Indoorooopilly, Queensland, pers. comm.). The difference between the cost per tonne before and after after research gives the unit cost saving to rice producers as a result of effective biological controls of salvinia introduced under PN8340. These estimates of unit cost savings are introduced in the research evaluation model to estimate monetary benefits from research.

Data on the price of rice per tonne is from IRRI (1995). Estimates of the elasticity of demand of demand and supply for rice are from the ACIAR Economic Evaluation Unit's database. Rice is an internationally traded commodity and thus a set of equations which takes into account world trade in rice is used in the estimate of benefits from research (Davis et al. 1987).

3.1.2 Fish—inland catch

Fish production affected by S. molesta

Salvinia has an effect on inland fish catch only in Sri Lanka, the Philippines and Kenya. Pablico et al. (1986) indicate that in the Philippines *S. molesta* is used as a fish food. In a survey of 46 farmers, Pablico et al. (1986) found that 35 farmers fed *S. molesta* to tilapia. The control of *S. molesta* may thus be neutral to producers of tilapia.

Doeleman (1990) notes that:

> In practice it has been found that salvinia contributes to fishing losses in affected reservoirs in two ways. Firstly, fish breeding is hampered thus reducing the stock of fish. Secondly, the preferred method of gillnetting is rendered ineffective by the weed.

Table 3. Assumption made in the estimation of the annual benefits by the commodities affected by salvinia (PN8340 and PN8340 extensions into Africa and South East Asia)

Base year 1990	Australia	Sri Lanka	Philippines	Africa (Kenya)	Africa (Zambia)
Rice					
Quantity produced, 1988-90 Averages ('000 t)	na	1534	6012	na	na
Percentage affected by salvinia	na	12%	6%	na	na
Quantity affected by salvinia, ('000)	na	184.08	343.54	na	na
Yield before research (t/ha) average 1990	na	3.5	3.5	na	na
Yield after research (t/ha)	na	3.61	3.61	na	na
Cost of production before research ($/ha)	na	$528	$528	na	na
Unit cost ($/t) before research	na	$151	$151	na	na
Cost of cleaning up salvinia ($/ha)	na	$8	$29	na	na
Cost of production after research ($/ha)	na	$520	$499	na	na
Unit cost ($/t) after research	na	$149	$143	na	na
Cost saving due to research ($/t)	na	$2.31	$8.16	na	na
Price of rice	na	$235	$235	na	na
Elasticity of supply	na	$0	$0	na	na
Elasticity of demand	na	$0	$0	na	na
Fish— Inland Catch					
Quantity produced, 1988–90 Averages ('000s t)	na	45.06	90.28	5.94	na
Percentage affected by salvinia	na	5%	5%	5%	na
Quantity affected by salvinia ('000)	na	2.25	4.51	0.30	na
Yield before research (t/ha) average 1990	na	0.283	0.283	0.3177	na
Yield after research (t/ha)	na	0.34	0.34	0.36	na
Cost of production before research ($/ha)	na	$205	$205	$205	na
Unit cost ($/t) before research	na	$723	$723	$644	na
Cost of cleaning up salvinia ($/ha)	na	$8.07	$28.57	$8.07	na
Cost of production after research ($/ha)	na	$197	$176	$197	na
Unit cost ($/per ton) after research	na	$695	$622	$619	na
Cost saving due to research ($/t)	na	$28.52	$100.96	$25.40	na
Price of fish per ton	na	$263	$263	$263	na
Elasticity of supply	na	0.80	0.80	0.80	na
Elasticity of demand	na	0.65	0.65	0.65	na
Waterways					
Area affected (ha)	na	50000	18229	20988	25911
Cost of clearing before research – ($A/ha)	na	$5.86	$5.86	$5.86	$5.86
Total cost of clearing before research – ($A/year)	na	$292964	$106806	$122974	151820
Cost of clearing after research – ($A/ha)	na	0	0	0	0
Cost saving per annum ($A'000, 1990)	na	$293	$107	$123	$152
Human Health					
Expenditure on health per year ($A'000)	na	$381250	$1103750	$468750	$146250
Proportion of expenditure on children 0–15 years of age	na	0.53	0.53	0.66	0.66
Expenditure on children 0–15 years of age per year ($A'000)	na	$202443750	$586091250	$311250000	$97110000
Increase in vector diseases due to salvinia	na	1.50%	1.50%	1.50%	1.50%
Percentage of budget spent on malaria etc	na	0.01	0.01	0.11	0.11
Human health costs saved per year ($A'000, 1990)	na	$5.24	$7.22	$0.18	$6.39

S. molesta is likely to affect inland fish catch. To estimate total inland fish catch, use is made of estimates of inland water resources, and of fish yields per hectare of inland water resources in Sri Lanka, and the Philippines (De Silva 1987). Lake Naivasha, in Kenya, has several species of tilapia and black bass (introduced) which are the basis of commercial and sport fishing (Encyclopaedia Britannica, 1989).

The presence of salvinia in a water reservoir increases production costs per hectare and lowers yields of inland fish catch. Better control of salvinia will reduce total production costs while simultaneously increasing yields of fish.

The key parameters describing the impact on inland fish catch are summarised in Table 3. The data on the proportion of inland fish catch affected by salvinia in Sri Lanka are from Doeleman (1990). Yields before research were obtained from De Silva (1987). Doeleman (1990) estimated that control of salvinia would reduce fish losses by 20–40 percent. This result is used in estimating the yields of fish after research.

Cost of production before research—fish

Information on costs of production by small-scale fishermen is not readily available. In this paper the before-research cost of production is based on Agbayani et al. (1989).

The research impact of the project with respect to fish

As for rice the successful control of salvinia led to a reduction in the cost of producing inland fish (see Table 3), which in turn led to unit cost savings to fish producers. These estimates of unit cost savings are introduced in the research evaluation model to estimate monetary benefits from research. Information on the price of fish was obtained from Amarasinghe (1987).

The annual benefits to fish producers and consumers

The following equation for a closed economy model (see McMeniman and Lubulwa, 1996) is used to estimate total annual benefits accruing to the fish sector:

$$\Delta ES_c = k_c Q_{fc} + 0.5(Q_{fc}/P_{fc})\,[\varepsilon_s \varepsilon_d k_{cf}^2/(\varepsilon_s+\varepsilon_d)]$$

where

- ΔES_c is the change in economic surplus as a result of better control of *S. molesta*
- k_c is the absolute value of the cost reduction in country *c*
- Q_{fc} is the quantity of fish affected by *S. molesta* before research
- P_{fc} is the price of fish
- ε_s is the elasticity of supply
- ε_d is the elasticity of supply.

3.1.3 Waterways

Salvinia impinges on activities other than rice production and fishing. Doeleman (1990) listed the following nuisance effects of the weed: (i) disruption to power generation; (ii) disruption of water transport; and (iii) difficulty in washing and bathing. To avoid these nuisance effects, waterways have to be cleaned. An estimate of the cost of cleaning waterways is derived from Thomas and Room (1986) who claimed that:

> …to reduce and keep the salvinia infestation of the Sepik flood plain in Papua New Guinea to less than 10 percent of the water surface would require an initial outlay of $US 1 million followed indefinitely by an annual outlay of $US 500,000.

The annual cleaning cost per hectare is calculated by annualising the initial outlay in Thomas and Room (1986) over a 50-year lifespan at a 4 percent per annum rate of discount.

The annual welfare benefits from having waterways (W_c) clear of *S. molesta* are estimated by the following equation:

$$W_c = k_{cw} * A$$

where

W_c is an estimate of the annual benefits from waterways clear of *S. molesta*;

k_{cw} is the reduction in the cost of cleaning water ways as a result of better control of salvinia;

A is the surface area of water affected by salvinia before research.

3.1.4 Human health benefits

S. molesta may create conditions more favourable to mosquiot breeding. Of particular concern are the mosquito-borne diseases—malaria, filariasis, dengue fever and encephalitis. The extent of salvinia's contribution to mosquito-borne diseases is not known. There are no field studies to provide guidance to the costs of salvinia in terms of mosquito-borne diseases. With respect to these diseases we follow Doeleman (1990) and assume that the monetary value of the human health benefits can be estimated as a function of the national budget spent on health services.

The annual human health benefits to country *c* from the control of salvinia (H_c) are thus given by the following equation:

$$H_c = M_c * \Delta V_c * R_c * B_c * S_c$$

where:

H_c is the annual human health benefit accruing to country *c* as a result of better control of *S. molesta*;

M_c is the proportion of the health budget in country *c* spent on mosquito-borne diseases. The most important of the mosquito-borne diseases in the countries involved in project PN8340 is malaria. Thus, estimates by World Bank (1993) of the disability adjusted life years (DALY) lost due to malaria as compared with other diseases are used to estimate M_c. M_c = (DALY lost due to malaria)/ (DALY lost due to all diseases).

ΔV_c is the decrease in the incidence of mosquito-borne diseases as a result of better control of *S. molesta*. Estimates of this parameter are from Doeleman (1990).

R_c is the proportion of the health budget spent on children 0–15 years of age. World Bank (1993) suggests that the DALY lost due to malaria in the over 15 years of age group is zero.

B_c is the total health budget in country *c*. Data on health budgets are from World Bank (1993).

S_c is a measure of the prevalence of *S. molesta* in country *c*.

Table 3 gives a summary of the annual human health benefits from better control of *S. molesta* in the countries that collaborated in PN8340. The benefits to Australia from the control of salvinia are excluded from this analysis. Most of these benefits had already been realised in Australia before the establishment of ACIAR.

Table 4 summarises the flows of benefits from research, and the research costs, on *S. molesta*. An important factor in the estimation of the flow of benefits from biological control of *S. molesta* is the weed damage matrix. A weed damage matrix reflects the extent to which a biological control has spread in the target area since its establishment and the level of control the agent is providing against the weed. ‘Zero’ in the weed damage matrix indicates that either the biological control has not yet been established, or the biological control has no impact on the weed or both. In the *S. molesta* damage matrix, zeroes represent the time when research was still under way in a country to determine host specificity of the weevil and other parameters before the weevil is introduced. The numeral ‘1’ in the matrix indicates that the biological control has spread to the whole of the target area and provided effective control against the weed.

Once established, the control agent works very rapidly. The benefits from control start accruing from the point the control agent is established. The benefits from research started accruing at different times in the different countries. Sri Lanka was the earliest beneficiary since the ACIAR project was implemented first in that country. The countries in Southeast Asia and Africa started later because the control agents from the ACIAR project were introduced later in those countries.

Matrix showing the proportion of *S. molesta* damaged by the biological controls

Year	Sri Lanka	Malaysia	Philippines	Kenya (Lake Naivasha)	Zambia (Ndola)
1984	0	0	0	0	0
1985	0	0	0	0	0
1986	0	0	0	0	0
1987	1	0	0	0	0
1988	1	0	0	0	0
1989	1	0	0	0	0
1990	1	0	0	0	0
1991	1	0	0	0	0
1992	1	0	1	1	1
1993	1	0	1	1	1
1994 onwards	1	0	1	1	1

Table 4. Summary of benefits, by commodity, from controlling *Salvinia molesta* ((PN8340 and PN8340 extensions into Africa and South East Asia)

Year no	Calender year	Rice	Fish	Waterway related benefits	Reduced incidence of mosquito-borne disease	Total benefits	Total research and related costs	Net benefits
1	1984	$0	$0	$0	$0	$0	$274	($274)
2	1985	$0	$0	$0	$0	$0	$155	($155)
3	1986	$0	$0	$0	$0	$0	$86	($86)
4	1987	$425	$65	$293	$5	$788	$144	$644
5	1988	$425	$65	$293	$5	$788	$101	$686
6	1989	$484	$76	$297	$7	$864	$38	$826
7	1990	$484	$76	$297	$7	$864	$23	$841
8	1991	$484	$76	$297	$7	$864	$54	$810
9	1992	$3301	$551	$679	$21	$4552	$0	$4552
10	1993	$3301	$551	$679	$21	$4552	$0	$4552
11	1994	$3301	$551	$679	$21	$4552	$0	$4552
12	1995	$3301	$551	$679	$21	$4552	$0	$4552
13	1996	$3301	$551	$679	$21	$4552	$0	$4552
14	1997	$3301	$551	$679	$21	$4552	$0	$4552
15	1998	$3301	$551	$679	$21	$4552	$0	$4552
16	1999	$3301	$551	$679	$21	$4552	$0	$4552
17	2000	$3301	$551	$679	$21	$4552	$0	$4552
18	2001	$3301	$551	$679	$21	$4552	$0	$4552
19	2002	$3301	$551	$679	$21	$4552	$0	$4552
20	2003	$3301	$551	$679	$21	$4552	$0	$4552
21	2004	$3301	$551	$679	$21	$4552	$0	$4552
22	2005	$3301	$551	$679	$21	$4552	$0	$4552
23	2006	$3301	$551	$679	$21	$4552	$0	$4552
24	2007	$3301	$551	$679	$21	$4552	$0	$4552
25	2008	$3301	$551	$679	$21	$4552	$0	$4552
26	2009	$3301	$551	$679	$21	$4552	$0	$4552
27	2010	$3301	$551	$679	$21	$4552	$0	$4552
28	2011	$3301	$551	$679	$21	$4552	$0	$4552
29	2012	$3301	$551	$679	$21	$4552	$0	$4552
30	2013	$3301	$551	$679	$21	$4552	$0	$4552
		Present value of benefits and costs ($Am, 1990)						
		$19.22	$3.18	$4.65	$0.121	$27.16	$0.70	$26.47
	Accruing to						**Rate of return 76%**	
	Australia	$0.00	$0.00	$0.00	$0.000	$0.00		
	Sri Lanka	$3.69	$0.56	$2.54	$0.045	$6.84		
	Philippines	$15.53	$2.58	$0.59	$0.040	$18.73		
	Malaysia	$0.00	$0.00	$0.00	$0.000	$0.00		
	Kenya	$0.00	$0.04	$0.68	$0.001	$0.72		
	Zambia	$0.00	$0.00	$0.84	$0.035	$0.87		
		$19.22	$3.18	$4.65	$0.121	$27.16		

Most of the benefits accrued to producers and consumers of rice in the countries that collaborated on the project. The next highest benefit accrued to users of waterways without salvinia, and fish. A small proportion of the total benefits is attributed to human health as a result of reduced incidence of mosquito-borne diseases.

Project PN8340 (control of salvinia) is estimated to have generated a total of $27.72 million over a 30-year time horizon with a rate of return of 77 percent. This estimated rate of return is lower than that (287% to 651%) estimated by Doeleman (1990). Possible explanations for this difference include:

(a) this study is using a discount rate of 8 percent per annum whereas Doeleman (1990) used discount rate of 5 percent per annum. This study used a rate of 8 percent partly to be consistent with the guidelines of the Department of Finance (1991, p. 57), and to conform with the practice of ACIAR’s Economic Evaluation Unit;

(b) this study uses a 30-year time horizon whereas Doeleman (1990) used a time horizon of 25 years. A time horizon of 30 years is now routinely applied in all evaluations by the Economic Evaluation Unit;

(c) while Doeleman (1990) used the value-of-output model in determining the research impacts, this study has, in line with Davis et al. (1987) used a welfare-based model in the estimation of the benefits associated with agricultural commodities—rice and fish. In the estimation of non-agricultural benefits from research—human health and waterways — we have used the same method as Doeleman (1990).

3.2 *Mimosa pigra* (PN8339, PN8722 AND PN9319)

Forno (1992) summarised available control agents from ACIAR projects PN8339, PN8722 and PN9319 for biological control of *M. pigra* as follows:

Species tested	Plant part attacked	Established	Status
Bruchidae			
Acanthoscelides puniceus	Mature seeds	In Australia, Yes In Thailand, Yes	<1% mature seed destroyed 1–20% mature seed destroyed
Acanthoscelides quadridentatus	Mature seed	In Australia, Yes In Thailand, Yes	<1% mature seed destroyed 1–20% mature seed destroyed
Chrysomelidae			
Chlamisus mimosae	Pinnae and stems	In Australia, Yes In Thailand, Yes	No significant effect No significant effect
Curculionidae			
Apion aculeatum	Flower buds		Released in Thailand and Australia
Gracillariidae			
Neurostrota gunniella	Pinnules and stems	Australia, Yes Thailand, not released	Spreading rapidly; widespread tip damage
Sesiidae			
Carmenta mimosa	Stems	Australia, released	Established and spreading Thailand has approved its release
Fungal pathogens			
Phloeospora sp. *nov*	Sems, leaves, and seed pods	Australia, released	Released in Australia at end of 1994 (Dr Jim Cullen CSIRO, pers. comm., January 1997)
Diabole cubensis	Leaves	Australia, soon to be released	Not yet released in Australia. Waiting for the appropriate climate conditions (Dr Jim Cullen CSIRO, pers. comm., January 1997)

Many biological control agents have already been released in Australia and Thailand. The purpose of PN9319 was to extend these biological control agents to Indonesia, Malaysia and Vietnam. Project PN9319 is not yet completed, but since it is a technology transfer project—transferring the technologies developed in projects PN8339 and PN8722 to the other countries—this paper provides some preliminary estimates of benefits from the project.

Data on the extent of the spread of *M. pigra* in Australia are readily available (see, for example: Day and Parsons 1986; Miller 1988; Beckmann 1990; Pitt and Miller 1989; Forno 1993). Robert (1982) describes the extent of the problem in Thailand. While *M. pigra* is acknowledged as a problem weed, potentially at least, in Indonesia, Malaysia and Vietnam, quantitative data on the extent of its spread are not available. One of the objectives of a current project (PN9319) is to undertake surveys of these countries to establish the extent of the problem. The current preliminary estimates are based the best documentation available at the time of this study. A more detailed evaluation including some site visits and surveys of some locations infested with *M. pigra* in Thailand is to be undertaken by a group of economists based in Thailand under a collaborative project between the Economic Evaluation Unit of ACIAR and Thailand (ACIAR, 1996). This collaborative project is planned to start in July 1997.

In this preliminary evaluation, the control of *M. pigra* affected five main commodities: rice, beef and buffalo; palm oil; waterways (reservoirs, canals and rivers); and tourism (see Table 2). Not all these commodities were affected to the same extent in all ACIAR's mandate countries. The impact the control of *M. pigra* had on each of these commodities is discussed in turn.

3.2.1 Rice

Rice production affected by M. pigra

Waterhouse(1993) indicates that rice is one of the commodities that is affected by *M. pigra* in Southeast Asia. Table 5 summarises the key assumptions made in the estimation of the benefits to rice producers and consumers derived from better control of *M. pigra*. The data on rice production ares from FAO (1994b). The estimates of the proportion of irrigated rice are from IRRI (1995). The percentage of rice affected by *M. pigra* is based on estimates by Robert (1982) on the importance of *M. pigra* in crop production and on indications of degree of importance of *M. pigra* in Southeast Asia in Waterhouse (1993). In addition, Sivapragasam et al. (undated) provided some qualitative data on the importance of *M. pigra* in Malaysia. Yields before research were for 1990 the base year, obtained from IRRI (1995) for the relevant countries. The cost of production for rice before research is based on IRRI (1995).

The price of rice is the rice export price quotation in the base year (1990) in Thailand as published in ABARE (1996). The estimates of elasticity of demand and supply are from a database in ACIAR's Economic Evaluation Unit.

Rice is an internationally traded commodity and so the benefits in Table 6 are based on a general model which allows for trade in rice and for changes in the world price of rice as the cost of producing rice changes in the countries that were involved in the ACIAR-supported projects on *M. pigra*.

Table 5. Assumptions on which the preliminary estimates of the annual benefits of controlling *Mimosa pigra* (PN8339, PN8722, and PN9319) are based.

Base year 1990	Australia (Northern Territory)	Thailand	Indonesia	Malaysia	Vietnam
Rice production—Total ('000 t, average 1989–1990)	na	12727	28509	1123	11963
Irrigated rice	na	891	20527	741	6340
Percentage of rice affected by *Mimosa pigra*	na	0.20	0.07	0.02	0.03
Quantity of rice affected by *Mimosa pigra*	na	178.18	1436.86	14.82	190.20
Yield before research (t/ha) average 1990	na	3.02	4.35	3.10	3.11
Cost of producing rice before research ($/ha)	na	1083	1083	1083	1083
Cost of controlling *Mimosa pigra* ($/ha) — before research	na	71	71	150	71
Unit cost of producing rice before research ($/t)	na	382	265	398	371
Cost of controlling *Mimosa pigra* ($/ha) — with biological control	na	4	4	4	4
Unit cost of producing rice after research ($/t)	na	360	250	351	350
Unit cost saving in the production of rice after research ($/t)	na	22	15	47	22
Price of rice	na	406	406	406	406
Elasticity of supply	na	0.30	0.30	0.30	0.30
Elasticity of demand	na	0.10	0.10	0.10	0.10
Beef and buffalo meat production ('000 t, average 1988–1990)	100	230	296	na	190
Percentage of beef and buffalo production affected by *Mimosa pigra*	0.05	0.02	0.01	na	0.003
Beef and buffalo production affected by *Mimosa pigra* ('000 t, 1990)	5.02	4.60	2.07	na	0.57
Beef and buffalo produced per ha (mt)	0.55	0.55	0.55	na	0.55
Cost of producing beef and buffalo before research ($/t)	600	600	600	na	600
Cost of controlling *Mimosa pigra* ($/t) — before research	131	131	131	na	131
Unit cost of producing beef and buffalo before research ($/t)	731	731	731	na	731
Cost of controlling *Mimosa pigra* ($/ha) — with biological control	4	4	4	na	4
Unit cost of producing beef and buffalo after research ($/t)	604	604	604	na	604
Unit cost saving in the production of beef and buffalo after research ($/t)	127	127	127	na	127
Price of beef and buffalo ($A/t)	962	962	962	na	962
Elasticity of supply	0.40	0.40	0.40	na	0.40
Elasticity of demand	0.40	0.40	0.40	na	0.40
Palm oil production, 1988–90 averages ('000 t)	na	195	2071	5727	0
Percentage affected by *Mimosa pigra*	na	0.02	0.01	0.02	na
Quantity affected by *Mimosa pigra* ('000 t)	na	4	14	115	na
Cost saving due to research ($/t)	na	22	22	15	na
Price of palm oil ($A/t)	na	495	495	495	na
Elasticity of supply	na	0.16	0.16	0.16	na
Elasticity of demand	na	0.44	0.44	0.44	na
Estimate of the annual welfare gain ($A'000, 1990)	na	87	324	1776	na
Volume of reservoirs in a country (cubic km)	800	110	2530	456	376
Cost of controlling *Mimosa pigra* before research ($A'000/cubic km)	0.0374	0.0374	0.0374	0.0374	0.0374
Cost of controlling *Mimosa pigra* after research ($A'000/cubic km)	0.0041	0.0041	0.0041	0.0041	0.0041
		Annual benefit per cubic km as a result of control			
Irrigation water benefits ($A'000/cubic km)	$16.400	$16.400	$16.400	$16.400	$16.400
Aquaculture and fresh water fish culture benefits ($A'000/cubic km)	$0.013	$0.013	$0.013	$0.013	$0.013
Power generation benefits ($A'000/cubic km)	$0.000	$0.532	$0.532	$0.532	$0.532
Flood control benefits ($A'000/cubic km)	$0.205	$0.205	$0.205	$0.205	$0.205
Wier repair benefits ($A'000/cubic km)	$0.000	$0.009	$0.009	$0.009	$0.009
Annual benefit due to research freeing reservoirs of *Mimosa pigra* ($A'000/cubic km)	164	82	1887	340	280

The research impact of the project with respect to rice

The before-research cost of controlling *M. pigra* in rice production is based on the estimate by Robert (1982) of the cost controlling *M. pigra* in irrigation systems in Thailand managed by the Royal Irrigation Department of the Ministry of Agriculture. The most common method of control is mechanical—involving cutting and destroying the mimosa plants. There is a cost of controlling *M. pigra* after research. This is also based on Robert (1982) whose estimate is based on interviews with Dr Banpot Napompeth (Director of the National Biological Control Research Centre)—the Thai project leader of the two ACIAR projects on mimosa in Thailand (PN8339 and PN8722). The cost of control after research relates to the cost raising and releasing the biological controls.

3.2.2 Beef and buffalo meat

Beef and buffalo meat production affected by M. pigra

M. pigra affects beef and buffalo production in two ways. First, the spread of *M. pigra* reduces the area used for pasture and for grazing of animals. Secondly, growth of *M. pigra* along rivers, canals and other waterways, restricts access of livestock to water.

Table 5 summarises the key assumptions made in the estimation of the benefits to producers and consumers of beef and buffalo meat derived from better control of *M. pigra*. The data on beef and buffalo production are from FAO(1994b). The percentage of beef and buffalo affected by mimosa is small. Robert (1982) commented that

> Current *Mimosa pigra* control efforts already provide a weed-free area greater than that demanded for pasture.

The impacts of *M. pigra* on beef production are included in this analysis despite the comments in Robert (1982) because it is now 14 years since the study during which *M. pigra* has been spreading and covering increasingly larger areas in Thailand.

3.2.3 Palm oil

Sivapragasam (undated) states that:

> *Mimosa pigra*'s recent encroachment into immature oil palm plantations has caused significant concern to the government.

Table 5 summarises the key assumptions made in the estimation of the benefits to producers and consumers of palm oil derived from better control of *M. pigra*.

3.2.4 Reservoirs

Day and Parsons (1986) note that:

> *Mimosa pigra* chokes waterways including irrigation ditches, changes the flow of rivers, has invaded a number of reservoirs and is accelerating their siltation (which it is believed will reduce effective life of some reservoirs by about 75 percent).

In this preliminary assessment, an estimate of benefits associated with reservoirs due to better control of *M. pigra* is based on Robert (1982).

Robert (1982) assumed that, without *M. pigra,* a reservoir could last for about 100 years. However, if there is *M. pigra*, then the life of a reservoir is reduced to only 25 years. The difference between the flow of benefits from a reservoir without *M. pigra* and a flow of benefits with *M. pigra* provides an estimate of the benefit achievable from better control of *M. pigra*. In Table 6 the estimates by Robert (1982) are used to estimate the benefit per cubic metre of reservoir derived from better control of *M. pigra*. Table 5 shows the categories of reservoir-related benefits included in the analysis.

Data on reservoir capacity in the different countries is obtained from World Resources Institute (1994). Estimates of the cost of control before and after research are based on Robert (1982).

The annual welfare benefits from having reservoirs (R_c) clear of *M. pigra* are estimated by the following equation:

$$R_c = b_{cw} * A$$

where

R_c is the annual welfare benefits from reservoirs clear of *M. pigra*;

b_{cw} is the is the annual benefit per cubic metre of reservoir, based on Robert (1982), as a result of better control of *M. pigra*;

A is the total capacity of reservoirs in a country.

Table 6 shows the total benefits from the control of *M. pigra* over a period of 30 years. These preliminary estimates indicate that the three projects are associated with a benefit of about $A23,000,000. Most of those benefits are associated with rice production, followed by those due to extensions in the lives of reservoirs as a result of better control of *M. pigra*, then the palm oil sector, then the beef and buffalo sector. The three projects on the control of *M. pigra* have a rate of return of 26 percent.

A major assumption which determines the size of the benefits is the matrix which indicates how far the biological controls have spread in the target area and the extent to which they are causing damage to *M. pigra*. A major difference between the control of *M. pigra* and the control of *S. molesta* is that the biological controls for mimosa take a long time to have an impact on the stock of *M. pigra* weeds. For *M. pigra*, it is assumed that it will take some time before the speed at which *M. pigra* spreads is overtaken by the rate of destruction of the weed by the controls in question.

The matrix of *M. pigra* 'spread and damage' at the top of the next page was used in this study. The entries in the *M. pigra* damage matrix embody the following assumptions. First, *M. pigra* is very different from salvinia. The control agent for salvinia damaged the salvinia weed as soon as the agent was established. With *M. pigra*, even when the control agents are well-established, it is likely to take time before the agent makes visible impact on the weed. An estimate when this is likely to happen is indicated by the first time a non-zero entry appears in the damage matrix. Second, implicit in the *M. pigra* damage matrix is an assumption that over the 15 years the coverage of *M. pigra* in the countries that collaborated on the *M. pigra* projects could be reduced by up to 30 percent. However, this may be an optimistic assumption. Other scenarios as examined in section 4 of the paper where sensitivity analyses on selected variables are discussed.

Table 6. **The flow of benefits and costs over time as a result of better control of *Mimosa pigra* in Australia, Thailand, Indonesia, Malaysia and Vietnam (PN8339, PN8722, and PN9319).**

Year Ño	Calender year	Rice	Beef and Buffalo	Palm oil	Reservoirs	Total benefits	Total research and related costs	Net benefits
1	1984	$0	$0	$0	$0	$0	$130	($130)
2	1985	$0	$0	$0	$0	$0	$316	($316)
3	1986	$0	$0	$0	$0	$0	$280	($280)
4	1987	$0	$0	$0	$0	$0	$193	($193)
5	1988	$0	$0	$0	$0	$0	$140	($140)
6	1989	$0	$0	$0	$0	$0	$256	($256)
7	1990	$0	$0	$0	$0	$0	$277	($277)
8	1991	$0	$0	$0	$0	$0	$157	($157)
9	1992	$0	$0	$0	$0	$0	$58	($58)
10	1993	$0	$0	$0	$0	$0	$22	($22)
11	1994	$0	$0	$0	$0	$0	$0	$0
12	1995	$0	$0	$0	$0	$0	$0	$0
13	1996	$0	$0	$0	$0	$0	$0	$0
14	1997	$0	$0	$0	$0	$0	$0	$0
15	1998	$0	$0	$0	$0	$0	$0	$0
16	1999	$199	$30	$12	$2753	$2982	$0	$2982
17	2000	$398	$64	$25	$2753	$3214	$0	$3214
18	2001	$1950	$80	$85	$2753	$4782	$0	$4782
19	2002	$3503	$112	$148	$2753	$6367	$0	$6367
20	2003	$5057	$170	$214	$2753	$7979	$0	$7979
21	2004	$6612	$216	$283	$2753	$9581	$0	$9581
22	2005	$7968	$229	$341	$2753	$10949	$0	$10949
23	2006	$9326	$242	$402	$2753	$12320	$0	$12320
24	2007	$9326	$242	$402	$2753	$12320	$0	$12320
25	2008	$9326	$242	$402	$2753	$12320	$0	$12320
26	2009	$9326	$242	$402	$2753	$12320	$0	$12320
27	2010	$9326	$242	$402	$2753	$12320	$0	$12320
28	2011	$9326	$242	$402	$2753	$12320	$0	$12320
29	2012	$9326	$242	$402	$2753	$12320	$0	$12320
30	2013	$9326	$242	$402	$2753	$12320	$0	$12320
		Present value of benefits and costs ($Am, 1990)						
		$15.19	$0.45	$0.66	$7.43	$23.06	$1.30	$21.77
Accruing to							**Rate of return 26%**	
	Australia	$0.00	$0.25	$0.00	$0.44	$0.69		
	Thailand	$2.43	$0.10	$0.15	$0.22	$2.91		
	Indonesia	$10.48	$0.08	$0.44	$5.09	$16.09		
	Malaysia	$0.33	$0.00	$0.06	$0.92	$1.31		
	Vietnam	$1.94	$0.02	$0.00	$0.76	$2.72		

Matrix showing the proportion of *M. pigra* damaged by the biological controls

Year no	Year	Malaysia	Thailand	Vietnam	Australia
1-15	1984–1998	0	0	0	0
16	1999	0	0.05	0	0.05
17	2000	0	0.1	0	0.1
18	2001	0.05	0.15	0.05	0.15
19	2002	0.1	0.2	0.1	0.2
20	2003	0.15	0.25	0.15	0.25
21	2004	0.2	0.3	0.2	0.3
22	2005	0.25	0.3	0.25	0.3
23	2006	0.3	0.3	0.3	0.3
24	2007	0.3	0.3	0.3	0.3
25	2008	0.3	0.3	0.3	0.3
26	2009	0.3	0.3	0.3	0.3
27	2010	0.3	0.3	0.3	0.3
28	2011	0.3	0.3	0.3	0.3
29	2012	0.3	0.3	0.3	0.3
30	2013	0.3	0.3	0.3	0.3

3.3 Biological control of pests and weeds in the South Pacific: four projects that succeeded and made an economic impact

3.3.1 Fruit piercing moths (PN8802A and PN9308)

Soon and Hill (1992), in their review of ACIAR Project 8802A, concluded as follows:

> Four of the five objectives concerning the fruit-piercing moth subproject have been satisfactorily achieved. The fifth objective to measure the impact on numbers of fruit-piercing moths and their damage to fruit could not be fully fulfilled because of a variety of reasons.

Subproject 8802A introduced into Tonga two parasites (*Ooencyrtus crassulus and Ooencyrtus sp. LPL531*) of the fruit piercing moth. The project also introduced and established parasites of the moth to Fiji and Samoa. However, because of the lack of crop loss and damage data relating to the activity of the parasites, Soon and Hill (1992) could not determine the real impact and benefit contributed by the parasites. PN9308 completed the research started under PN8802A.

This economic evaluation is largely based on the following assessments by Sands (1995) and Muniappan and Fay (1995):

Western Samoa:

Sands (1995, p.4) indicated that fruit in Western Samoa continues to suffer from appreciable levels of moth damage. This is interpreted to mean that the biological controls against the moth have not worked well in that country. Muniappan and Fay (1995) while not so negative, do not indicate significant impact at this stage, and say that:

> The introduced parasitoids appear to be contributing to some reduction in moth populations in Western Samoa. Further time is required to detail increased parasitism levels and to undertake further crop loss assessment and moth population decline confirmation—the affected countries might then have the confidence to engage in additional fruit production.

Tonga

The three parasites of the moth — *Telenomus* sp., *Ooencyrtus* sp. and *O. crassulus* — have established, but have only recently begun to have an impact on moth populations in Tonga. Sands (1995). Muniappan and Fay (1995) confirm this assessment.

Fiji

Progress towards biological control has been achieved following establishment of the two exotic parasitoids from PNG, *Telenomus* sp. and*Ooencyrtus* sp. This has been followed by a decrease in unmarketable fruit at Batiri Orchard from about 40% to less than 5% with record-quality fruit marketed in 1994. Muniappan and Fay (1995) confirm this assessment.

Australia

While fruit-piercing moths occur in Australia, and while there are potential benefits to producers of most tropical and subtropical fruit in eastern Australia, no benefits have accrued to Australia as yet. This is because permission to import the biological controls discovered under these two ACIAR projects has not yet been granted by the Australian Quarantine Inspection Service and the Australian Nature Conservation Agency (Dr Don Sands, CSIRO, pers. comm., January 1997).

Fruit piercing moths affect many fruits, but the benefits discussed in this paper are restricted to three fruits: orange, pineapple, and papaya (see Table 7). While ACIAR (1993) lists these fruits as among those which are affected by the fruit piercing moth, it was not possible to obtain data about their production.

The data on citrus production are from FAO (1994b). Yields for citrus fruit are based on Turkington and Revelant (1994) for Australia and ACIAR (1993) for the South Pacific countries.

The production costs per tonne are estimated from Asian Development Bank (1996). The project is assumed to increase marketed output of citrus fruit by up to 35 % (Sands 1995). This result is used to estimate the after-research yields. Data on price of oranges are from ABARE (1996). Other prices are from Asian Development Bank (1996).

Table 7 lists the assumptions used in estimating a farm-level cost saving as a result of the technologies developed under this project.

Table 8 shows that this project, over a period of 30 years, is likely to generate total benefits of $A0.6 million and a rate of return of just over 7 per cent per annum. However, this estimate is based on only those three susceptible fruits for which data were available. Inclusion of all susceptible fruits would lead to a higher rate of return. Nonetheless, this estimate concurs with the assessment by Muniappan and Fay (1995) who noted that:

> At current levels of fruit production the impact in dollar terms is not great.

The estimate in Table 8 has allowed for a possible 1 percent per annum growth in the production of the selected fruits from the point the biological controls are established in a collaborating country.

Table 7. Assumptions used in estimating the annual benefits from the biological control of fruit piercing moth.

Base year 1990	**Australia**	**Fiji**	**Western Samoa**	**Tonga**
Oranges				
Quantity of oranges produced	496.925	0.541	1.33	2.700
Proportion of oranges affected by fruit piercing moth	na	1.00	1.00	1.00
Quantity of oranges affected by fruit piercing moth	na	0.541	0	2.700
Yield before research (t/ha) average 1990	45	23.48	23.48	23.48
Cost of producing oranges before research ($/ha)	na	376	376	376
Unit cost of producing oranges before research ($/t)	na	16.01	16.01	16.01
Yield after research (t/ha) average 1990	na	32	23	32
Unit cost of producing oranges after research ($/t)	na	11.86	16.01	11.86
Unit cost saving in the production of oranges after research ($/t)	na	4.15	0.00	4.15
Price of oranges	na	115	115	115
Elasticity of supply	na	2.20	2.20	2.20
Elasticity of demand	na	0.40	0.40	0.40
Pineapples				
Quantity of pineapples affected by fruit piercing moth	na	4.05	3	1.52
Percentage of pineapples affected by fruit piercing moth	na	1.00	1.00	1.00
Yield before research (t/ha) average 1990	na	35.97	35.97	35.97
Cost of producing pineapples before research ($/ha)	na	1258.00	1258.00	1258.00
Unit cost of producing pineapples before research ($/t)	na	34.98	34.98	35
Yield after research (t/ha) average 1990	na	55.33	55.33	55.33
Unit cost of producing pineapples after research ($/t)	na	23	23	23
Unit cost saving in the production of pineapples after research ($/t)	na	12	12	12
Price of pineapples	na	200	200	200
Elasticity of supply	na	0.40	0.40	0.40
Elasticity of demand	na	0.40	0.40	0.40
Papaya				
Quantity produced, 1988-90 Averages ('000 t)	na	0.26	na	na
Quantity of papaya affected by fruit piercing moth	na	0.26	na	na
Percentage of papaya affected by fruit piercing moth	na	1	na	na
Yield before research (t/ha) average 1990	na	10.08	na	na
Cost of producing papaya before research ($/ha)	na	1203	na	na
Unit cost of producing papaya before research ($/t)	na	119.35	na	na
Yield after research (t/ha) average 1990	na	12.60	na	na
Unit cost of producing papaya after research ($/t)	na	95	na	na
Unit cost saving in the production of papaya after research ($/t)	na	24	na	na
Price of papaya	na	150.00	na	na
Elasticity of supply	na	0.40	na	na
Elasticity of demand	na	0.40	na	na

[na] denotes that the technology has not yet had an impact in the country. In the case of Australia the various controls have not been cleared for importation into the country.

Table 8. A summary of benefits, by selected commodity, from controlling fruit piercing moth

Year No	Calender year	Oranges	Pineapple	Papaya	Total benefits	Total research and related costs	Net benefits
1	1988	$0	$0	$0	$0	$103	($103)
2	1989	$0	$0	$0	$0	$122	($122)
3	1990	$0	$0	$0	$0	$42	($42)
4	1991	$0	$0	$0	$0	$0	$0
5	1992	$0	$0	$0	$0	$0	$0
6	1993	$0	$0	$0	$0	$391	($391)
7	1994	$0	$0	$0	$0	$319	($319)
8	1995	$0	$0	$0	$0	$0	$0
9	1996	$2	$50	$3	$53	$0	$53
10	1997	$2	$51	$4	$53	$0	$53
11	1998	$20	$106	$4	$126	$0	$126
12	1999	$20	$107	$4	$127	$0	$127
13	2000	$20	$108	$4	$128	$0	$128
14	2001	$20	$109	$4	$129	$0	$129
15	2002	$20	$110	$4	$130	$0	$130
16	2003	$21	$111	$4	$132	$0	$132
17	2004	$21	$112	$4	$133	$0	$133
18	2005	$21	$113	$4	$134	$0	$134
19	2006	$21	$114	$4	$135	$0	$135
20	2007	$21	$115	$4	$137	$0	$137
21	2008	$21	$116	$4	$138	$0	$138
22	2009	$22	$117	$4	$139	$0	$139
23	2010	$22	$118	$4	$140	$0	$140
24	2011	$22	$119	$4	$141	$0	$141
25	2012	$22	$120	$4	$143	$0	$143
26	2013	$22	$121	$4	$144	$0	$144
27	2014	$23	$122	$4	$145	$0	$145
28	2015	$23	$123	$4	$146	$0	$146
29	2016	$23	$124	$4	$147	$0	$147
30	2017	$23	$125	$4	$149	$0	$149
		Present value of benefits and costs ($Am, 1990)					
		$0.10	$0.56	$0.02	$0.66	$0.67	($0.00)
Benefits to						**Rate of return 7.94%**	
	Australia	$0.00	$0.00	$0.00	$0.00		
	Fiji	$0.01	$0.30	$0.02	$0.33		
	Western Samoa	$0.03	$0.17	$0.00	$0.20		
	Tonga	$0.06	$0.09	$0.00	$0.15		

3.3.2 Banana skipper (PN8802-C)

Subproject 8802-C had the following objectives:

- monitor banana skipper populations and damage at selected sites in Papua New Guinea before introduction of exotic natural enemies;
- identify natural enemies attacking banana skipper life stages in Papua New Guinea at present;
- arrange host-specificity testing of relevant exotic parasites against appropriate Hesperiidae, and seek clearance for release of any that are adequately host specific against banana skipper;
- arrange mass production and release of parasites approved for liberation; and
- monitor effects on banana skipper populations after release of exotic natural enemies.

Soon and Hill (1992) in their review of ACIAR project 8802–C concluded that all objectives of the original project had been met.

An evaluation of the benefits accruing to Papua New Guinea was undertaken using the assumptions in Table 9. A key assumption is the extent of fruit weight loss attributable the skipper. Waterhouse and Norris (1989) state that:

> The banana plant produces leaves in excess of its needs for fruit production. Defoliation at 0, 10, 20, 30 and 40 percent at 35 day intervals for four years showed that there was no significant loss in fruit weight until 20% or more leaf area had been removed. Defoliation at the time of appearance of the fruiting bud caused the greatest reduction in fruit weight. Fifty percent defoliation at this time caused 28 percent loss in fruit weight.

Table 9 lists the assumptions on which the estimates of research benefits from this project are based. Production data are from FAO (1994a, b). An estimate of the proportion of bananas affected by banana skipper is based on two pieces of information: (i) Waterhouse and Norris (1989) who indicate that some parts of Papua New Guinea were not affected by the banana skipper; and (ii) information indicating that in the wet season in PNG mainland, between January and April of each year, the banana skipper was controlled by rain, to which it is sensitive (Dr Don Sands, CSIRO, Brisbane, pers. comm., January 1997). Estimates of the cost of production of bananas were based on PCCARD (1986). The yields of bananas in subsistence farming in Papua New Guinea are from Densley (1978, p. 48).

Soon and Hill (1992) note that bananas are not a significant commercial crop in Papua New Guinea, but that the banana is a major commodity for subsistence use in PNG. In assessments by ACIAR's Economic Evaluation Unit (see, for example, Davis and Lubulwa, 1995), bananas are a commodity ranked in priority group 1. This high ranking is partly due to the high level of production of bananas in PNG— over 1 million tonnes are produced every year (see Table 9).

In this analysis it is assumed that the biological control is currently affecting about 70 percent of banana production in Papua New Guinea, since there are still occasional outbreaks of the skipper (Dr Don Sands, CSIRO, pers. comm., January 1997).

Thus, the banana skipper damage matrix in Papua New is assumed to be as follows:

Year	Damage matrix for PNG
1988	0
1989	0
1990	0
1991	0.05
1992	0.1
1993	0.15
1994	0.2
1995	0.25
1996	0.3
1997	0.35
1998	0.4
1999	0.45
2000	0.5
2001	0.55
2002	0.6
2003	0.65

Table 9. Assumptions used in the estimates of the annual benefits on bananas affected by banana skipper (PN8802–C)

Items	Papua New Guinea
Base year 1990	
Banana production — total (’000 t, average 1989–1990)	1150
Proportion of banana production affected by banana skipper	0.5
Quantity of banana production affected by banana skipper	575
Farm inputs in the production of bananas (per 13 kg carton) (Source: PCCARD, 1986, p. 22)	
Land preparation	$0.02
Weed control	$0.03
Propping or tying	$0.06
Labour	$1.31
Sundry	$0.02
Total cost per 13 kg carton ($A)	$1.44
Number of 13 kg cartons produced in PNG per ha (mixed cropping)	2
Total production per hectare (mt)	0.03
Total production cost per hectare ($A)	3.32
Yield decrease due to banana skipper	0.1
Yield before research (t/ha)	0.023
Yield after research (t/ha)	0.03
Cost of production before research ($A/ha)	$3.32
Unit cost of production before research ($A/t)	$142.01
Unit cost of production after research ($A/t)	$127.81
Cost saving ($A/t)	$14.20
Ceiling level of entries in the banana skipper spread and damage matrix	0.70
Price of bananas ($A/t)	$275.00
Elasticity of supply	0.4
Elasticity of demand	0.4

The benefits from this project are estimated using a closed economy model since all of them are assumed to have accrued to the subsistence sector in PNG where there is little if any trade in bananas. Table 10 shows the annual benefits accruing to PNG. This project is estimated to generate benefits equal to about $A23 million over 30 years, with a rate of return of 81 percent.

Table 10. Summary of benefits from controlling banana skipper (ACIAR project PN8802–C)

No.	Year	Australia* Banana	PNG Banana	Total benefits Banana	Research costs $A000's (1990)	Net benefits $A000's (1990)
1	1988	$0	$0	$0	100.05	($100)
2	1989	$0	$0	$0	156.34	($156)
3	1990	$0	$0	$0	52.9	($53)
4	1991	$0	$214	$214	0	$214
5	1992	$0	$450	$450	0	$450
6	1993	$0	$705	$705	0	$705
7	1994	$0	$982	$982	0	$982
8	1995	$0	$1279	$1279	0	$1279
9	1996	$0	$1596	$1596	0	$1596
10	1997	$0	$1934	$1934	0	$1934
11	1998	$0	$2293	$2293	0	$2293
12	1999	$0	$2673	$2673	0	$2673
13	2000	$0	$3073	$3073	0	$3073
14	2001	$0	$3493	$3493	0	$3493
15	2002	$0	$3935	$3935	0	$3935
16	2003	$0	$4397	$4397	0	$4397
17	2004	$0	$4879	$4879	0	$4879
18	2005	$0	$4879	$4879	0	$4879
19	2006	$0	$4879	$4879	0	$4879
20	2007	$0	$4879	$4879	0	$4879
21	2008	$0	$4879	$4879	0	$4879
22	2009	$0	$4879	$4879	0	$4879
23	2010	$0	$4879	$4879	0	$4879
24	2011	$0	$4879	$4879	0	$4879
25	2012	$0	$4879	$4879	0	$4879
26	2013	$0	$4879	$4879	0	$4879
27	2014	$0	$4879	$4879	0	$4879
28	2015	$0	$4879	$4879	0	$4879
29	2016	$0	$4879	$4879	0	$4879
30	2017	$0	$4879	$4879	0	$4879
Net present value of benefits and costs in $AM, 1990						
		$0.00	$22.495	$22.50	$0.27	$22.23
				Banana—Rate of return 81%		

* Though the banana skipper never crossed to Australia, there are benefits from its effective control. The benefits to Australia are being estimated by an external consultant using the Climex model and will be published in a separate report.

Soon and Hill (1992) indicated that there were various other unquantifiable positive impacts of the project which included:

- the restoration of ‘normalcy’ to village banana production; and
- the opportunity to educate members of the general public in a very practical way about the potential benefits to biological control of pests as an alternative to pesticides.

Australia also benefited in that the advance of the pest towards Australia was stopped. Australian scientists now have the knowledge of the insect and its natural enemies to deal with it promptly.

3.3.3 Breadfruit mealybug (PN9111);

This project was a great success. The reviewers of the project, Macfarlane and Waterhouse (1995), summed up their assessment of the project as follows:

> The review team considered that good progress has been made towards all four objectives. A thorough survey of natural enemies in Australia revealed potential control agents. A predacious beetle (*Rodolia limbata* Blackburn) specific to the mealybug bred easily and was suitable as a biological control agent. Introductions were made first to the Federated States of Micronesia. A shipment was planned to Kiribati shortly after the review. It has not been necessary for the beetles to be multiplied and spread within the Federated States of Micronesia, because only one island has severe mealybug problems. Monitoring in FSM has shown rapid and spectacular control of the mealybug, to the extent that members of the public there have commented on the success.

While the project refers to breadfruit mealybug, Sands and Brancatini (1994) point out that *Icerya aegyptiaca* infests a wide range of plants including cucurbits, banana, taro, coconut, and citrus. Nevertheless, since the focus of PN9111 was breadfruit mealybug, the evaluation of the projects’ impact is restricted to breadfruit.

Unfortunately, despite the importance of breadfruit in the South Pacific, production data are not readily available. In this analysis, production of breadfruit in the collaborating countries is estimated (Table 11) on the following bases:

(i) data on population in the South Pacific countries, the proportion of households in rural areas, and the average family size were obtained from Norman and Ngaire (1994);

(ii) the numbers of breadfruit trees per households were estimated by Sands and Brancatini (CSIRO, pers. comm., January 1997);

(iii) the numbers of fruit per tree, the yields per hectare, and the weight of a breadfruit are from Verheij and Coronel (1991).

Estimates of the cost of production were based on ANZDEC (1994). Breadfruit is a subsistence staple food in the South Pacific and is generally not traded, even in village markets (Dr D. Sands, CSIRO, pers. comm., January 1997). An approximation of the price of breadfruit is based on the prices of staple foods in the region (Asian Development Bank, 1996).

Table 11 shows the assumptions made in estimating the annual benefit from the biological control of breadfruit mealybug in the countries that collaborated in the project. Table 12 shows the estimate of benefits from project PN9111.

Table 11. The assumptions made in estimating the annual benefit from the biological control of breadfruit mealybug (PN9111).

Base year 1990	Federated States of Micronesia	Kiribati	Marshall Island	Palau
Breadfruit production—total ('000 t, average 1989–1990)				
Population (1990)	100520	72298	49969	16386
Family size	7	7	7	7
Estimate of number of households	14360	10328	7138	2341
Number of households per village cluster	12	12	12	12
Number of village clusters	1197	861	595	195
Proportion of households in the rural areas	0.60	0.60	0.60	0.60
Number of breadfruit trees per village cluster (low estimate)	12	12	12	12
Number of breadfruit trees per village cluster (high estimate)	20	20	20	20
Total number breadfruit trees (low estimate)	8616	10328	7138	2341
Total number breadfruit trees (high estimate)	14360	17214	11897	3901
Number of fruits per tree (low estimate)	200	200	200	200
Number of fruits per tree (high estimate)	700	700	700	700
Weight per fruit (low estimate, kg)	0.4	0.4	0.4	0.4
Weight per fruit (high estimate, kg)	1.2	1.2	1.2	1.2
Total annual production (low estimate, '000 t)	0.69	0.83	0.57	0.19
Total annual production (high estimate, '000 t)	12	14	10	3
Yield before research (t/ha) average 1990	16.00	16.00	16.00	16.00
Imputed cost of production before research ($/ha)	424	424	424	424
Imputed unit cost of production before research ($/t)	27	27	27	27
Yield after research (t/ha) average 1990	24	24	24	24
Imputed unit cost of production after research ($/t)	17.68	17.68	17.68	17.68
Unit cost saving in the cost of production after research ($/t)	8.84	8.84	8.84	8.84
Price of breadfruit — $A/t	650	650	650	650

3.4 Biological control of pests and weeds in the South Pacific: three projects that led to unintended but unquantifiable economic impact

3.4.1 Leucaena psyllid (PN8802–D)

Soon and Hill (1992), in their end of project review, indicated that the project successfully developed a quick sampling technique to estimate psyllid abundance and plant damage. But overall, they found that: 'the results of this Subproject do not favour the potential for biological control of *Heteropsylla cubana* in Australia'. The parasites tested (*Psyllaephagus yaseeni* and *Tamarixia leucaenae*) by the project were not host-specific enough and seemed to feed on *Heteropsylla spinulosa* which was introduced in Australia and Western Samoa to control *M. invisa*.. Furthermore, *Leucaena leucocephala* is regarded as a weed in some countries (Western Samoa included) in the South Pacific, and as a useful plant in other countries.

Table 12. Flow of benefits from the control of breadfruit mealybug (PN9111)

Year No		Australia	Fiji	Western Samoa	Tonga	Total benefits	Research costs	Net benefits
		Breadfruit	**Breadfruit**	**Breadfruit**	**Breadfruit**	**Breadfruit**	**$A'000s, 1990**	**$A'000s 1990**
1	1992	$0	$0	$0.00	$0	$0	77.1658	($77)
2	1993	$0	$0	$0.00	$0	$0	158.42	($158)
3	1994	$0	$0	$0.00	$0	$0	136.8996	($137)
4	1995	$0	$0	$0.00	$0	$0	114.9328	($115)
5	1996	$0	$107	$0.00	$0	$107	143.88605	($37)
6	1997	$0	$107	$0.00	$0	$107	213.2	($106)
7	1998	$0	$107	$127.96	$0	$235	0	$235
8	1999	$0	$107	$127.96	$117	$352	0	$352
9	2000	$0	$108	$129.24	$119	$356	0	$356
10	2001	$0	$109	$130.52	$120	$359	0	$359
11	2002	$0	$110	$131.79	$121	$363	0	$363
12	2003	$0	$111	$133.07	$122	$366	0	$366
13	2004	$0	$112	$134.35	$123	$370	0	$370
14	2005	$0	$113	$135.63	$124	$373	0	$373
15	2006	$0	$114	$136.91	$126	$377	0	$377
16	2007	$0	$115	$138.19	$127	$380	0	$380
17	2008	$0	$116	$139.47	$128	$384	0	$384
18	2009	$0	$117	$140.74	$129	$387	0	$387
19	2010	$0	$118	$142.02	$130	$391	0	$391
20	2011	$0	$120	$143.30	$132	$394	0	$394
21	2012	$0	$121	$144.58	$133	$398	0	$398
22	2013	$0	$122	$145.86	$134	$401	0	$401
23	2014	$0	$123	$147.14	$135	$405	0	$405
24	2015	$0	$124	$148.41	$136	$408	0	$408
25	2016	$0	$125	$149.69	$137	$412	0	$412
26	2017	$0	$126	$150.97	$139	$415	0	$415
27	2018	$0	$127	$152.25	$140	$419	0	$419
28	2019	$0	$128	$153.53	$141	$423	0	$423
29	2020	$0	$129	$154.81	$142	$426	0	$426
				Present value of benefits and costs in $A m, 1990				
						Rate of return 26%		
		$0.00	$0.898	$0.91	$0.77	$2.57	$0.63	$1.94

Despite these problems, Soon and Hill (1992) concluded as follows:

> The research outputs of this project have now enabled Australia to gauge the potential threat of *Psl-laephagus yaseeni* and *Tamarixia leucaenae* (the two parasites tested in the project) to the biological control of *M. invisa* in Australia and Western Samoa. This is a tremendous benefit. By having this information to decide against their introduction, the potential negative impact of these parasites have been avoided. What this will relate to in terms of cost-benefits can only be speculative since the real impact will not be known because the parasites are not introduced. The lack of economic data associated with the non-introduction makes the return on investment difficult to assess.

3.4.2 Banana aphids (PN8802–E and CS2–92–828)

Soon and Hill (1992) concluded that:

> Had the parasite (*Aphidius colemani*) not established on melon aphid (and taro), the returns on this subproject would be minimal, since the banana aphid seems to have remained unaffected by its release.

Soon and Hill (1992) recommended an extension of work to determine exactly what the parasite (*Aphidius colemani*) is doing in Tonga.. This was done under CS2–92–828. The conclusion that the parasite does not have any impact on banana aphids was confirmed by Wellings et al. (1994). On the unintended positive impacts, Wellings et al. (1994), also conclude that:

> When number of *Aphis gossypii* were high in the field the parasatoid (*Aphidius colemani*) was easily found and parasitism rates reached 60%. The reduction in populations of this aphid may well be significant in future attempts to control the damage caused by plant virus disease in pumpkin squash crops. Further research is needed to look at all the aspects associated with control of plant virus disease in Tonga.

However, biological control of disease vectors is usually ineffective, since a small number of vectors can spread a large amount of disease, and biological control rarely gets near 100 percent of the target (Dr Paul Ferrar, ACIAR, pers. comm., January 1997). In this paper this project is put in the category of projects which may have positive impacts but which are unquantifiable at this stage. Before economic impact can be estimated, it is necessary to establish the extent of damage *Aphis gossypii* causes in taro and curcubits and what level of control (*Aphidius colemani*) provides.

3.5 Biological control of pests and weeds in the South Pacific: three projects that failed to make an economic impact

This section briefly discusses three ACIAR-supported biological control projects which failed to deliver significant benefits to countries in the South Pacific. The following table summarises the reasons these three projects failed to generate economic benefits.

PN8569 Control target—*Mimosa invisa*	PN8718 Control target—passion fruit scale	PN8802–B Control target—banana weevil
An appropriate technology was not found in the duration of the project	An appropriate technology was discovered. However the passion fruit industry in Western Samoa collapsed (Soon and Hill, 1992, p.32)	An appropriate technology was discovered. However the banana industry in Tonga collapsed (Soon and Hill, 1992, p.32)
Not enough funding was provided to the activity		
Control agents were introduced under funding from other sources		
	Countries affected by research	
Australia, Western Samoa	Australia, Western Samoa	Australia, Tonga

3.5.1 Mimosa invisa *(PN8569)*

The purpose of this project was to enable the Queensland Lands Department to continue for six months to October 1986, a program seeking natural enemies of the weed *M. invisa* in South America, particularly Brazil. *M. invisa* is among the worst pests in Western Samoa, Vanuatu, Solomon Islands, Papua New Guinea, New Caledonia and French Polynesia. It also occurs in several other Pacific Islands and various countries in Southeast Asia. Unfortunately, this small project did not generate any documented results and consequently no research benefits flowed from the activity.

Under this project, two natural enemies of *M. invisa* were released in Western Samoa. Neither of the two control agents prospered; one failed to establish altogether; one became established but failed to build up to numbers that could have an impact in Western Samoa, even though the same biological control had had a major impact on *M. invisa* in Papua New Guinea under an non-ACIAR project (Dr Paul Ferrar, ACIAR, pers. comm., January 1997).

3.5.2 Passion fruit scale (PN8718)

The aim of this project was to test parasitic insects that may control passion fruit scale. A successful parasite, *E. diaspidicola,* was found, but due to the collapse of the passion fruit industry in Samoa the benefits accruing to the project are zero.

3.5.3 Banana weevil (PN8802–B)

Soon and Hill (1992) in their review of ACIAR project 8802–B concluded as follows:

> From the brief and scanty reporting given to the reviewers the conclusion is that most of the original proposed objectives have not been achieved, particularly with respect to their fulfilment in the stated country, Tonga. Only the evaluation and selection of nematode strains and determination of the efficacy of nematode treatment have been completed. The development of the delivery technology has been achieved within Australia but not transferred to Tonga as proposed in the objectives.

Part of the reason for this was the failure of the Tongan banana industry, leading to the view that there was little point in doing more work in that country.

At present, growers in Australia are still awaiting the technology (Paul Ferrar, pers. comm., January 1997). The benefits to this subproject are therefore zero.

4. SENSITIVITY ANALYSIS

This section briefly discusses sensitivity analyses which were undertaken on the projects generating quantifiable economic impacts.

4.1 *Salvinia molesta* (PN8340)

Table 13. Sensitivity analysis – PN8340—*Salvinia molesta*

	Total net present value (A$ million)
Base case	27.02
Increase unit cost reduction by 100%	46.79
Decrease unit cost reduction by 50%	17.17
Increase % rice affected by salvinia by 100%	48.97
Decrease % rice affected by salvinia by 50%	17.26
Increase vector disease to 3%	27.16

Table 13 shows that changing the cost reduction and the area of rice affected by salvinia has a major impact on the total NPV, whereas increasing the percentage of vector disease has only a small impact on NPV, increasing it from $27.02m to $27.16m.

4.2 *Mimosa pigra*

Table 14. Sensitivity analysis—PN8339, PN 8722, PN9319—*Mimosa pigra*

	Total net present value (A$ million)
Base case	21.77
Increase unit cost reduction by 100%	37.07
Decrease unit cost reduction by 50%	13.84
Increase % rice affected by *Mimosa pigra* by 100%	37.15
Decrease % rice affected by *Mimosa pigra* by 50%	14.07
Increase % beef & buffalo production affected by *Mimosa pigra* by 100%	22.37
Decrease % beef & buffalo production affected by *Mimosa pigra* by 50%	21.58

Table 14 illustrates that changing the unit cost reduction and the area of rice affected by mimosa has a significant effect on the total NPV. Changing the production of beef and buffalo affected by mimosa has no significant effect.

4.3 Fruit piercing moth

Table 15. Sensitivity analysis—PN8802–A, PN9308—fruit piercing moth

	Total net present value (A$ million)
Base Case	0.00
Increase unit cost reduction by 100%	0.09
Decrease unit cost reduction by 50%	–0.05
Increase growth rate to 2%	0.05
Increase growth rate to 3%	0.11

Once again it can be seen that changing the cost reduction has a significant impact on total NPV. Given that, in this analysis, there are various other fruits which would benefit from the fruit piercing moth but have not been included, a growth rate factor has been introduced into the analysis for the crops that are included. Increasing this factor from 1% to 2% and 3% increases the NPV from $nil to $0.05 million and $A0.11 million, respectively.

4.4 Banana skipper

Table 16. Sensitivity analysis—PN8802–C—banana skipper

	Total net present value (A$ million)
Base case	22.23
Yield decrease due to skipper 5%	10.37
Yield decrease due to skipper 20%	50.58
Increase maximum spread and damage to 80%	24.29
Decrease maximum spread and damage to 30%	10.70
80% total production affected by skipper	35.72
30% total production affected by skipper	13.23

In the base case analysis it is assumed that the yield decrease due to banana skipper is 10%. By increasing the percentage yield loss to 20% the NPV increases from $A22.23m to $A50.58m. Reducing the percentage to 5%, decreases the NPV to $A10.37m. In the base case it is assumed that the skipper will spread to 70% of the total affected area. Increasing this area to 80% raises the NPV to $A24.29m. Similarly, if the area of spread is decreased to 30% the NPV falls to $A10.70m. Changing the total area of production also has an impact on the NPV as shown in Table 16.

4.5 Breadfruit mealybug

Table 17. Sensitivity analysis—PN9111–C—breadfruit mealybug

	Total net present value (A$ million)
Base case	1.94
Increase unit cost reduction by 100%	4.46
Decrease unit cost reduction by 50%	0.66
Average weight of fruit 0.8kg	1.09
Average no. trees per village cluster	1.43
Average no. fruits per tree	1.02

Once again, the unit cost reduction has a major impact on total NPV. In the base case analysis the high estimates were used for weight of fruit, number of trees per village cluster and number of fruits per tree. The sensitivity used an average of the low and high estimates for all three parameters which reduced the NPV from $A1.94m to $A1.09m, $A1.43m and $A1.02m, respectively.

5. CONCLUDING REMARKS

This paper has discussed economic evaluations of 15 completed ACIAR-supported research activities funded between 1983 and 1996. The model used in these evaluations is the economic surplus model as developed by Davis et al. (1987) and Alston et al. (1995). Where the commodity affected by research is a non-traded subsistence commodity, a closed economy variation of the model is used. Where a commodity affected by research is a traded one, then an open economy, traded good variation of the model is applied.

The preliminary estimates indicate the following. First, the control of *S. molesta* was a major success and generated benefits to ACIAR's partner countries estimated at about $A27 million and a rate of return of 77 percent. This is followed by the control of *M. pigra* which is estimated to generate, over a 30-year time horizon, benefits of about $A22 millions and a rate of return of about 26 percent.

To date there have been 10 completed projects in Papua New Guinea and the South Pacific region. These projects fall into the following three main groups:

(a) four projects made a quantifiable economic impact with rates of return ranging from 8 percent to 81 percent;

(b) three projects made unintended positive, but unquantifiable economic impacts; and

(c) three projects had noimpact. The most common economic explanation for the failure to make an impact was that the industries targeted by the biological controls collapsed.

Section 4 presented some sensitivity analyses on selected key variable.

Overall, ACIAR's experience with biological control has been a success. Of a total of 15 discrete research activities in the area of biological control, only three failed to generate an economic impact. Those that failed involved very small investments of ACIAR funds. Two of those which failed did so not because the projects did not discover appropriate control agents, but because the targeted industries collapsed after the start of the project. It is appropriate to end with a quotation from Soon and Hill (1992) who reviewed many of the projects evaluated in this paper. Soon and Hill (1992) concluded when summing up one of the failed projects:

> It is noted that the actual economic impact of this work has so far been limited because passion fruit is no longer an important crop in Western Samoa. However, it is one of the advantages of classical biological control that it is a permanent solution. should the industry be revived, Western Samoan farmers can be confident that the scale will not be a constraining factor.

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