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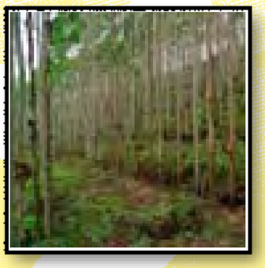
IMPACT ASSESSMENT SERIES **46**



Australian Government
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Mite pests of honey bees in the Asia–Pacific region

Michael Monck and David Pearce
Centre for International Economics, Canberra

July 2007

Australian Government
Australian Centre for International Agricultural Research

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

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Foreword

Mite pests of bees are one of the major production constraints facing the apiary industry throughout the world. In most countries, the mites are present and have a significant impact on productivity and production costs. In Australia, the only country in the world without these mites, the maintenance of effective quarantine strategies against them is a major aim.

The Australian Centre for International Agricultural Research (ACIAR) has funded research on these important pests for about 15 years. The outcomes of this research have made a significant contribution internationally to a better understanding of the mites, especially *Varroa* species, and their host conditions.

The outcomes of the research are a good example of the mutual benefits inherent in ACIAR's collaborative research model.

Research in ACIAR partner countries on a pest that is also a serious threat to Australia can provide synergisms leading to breakthroughs that would not be as likely to occur if the research were done in isolation in each country. So it was in the research reported here. A partnership of entomological experts from Australia and those from countries where the mite pests are present, but in different environments, led to major advances in understanding of mite–bee relationships.

These, in turn, permitted development of not only some simple control measures for smallholder beekeepers, but also some important new strategies to significantly improve quarantine procedures.

The work has also had a significant impact on the scientific community, as evidenced by the very high citation rate (third among all papers of CSIRO Entomology) of one of the papers resulting from the research.

This impact assessment study highlights the substantial benefits that can be gained for both Australia and partner countries from collaborative research. In this case, due to the significance of the threat and relative size of the industry, the benefits to Australia are very large. While the benefits in partner countries are smaller, they accrue to the poorer smallholder sector, which is one of ACIAR's main targets.

Peter Core
Director
ACIAR

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A number of others, especially within the industry, have offered input into the report, and we extend our thanks to them as well.

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Summary

The projects examined in this impact assessment are concerned with increasing understanding about major mite pests of bees—*Tropilaelaps clareae, Varroa jacobsoni* and *V. destructor.* These mites cause significant damage to honey bees. The projects were carried out in Australia, Indonesia, Papua New Guinea and the Philippines.

The research undertaken in the projects has substantially increased understanding about these two pests, to the extent that the picture of their spread and therefore of the risks they pose has changed fundamentally over the course of the research.

There are two major benefits from the research: first, to beekeeping through better understanding of mite-control methods; and second, to quarantine procedures, through better understanding of the true nature of the risks posed by the mites. These two benefits have, in turn, economic effects through maintaining the value of honey production and the indirect (but nevertheless substantial in some cases) pollination benefits of honey bees.

The value of the research is estimated using a standard economic surplus framework. Net increases in economic surplus as a result of the research are summarised below. Benefits for Papua New Guinea have not been quantified due to unavailability of data.

Present value of increased economic surplus

Benefit	Value (A$m)
Philippines — honey production	2.8
— pollination	1.1
Indonesia — honey production	2.4
Australia — honey production and pollination	66.4

Source: Centre for International Economics estimates

Net benefit–cost outcomes, incorporating project costs are summarised below.

There are greater potential benefits than those we have quantified here. In particular, the research has shown that it is possible to eliminate *Varroa* mites from Indonesia. However, for this benefit to be realised, considerable institutional development would be required. Similarly, for a variety of reasons, cost-effective means of mite control are being adopted only very slowly in Indonesia. Both of these potential benefits point to fruitful areas for further research.

Further, the scientific work underlying these projects has been groundbreaking, leading to the third most cited paper to come from CSIRO Entomology and to substantially improved understanding of the mites worldwide. There are therefore likely to be substantial benefits to other countries, but these have not been included here because of difficulties in calculating and attributing them.

Summary project outcomes

Gross benefits (present value A$m)	
Total	72.6
Australia	66.4
Partner countries	6.3
Net benefits (present value A$m)	
Total	68.4
Partner countries only	2.0
Benefit:cost ratio	
Total	17.2:1
Partner countries only	1.5:1
Internal rate of return (%)	
Total	27
Partner countries only	6.6

Source: Centre for International Economics estimates

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1 Introduction

This report provides an economic impact assessment of four ACIAR-funded projects related to mite pests of bees. The commissioned organisation in all cases was CSIRO Entomology, Australia. Details of the projects are summarised in Table 1.

Because these projects were largely sequential, with knowledge building from one to the other, we have treated them here collectively, and undertaken a single impact evaluation to incorporate them all. The impact analysis presented here builds on earlier work of Pearce et al. (2006) which evaluated the Australian benefits of the projects. In this report, we complete the evaluation by estimating partner country benefits and combining them with the Australian benefits to provide an overall impact assessment.

Chapter 2 summarises the key research inputs, outputs and outcomes. Chapter 3 estimates the economic value of the impact of the research. Chapter 4 draws some conclusions.

Table 1. Description of bee-mite related projects

Project	One hundred word summary
AS2/1990/028: *Improved methods in the epidemiology and control of mites and other diseases of bees in Papua New Guinea* **Partner country**: Papua New Guinea **Collaborating institution**: Department of Agriculture and Livestock **Duration**: January 1991 to June 1994	Parasitic bee mites and diseases they carry currently threaten the successful beekeeping industry in the Eastern Highlands of Papua New Guinea, based on the European honey bee *Apis mellifera*. The mites are carried by the non-productive Asian bee, *Apis cerana*, which has spread from neighbouring Irian Jaya. The objectives of this project are to study the biology of the two known bee mites, *Varroa jacobsoni* and *Tropilaelaps clareae*, and to combat the mites through chemical controls and better hive management. Scientists will also try to isolate pathogens potentially suitable for controlling bee mites, and study the effects of Asian bee pathogens on the European honey bee.
AS2/1994/017: *Control of bee mites in Irian Jaya* **Partner country**: Indonesia **Collaborating institution**: Dinas Peternakan Propinisi Dati I, Livestock Service **Duration**: July 1995 to June 1999	Earlier project work undertaken in ACIAR Project AS2/1990/028 revealed that the Asian bee *Apis cerana* and two bee mites, *Varroa jacobsoni* and *Tropilaelaps clareae*, had spread from west to east across the island of New Guinea from Irian Jaya into neighbouring Papua New Guinea (PNG). Both bee and mites are believed to have been brought in from Java about 15–20 years ago, and the mite *T. clareae* has caused destruction of many honey-bee (*Apis mellifera*) colonies in PNG. This project aims to form a clear picture of the occurrence and effects of bee and bee mite introductions into Irian Jaya, as a basis for planning a long-term campaign to eradicate *T. clareae* from the island of New Guinea.
AS2/1994/018: *Improved methods for bee development and control of bee mites in Papua New Guinea* **Partner country**: Papua New Guinea **Collaborating institution**: Department of Agriculture and Livestock **Duration**: July 1995 to June 1999	Infestations of the Asian bee mite *Tropilaelaps* clareae threaten to destroy the beekeeping industry in Papua New Guinea (PNG). Australia's bee industry is also at risk if this mite or two other pests, the Asian bee (*Apis cerana*) and the varroa mite (*Varroa jacobsoni*) enter from PNG. This project, which builds on the earlier ACIAR project AS2/1990/028 , will monitor the spread of the Asian bee and the two mites in PNG. Scientists will also try to determine why the local variety of *V. jacobsoni* does not reproduce in honey-bee (*Apis mellifera*) colonies in PNG and how it differs from the *V. jacobsoni* that causes great damage in other countries. They will also expand their knowledge of *T. clareae* and *A. cerana*, and of another varroa mite, *V. underwoodi*, recently recognised in PNG.
AS2/1999/060: *Control of bees and bee mites in Indonesia and the Philippines* **Partner countries**: Indonesia and the Philippines **Collaborating institutions**: National Beekeeping Centre, Perum Perhutani, Indonesia; Don Mariano Marcos Memorial State University, Philippines; Dinas Peternakan Propinisi Dati I, Indonesia; University of the Philippines at Los Baños, Philippines **Duration**: July 2001 to June 2005	Two genera of parasitic mites of bees (*Varroa* and *Tropilaelaps*) have a pathogenic effect on bees and pose a significant constraint to honey production in some of Australia's neighbouring countries. They would seriously threaten Australia's honey industry (as well as those industries relying on bees for pollination) if they became established here. The project's broad aims are to test cheap, effective and appropriate control measures and to develop genetic markers to allow the origin of the mites, and bees that spread them, to be identified. The markers will be useful in assisting Philippine and Indonesian authorities in decision-making about the feasibility of eradication campaigns and/or the scope of control programs. Australia's capability to deal with future exotic incursions has also been strengthened. Through its various activities the project aims to generate and support local capacity to undertake and promote control programs and to continue research

Source: ACIAR project documents

2 Research inputs, outputs and outcomes

The research issues

The ACIAR projects considered here have focused on the threat that parasitic mites pose to bees. The mites in question are *Tropilaelaps clareae* and those coming from the genus *Varroa*. The main bee of interest was *Apis mellifera*, the European honey bee but, in the course of the research, a great deal was also learnt about *Apis cerana*, the Asian hive bee.

When the mites enter a country and remain undetected for long enough to become established, horticultural industries, along with honey-bee-related products, experience a sizeable drop in production. The United States and New Zealand offer vivid examples of the devastation the mites can cause to an established bee industry. The Philippines and Indonesia have also felt the effects of the mite (although to a lesser extent due to the higher presence of other bee species) and no doubt similar effects would be felt in Australia should an incursion take place.

Learning more about the mites and suitable means of control will reduce these impacts. Lowered costs of mite control and higher levels of related products will assist in improving the income of apiarists. Increased bee numbers will also have a positive impact on pollination, potentially lowering costs and increasing output in the agricultural sector of affected countries.

Tropilaelaps clareae

The *T. clareae* mite is harmless to its native host but fatal to the European honey bee. Its introduction into regions with honey industries that rely on *A. mellifera* would have dire consequences.

The mite is completely reliant on the bee brood (i.e. larval stage) for survival and cannot survive on adult bees, a fact that has been exploited and is now resulting in the successful eradication of this pest from islands near Irian Jaya—proof that it can be done. The most recent of the projects focused on the feasibility of using formic acid as a means of mite control cheaper than other commercially available alternatives and equipping local staff with the knowledge and techniques for eradication.

Varroa

Of the many species within the *Varroa* genus of mites, two are of particular interest: *Varroa jacobsoni* and *V. destructor*. *Varroa jacobsoni* is found on subspecies of *Apis cerana*, the Asian hive bee, found throughout the southern mainland of Asia, the Philippines and the Indonesian archipelago. Other subspecies of *A. cerana* are found throughout northern India, the Himalayan region, Pakistan, Nepal, China, Korea and Japan. However, it is only those subspecies found in eastern China, Korea and Japan that carry *V. destructor*.

Although *V. destructor* will attach to the south-eastern variant of *A. cerana*, it cannot reproduce on it, due to the lack of a specific chemical trigger in this subspecies, and thus dies out naturally. Likewise, when *V. jacobsoni* migrates to *A. mellifera* it also dies out. In addition, *A. mellifera* cannot survive in the wild in South-East Asia because of the tropical climate. The end result is that there is no wild reservoir for *V. destructor* in South-East Asia, it can survive only in managed *A. mellifera* hives and not the local variants of *A. cerana*. Furthermore, *V. jacobsoni* does not pose a threat to managed *A. mellifera* hives.

Two notable facts arise from this knowledge. Firstly, *V. destructor*, with no native host in the region, is an introduced pest and, secondly, with a coordinated effort, it could be eradicated. With no wild reservoir, once the mite is eradicated from managed hives it would not be able to survive in feral bee hives and would therefore remain eradicated unless reintroduced by human intervention.

The challenge

The affected countries have experienced obvious declines in production and their closeness to Australia presents significant quarantine problems. For Australia, the introduction of *T. clareae* would potentially cause greater losses than *V. destructor*. The establishment of either mite would lead to increased costs for managed European honey-bee hives and would decimate the feral bee population. Such an impact would see production of honey fall, losses in the export market for live bees and huge adverse impacts on crops due to reduced pollination levels. The outputs of other bee-related products would also fall. The challenge is therefore to control the mites using a method that is cheap and effective in the infected countries and which will simultaneously reduce the risks to Australia. Furthermore, the method must not compromise the quality of the honey or other bee-related products being produced.

The projects

Figures 1 and 2 illustrate the basic flows of outputs, outcomes and impacts for the four projects. These are discussed in more detail later but, in summary, the major outputs were an increase in scientific knowledge and a practical method for controlling the mites in beekeeping areas. In addition, the new scientific knowledge had a practical application through its use in quarantine in Australia.

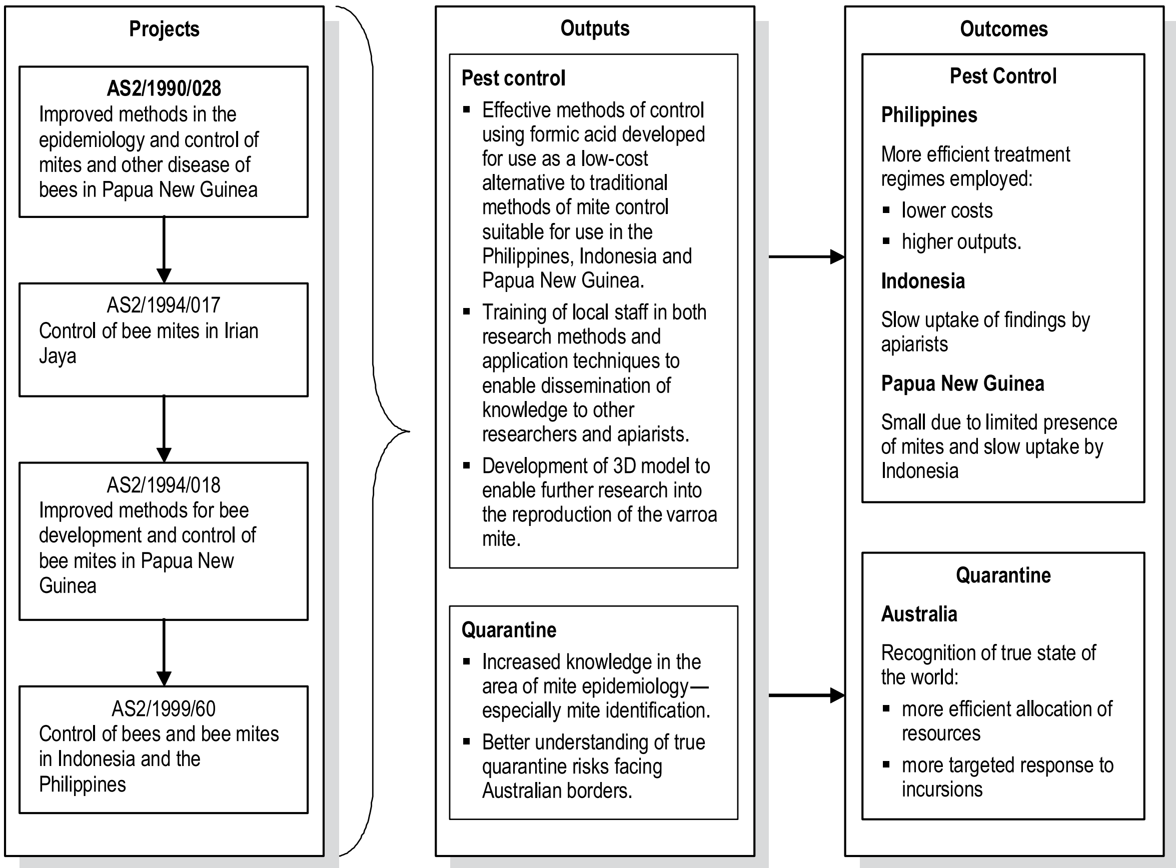

Figure 1. Summary project outputs and outcomes

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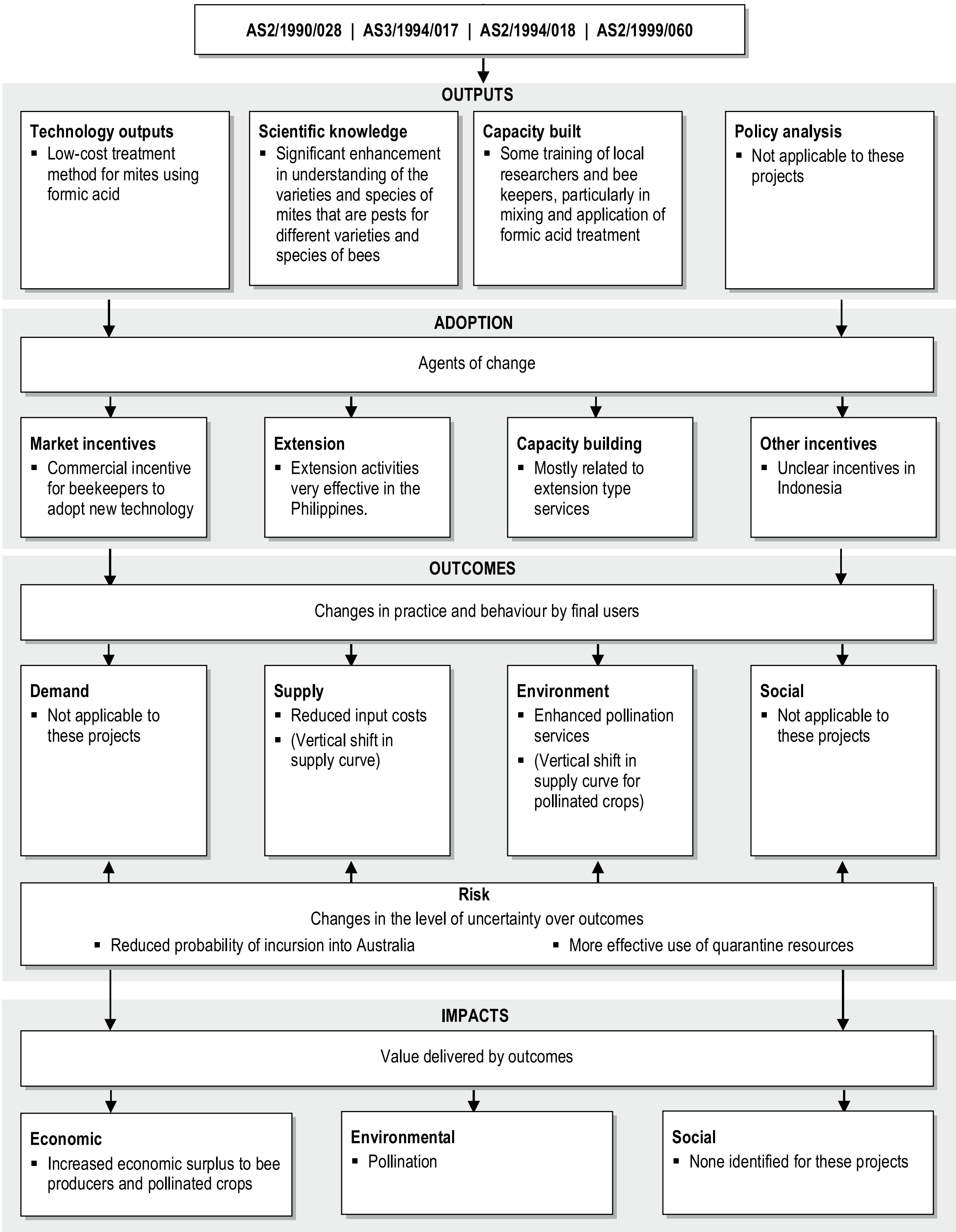

Figure 2. Flows of outputs to impacts

The major agents of adoption are the incentive facing beekeepers to reduce costs and the activities of extension services influenced by the project.

Table 2 summarises the project costs.

Research outputs

There are three main outputs from the research: increased scientific knowledge; training of researchers and farmers; and a practical control method for dealing with the mites in hives of honey bees.

Increased scientific knowledge

Before the research it was not known that:

- of the many types of *Varroa*, only one subspecies of *V. destructor* is a threat to *A. mellifera*
- this particular subspecies of *Varroa* cannot reproduce on the bees that are native to the areas covered by the research.

The research found that the different genotypes of mites and bees could coexist only in certain combinations. Table 3 shows the mites studied under the research and the types of bees on which they can reproduce.

Table 2. The projects and their budgets

Year	**Improved methodology in the epidemiology and control of mites and other diseases of bees in Papua New Guinea** AS2/1990/028 (current dollars)	**Control of bee mites in Irian Jaya** AS2/1994/017 (current dollars)	**Improved methods for bee development and control of bee mites in Papua New Guinea** AS2/1994/018 (current dollars)	**Control of bees and bee mites in Indonesia and the Philippines** AS2/1999/060 (current dollars)	**Deflator (2004 = 100)**	**Total in constant 2004 dollars**
1990	86,800				75.1	115,613
1991	105,522				76.6	137,813
1992	105,489				77.8	135,506
1993	153,263				78.8	194,566
1994					79.4	
1995		111,982	154,308		80.8	329,445
1996		89,687	133,559		82.5	270,568
1997		75,575	128,115		83.6	243,712
1998		88,873	75,984		84.0	196,204
1999					84.5	
2000					88.0	
2001				519,855	91.4	568,495
2002				540,177	93.8	576,001
2003				516,621	96.8	533,968
Present value in 2004						**4,220,577**

Source: ACIAR project documents. Deflator taken from Gordon and Davis (2007).

Table 3. Mites and the bees they can reproduce on

	North-east Asian *Apis cerana*	South-East Asian *A. cerana*	*Apis mellifera*
Varroa jacobsoni		■	
V. destructor	■		■
Tropilaelaps clareae			■

Training of researchers and farmers

Since making these discoveries many papers have been published (the third most cited paper from CSIRO Entomology was written on this topic) and the knowledge has been shared with researchers and beekeepers across the world. Training seminars have been given and, especially in the Philippines, groups have been established to disseminate the findings to individual beekeepers.

While there is a potential capacity-building benefit from the research, much of this training has actually contributed by helping ensure adoption of the research findings.

Practical, low-cost control methods

Research in the Philippines and Indonesia determined that the use of formic acid in low concentrations did not reduce *A. mellifera* worker-bee longevity but did kill adult *T. clareae* and *V. destructor* mites. The research proposed a protocol for mite control using this method.

The method of application involved inserting a mixture of formic acid into the hives at regular intervals. At the correct dosage levels, approximately 65% acid in water, the evaporation of the acid in the hives is sufficient to kill the mites.

Research outcomes

The Philippines

The adoption of research findings in the Philippines, particularly in terms of the formic-acid control method, has been impressive, with many apiarists using the new control methods. A major component of this appears to be some very effective extension services provided specifically to beekeepers in the Philippines.

Researchers at the Don Marianos Marcos Memorial State University (DMMMSU, pers. comm.) estimate that the cost of treating a hive using existing methods is approximately 500 Philippine pesos (PHP) per year. Changing to formic acid reduces this to about 200 PHP. Using an exchange rate of 40.78 PHP[1] per Australian dollar, this equates to A$12.25 for traditional treatments and A$4.90 for the new methods, a saving of roughly A$7 per year per hive. Not all apiarists have adopted formic acid as a means of treatment, but researchers at DMMMSU and the University of the Philippines at Los Baños (UPLB) expect that almost 100% of keepers will use the method after 10 years (beginning 2004).

Indonesia

Adoption of the research findings in Indonesia has been considerably slower than in the Philippines. There appear to be three broad reasons for this.

- First, the bee industry in Indonesia (which seems to be more commercialised than in the Philippines) appears to have access to bulk chemicals at relatively low prices, making the new treatment less competitive than in the Philippines. Industry people contacted during field visits were unwilling to provide information on the current costs of chemicals, so we are unable to confirm the overall importance of this effect.
- Second, the extension programs in Indonesia are different to those in the Philippines, and there is some suggestion that extension officers use and distribute bulk chemicals (for traditional treatments) and to date have not undertaken significant extension of the formic-acid treatment.

1 This is the average from 2004 to 2006, taken from Gordon and Davis (2007).

- Third, the application of formic acid as it is currently understood in Indonesia involves a relatively expensive modification to each hive, involving a net cost increase of around A$5 per hive. This further reduces the cost saving available from the new treatment. The reasons behind this particular usage are unclear, but it is possible that this will change significantly over time.

Papua New Guinea

In the course of this project we were unable to obtain information on the specific uptake of research findings in Papua New Guinea (PNG). To date, the mites have not managed to migrate further east than the Strickland Gorge, so there are likely to be limited benefits to a new treatment regime. However, the mites still pose a quarantine risk to PNG, and increased knowledge about the nature of the mite threats is likely to provide quarantine benefits. We were unable to find any data to test this proposition, however, so we have assumed that the impact is zero.

Australia

As set out in Pearce et al. (2006), the increased knowledge about the nature of bee-mite quarantine threats facing Australia has led to changed views within the Australian agencies concerned, and to quarantine benefits that are quantified further below.

3 Value of the research

Nature of the benefits

Benefits from the research arise through two mechanisms: pest control and quarantine. Each of these mechanisms may have an impact on honey production as a direct product of bees, and on pollination, an indirect by-product of managed bee systems. Increased knowledge may also lead to quarantine benefits, which will, in turn, have implications for honey production and for pollination. Table 4 shows which areas are applicable to each of the countries involved in the projects.

For the Philippines and Indonesia, both types of mites are already present, so benefits will arise from pest control. To the extent that pest control allows an increase in hive numbers, there may also be indirect pollination benefits in each country.

For PNG and Australia, benefits arise through improvements in quarantine control that, in turn, have benefits by maintaining honey production and pollination services at levels higher than they would be if an incursion did take place.

Pest control, pollination and quarantine benefits can all ultimately be analysed within a standard demand, supply and surplus framework. Figure 3 illustrates such a framework for the case of a tradeable product (where the demand curve is the same as the world price line). In this case, all of the change in economic surplus accrues to producers, and none to consumers.

- Research leading to improved pest control has two broad effects: lowering the costs of production and increasing yields. Both of these can be modelled as a downward shift in the product supply curve (initially *S′*, moving to *S*) with a subsequent increase in output, reduction in price and net economic surplus equal to the shaded area.
- Research leading to increased pollination services also leads to a yield increase and a vertical shift in the supply curve—in this case the supply curve for the product being pollinated—and the same area of net economic surplus.
- Research that improves quarantine outcomes has the effect of avoiding an upward shift in the supply curve (from *S* to *S′*), where the supply curve may refer to honey production or to supply of a pollinated product (the nature of the surplus estimated for Australia is discussed in Pearce et al. (2006)).

Table 4. Sources of benefits

Country	Pest control		Quarantine	
	Honey	Pollination	Honey	Pollination
Philippines	■	■		
Indonesia	■	■		
Papua New Guinea			■	■
Australia			■	■

Implementing the framework illustrated in Figure 3 requires information on:

- the initial position of the supply and demand curves—that is, the initial amount produced and at what price
- any autonomous (that is, not dependent on research) change in the position of these curves over time—this is, the dynamic baseline against which the research is evaluated
- the supply and demand elasticities for the relative product
- the extent of the vertical shift in the supply curve as a consequence of the research and over time as a consequence of adoption of the research findings
- the changed probabilities of incursion, as a result of the research, in the case of quarantine benefits.

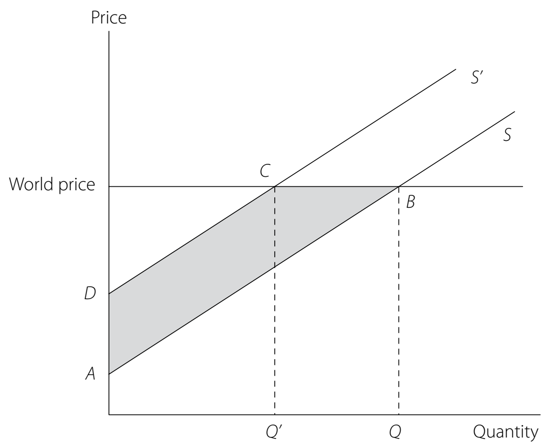

Figure 3. Change in economic surplus

Summary of assumptions and benefits valued

Of the full set of benefits identified in Table 4, we have been able to quantify only a subset. These are summarised in Table 5.

Table 6 sets out the key assumptions adopted in quantifying the pest control benefits for the Philippines and Indonesia set out in Table 5. These assumptions are further discussed below. The key assumptions underlying the quantification of quarantine benefits are set out in Pearce et al. (2006) and discussed further below.

Quantifying partner-country benefits

Benefits to honey production

Table 7 sets out the basic information required to evaluate the impact of improved mite-control methods on honey supply in the Philippines and Indonesia.

Philippines

Apis mellifera honey production is currently around 107 tonnes, with a farm value of around A$260,000. This makes it a very small industry, although in field visits we found great optimism about its potential growth. We have assumed baseline growth of 6% initially, then 3% a year for the remainder of the evaluation period to 2035. This baseline autonomous growth leads to post-research growth being very conservative compared with

Table 5. Benefits quantified in this report

Country	Pest control		Quarantine	
	Honey	Pollination	Honey	Pollination
Philippines	Quantified	Quantified using coconut as an example	–	–
Indonesia	Quantified	Not quantified	–	–
PNG	–	–	Not quantified	Not quantified
Australia	–	–	Quantified as in Pearce et al. (2006)	Quantified as in Pearce et al. (2006)

estimates from the Philippines (BEENET Philippines, 2004). While these estimates are largely designed to inspire the industry, it would be a mistake to assume zero autonomous growth.

Estimates of cost savings and yield increases from the research are significant, implying an up to 36% vertical shift in the supply curve. These significant savings underlie what is expected to be a very rapid uptake.

Based on information collected on field visits, we assume that there will be full adoption of the research findings by 2015. Our assumed adoption rate follows a standard *S*-curve, with 50% adoption achieved by 2008.

Estimates of the increase in economic surplus resulting from the cost savings and yield increases between 2004 and 2035 are set out in Table 8.

Table 6. Key assumptions for quantification of partner country benefits

Variable	Philippines	Indonesia	Discussion
Honey benefits			
Initial position of demand and supply curves	Set out in Table 7	Set out in Table 7	Honey production is not known with precision. Most estimates are based on discussions during field visits and should be viewed as approximate.
Elasticity of supply	3	2	There is limited information on honey supply elasticities. Econometric evidence from the US (Willett and French 1991) suggests a long run elasticity of 1. We expect supply elasticities to be higher in the partner countries, particularly the Philippines.
Elasticity of demand	Assumed infinite	Assumed infinite	Both countries are assumed to be price takers in the market for honey (they both import).
Autonomous growth	6% per year for two years, then 3% for all remaining years	1% per year throughout	Filed visits to the Philippines found great optimism about the prospects for the industry. These growth estimates are conservative. Indonesian prospects are uncertain, but 1% is considered reasonable.
Cost saving from research	Set out in Table 7	Set out in Table 7	These estimates were obtained from field visits.
Pollination benefits			
Coconut case study			
Initial position of demand and supply curves	Value of production A$998 million at A$95 per tonne	Not applicable (na)	Based on FAO data
Elasticity of supply	Set at 1	na	Designed as a neutral assumption
Elasticity of demand	Assumed infinite	na	Price taker on the world market
Autonomous growth	Assumed zero	na	Conservative assumption
Yield increase from research	Determined by implied increase in hive numbers calculated from the Philippine benefits	na	See discussion in the text

Source: Centre for International Economics' estimates based on data sources stated

The present value of the increased economic surplus is around A$2.76 million. This is a large benefit given a very small initial industry size. However, the industry is expected to roughly double over the assessment period. With zero growth, the benefits would be only A$1.7 million. Alternatively, with zero supply response, benefits would be only A$1.8 million.

Indonesia

Apis mellifera honey production is currently around 588 tonnes, with a farm value of around $1.76 million. This is a considerably larger industry than that in the Philippines, with a larger number of commercial operators.

However, as discussed above, there is considerable uncertainty about the adoption of the research findings in Indonesia. There are two layers of uncertainty here: first, the actual magnitude of the cost saving of the research, and second, the uptake of the research findings, whatever their magnitude. While adoption is unclear at the moment, we anticipate that it will increase as the benefits of the formic acid control method are further explored and the costs of applying it are reduced.

To capture this, we have modelled the Indonesian benefits using two *S*-curve profiles, one for the cost change as a result of the research, and the other for the adoption of the research. We assume that the net cost change starts low and reaches the maximum benefit (A$900) only after 2035. Half of the benefits are achieved by 2019. In terms of adoption, we assume this also starts low and reaches 80% by 2035. Half of this is achieved by 2019.

Table 7. Key honey production and cost estimates (*Apis mellifera*) 2004

Variable	Unit	Philippines	Indonesia[a]
Hives (*Apis mellifera*)	number	5,369	29,400
Honey production	tonnes	107	588
Yield (before research)	kg/hive	20	20
Farm price	A$/kg	2.45	3.00
Mite control cost (before research)	A$/hive	12.75	Uncertain, but 12.75 at most
Mite control cost (after research)	A$/hive	4.90	Uncertain; probably around 9.90, but could reduce to 4.90 over time
Yield (after research)	kg/hive	25	Uncertain, but potential to increase to 25
Cost savings from reduced mite-control costs	A$/tonne (honey)	392.50	142.50 initially, possibly increasing to 392.5 over time
Cost saving from after-research yield increase	A$/tonne (honey)	490.00	Could be up to 600
Total cost saving	A$/tonne (honey)	882.50	142.50 initially, increasing to around 900 over time

[a] Hive and production numbers for Indonesia are calculated as follows. Total hive numbers (*A. mellifera* and *A. cerana*) are around 50,000. Total honey production is 630 tonnes. Given that *A. mellifera* yields (around 20 kg/hive) are higher than *A. cerana* yields (around 2 kg/hive), the breakdown between *A. mellifera* and *A. cerana* production can be calculated to satisfy the known constraint of total hive numbers and total honey production. The number of *A. mellifera* hives equals: total production – (*A. cerana* yield × total hive numbers)/(*A. mellifera* yield – *A. cerana* yield).

Sources: Centre for International Economics' calculations based on data from: FAO online statistics, University of the Philippines at Los Baños (UPLB) Bee Program, Don Marianos Marcos Memorial State University, National Apiculture Research and Development Institute (Philippines), National Beekeeping Centre, Parung Panjang, Indonesia.

Table 8. Calculation of honey benefits to the Philippines[a]

Year	Net cost change (A$)	Net cost change (proportionate)	Adoption rate (proportion)	Base growth (proportion)	Base output (tonnes)	Change in economic surplus (A$)
2004	882.50	0.36	0.06	0.06	107.0	5,581
2005	882.50	0.36	0.11	0.06	113.4	11,564
2006	882.50	0.36	0.20	0.03	116.8	22,574
2007	882.50	0.36	0.33	0.03	120.3	41,552
2008	882.50	0.36	0.50	0.03	123.9	69,461
2009	882.50	0.36	0.67	0.03	127.7	102,451
2010	882.50	0.36	0.80	0.03	131.5	133,426
2011	882.50	0.36	0.89	0.03	135.4	157,732
2012	882.50	0.36	0.94	0.03	139.5	175,151
2013	882.50	0.36	0.97	0.03	143.7	187,629
2014	882.50	0.36	0.99	0.03	148.0	197,163
2015	882.50	0.36	0.99	0.03	152.4	205,132
2016	882.50	0.36	1.00	0.03	157.0	212,352
2017	882.50	0.36	1.00	0.03	161.7	219,271
2018	882.50	0.36	1.00	0.03	166.6	226,131
2019	882.50	0.36	1.00	0.03	171.6	233,060
2020	882.50	0.36	1.00	0.03	176.7	240,125
2021	882.50	0.36	1.00	0.03	182.0	247,367
2022	882.50	0.36	1.00	0.03	187.5	254,807
2023	882.50	0.36	1.00	0.03	193.1	262,461
2024	882.50	0.36	1.00	0.03	198.9	270,340
2025	882.50	0.36	1.00	0.03	204.8	278,453
2026	882.50	0.36	1.00	0.03	211.0	286,808
2027	882.50	0.36	1.00	0.03	217.3	295,413
2028	882.50	0.36	1.00	0.03	223.8	304,276
2029	882.50	0.36	1.00	0.03	230.6	313,404
2030	882.50	0.36	1.00	0.03	237.5	322,806
2031	882.50	0.36	1.00	0.03	244.6	332,490
2032	882.50	0.36	1.00	0.03	251.9	342,465
2033	882.50	0.36	1.00	0.03	259.5	352,739
2034	882.50	0.36	1.00	0.03	267.3	363,321
2035	882.50	0.36	1.00	0.03	275.3	374,221
Present value						**2,755,638**

[a] Supply elasticity is set at 3. The base price is A$2,450 per tonne (constant in all years). The discount rate is 5%. The adoption rate is specified as: adoption in year $t = 1/(1 + \exp(0.7*(4-t)))$ where exp is the natural exponent, and t is indexed from 0 to 32.

Source: Centre for International Economics' calculations

Given the lack of adoption that is currently evident, it would be inappropriate to assume a higher adoption profile. At the same time, however, there is evidence that there will ultimately be some benefits, so it would be inappropriate to assume zero benefits.

Table 9 sets out estimates of the change in economic surplus resulting from this adoption profile. The present value of the increase in surplus is A$2.4 million. This is a similar order of magnitude to the Philippines, despite the much lower adoption profile, reflecting the fact that the Indonesian industry is around seven times larger than the Philippine industry. The industry is also expected to grow over the evaluation period with smaller gains (A$1.9 million) under an assumption of zero growth.

The benefits in Table 9 are considerably lower than they would be with full adoption. Even with the lower cost-savings profile for Indonesia, a more rapid adoption profile (the same as that for the Philippines, for example) would bring benefits of A$4.3 million.

Pollination benefits

To estimate pollination benefits we have chosen to quantify potential benefits in a single crop in the Philippines: coconuts. This crop was chosen because of its importance to the economy and because of its potential dependence on pollination. The calculations are designed to be illustrative without being misleading or distorting the estimated benefits from the project. While there is a risk that including uncertain pollination benefits may overstate the benefits of the research, it would also be a mistake to ignore the potential for benefits from this source. Because of underlying uncertainties in Indonesia, we have not quantified any pollination benefits there.

Clearly, tropical crops that have significant production values and are dependent on pollination (Table 10) are currently pollinated by a variety of insects, including native Asian honey bees (*A. cerana*). Given the relatively low numbers of *A. mellifera*, it cannot be claimed that these crops are dependent on the European honey bee for pollination. However, it is still possible that an increase in *A. mellifera* hive numbers (as a consequence of the research) could lead to additional or incremental pollination benefits.

While there is currently no definitive research on the value of managed pollination services in the tropics (Free 2005), there are some suggestions that tropical crop yields could be improved by additional pollination services. Anecdotal evidence is available from the Philippines (gathered during field visits), that managed pollination has led to yield increases in some tropical crops, although the magnitude of the yield increase is unknown. In countries in South America, some research has shown that increased access to pollination services can increase yields by up to 20% (Ricketts 2004; Ricketts et al. 2004).

In addition, there are concerns throughout a number of tropical areas that vegetation, and forests in particular, serving as reservoirs for native pollinators are declining as agriculture expands by land clearing (Ricketts 2004). This means that managed pollination services may become increasingly important for some crops in the future.

While there are no precise data on the marginal pollination benefits of increased *A. mellifera* hive numbers, drawing on two pieces of information we can make an indicative calculation. First, Manning (2006) suggests that, for coconuts, the optimal number of hives for pollination is 2–3 per hectare. Second, from Gill (1989), we know that the dependence of coconut yields on pollination services is 60%. From this, it can be inferred that, as the increment in hive numbers as a result of the *Varroa* research moves towards the optimum, the maximum possible increase in yields is 60%.

We calculate the potential pollination benefits as follows. Increased pollination services lead to an increase in yield and so correspond to a vertical shift in the supply curve of, in this case, coconuts. The amount of this shift (the yield increase) is equal to the increment in hive numbers (that is, the increase in hive numbers as a consequence of the research) as a proportion of the optimal number of hives multiplied by the total potential yield increase. There are 3.26 million hectares of coconuts planted, so the optimal number of hives is around 6.5 million. To calculate benefits in this case, we assume that the potential yield increase is 10%.

Calculations of the change in economic surplus as a consequence of pollination benefits are set out in Table 11. The present value of the increase in surplus is around A$1 million.

Table 9. Calculation of honey benefits to Indonesia[a]

Year	Net cost change[b] (A$)	Net cost change (proportion)	Adoption rate[c] (proportion)	Base growth (proportion)	Base output (tonnes)	Change in economic surplus (A$)
2004	42.68	0.01	0.00	0.01	588.0	50
2005	51.59	0.02	0.00	0.01	593.9	90
2006	62.22	0.02	0.00	0.01	599.8	164
2007	74.86	0.02	0.01	0.01	605.8	296
2008	89.78	0.03	0.01	0.01	611.9	533
2009	107.28	0.04	0.01	0.01	618.0	954
2010	127.67	0.04	0.02	0.01	624.2	1 697
2011	151.18	0.05	0.03	0.01	630.4	2 991
2012	178.03	0.06	0.05	0.01	636.7	5 213
2013	208.33	0.07	0.07	0.01	643.1	8 955
2014	242.05	0.08	0.10	0.01	649.5	15 108
2015	279.02	0.09	0.13	0.01	656.0	24 906
2016	318.91	0.11	0.19	0.01	662.6	39 899
2017	361.18	0.12	0.25	0.01	669.2	61 737
2018	405.15	0.14	0.32	0.01	675.9	91 727
2019	450.00	0.15	0.40	0.01	682.6	130 250
2020	494.85	0.16	0.48	0.01	689.5	176 322
2021	538.82	0.18	0.55	0.01	696.4	227 646
2022	581.09	0.19	0.61	0.01	703.3	281 202
2023	620.98	0.21	0.67	0.01	710.4	334 071
2024	657.95	0.22	0.70	0.01	717.5	384 038
2025	691.67	0.23	0.73	0.01	724.6	429 791
2026	721.97	0.24	0.75	0.01	731.9	470 810
2027	748.82	0.25	0.77	0.01	739.2	507 118
2028	772.33	0.26	0.78	0.01	746.6	539 054
2029	792.72	0.26	0.79	0.01	754.1	567 096
2030	810.22	0.27	0.79	0.01	761.6	591 762
2031	825.14	0.28	0.79	0.01	769.2	613 548
2032	837.78	0.28	0.80	0.01	776.9	632 907
2033	848.41	0.28	0.80	0.01	784.7	650 234
2034	857.32	0.29	0.80	0.01	792.5	665 873
2035	864.75	0.29	0.80	0.01	800.5	680 114
Present value						2 423 936

[a] Supply elasticity is 2. Base price is A$3,000 per tonne (constant in all years).

[b] The net cost change profile is specified as: Net cost change in year t = 900/(1+exp(0.2*(15–t))) where exp is the natural exponent, and t is indexed from 0 to 32.

[c] The adoption profile is specified as: adoption in year t = 0.8/(1+exp(0.4*(15–t))) where exp is the natural exponent, and t is indexed from 0 to 32.

Source: Centre for International Economics' estimates

This estimate is clearly sensitive to a variety of assumptions. It is most sensitive, however, to assumptions set out in Table 8 concerning the *honey* benefits to the Philippines. For example, reducing the honey supply elasticities from 3 (Table 8) to 2 has an effect on the implied increase in the number of hives, reducing the net cost change in Table 11, which reduces the pollination benefits to $600,000.

Benefits to Australia

The benefits to Australia of these research projects are set out in detail in Pearce et al. (2006).

The underlying value of this research to Australia is to provide a better understanding of the quarantine risks facing Australia from mites, and to better allocate quarantine resources so as to minimise the risk of incursion. The value of the research is therefore an *avoided* cost of incursion.

There are two costs to a mite incursion: lost honey production as a consequence of the mite and lost pollination services as a consequence of the effect of the mite on feral European honey-bee populations. Unlike in Asia, these pollinators are crucial in Australia, and by far the greatest cost of an incursion would be through the loss of pollination services. Gordon and Davis (2003) estimate the value of pollination services to be around A$1.7 billion.

Table 10. Value and pollination dependence of selected crops 2003

Country and crop	Value (A$m[a])	Dependence on pollination (%)
Philippines		
Coconut	998	60
Coffee	115	70
Mango	492	90
Indonesia		
Coconut	2,222	60
Coffee	1,016	70
Mango	999	90

[a] Calculated using A$1 = US$0.70

Sources: FAO online statistics, Gill (1989) and personal communication with University of the Philippines at Los Baños Bee Program

The expected cost of an incursion depends not only on the potential cost should an incursion occur, but also on a variety of probabilities related to that incursion. In its simplest form, the expected cost of an incursion is equal to the probability of incursion multiplied by the cost of incursion. The benefits of research are therefore equal to the change in the probability of incursion (as a result of the research) multiplied by the cost of the incursion.

There are, however, a number of other probabilities that need to be considered in determining the expected cost of an incursion. These include:

- given an incursion, the probability of early detection
- given early detection, the probability that the mite can be eradicated
- given eradication is possible, the probability that an attempt is made to eradicate, and, if an attempt is made, the probability of success
- given late detection, the probability that the mite is eradicable.

There are also various costs, including the cost of eradication, the cost of detection and so on, that need to be incorporated in the calculation. In addition, estimates of the persistence of damage following an incursion and the underlying baseline growth rate of the sectors affected also need to be incorporated.

Pearce et al. (2006) use a fully specified recursive Markov-chain model that accounts for these probabilities and has at its core the economic surplus loss (from honey and from pollination services) as the result of an incursion.

Pearce et al. (2006) concluded that, overall, the ACIAR-funded research, by improving quarantine outcomes, had the effect of lowering the probability of an incursion from 0.04 to 0.02. The effect of this reduction is an annualised stream of benefits of $4.2 million. Pearce et al. (2006) conducted a range of sensitivity analyses, indicating a possible range of 50% on either side of these annual benefits.

Table 11. Calculation of pollination benefits for coconuts in the Philippines[a]

Year	Implied increase in hive numbers[b] (A$)	Net cost change[c] (%)	Adoption rate (proportion)	Base growth (proportion)	Base output (tonnes)	Change in economic surplus (A$)
2004	251	0.0004	1.0	0	10,500,000	3,856
2005	500	0.0008	1.0	0	10,500,000	7,681
2006	915	0.0014	1.0	0	10,500,000	14,042
2007	1,531	0.0024	1.0	0	10,500,000	23,510
2008	2,288	0.0035	1.0	0	10,500,000	35,126
2009	3,035	0.0047	1.0	0	10,500,000	46,607
2010	3,649	0.0056	1.0	0	10,500,000	56,025
2011	4,098	0.0063	1.0	0	10,500,000	62,925
2012	4,420	0.0068	1.0	0	10,500,000	67,861
2013	4,661	0.0072	1.0	0	10,500,000	71,569
2014	4,859	0.0075	1.0	0	10,500,000	74,602
2015	5,034	0.0077	1.0	0	10,500,000	77,301
2016	5,201	0.0080	1.0	0	10,500,000	79,858
2017	5,365	0.0083	1.0	0	10,500,000	82,376
2018	5,530	0.0085	1.0	0	10,500,000	84,911
2019	5,698	0.0088	1.0	0	10,500,000	87,490
2020	5,870	0.0090	1.0	0	10,500,000	90,131
2021	6,047	0.0093	1.0	0	10,500,000	92,844
2022	6,228	0.0096	1.0	0	10,500,000	95,634
2023	6,415	0.0099	1.0	0	10,500,000	98,505
2024	6,608	0.0102	1.0	0	10,500,000	101,461
2025	6,806	0.0105	1.0	0	10,500,000	104,506
2026	7,010	0.0108	1.0	0	10,500,000	107,642
2027	7,220	0.0111	1.0	0	10,500,000	110,871
2028	7,437	0.0114	1.0	0	10,500,000	114,198
2029	7,660	0.0118	1.0	0	10,500,000	117,624
2030	7,890	0.0121	1.0	0	10,500,000	121,153
2031	8,127	0.0125	1.0	0	10,500,000	124,787
2032	8,371	0.0129	1.0	0	10,500,000	128,531
2033	8,622	0.0133	1.0	0	10,500,000	132,388
2034	8,880	0.0137	1.0	0	10,500,000	136,359
2035	9,147	0.0141	1.0	0	10,500,000	140,451
Present value						**1,072,949**

[a] Supply elasticity is set at 1. The base price is A$95 per tonne (constant in all years).

[b] Implied increase in hive numbers is calculated from the estimates of Philippine honey benefits. For a given supply elasticity, the increase in honey production is easily estimated from the vertical shift in the supply curve. Accounting for the yield increase as a result of the research, the implied increment in the number of hives can be calculated.

[c] The net cost change is calculated by dividing the increment in hive numbers by the optimal number of hives (6.5 million) and then multiplying by 0.1, an estimate of the proportionate increase in yield resulting from optimal pollination.

Source: Centre for International Economics' estimates

Over the time frame used here, these annual benefits come to a present value of A$66.4 million.

Total benefit–cost results

Table 12 summarises the streams of benefits and gives the 2004 present value of project costs. (Full streams of project costs are shown in Table 2.) Table 13 sets out the summary research impact measures.

Total benefits are A$72.6 million, 90% of which are benefits to Australia. Net benefits are $68.4 million. If only the benefits to partner countries are included, then net benefits are $2 million. The overall benefit:cost ratio for the project is 17.2:1 (corresponding to an internal rate of return of 27%). If only the benefits to partner countries are included, then the benefit:cost ratio is 1.5:1 (corresponding to an internal rate of return of 6.6%).

Sensitivity analysis

The overall results clearly depend on a number of underlying assumptions, in particular those relating to autonomous growth rates and adoption profiles, as well as the indirect effect of honey supply elasticities on pollination benefits. We have used Monte Carlo analysis to simulate the results for a probability distribution of underlying assumptions, adopting the typical Bayesian assumption that the distribution of parameters is uniform. We have used a 50% variation around the assumptions set out above.

Sensitivity results in terms of a 95% confidence interval are presented in Table 14. The confidence interval of total gross benefits is around 40% around the midpoint. This is mostly driven by variation in the Australian component. There is around a 30% variation in partner-country gross benefits.

The project generates net benefits under all the project settings, both in terms of total benefits and when only the partner benefits are considered. The total benefit:cost ratio varies from around 10:1 to 25:1 which would be considered as being in the same broad order of magnitude. The internal rate of return varies from 21% to 30%, again within the same overall order of magnitude.

Importantly, this sensitivity analysis does not include any net negative results within the reported confidence interval.

Table 12. Total benefits and costs (A$)

Year	Honey production benefits		Pollination benefits	Total partner benefits	Australian benefits	Total benefits	Research cost
	Philippines	Indonesia	Philippines				
2004	5,581	50	3,856	9,486	4,200,000	4,209,486	4,220,577[a]
2005	11,564	90	7,681	19,335	4,200,000	4,219,335	
2006	22,574	164	14,042	36,779	4,200,000	4,236,779	
2007	41,552	296	23,510	65,358	4,200,000	4,265,358	
2008	69,461	533	35,126	105,120	4,200,000	4,305,120	
2009	102,451	954	46,607	150,013	4,200,000	4,350,013	
2010	133,426	1,697	56,025	191,147	4,200,000	4,391,147	
2011	157,732	2,991	62,925	223,648	4,200,000	4,423,648	
2012	175,151	5,213	67,861	248,225	4,200,000	4,448,225	
2013	187,629	8,955	71,569	268,153	4,200,000	4,468,153	
2014	197,163	15,108	74,602	286,872	4,200,000	4,486,872	
2015	205,132	24,906	77,301	307,339	4,200,000	4,507,339	
2016	212,352	39,899	79,858	332,109	4,200,000	4,532,109	
2017	219,271	61,737	82,376	363,385	4,200,000	4,563,385	
2018	226,131	91,727	84,911	402,769	4,200,000	4,602,769	
2019	233,060	130,250	87,490	450,799	4,200,000	4,650,799	
2020	240,125	176,322	90,131	506,579	4,200,000	4,706,579	
2021	247,367	227,646	92,844	567,856	4,200,000	4,767,856	
2022	254,807	281,202	95,634	631,643	4,200,000	4,831,643	
2023	262,461	334,071	98,505	695,037	4,200,000	4,895,037	
2024	270,340	384,038	101,461	755,839	4,200,000	4,955,839	
2025	278,453	429,791	104,506	812,750	4,200,000	5,012,750	
2026	286,808	470,810	107,642	865,259	4,200,000	5,065,259	
2027	295,413	507,118	110,871	913,402	4,200,000	5,113,402	
2028	304,276	539,054	114,198	957,527	4,200,000	5,157,527	
2029	313,404	567,096	117,624	998,124	4,200,000	5,198,124	
2030	322,806	591,762	121,153	1,035,721	4,200,000	5,235,721	
2031	332,490	613,548	124,787	1,070,826	4,200,000	5,270,826	
2032	342,465	632,907	128,531	1,103,903	4,200,000	5,303,903	
2033	352,739	650,234	132,388	1,135,361	4,200,000	5,335,361	
2034	363,321	665,873	136,359	1,165,554	4,200,000	5,365,554	
2035	374,221	680,114	140,451	1,194,786	4,200,000	5,394,786	
Present value	2,755,638	2,423,936	1,072,949	6,252,523	66,371,242	72,623,765	4,220,577

[a] Research cost has been expressed in 2004 dollars and accumulated to 2004.

Source: Centre for International Economics' estimates

Table 13. Summary project outcomes

Gross benefits (present value A$m)	
Total	72.6
Australia	66.4
Partner countries	6.3
Total cost of research	4.2
Net benefits (present value A$m)	
Total	68.4
Partner countries only	2.0
Benefit:cost ratio	
Total	17.2:1
Partner countries only	1.5:1
Internal rate of return (%)	
Total	27
Partner countries only	6.6

[a] Internal rate of return calculated from the full-time series of costs set out in Table 2.
Source: Centre for International Economics' estimates

Table 14. Confidence intervals (95%) for key research outcomes

	Lower	**Upper**
Gross benefits (present value, A$m)		
Total	41.0	104.2
Australia	34.8	97.9
Partner countries	4.4	8.4
Research cost	4.2	4.2
Net benefits (present value A$m)		
Total	36.8	99.9
Partner countries only	0.2	4.1
Benefit:cost ratio		
Total	9.7:1	24.6:1
Partner countries only	1.1:1	1.9:1
Internal rate of return (%)		
Total	21.1	30.2
Partner countries only	5.2[a]	7.9

[a] The lower bound on this internal rate of return (IRR) may be inaccurate, as the IRR is not defined in all circumstances.
Source: Centre for International Economics' estimates

4 Conclusions

This paper examined four projects involving bees and their pests, funded by ACIAR over the past decade. The projects were undertaken in conjunction with industry, government and universities in the Philippines, Indonesia and Papua New Guinea, along with the Australian commissioned organisation, CSIRO Entomology.

The first project began in 1990, with each of the subsequent projects building upon the findings of its predecessors. The total expenditure for the four projects (in present value real terms) was A$4.2 million.

Estimated benefits for the projects were A$3.7 million for the Philippines (including both beekeeping and pollination benefits), A$2.4 million for Indonesia (beekeeping benefits) and A$66.4 million for Australia (both beekeeping and pollination benefits).

Table 13 summarised the impact outcomes for the project.

The benefit:cost ratio for partner countries only is 1.5:1 (with an internal rate of return of 6.6%). However, these projects have also generated significant benefits to Australia, so that the total benefit:cost ratio for the research is 17.2:1 (with an internal rate of return of 27%).

A net return to partner countries, along with significant benefits to Australia, illustrates the extraordinary synergies that can arise in the research funded by ACIAR. In this case, a major pest in Asia and the Pacific is also potentially destructive in Australia, so that research targeted in partner countries almost inevitably has benefits also for Australia.

There are potential benefits in addition to those presented here. Given the lack of a native reservoir for *V. destructor* in the countries involved and, indeed, throughout most of South-East Asia, the benefits to the region could be much higher. Theoretically, a concerted effort could be made to eradicate the mites (as was demonstrated on an island off Irian Jaya) and, with suitable quarantine and education, the region could remain mite free. Reintroduction could occur only through trafficking of bees by humans from infected areas into mite-free areas. *Apis mellifera* could then exist in the presence of *A. cerana* and *V. jacobsoni*, with no need for intervention of any kind. The benefit to partner countries of full eradication (with relatively rapid adoption as assumed for the Philippines above) could be up to $20 million.

Clearly, however, these additional benefits require further research and institutional development, potentially fruitful areas for further ACIAR funding.

Further, the scientific work underlying these projects has been groundbreaking, leading to the third most-cited paper to come from CSIRO Entomology and to substantially improved understanding of the mites worldwide. There are therefore likely to be substantial benefits to other countries, but these have not been included here because of difficulties calculating and attributing them.

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