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AN ECONOMIC EVALUATION OF REALISED AND POTENTIAL IMPACTS OF 15 OF ACIAR'S BIOLOGICAL CONTROL PROJECTS (1983-1996): SOME PRELIMINARY ESTIMATES

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Abstract[#]

Key words: Biological control, research evaluation

ACIAR over the 10 year period from 1983 invested significantly in biological control research. This paper estimates the welfare benefits from completed biological control projects funded by ACIAR over this period. The projects dealt with the control of the following:

- *Salvinia molesta* in Sri Lanka, Philippines, Malaysia and Africa;
- *Mimosa pigra* in Australia, Thailand, Indonesia, Malaysia, and Vietnam;
- Fruit piercing moths in Australia, Fiji, Western Samoa, and Tonga;
- Banana skipper in Australia and Papua New Guinea;
- Bread fruit mealybug in Kiribati, Federated States of Micronesia involving the Island states of Yap, Truk, Ponape, Kosrae in Caroline Island, Marshall Island and Palau;
- Banana aphids in Australia and Tonga;
- *Leucaena psyllid* in Australia;
- *Mimosa invisa* in Australia and Western Samoa;
- Passion fruit white scale in Australia and Western Samoa;
- Banana weevil in Australia and Tonga;

The preliminary estimates indicate the following. First, the control of *salvinia 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 followed by the control of *mimosa 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 has been 10 completed projects in Papua New Guinea and the South Pacific region. These projects fall into the following three main groups:

- (a) 4 projects made a quantifiable economic impact with rates of return ranging from 9 percent to 81 percent;
- (b) 3 projects made unintended positive, but unquantifiable economic impacts; and
- (c) 3 projects did not make an impact. The most common economic explanation for the failure to make an impact was that the industries targeted by the biological controls collapsed.

Overall, ACIAR's experience with biological control (1983-1996) has been a success. Out of a total of 15 discrete research activities in the area of biological control, only 3 failed to generate an economic impact.

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1. INTRODUCTION

ACIAR, over the 10 year period from 1983, 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 these chemical controls - inadequacies which include the fact that:

- chemical control has promoted resistant pests by killing all but those resistant to the pesticides and thus contributing to pesticide obsolescence;
- 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. However, the new 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 wild life health problems; and
- there has been a tendency for overuse of chemicals - for example in those cases where chemicals are applied on a schedule regardless of pest incidence.

There are two additional considerations which have been important to ACIAR in investing in biological control research. First, while chemical controls 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 outlays is a hindrance to the adoption of even the best controls. Thus the cashless nature of the biological controls methods developed in ACIAR projects was a particularly attractive attribute of the technologies.

Second, while many technologies requires conscious decisions by farmers to adopt or reject a technology, 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.

The 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), and Auld, Menz and Tisdell (1987).

The rest of the paper is divided up as follows. Section 2 presents a brief description of the research projects - the objectives, their achievement 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 areas¹:

- * Salvinia (PN8340, and PN8340-extension into Africa and South East 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);
 - * - bread fruit 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 instead of as separate research activities. The rest of the paper deals with the fifteen completed activities indicated above.

Table 1 summarises key aspects of the selected projects. In table 1 the start date refers to the date ACIAR started 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 rate of discount.

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.

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; CS2-92-828	PN8569	PN8718	PN8802-B
Control target	Salvinia molesta	Mimosa pigra	Fruit Piercing 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 (\$A, m, 1990)	27.72	23.06	0.66	22.50	2.57	Project led to a decision not to introduce 2 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)	1	3	2	1	1	1	2	1	1	1
Countries involved in the research project	Australia, Sri Lanka, Philippines, and 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

- **Biological control of *Salvinia molesta* (PN8340 and its extensions to Africa and South east Asia)**

Salvinia (Salvinia molesta) is a floating fern. Thick mats of salvinia halt the movement of boats, block irrigation channels, stop rice-growing and fishing and kill submerged plants and animals by cutting off light and oxygen. *Salvinia (Salvinia molesta)* comes originally from south-eastern Brazil, where specially adapted insects keep its growth in check. Because it grows so fast, doubling 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 weevil, *Cyrtobagous* sp. to Sri Lanka, Malaysia, the Philippines, and Africa (Kenya and Zambia).

- ***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 paddy-fields, 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 herbicidal applications to increase pressure on the plant.

The aim of this suite of 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, PN8722 identified and released eight control agents of *mimosa 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

- **Fruit piercing moths in South Pacific (PN8802-A 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 and kiwi fruit as well as capsicum and tomatoes are all particularly susceptible. Moths (males and females) attack both unripe and ripe fruits but most damage is caused at the ripening stage by puncturing the fruit and sucking the juice. Rots quickly enter and destroy the whole fruit. A single moth can cause severe damage whilst several moths can devastate a whole crop.

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

- **Banana skipper (PN8802-C)**

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

moved 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. In conjunction with the PNG Department of Agriculture and Livestock, the research team tested the suitability of known enemies 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.

- **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 substitutes such as rice and wheat flour. Breadfruit is also a valuable source of timber 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 even kill mature trees.

During the first phase of PN9111, a predacious beetle (*Rodolia limbata* Blackburn) specific to the mealybug 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 active the project team will introduce the biological control breadfruit mealybug to other South Pacific Islands.

- **Banana aphids (PN8802-E and CS2-92-828)**

Sub-project PN8802-E aimed at controlling the banana aphid (*Pentalonia nigronervosa*) in Tonga. While it does cause damage in its own right, its most important characteristic is that it is the vector of banana bunchy top, one of this fruit's most serious virus diseases. The team used the aphid's known parasites from Australia to reduce its numbers in Tonga.

The objectives of CS2-92-828 was to monitor the establishment of the aphid parasitoid *Aphidius colemani* in the Kingdom of Tonga.

- **Leucaena psyllid (PN8802-D)**

This project dealt aimed at controlling a Leucaena psyllid called *Heteropsylla cubana*, from its native range in Central America. The psyllid is a sup-sucking insect which concentrates on the soft, growing tips of *Leucaena leucocephala* plants - a multi-purpose tree legume.

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 sub-project 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 situation.

- **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. *Mimosa 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 South East Asia.

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

- **Passion fruit white scale in western Samoa (PN8718)**

Until 1984, passion fruit pulp ranked as third most important agricultural export for Western Samoa. Suddenly in late 1984, the passion fruit industry collapsed. Vines throughout the Island were engulfed and destroyed by white scale insects (*Pseudaulacaspis pentagona*). This project under the leadership of a CSIRO scientist, Dr Sands, identified a suitable parasite (*Encarsia diaspidicola*), a wasp almost too small to see with the naked eye) and arranged for its importation into Western Samoa. Parasites 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, a parasite (*Encarsia diaspidicola*) can only live on the passionfruit scales. The female lays her eggs inside the scale insect, where the larva feed, meanwhile killing the pest. The larva develop into a small wasp which in turn seek out other scales again for egg laying. This process continue, keeping the pest under control. The biological control agent cannot live on any other insect, animal, plant or human being.

- **Banana weevil (PN8802-B)**

Banana weevil borer causes considerable trouble as a major pest of bananas in Tonga and elsewhere in the tropics. It tunnels in the corn, producing physical damage and promoting fungal and bacterial rot. 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 attack and kill banana weevils very effectively. This sub-project conducted parallel trials in Tonga, adapting techniques for deeper-planted bananas as grown under Pacific conditions.

3. THE 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 different projects discussed in section 2. The following assumptions are overarching: The base year is 1990. The time horizon is 30 years for all the projects. The discount factor is set at 8 per cent per annum in line with the recommendation of the Department of Finance (1991).

A first step in the estimation of the impact of agricultural research is an identification of the agricultural commodities 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.

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

	PN8340 and extensions to Africa and South east Asia	PN8339 - PN8722 - PN9319	PN8802-A PN9308	PN8802-C	PN9111	PN8802-D	PN8802-E CS2-92-828	PN8569	PN8718	PN8802-B
Control target	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							✓			
Bread fruit					✓					
Passion fruit									✓	
Orange			✓							
Papaya			✓							
Pineapple			✓							
Pepper			✓							
Capsicum			✓							
Tomato			✓							
Human health	✓									
Water ways	✓	✓								
Tourism		✓								
Countries affected by research	Australia, Sri Lanka, Philippines, and Malaysia 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

3.1 Biological control of *Salvinia* (PN8340 and PN8340 extension to Africa and South east Asia)

The control of *salvinia* affected four main commodities as indicated in Table 2, and these are rice, fish, waterways, and human life. 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 one of these commodities is discussed in turn.

3.1.1 Rice

Rice production affected by salvinia molesta

Doeleman (1990) notes that amongst 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 acts as a hindrance to production by its competition with rice for space and nutrients and by interference 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* only has an effect on rice production in Sri Lanka, Philippines and Malaysia. 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). Bakar et al (1989) was the source for estimates of the proportion of rice crop affected by *salvinia* in Malaysia. 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 to 3 percent. This result is used in estimating the yields of paddy rice after research.

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). This data was used as a basis for estimating unit costs of rice production - before research - in the Philippines. The cost of production of rice before research in Sri Lanka and Malaysia are based on estimates in IRRI (1995). Unit costs of production (\$/ton) were estimated by dividing the total cost per hectare by the yield of rice per ton.

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 2-3 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 dollars 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 Philippines, Pablo et al (1986) quoted a figure of pesos 800 to 1200 per hectare for the annual removal of salvinia molesta, before planting. The successful control of salvinia in these three countries led to a reduction in the cost of producing rice as indicated in Table 3. The difference between the cost per ton before and the cost 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 saving are introduced in the research evaluation model to estimate monetary benefits from research.

Data on the price of rice per ton is from IRRI (1995). Estimates of the elasticity of demand of demand and supply for rice are from ACTAR's 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).

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	Malaysia	Africa (Kenya)	Africa (Zambia)
RICE						
Quantity produced, 1988-90 Averages ('000 mt)	na	1,534	6,012	1,123	na	na
Percentage affected by salvinia	na	12%	6%	1%	na	na
Quantity affected by salvinia, ('000s)	na	184.08	343.54	11.23	na	na
Yield before research (t/ha) ave 1990	na	3.5	3.5	3.5	na	na
Yield after research (t/ha)	na	3.61	3.61	3.61	na	na
Cost of production before research (\$/ha)	na	\$528	\$528	\$528	na	na
Unit Cost (\$/per ton) before research	na	\$151	\$151	\$151	na	na
Cost of cleaning up salvinia (\$/ha)	na	\$8	\$29	\$18	na	na
Cost of production after research (\$/ha)	na	\$520	\$499	\$510	na	na
Unit Cost (\$/per ton) after research	na	\$149	\$143	\$146	na	na
Cost saving due to research (\$/t)	na	\$2.31	\$8.16	\$5.23	na	na
Price of rice	na	\$235	\$235	\$235	na	na
Elasticity of supply	na	\$0	\$0	\$0	na	na
Elasticity of demand	na	\$0	\$0	\$0	na	na
FISH - INLAND CATCH						
Quantity produced, 1988-90 Averages ('000s mt)	na	45.06	90.28	24.83	5.94	na
Percentage affected by salvinia	na	5%	5%	0.85%	5%	na
Quantity affected by salvinia, ('000s)	na	2.25	4.51	0.21	0.30	na
Yield before research (t/ha) ave 1990	na	0.283	0.283	0.353	0.3177	na
Yield after research (t/ha)	na	0.34	0.34	0.42	0.36	na
Cost of production before research (\$/ha)	na	\$205	\$205	\$205	\$205	na
Unit Cost (\$/per ton) before research	na	\$723	\$723	\$580	\$644	na
Cost of cleaning up salvinia (\$/ha)	na	\$8.07	\$28.47	\$18.32	\$8.07	na
Cost of production after research (\$/ha)	na	\$197	\$176	\$186	\$197	na
Unit Cost (\$/per ton) after research	na	\$695	\$622	\$528	\$619	na
Cost saving due to research (\$/t)	na	\$28.52	\$100.96	\$51.90	\$25.40	na
Price of fish per ton	na	\$263	\$263	\$263	\$263	na
Elasticity of supply	na	0.80	0.80	0.80	0.80	na
Elasticity of demand	na	0.65	0.65	0.55	0.65	na
WATERWAYS						
Area affected (ha)	na	50,000	18,229	746	20,988	25,911
Cost of clearing before research - (\$/ha)	na	\$5.86	\$5.86	\$5.86	\$5.86	\$5.86
Total cost of clearing before research - (\$A, pa)	na	\$292,964	\$106,806	\$4,370	\$122,974	\$151,820
Cost of clearing after research - (\$/ha)	na	0	0	0	0	0
Cost saving per annum (\$A, '000s, 1990)	na	\$293	\$107	\$4	\$123	\$152
HUMAN HEALTH						
Expenditure on health per year (\$A, '000)	na	\$381,250	\$1,103,750	\$1,573,750	\$468,750	\$146,250
Proportion of expenditure on children 0-15 years of age	na	0.53	0.53	0.53	0.66	0.66
Expenditure on children 0-15 years of age per year (\$A, '000)	na	\$202,443.75	\$586,091.250	\$835,661.250	\$311,250.00	\$97,110.00
Increase in vector diseases due to salvinia	na	1.50%	1.50%	1.50%	1.50%	1.50%
Percentage of budget spent on malaria etc	na	0.01	0.01	0.01	0.11	0.11
Human health costs saved per year (\$A, '000s, 1990)	na	\$5.24	\$7.22	\$1.80	\$0.18	\$6.39

3.1.2 Fish - Inland catch

Fish production affected by salvinia molesta

Salvinia only has an effect on inland fish catch in Sri Lanka, Malaysia, Philippines and Kenya. Publico et al (1986) indicates that in the Philippines *salvinia molesta* is used as a feed. In a survey of 46 farmers, Publico et al (1986) found that 35 farmers fed *salvinia molesta* to tilapia. The control of *salvinia 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'.

Salvinia 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 resource in Sri Lanka, Malaysia and Philippines published in 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 of water resource 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 is from Doeleman (1990). Baker et al (1989) indicated that in Malaysia the proportion of waterways affected by *salvinia* was about 0.85 percent. Yields before research were obtained from De Silva (1987). Doeleman (1990) estimated that control of *salvinia* would reduce fish losses by 20 to 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 catch 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 is 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:

$$\Delta ES_c = k_c Q_{fc} + 0.5(Q_{fc}/P_{fc})[\epsilon_s \epsilon_d k_c^2 / (\epsilon_s + \epsilon_d)]$$

where

ΔES_c is the change in economic surplus as a result of better control of *Salvinia molesta*

k_c is the absolute value of the cost reduction in country c

Q_{fc} is the quantity of fish affected by *Salvinia 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 Water ways

Salvinia does impinge 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) making washing and bathing more difficult. 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 *Salvinia 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 *Salvinia 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

Salvinia molesta has the potential to increase the breeding opportunities of the mosquito. Of particular concern are the mosquito-borne diseases of 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 *Salvinia 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 to other diseases are used to estimate M_c . $M_c = (\text{DALY lost due to malaria}) / (\text{DALY lost due to all diseases})$

ΔV_c is the decrease in the incidence of mosquito-borne diseases as a result of better control of *Salvinia 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 is from World Bank (1993).

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

Table 3 shows a summary of the annual human health benefits from better control of *Salvinia 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 formation of ACIAR.

Table 4 summarises the flows of benefits from research, and the research costs, on *Salvinia molesta*. An important factor in the estimation of the flow of benefits from biological control of *Salvinia 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. A 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 *Salvinia 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. A number of 1 indicates that the biological control has spread to the whole of the target area and provided effective control against the weed.

The control agent once established 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 points in time in the different countries. Sri Lanka was the earliest

beneficiary since the ACIAR project in question started in Sri Lanka. The countries in south east Asia and Africa started later because the control agents from the ACIAR project were introduced later in those countries.

A matrix showing the proportion of <i>Salvinia molesta</i> 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	1	0	0	0
1990	1	1	0	0	0
1991	1	1	0	0	0
1992	1	1	1	1	1
1993	1	1	1	1	1
1994 Onwards	1	1	1	1	1

Most of the benefits accrue 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 thirty 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). The possible explanations for this difference include:

- (a) this study is using a discount rate of 8 percent per annum whereas Doeleman (1990) used a rate of discount 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, p57), and to be in line with ACIAR's Economic Evaluation Unit practice of using a rate of discount of 8 percent;
- (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 ACIAR's 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 the human health and other benefits from research which are associated with non-agricultural commodities - human health and water ways, we have used the same method as Doeleman (1990).

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	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
10	1993	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
11	1994	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
12	1995	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
13	1996	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
14	1997	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
15	1998	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
16	1999	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
17	2000	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
18	2001	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
19	2002	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
20	2003	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
21	2004	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
22	2005	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
23	2006	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
24	2007	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
25	2008	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
26	2009	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
27	2010	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
28	2011	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
29	2012	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
30	2013	\$3,301	\$551	\$679	\$21	\$4,552	\$0	\$4,552
Present value of benefits and costs (\$AM, 1990)		\$19.64	\$3.26	\$4.68	\$0.13	\$27.72	\$0.70	\$27.02
Accruing to							Rate of return	77%
	Australia	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00		
	Sri Lanka	\$3.69	\$0.56	\$2.54	\$0.05	\$6.84		
	Philippine s	\$15.53	\$2.58	\$0.59	\$0.04	\$18.73		
	Malaysia	\$0.43	\$0.08	\$0.03	\$0.01	\$0.55		
	Kenya	\$0.00	\$0.04	\$0.68	\$0.00	\$0.72		
	Zambia	\$0.00	\$0.00	\$0.84	\$0.04	\$0.87		
		\$19.64	\$3.26	\$4.68	\$0.13	\$27.72		

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 *Mimosa pigra* as follows:

Species tested	Plant part attacked	Established	Status
INSECTS			
Bruchidae			
<i>Acanthoscelides puniceus</i>	mature seeds	In Australia, Yes.	<1% mature seed destroyed
		In Thailand, Yes	1%-20% mature seed destroyed
<i>Acanthoscelides quadridentatus</i>	mature seed	In Australia, Yes.	<1% mature seed destroyed
		In Thailand, Yes	1%-20% mature seed destroyed
Chrysomelidae			
<i>Chlamisus mimosae</i>	pinnae and stems	In Australia, Yes.	No significant effect
		In Thailand, Yes	No significant effect
Curculionidae			
<i>Apion aculeatum</i>	flower buds		Released in Thailand and Australia
Gracillariidae			
<i>Neurostrota gunniella</i>	pinnules and stems	Australia, Yes	Spreading rapidly; widespread tip damage
		Thailand, not released	
Sesiidae			
<i>Carmenta mimosae</i>	stems	Australia, released	Established and spreading
			Thailand has approved its release
Fungal pathogens			
<i>Phloeospora sp. nov</i>	stems, leaves, and seed pods	Australia, released	Released in Australia at the end of 1994 (Dr Jim Cullen, CSIRO, pers comm, January 1997)
<i>Diabole cubensis</i>	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)

There is a large set of biological control agents which have already been released in Australia and Thailand. The purpose of PN9319 was to extend these biological control to Indonesia, Malaysia and Vietnam. The project PN9319 is not yet completed. However, since it is a technology transfer project, transferring the technologies developed in the 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 *Mimosa pigra* in Australia is readily available (see for example, Day and Parsons (1986), Miller (1988), Beckmann (1990), Pitt and Miller (1989), and Forno (1993). Robert (1982) describes the extent of the problem in Thailand. While *Mimosa pigra* is acknowledged as a problem weed, potentially at least, in Indonesia, Malaysia and Vietnam, quantitative data on the extent of its spread is 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 *Mimosa 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 *Mimosa pigra* affected five main commodities as indicated in Table 2, and these are rice, beef and buffalo, palm oil, water ways (reservoirs, canals, and rivers), and tourism. Not all these commodities were affected to the same extent in all ACIAR's mandate countries. The impact the control of *Mimosa pigra* on each one of these commodities is discussed in turn.

3.2.1 Rice

Rice production affected by Mimosa pigra

Waterhouse(1993) indicates that rice is one of the commodities that is affected by *Mimosa pigra* in South east Asia. Table 5 summarises the key assumptions made in the estimation of the benefits to rice producers and consumers derived from better control of *Mimosa pigra*. The data on rice production is from FAO(1994b). The estimates of the proportion of irrigated rice are from IRRI (1995). The percentage of rice affected by *Mimosa pigra* is based on estimates by Robert (1982) on the importance of *Mimosa pigra* in crop production and on indications of degree of importance of *Mimosa pigra* in South east Asia in Waterhouse(1993). In the case of Indonesia some indicative data was obtained from Tjitrosoedirdjo et al (undated). In addition Sivapragasam et al (undated) provided some qualitative data on the importance of *Mimosa 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 *Mimosa pigra*.

The research impact of the project with respect to rice

The cost of controlling *Mimosa pigra* - before research, in rice production is based on the estimate by Robert (1982) of the cost controlling *Mimosa 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 *Mimosa 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, PN8339 and PN8722, on mimosa based in Thailand. The cost of control after research relates to the cost raising and releasing the biological controls.

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 ('000s, mt, Average 1989-1990)	na	12,727	28,509	1,123	11
Irrigated rice	na	891	20,527	741	6
Percentage of rice affected by <i>Mimosa pigra</i>	na	0.20	0.07	0.02	0
Quantity of rice affected by <i>Mimosa pigra</i>	na	178.18	1436.86	14.82	18
Yield before research (t/ha) ave 1990	na	3.02	4.35	3.10	1
Cost of producing rice before research (\$/ha)	na	1,083	1,083	1,083	1
Cost of controlling <i>Mimosa pigra</i> (\$/ha) - before research	na	71	71	150	1
Unit cost of producing rice before research (\$/mt)	na	382	265	398	1
Cost of controlling <i>Mimosa pigra</i> (\$/ha) - with biological control	na	4	4	4	1
Unit cost of producing rice after research (\$/mt)	na	360	250	351	1
Unit cost saving in the production of rice after research (\$/mt)	na	22	15	47	1
Price of rice	na	408	408	408	1
Elasticity of supply	na	0.30	0.30	0.30	1
Elasticity of demand	na	0.10	0.10	0.10	1
BEEF AND BUFFALO MEAT PRODUCTION ('000s, Average 198-1990, Mt)	100	230	296	na	0
Percentage of beef and buffalo production affected by <i>Mimosa pigra</i>	0.05	0.02	0.01	na	0
Beef and buffalo production affected by <i>Mimosa pigra</i> ('000s, 1990, Mt)	5.02	4.60	2.07	na	0
Beef and buffalo produced per ha (mt)	0.55	0.55	0.55	na	0
Cost of producing beef and buffalo before research (\$/mt)	600	600	600	na	0
Cost of controlling <i>Mimosa pigra</i> (\$/mt) - before research	131	131	131	na	0
Unit cost of producing beef and buffalo before research (\$/mt)	731	731	731	na	0
Cost of controlling <i>Mimosa pigra</i> (\$/ha) - with biological control	4	4	4	na	0
Unit cost of producing beef and buffalo after research (\$/mt)	604	604	604	na	0
Unit cost saving in the production of beef and buffalo after research (\$/mt)	127	127	127	na	0
Price of beef and buffalo (\$A/mt)	962	962	962	na	0
Elasticity of supply	0.40	0.40	0.40	na	0
Elasticity of demand	0.40	0.40	0.40	na	0
PALM OIL Quantity produced, 1988-90 Averages ('000s mt)	na	195	2,071	5,727	11
Percentage affected by <i>Mimosa pigra</i>	na	0.02	0.01	0.02	0
Quantity affected by <i>Mimosa pigra</i> ('000s)	na	4	14	115	1
Cost saving due to research (\$/t)	na	22	22	15	1
Price of palm oil (\$A/mt)	na	495	495	495	1
Elasticity of supply	na	0.10	0.10	0.10	1
Elasticity of demand	na	0.44	0.44	0.44	1
Estimate of the annual welfare gain (\$A, '000, 1990)	na	87	324	1,776	1

Table 5 cont. 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
VOLUME OF RESERVOIRS IN A COUNTRY cubic km)	800	110	2,530	458	37
Cost of controlling <i>Mimosa pigra</i> before research (000s \$A/cubic km)	0.0374	0.0374	0.0374	0.0374	0.037
Cost of controlling <i>Mimosa pigra</i> after research (000s \$A/cubic km)	0.0041	0.0041	0.0041	0.0041	0.004
Annual benefit per cubic km as a result of control					
Irrigation water benefits (000s \$A/cubic km)	\$16.400	\$16.400	\$16.400	\$16.400	\$16.40
Aquaculture and fresh water fish culture benefits(000s \$A/cubic km)	\$0.013	\$0.013	\$0.013	\$0.013	\$0.01
Power generation benefits (000s \$A/cubic km)	\$0.000	\$0.532	\$0.532	\$0.532	\$0.53
Flood control benefits (000s \$A/cubic km)	\$0.205	\$0.205	\$0.205	\$0.205	\$0.20
Wler repair benefits (000s \$A/cubic km)	\$0.000	\$0.009	\$0.009	\$0.009	\$0.00
Annual benefit due to research freeing reservoirs of <i>Mimosa pigra</i> (000s \$A/cubic km)	164	82	1,887	340	28

3.2.2 Beef and buffalo meat

Beef and buffalo meat production affected by Mimosa pigra

Mimosa pigra affects beef and buffalo production in two ways. First, the spread of *Mimosa pigra* reduces the area used for pasture and for grazing of animals. Secondly, growth of *Mimosa pigra* along rivers, canals and other water ways, 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 *Mimosa pigra*. The data on beef and buffalo production is 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 *Mimosa pigra* on beef production are included in this analysis despite the comments in Robert (1982) because it is now 14 years since the study and in that period *Mimosa pigra* has been spreading and covering larger and 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 *Mimosa 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 *Mimosa pigra* is based on Robert (1982). Robert (1982) assumed that without *Mimosa pigra* a reservoir could last for about 100 years. However, if there is *Mimosa pigra*, then the life of a reservoir is reduced to only 25 years. The difference between the flow of benefits from a reservoir without *Mimosa pigra* and a flow of benefits with *Mimosa pigra* provides an estimate of the benefit achievable from better control of *Mimosa 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 *Mimosa 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 Resource 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 *Mimosa pigra* are estimated by the following equation:

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

where

- R_c is the annual welfare benefits from reservoirs clear of *Mimosa 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 *Mimosa pigra*;
 A is the total capacity of reservoirs in a country.

Table 6 shows the total benefits from the control of *Mimosa pigra* over a period of 30 years. These preliminary estimates indicate that the three projects are associated with a benefit of about 23 million dollars (\$A). Most of those benefits are associated with rice production, followed in magnitude by the benefits to the different countries due to extensions in the lives of reservoirs as a result of better control of *Mimosa pigra*, then the palm oil sector, and the beef and buffalo sector. The three projects on the control of *Mimosa pigra* have a rate of return of 26 percent.

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

The following *Mimosa pigra* 'spread and damage' matrix is used in this study.

A matrix showing the proportion of <i>Mimosa pigra</i> 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

The entries in the *Mimosa pigra* damage matrix embody the following assumptions. First, *Mimosa pigra* is very different from salvinia. The control agent for salvinia damaged the salvinia weed as soon as the agent was established. With *Mimosa 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 *Mimosa pigra* damage matrix is an assumption that over the 15 years the coverage of *Mimosa pigra* in the countries that collaborated on the *Mimosa 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 no	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	\$2,753	\$2,982	\$0	\$2,982
17	2000	\$398	\$64	\$25	\$2,753	\$3,214	\$0	\$3,214
18	2001	\$1,950	\$80	\$85	\$2,753	\$4,782	\$0	\$4,782
19	2002	\$3,503	\$112	\$148	\$2,753	\$6,367	\$0	\$6,367
20	2003	\$5,057	\$170	\$214	\$2,753	\$7,979	\$0	\$7,979
21	2004	\$6,612	\$216	\$283	\$2,753	\$9,581	\$0	\$9,581
22	2005	\$7,868	\$229	\$341	\$2,753	\$10,949	\$0	\$10,949
23	2006	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
24	2007	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
25	2008	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
26	2009	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
27	2010	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
28	2011	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
29	2012	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
30	2013	\$9,326	\$242	\$402	\$2,753	\$12,320	\$0	\$12,320
Present value of benefits and costs (\$AM, 1990)		\$15.19	\$0.45	\$0.66	\$7.43	\$23.06	\$1.30	\$21.77
Benefits to							Rate of return	28%
	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		

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 (PN8802-A & PN9308)

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

Four of the five objectives concerning the fruit-piercing moth sub-project 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.

Sub-project 8802-A 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 PN8802-A.

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 Western Samoa. Muniappan and Fay (1995) while not as 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. However, parasitoids have only recently began 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., *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 producers of most tropical and subtropical fruit in eastern Australia, no benefits have accrued to

Austrana as yet. This is because permission to import the biological control agents for 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, personal communication, January 1997).

The fruit piercing moth affects many fruits. However, the benefits in this paper are based on the following four fruits: Orange, Pineapple, and Papaya (see Table 2). ACIAR (1993) lists these fruits as among those which are affected by the fruit piercing moth, but it was not possible to get production and other data on these fruits.

The data on citrus production is 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 cost of production per ton 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 after research yields. Data on price of oranges is 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 \$A 0.6 millions and a rate of return of just over 7 per cent per annum. However, this estimate is based on only three susceptible fruits for which some data was 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) ave 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 (\$/mt)	na	16.01	16.01	16.01
Yield after research (t/ha) ave 1990	na	32	23	32
Unit cost of producing oranges after research (\$/mt)	na	11.86	16.01	11.86
Unit cost saving in the production of oranges after research (\$/mt)	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) ave 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 (\$/mt)	na	34.98	34.98	35
Yield after research (t/ha) ave 1990	na	55.33	55.33	55.33
Unit cost of producing pineapples after research (\$/mt)	na	23	23	23
Unit cost saving in the production of pineapples after research (\$/mt)	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 ('000s mt)	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) ave 1990	na	10.08	na	na
Cost of producing papaya before research (\$/ha)	na	1,203	na	na
Unit cost of producing papaya before research (\$/mt)	na	119.35	na	na
Yield after research (t/ha) ave 1990	na	12.60	na	na
Unit cost of producing papaya after research (\$/mt)	na	95	na	na
Unit cost saving in the production of papaya after research (\$/mt)	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 (LAM, 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)

Sub-project 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 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 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 is 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 was 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 the rain since the skipper was sensitive to rain (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. However, bananas 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 is a high priority commodity and is ranked in priority group 1. This high ranking is partly due to the high level of production of bananas in PNG, over 1 million tons are produced every year (see Table 9).

In this analysis it is assumed that the biological 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
2004-2017	0.7

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 (000s, mt, Avg 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 (tons/ha)	0.023
Yield after research (tons/ha)	0.03
Cost of production before research (\$A/ha)	\$3.32
Unit cost of production before research (\$A/ton)	\$142.01
Unit cost of production after research (\$A/ton)	\$127.61
Cost saving (\$A/ton)	\$14.20
Ceiling level of entries in the banana skipper spread and damage matrix	0.70
Price of bananas (\$A/ton)	\$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 the benefits are assumed to have accrued to the subsistence sector in PNG where there is limited trade, if at all, in bananas.

Table 10 shows the annual benefits accruing to PNG. This project is estimated to generate benefits equal to about \$A23 millions over a 30 year time horizon, with a rate of return of 81 percent.

Table 10: Summary of benefits from controlling banana skipper (ACIAR project PN8802-C)

		Australia	Papua New Guinea	Total benefits	Research costs	Net Benefits
		Banana	Banana	Banana	\$A, 000s, 1990	\$A, 000s, 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	\$1,279	\$1,279	0	\$1,279
9	1996	\$0	\$1,596	\$1,596	0	\$1,596
10	1997	\$0	\$1,934	\$1,934	0	\$1,934
11	1998	\$0	\$2,293	\$2,293		\$2,293
12	1999	\$0	\$2,673	\$2,673		\$2,673
13	2000	\$0	\$3,073	\$3,073		\$3,073
14	2001	\$0	\$3,493	\$3,493		\$3,493
15	2002	\$0	\$3,935	\$3,935		\$3,935
16	2003	\$0	\$4,397	\$4,397		\$4,397
17	2004	\$0	\$4,879	\$4,879	0	\$4,879
18	2005	\$0	\$4,879	\$4,879	0	\$4,879
19	2006	\$0	\$4,879	\$4,879	0	\$4,879
20	2007	\$0	\$4,879	\$4,879	0	\$4,879
21	2008	\$0	\$4,879	\$4,879	0	\$4,879
22	2009	\$0	\$4,879	\$4,879	0	\$4,879
23	2010	\$0	\$4,879	\$4,879	0	\$4,879
24	2011	\$0	\$4,879	\$4,879	0	\$4,879
25	2012	\$0	\$4,879	\$4,879	0	\$4,879
26	2013	\$0	\$4,879	\$4,879	0	\$4,879
27	2014	\$0	\$4,879	\$4,879	0	\$4,879
28	2015	\$0	\$4,879	\$4,879	0	\$4,879
29	2016	\$0	\$4,879	\$4,879	0	\$4,879
30	2017	\$0	\$4,879	\$4,879	0	\$4,879
	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%

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 retarded. Australian scientists now have the knowledge of the insect and its enemies to deal with it promptly.

3.3.3 Bread fruit 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. Since the focus of PN9111 was bread fruit mealybug, the evaluation of the projects' impact is restricted to breadfruit.

Unfortunately, despite the importance of bread fruit in the South Pacific, bread fruit production data is not readily available. In this analysis production of bread fruit in the collaborating countries is estimated based on the following data shown in Table 11.

- (i) data on population in the South Pacific countries, the proportion of households in rural areas, and the average family size was obtained from Norman and Ngaire (1994).
- (ii) the number of bread fruit trees per households were estimated by Sands and Brancatini (CSIRO, pers comm, January 1997);
- (iii) the number of fruits per tree, the yields per hectare, and the weight of a bread fruit are from Verheij and Coronel (1991)

Estimates of the cost of production were based on ANZDEC (1994). Bread fruit is a subsistence staple food in the South Pacific and is generally not traded, not even in village

markets (Dr Sands, CSIRO, pers comm, January 1997). An approximation of the price of bread fruit 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 bread fruit 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 bread fruit mealybug(PN9111)

Base year 1990	Federated States of Micronesia	Kiribati	Marshall Island	Palau
BREADFRUIT PRODUCTION - TOTAL (000s, mt, Aveg 1989-1990)				
Population (1990)	100,520	72,298	49,969	16,386
Family size	7	7	7	7
Estimate of number of households	14,360	10,328	7,138	2,341
Number of households per village cluster	12	12	12	12
Number of village clusters	1,197	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)	8,616	10,328	7,138	2,341
Total number breadfruit trees(high estimate)	14,360	17,214	11,897	3,901
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, mt)	0.69	0.83	0.57	0.19
Total annual production (high estimate, '000, mt)	12	14	10	3
Yield before research (t/ha) ave 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 (\$/mt)	27	27	27	27
Yield after research (t/ha) ave 1990	24	24	24	24
Imputed unit cost of production after research (\$/mt)	17.68	17.68	17.68	17.68
Unit cost saving in the cost of production after research (\$/mt)	8.84	8.84	8.84	8.84
Price of breadfruit - \$A/ton	650	650	650	650

Table 12 Flow of benefits from the control of bread fruit mealybug (PN9111)

		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	136.8906	(\$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
30	2021	\$0	\$130	\$156.08	\$143	\$430	0	\$430
Present values of Benefits and costs (\$AM, 1990)		\$0.00	0.898	\$0.91	\$0.77	\$2.57	\$0.63	\$1.94
						Rate of return	26%	

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 over all, Soon and Hill (1992) found that: 'the results of this sub-project 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 mimosa invasa. 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.

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 *Psyllaephagus yaseeni* and *Tamarixia leucaenae* (the two parasites tested in the project) to the biological control of mimosa invasa 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 sub-project would be minimal, since the banana aphid seems to have remained unaffected by its release.'

Soon and Hill (1992) recommended an extension 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, Hart and Kami (1994). On the unintended positive impacts, Wellings, Hart and Kami (1994), also conclude that:

'When number of *Aphis gossypii* were high in the field the parasitoid (*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 a hundred 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 cucurbits 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 table below summarises the reasons why these projects failed to generate economic benefits.

Reason why three biological control projects that did not generate positive economic benefits

	PN8569	PN8718	PN8802-B
Control target	<i>Mimosa invisa</i>	Passion fruit scale	Banana weevil
1.	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, p32)	An appropriate technology was discovered. However the banana industry in Tonga collapsed (Soon and Hill, 1992, p32)
2.	Not enough funding was provided to the activity		
3.	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 *Mimosa invisa* in South America, particularly Brazil. *Mimosa 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 South east Asia. Unfortunately this small project did not generate any documented results and consequently no research benefits flowed from the activity.

Under this project two biological control agents against mimosa 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 numbers that could have an effect in Western Samoa, even though the same biological control had had a major impact on mimosa 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 and a successful parasite *E. diaspidicola* was found. However, 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 H¹ (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 because of the failing Tongan banana industry that resulted in the view that there was little point in doing more work in that country.

At this point in time growers in Australia are still awaiting the technology (Paul Ferrar -pers comm, January 1997). The benefits to this sub-project 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. Increasing the percentage of vector diseases however, only increases the NPV from \$27.02 M 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 <i>Mimosa pigra</i> by 100%	37.15
Decrease % rice affected by <i>Mimosa pigra</i> by 50%	14.07
Increase % beef & buffalo production affected by <i>Mimosa pigra</i> by 100%	22.37
Decrease % beef & buffalo production affected by <i>Mimosa pigra</i> 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 & buffalo affected by mimosa does not have any 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 in this analysis that there are various other fruits which would benefit from the fruit piercing moth but have not been included in the analysis, a growth rate factor has been introduced into the analysis for the crops that are included. By increasing this factor from 1% to 2% and 3% increases the NPV from \$A0.00 million 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 \$A22.23 m to \$A50.58M. By decreasing 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. By increasing this area to 80% increases the NPV to \$A24.29M. Similarly if the area of spread is decreased to 30% the NPV decreases to \$A10.70M. Changing the total area of production also has an impact on the NPV as shown in Table 16.

4.5 Bread Fruit 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 3 parameters which reduced the NPV from \$A1.94 M 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 *Salvinia 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 followed by the control of *Mimosa 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) 4 projects made a quantifiable economic impact with rates of return ranging from 8 percent to 81 percent;
- (b) 3 projects made unintended positive, but unquantifiable economic impacts; and
- (c) 3 projects did not make an impact. 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. Out of a total of 15 discrete research activities in the area of biological control, only 3 failed to generate an economic impact. Those which 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. Rather 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 as follows 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.'

REFERENCES

- ABARE 1996. Australian commodity Statistics. Australian bureau of Agricultural and resource Economics (ABARE), Canberra.
- ACIAR 1993 Project no 9308: The biological control of fruit piercing fruit in the South Pacific. ACIAR project proposal document, ACIAR, Canberra.
- ACIAR 1996. Economic evaluation of the Thailand - Australian collaborative projects funded by ACIAR -stage 2. Proposal for funding by ACIAR, mimeograph.
- Agbayani, R. F., Baliao, D. D., Franco, N. M., Tícar, R. B., and N. G. Guanzon, Jr. 1989. An economic analysis of the modular pond system of milkfish production in the Philippines. *Aquaculture*, 83, pp 249-259
- Alston J. M., Norton, G. W. and Pardey, P. D. 1995. Science under scarcity. Principles and practice for agricultural research evaluation and priority setting. Cornell University Press, Ithaca
- Amarasinghe, U. S. 1987. The role of fishermen in implementing management strategies in the reservoirs of Sri Lanka. In S. S. De Silva. Editor. 1987. Reservoir fishery management and development in Asia. proceedings of a workshop held in Kathmandu, Nepal, 23-28 November 1987. International Development and Research Centre, Canada.
- ANZDEC 1994. Socio-economic data and financial economic analysis. Annex 5 to ANZDEC 1994 Papua new Guinea: Agricultural research and extension Project (Phase II) Prepared for the Government of Papua New Guinea and the Asian Development Bank April 1994.
- Asian Development Bank 1996. Fiji agriculture sector review. A strategy for growth and diversification. Asian development Bank and Fiji Ministry of Agriculture, Fisheries and Forest. Fiji.
- Auld, B. A. Menz, K. M. and Tisdell, C. A. 1987. Weed control economics. Academic Press, Harcourt Brace Jovanovich, Publishers, London.
- Bakar, B., Lim, G. S., Razali B., Soetikno, S. S., Tay, B. L., Y. Otham M. R., Ismail, and M. H. Julien 1989. Biological control of *Salvinia molesta* using *Cyrtobagous salviniae* Calder & Sands in Malaysia - preliminary report of the host specificity tests and recommendation for future actions. mimeograph, Malaysian Agricultural Research and development Institute (MARDI), Malaysia.
- Beckmann, R. 1990. Mimosa threatens Kakadu. *Ecos* 65, Spring 1990. (a magazine published by CSIRO)
- Davis, J. S. and Lubulwa, G. 1995. An overview of ACIAR's Economic Evaluation Activities with an Animal Sciences Program focus. Economic Evaluation Unit Working Paper No. 15. ACIAR, Canberra

- Davis, J. S., P. O. Oram and J. G. Ryan, 1987, Assessment of agricultural research priorities: An international perspective, Australian Centre for International Agricultural Research in collaboration with the International Food Policy Research Institute, Canberra.
- Day, M. F. and Parsons, W. T. 1986. Report of a review of Project No. 8339: Control of *Mimosa pigra*, ACIAR, Canberra June 1986.
- Densely, B. Editor. 1978. Agriculture in the economy A series of review papers. Department of Primary Industry, Papua New Guinea.
- Department of Agriculture, Philippines. 1993. The medium-term agricultural development plan: key production areas, targets, and programs. Department of Agriculture, Philippines, 3 May 1993.
- Department of Finance 1991. Handbook of cost-benefit analysis. Department of Finance. Australian Government Publishing Service, Canberra.
- De Silva, S. S. 1987. The reservoir fishery of Asia. In S. S. De Silva. Editor. 1987. Reservoir fishery management and development in Asia. proceedings of a workshop held in Kathmandu, Nepal, 23-28 November 1987. International Development and Research Centre, Canada.
- Doeleman, J. A. 1990. Biological control of salvinia. Economic Assessment Series No. 1, Australian Centre for International Agricultural Research, Canberra.
- Encyclopaedia Britannica, 1989. The new Encyclopaedia Britannica, Volume 8, Ready reference, Chicago.
- FAO. 1994a. Production year book. Food and Agriculture Organisation of the United Nations. Rome.
- FAO. 1994b. Food and Agriculture Organisation of the United Nations Data tapes on agriculture. Data prepared for the Economic Evaluation Unit, from the FAO data tapes by Prue Phillips, Australian National University.
- Far Eastern Economic Review. 1994. Asia 1994. Year book. A review of the events of 1993. 35th Edition. Review Publishing Company, Hong Kong.
- Forno, I. W. 1993. Biological control of *Mimosa pigra* in South East Asia. A Phase I proposal to ACIAR for funding., Mimeograph.
- IRRI. 1995. World Rice Statistics. 1993-94. International Rice Research Institute, Manila, Philippines.
- Macfarlane, R. and D. F. Waterhouse. 1995. ACIAR project review report. : Biological control of breadfruit mealybug (*Icerya aegyptiaca*) in the Pacific. ACIAR, Canberra.

- McMeniman, S. and Lubulwa, G. 1996. Project development assessment. the economic evaluation of the potential benefits of integrating apomixis into hybrid rice. Economic Evaluation Unit Working Paper. Draft.
- Miller, I. 1988. *Mimosa pigra* - A ministerial statement made by the minister of Primary Industry in the Northern Territory Legislative Assembly. March 1988.
- Muniappan, R. and H. A. C. Fay. 1995. ACIAR project review report: Biological control of fruit piercing moth in the South Pacific. ACIAR, Canberra
- Norman, D and Ngaire, D. Editors. 1994. Pacific Islands Yearbook. Fiji Times Ltd, Fiji.
- Pablico, P. P., Estorninos, L. E. Jr., Castin, E. M. and K. Moody. 1986. The occurrence of *Salvinia molesta* in central Philippines. Paper presented at the 17th Annual Conference of the pest control council of the Philippines, 8-10 May 1986, Amigo Terrace hotel, Iloilo City, Philippines
- PCCARD. 1986. Banana and plantain research and development. Proceedings of the International Seminar Workshop on Banana and Plantain Research and Development 25-27 February 1985. Philippine Council for Agriculture and Resources Research and Development (PCCARD), Los Banos, Philippines.
- Pitt, J. L. and Miller, I. L. 1989. A review of survey techniques for the detection of weeds with particular reference to *Mimosa pigra* L. in Australia and Thailand. Plant Protection Quarterly, Vol 3 (4), pp 149-155.
- Robert, G. L. 1982. Economic returns to investment in control of *Mimosa pigra* in Thailand. International Plant Protection Centre, Oregon State University, Corvallis, Oregon, USA.
- Sands, D. P. A. and Brancatini, V. A. 1994. Biological control of breadfruit mealybug (*Icerya aegyptiaca*) in the Pacific. Project No. 9111. 1 January - 31st December. CSIRO Division of Entomology. Australia.
- Sands, D. P. A. 1995. Biological control of fruit piercing moth (*Othreis fullonia*) in the South Pacific. Project No. 9308. Annual Report. 1 July 1994 - 30 June 1995. CSIRO Division of Entomology. Australia
- Sivapragasam, A., I. A. Anwar, I. M. Ridzuan, P. Durai, and S. M. Tan. Undated. *Mimosa pigra* (L): Problem and current status of research on biological control in Malaysia. Unpublished Report, Malaysian Agricultural Research and Development Institute (MARDI), Malaysia.
- Soon, L. G. and A. R. Hill 1992. ACIAR project review of PN8802. Biological control in the South Pacific. ACIAR, 1992.
- Thomas, P. A. and P. M. Room, 1986. Taxonomy and control of *Salvinia molesta*. Nature. vol 320, pp. 581-584.

- Turkington, R. and Revelant, L. 1994. The economics of orange production in the Riverina. NSW Agriculture.
- Verheij, E. W. M. and R. E. Coronel Editors. 1991. Edible Fruits and Nuts. Plant Resources of south-East Asia, (PROSEA) No. 2, Pudoc Wageningen, Bogor, Indonesia.
- Waterhouse, D. F. 1993. The major arthropod pests and weeds of agriculture in Southeast Asia: distribution, importance and origin. ACIAR Monograph No. 21. Australian Centre for International Agricultural Research, Canberra.
- Waterhouse, D. F. and Norris, K. R. 1989. Biological control Pacific prospects -- Supplement 1. ACIAR Monograph No 12, ACIAR, Canberra.
- Wellings, P. W., Hart, P. J., and V. Kami. 1992. Monitoring the establishment of the aphid parasitoid *Aphidius colemani* in the Kingdom of Tonga. Final report ACIAR small Project - CS2-92-8282. ACIAR 1994.
- World Bank. 1993. World Development Report 1993. Investing in Health. Oxford University Press, New York.
- World Resources Institute 1994. World Resources -1994-95. A report by the World Resources Institute in collaboration with The United Nations Environment Programme and the United Nations Development Programme. Oxford University Press, New York.