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The economic impact in Indonesia and Australia of investment in plantation forestry research, 1987–2009

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Research that works for developing countries and Australia

The economic impact in Indonesia and Australia of investment in plantation forestry research, 1987–2009

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Cover: Logs from Musi Hutan Persada's *Acacia mangium* plantations en route to the Tanjung Enim Lestari pulp mill in South Sumatra. Photo: Tony Bartlett

Foreword

The Australian Centre for International Agricultural Research (ACIAR) has been funding plantation forestry research in Indonesia since 1987, with the aim of improving the forestry sector in both Indonesia and Australia.

The 12 projects assessed in this study focus on the domestication of Australian trees for agroforestry, development of plantation management to improve productivity, and control of threats from pests, diseases and soil degradation.

Previous impact assessment studies of forestry projects in other countries have demonstrated high rates of return. This report describes the first economic impact study of ACIAR's plantation forestry research in Indonesia and Australia. Benefits were estimated for nine projects in the Australian trees projects cluster and two projects in the multipurpose trees projects cluster where there was clear evidence of significant uptake of technology outputs from the projects.

Like other ACIAR projects, co-contributions were made by Australian commissioned organisations and Indonesian and other partner institutions. In 2009 Australian dollar terms, the total present value of investment in plantation forestry research by ACIAR and contributing organisations was estimated to be about A$37 million.

Based on conservative assumptions about the proportion of plantation area subject to uptake of project outputs, the present value of realised benefits to date to Indonesia from the Australian trees projects cluster, which comprised approximately 50% of the total investment, was estimated to be A$3,842 million. This results in a benefit:cost ratio of 89 and an internal rate of return of 54%. Also, using conservative assumptions about future rates of planting of industrial pulpwood plantations, the present value of total benefits eventually could be as great as A$11,148 million.

While these estimated returns to the research investment are extraordinary, they reflect the huge scale of the Indonesian plantation industry, the very high rate of uptake by this industry of these research outputs and the large increases in productivity enabled by adoption of project outputs.

Significant benefits are also likely to accrue to Australia from the multipurpose trees projects, which accounted for 20% of the total investment by ACIAR and other agencies. These two projects enabled the development of a vibrant sandalwood plantation industry in the Ord River Irrigation Area in the north-west of Australia, which it is estimated will generate benefits with a present value of A$766 million after commercial-scale harvesting commences in about 4 years time. Overall, the estimated benefit:cost ratio was 322 and the internal rate of return was about 54%.

The results of this research will assist Indonesia to enhance the livelihoods of farmers through its new policy of supporting community-based commercial plantation development.

Nick Austin
Chief Executive Officer, ACIAR

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Abbreviations

AA	PT Arara Abadi (fibre supply company, part of the Sinar Mas group)
ACIAR	Australian Centre for International Agricultural Research
AIDAB	Australian International Development Assistance Bureau (now AusAID)
AKSENTA	a forest products industry consulting firm
APP	Asia Pulp and Paper (pulp and paper company, part of the Sinar Mas group)
APRIL	Asia Pacific Resources International Limited (fibre, pulp and paper producer)
ATSC	Australian Tree Seed Centre
AusAID	Australian Agency for International Development
BPK	Ministry of Forestry Directorate General for Forest Production Development & Management (Indonesia)
CALM	Department of Conservation and Land Management (Western Australia)
CFBTI	Center for Forest Biotechnology and Tree Improvement (Indonesia)
CIFOR	Center for International Forestry Research (headquarters in Bogor, Indonesia)
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
DAT	Domestication of Australian trees projects
ENT	East Nusa Tenggara Timur province (Indonesia)
FAO	Food and Agriculture Organization of the United Nations
FNQ	Far North Queensland
HPH	Hak Pengusahaan Hutan; Forest Concession Right
HT	Hutan Tanaman; timber plantation
HTI	Hutan Tanaman Industri; industrial timber plantation
ITC	Integrated Tree Cropping Limited
MAI	mean annual increment
MHP	PT Musi Hutan Persada (industrial forest plantation company)
MIS	managed investment scheme
MOFR	Ministry of Forestry (Indonesia)
MPTS	multipurpose trees
NPV	net present value
ORIA	Ord River Irrigation Area, Western Australia
PÖYRY	Jaakko Pöyry Group (forest industry consultants)
PNG	Papua New Guinea
QTLs	quantitative trait loci
R&D	research and development
RAPP	PT Riau Andalan Pulp and Paper (part of the APRIL group of companies)
RIRDC	Rural Industries Research and Development Corporation (Australia)
SAT	Seeds of Australian trees (for developing countries) project
TFS	Tropical Forestry Services Limited
WA	Western Australia

Summary

The widespread deforestation of 'natural' tropical rainforests in Indonesia and many other developing countries gave rise to a variety of problems. They included adverse changes in catchment hydrology, accelerated erosion, ecosystem degradation, loss of wildlife habitat and local shortages of fuelwood and timber. Plantation and farm forestry were often seen as ways to counter these problems and to meet the need for fuelwood, fodder, building poles and other forest products and, in particular, to meet a growing need for pulpwood feedstock for paper production.

Starting in 1987, the Australian Centre for International Agricultural Research (ACIAR) has invested continuously in a series of collaborative research projects between Australian and Indonesian scientists, with the aim of improving plantation forestry in both countries. In 1993, it also assumed responsibility for funding an ongoing project, 'Seeds of Australian trees for developing countries' (SAT), that previously had been funded by the Australian Agency for International Development (AusAID). The span of these projects, 12 in all, included silvicultural practices, the domestication of Australian trees for reforestation and agroforestry, control of fungal and insect pathogens, development of sustainable management systems and the application of molecular marker technologies for genetic improvement of forest plantations. This report describes a thematic cost–benefit study to assess realised and prospective economic impacts in both Indonesia and Australia that can be attributed to the investment by ACIAR (and AusAID) in these plantation forestry research projects.

Overview of projects

Some of the projects had identical or very similar objectives and, for expositional convenience, are grouped into clusters in this report. The first two projects funded by ACIAR are referred to as the *agroforestry projects* (or the *multipurpose trees projects*). The main focus in the Indonesian component was on multipurpose trees to meet the needs of smallholders in eastern Indonesia for fuelwood, forage and wood products, while the focus of the Australian component was to facilitate the development of a sandalwood plantation industry.

Six projects, including two earlier projects funded by AusAID, are referred to as the *industrial plantation domestication projects*, because the overarching aim was to improve and maintain plantation productivity and profitability through genetic enhancement and better plantation management of domesticated hardwood tree species. Four of these projects were essentially one continuous project with common outcomes and impacts, so in places they are collectively referred to as the Australian trees projects even although the natural range of some of these species extends beyond Australia and into Papua New Guinea (PNG) and Indonesia.

Another five projects are referred to as the *industrial plantation protection projects*, because the aim essentially was to protect plantation productivity and profitability from disease and pest threats. The first three projects were small surveys that sought to identify threats to tropical acacias from a range of insect pests and fungal pathogens. They gave rise to two larger projects on heartrot and rootrot that aimed to identify causal agents, establish the influence of provenance, silvicultural practices and the environment on incidence of rots, and develop control options to mitigate damage.

The remaining project is referred to as the *industrial plantation enhancement project*, as it contributed to a scientific basis for certification and verification of environmentally and socially responsible forestry.

For the agroforestry projects, the problems that motivated the research were developing shortages of fuelwood and timber due to deforestation, burning and overgrazing, and a serious decline in exports of sandalwood oil.

The basic motivation for the other projects was the recognition that plantations of Australian trees in Indonesia and elsewhere could make a contribution to tackling the problems of deforestation. Many species of Australian hardwood trees, most notably eucalypts and acacias, are widely planted in tropical and subtropical plantation forestry because they grow rapidly when the water supply is good, are highly adaptable to a wide variety of climates and perform well on infertile sites. Domestication of Australian hardwoods, including both *Eucalyptus globulus* and other temperate eucalypt species in Australia, and tropical *Eucalyptus* and *Acacia* species in a number of developing countries, has been one of the more impressive success stories of Australian forestry research.

Given the great diversity among species and provenances of Australian hardwoods, there was considerable potential to help meet economic, social and environmental needs in Indonesia for industrial wood, domestic building material, fuelwood, soil stabilisation and non-wood products by domestication of Australian trees. Midgley and Turnbull (2003) estimated that there were about 2 million hectares (ha) of acacias in plantations worldwide, of which about 1.2 million ha were in Indonesia.

Following the widespread establishment of plantations of *Acacia mangium* and other Australian hardwood species, Australian forest scientists were quick to realise that the sustainability of these plantations might be threatened by the emergence of pests and diseases.

In summary, the overall objective of the cluster of industrial plantation protection projects was to protect and preserve the gains in plantation productivity by genetic improvement achieved by the industrial plantation domestication projects against the threat of large production losses from pests and diseases.

The objective of the industrial plantation enhancement project was to contribute to scientific knowledge to enhance management of industrial forest plantations as part of a global movement to encourage more-sustainable management of forests by a system of accreditation of sustainable forest products.

Outputs and adoption

Important capacity-building outputs were produced by all projects. These have strengthened forest research institutions in Indonesia and Australia, and will continue to do so. By definition, further investment would be needed for such outputs to be transformed into technology outputs ready for adoption by end users. To date, adoption-ready technology outputs have been produced by the Australian trees projects, the agroforestry projects and the heartrot project. The rootrot and site management projects were still to be completed when this report was written, and it is too early to assess whether they will deliver technology outputs that are likely to be adopted on any significant scale in either Indonesia or Australia.

Technology outputs from the Australian trees projects included improved planting stock based on proven site-specific selection of species and provenances of Australian hardwood tree species, especially superior provenances of *A. mangium,* but also of *Acacia crassicarpa* and *Eucalyptus pellita*. This improved germplasm was complemented by an associated extension package about how best to grow the trees using good silvicultural practices and plantation management to increase productivity and protect soil nutrients and water resources (Nambiar and Brown 1997). Other complementary outputs included greatly improved seed orchard management, as well as associated knowledge and training. The resulting influence on plantation productivity and profitability was due to uptake of all components of the innovation package. Uptake of these outputs has been very extensive. The fact that almost all of the current area of about 1.5 million ha of industrial pulpwood plantations in Indonesia is planted to Australian hardwood tree species is one of the most successful outcomes of Australian forestry science to date, even although not all plantations will have adopted all of the technology outputs from the Australian trees projects.

In Australia, the agroforestry projects developed reliable establishment techniques for sandalwood plantations based on *Santalum album* (Indian sandalwood). This was a considerable achievement, because *S. album* is a root hemiparasite that extracts water and nutrients from host plants. Hence, both sandalwood and pre-established host plants have to be grown first in nurseries, then planted out. For plantations to be highly productive, Indian sandalwood needs to be established not only with a pot-host, but also with an intermediate host and at least one long-term host.

The fact that *S. album* needs a series of different host plants at various stages of its life cycle if it is to grow vigorously and be ready to harvest at a relatively young age greatly complicates the task of establishing and growing sandalwood plantations but, by the end of the project, operational-scale establishment survival figures of 90% were being achieved at Kununurra in Western Australia (WA), and plantation management methods had been developed to make high productivity plantations possible. These technology outputs from the research projects were the critical enabling inputs taken up by plantation forestry companies when they created a new plantation forestry industry in the Kimberley region of WA.

This industry has evolved from the first trial plantings to a commercial enterprise attracting large-scale corporate investment in a period of little more than 20 years, and is now a significant part of the crop mix in WA's Ord River Irrigation Area (ORIA). By November 2005, nearly 2,000 ha of commercial sandalwood plantations were growing in the area and being added to by further annual plantings of well over 200 ha. Harvesting is expected to commence soon.

Last, while the heartrot project did produce some technology outputs, extensive uptake of the technologies seems unlikely. *Acacia mangium* plantations in Indonesia are growing fibre almost exclusively for pulp, and serious heartrot problems can be avoided by keeping rotations short. In Australia, *Eucalyptus nitens* was found to be not as susceptible to heartrot as originally thought.

Estimated net benefits

In total, the present value of the direct investment by ACIAR in the 12 projects assessed in this study that can be attributed to the possible generation of benefits in Indonesia and Australia was $14.74 million, while the equivalent present value of the combined investment by ACIAR, its partners and other agencies was $37 million. Benefits were estimated for the Australian trees projects cluster and the multipurpose trees projects cluster, for which there was clear evidence of significant uptake of technology outputs from the projects.

The Australian trees projects cluster was the largest investment, making up approximately 50% of the total investment in plantation forestry projects. Based on conservative assumptions about the proportion of plantation area on which project outputs have been taken up, the present value of benefits realised to date from uptake of technology outputs from this series of projects by Indonesian industrial pulpwood plantations is estimated to be A$3,842 million. Furthermore, using conservative assumptions about future rates of planting of industrial pulpwood plantations, the value of total benefits could eventually be as high as A$11,148 million.

The next largest investment was in the multipurpose trees projects, which accounted for 20% of the total investment by ACIAR and other agencies. Widespread uptake of technology outputs from these two projects enabled the development of an irrigated sandalwood plantation industry in the ORIA. Benefits from this outcome are yet to be realised, because so far only small-scale trial plots have been harvested; commercial-scale harvesting of the *S. album* resource should commence in about 4 years time. It is estimated that benefits with a present value of A$766 million will be generated from these projects.

Benefits were not estimated for the other projects for one or other of the following reasons. There was no evidence of impact in Indonesia from the multipurpose trees projects, and in neither Indonesia nor in Australia for the molecular breeding project, the sustainability project, and the pest and disease survey projects. In Australia, there was insufficient evidence of uptake of technology outputs from the Australian trees projects to justify quantifying benefits. A similar lack of evidence of extensive uptake of technology outputs in either Indonesia or Australia was the reason for not estimating benefits for the heartrot project. For the rootrot and site management projects, it is too early to reliably assess whether there will be uptake or impacts.

Overall, the present value of total realised plus predicted benefits was estimated to be $11,914 million, given conservative assumptions about both the extent of adoption of outputs from the Australian trees project cluster, and about the outlook for further industrial plantation development in Indonesia. The corresponding net present value estimate was A$11,877 million. The benefit:cost ratio was 322 and the internal rate of return 54.4%. While these estimated returns to the investment in plantation forestry research are extraordinary, they reflect above all the huge scale of the Indonesian industrial pulpwood plantation industry and the very high rate of uptake by this industry of research outputs from the Australian trees projects.

While it was not possible to quantify the distributional impacts of these projects, it is clear that the Indonesian owners of industrial pulpwood plantations and associated companies have received the majority of these benefits, and will continue to be the major beneficiaries in the future. Some benefits accrue to the rural poor in Indonesia, from enhanced plantation productivity, additional employment in the forest industries, and implementation of the plantation companies' Corporate Social Responsibility programs in the regions where they operate. In Australia, most of the benefits from the sandalwood plantations accrue to investors in managed investment schemes (MISs), which include many small investors, and/or by shareholders in MIS companies.

Conclusions

Uptake of domesticated Australian hardwood tree species, together with associated knowledge about plantation propagation and management, has been an outstanding success in purely economic terms in Indonesia. In Australia, technical outputs from the two agroforestry projects also played a significant role in the establishment of commercial sandalwood plantations in the ORIA, which was the second significant outcome assessed in this thematic impact assessment study.

Despite these successful outcomes, compared with agricultural crops, plantation forestry is a relatively long-term investment. Even short-rotation forestry as practised in Indonesian pulpwood plantations takes 7 years to yield positive cash flows. It also is an enterprise with risks associated with fire, disease and pest threats. Nevertheless, the returns to this investment have been spectacular, with some benefits contributing to poverty alleviation.

Most of the science that produced these very large impacts in Indonesia was low tech. Research that enabled development of commercial sandalwood plantations in the ORIA was also relatively low tech. On the other hand, there has been a lack of uptake of outputs to date from those projects that involved high-tech and high-cost science.

For many years, the Indonesian forestry industry has been controlled by a small group of rich and powerful oligarchs who were able to appropriate most of the benefits from logging and plantation development. Nevertheless, the benefits to the rural poor in Sumatra and Kalimantan probably outweigh the combined cost of the investment by ACIAR and other agencies, although it is difficult to prove this contention.
In Australia, most of the benefits from increased sandalwood production flow to small investors and shareholders in MIS companies. Some employment opportunities have been generated for Indigenous people in these plantations, and employment is likely to expand once harvesting commences.

1 Introduction

Background

For more than 20 years, the Australian Centre for International Agricultural Research (ACIAR) has funded collaborative projects between Australian and Indonesian scientists with the aim of improving plantation forestry in both countries. The span of these studies has included silvicultural practices, the domestication of Australian trees[1] for reforestation and agroforestry, control of insect pests and fungal pathogens, development of sustainable management systems and the application of molecular marker technologies for genetic improvement of forest plantations. The potential exists for these projects to generate significant benefits in Indonesia and Australia so long as planned outputs are achieved and adopted.

As part of its ongoing Impact Assessment Program, ACIAR commissioned Economic Research Associates to conduct a thematic cost–benefit analysis of the realised and prospective economic impacts in both Indonesia and Australia that can be attributed to ACIAR's investment in 12 plantation forestry research projects. This report describes the findings of that study.

Overview of the projects

The following 12 projects were included in the thematic impact assessment study:

- FST/1986/013 – Fuelwood and sandalwood silviculture in eastern Indonesia
- FST/1990/043 – Multipurpose tree and sandalwood silviculture in Indonesia
- FST/1993/118 – Seeds of Australian trees (SAT) project
- FST/1995/110 – Fungal pathogens as a potential threat to tropical acacias
- FST/1995/124 – Potential insect threat to plantations of acacias and eucalypts in tropical Asia
- FST/1996/182 – Testing and developing criteria and indicators for sustainable management of tropical plantation forests
- FST/1997/035 – Fungal pathogens as a potential threat to tropical acacias
- FST/1998/096 – Domestication of Australian trees (DAT) for reforestation and agroforestry systems in developing countries
- FST/2000/122 – Application of molecular marker technologies for genetic improvement of forest plantation species in Indonesia and Australia
- FST/2000/123 – Heartrots in plantation hardwoods in Indonesia and South-East Australia
- FST/2003/048 – Management of fungal rootrot in plantation acacias in Indonesia

1 Note that the natural range of some of the species that are collectively referred to in this report as Australian trees extends beyond Australia. In particular, some of the most productive provenances were collected in Papua New Guinea and Indonesia.

- FST/2004/058 – Realising genetic gains in Indonesian and Australian plantations through water and nutrient management.

The first two of these projects (FST/1986/013 and FST/1990/043) had essentially the same set of aims and were, in effect, a single, long project. In this report, these two projects will be referred to as the *agroforestry projects* because the focus of the Indonesian component was on small woodlots of multipurpose trees as a critical component of mixed-farming systems to meet the needs of smallholders in the eastern Indonesian province of East Nusa Tenggara (ENT) for fuelwood, forage and wood products, as well as to maintain soil fertility and stability. Furthermore, the ultimate aim of the Australian component of both projects was to facilitate the development of a sandalwood plantation industry in the Kimberley region of Western Australia (WA).

The remaining 10 projects will be referred to collectively as the *industrial plantation projects* because, in one way or another, all involved research to improve commercial plantations of fast-growing Australian hardwood species.

Four of the 10 industrial plantation projects (FST/1993/118, FST/1998/096, FST/2000/122 and FST/2004/058) will be referred to as the *industrial plantation domestication projects*, because the aim of this cluster of projects was, in essence, to improve and exploit potential plantation productivity and profitability, either through genetic enhancement or through improved plantation management to achieve greater realisation of genetic potential. Moreover, as will be discussed in more detail below, FST/1993/118 and FST/1998/096 were essentially a continuation of earlier aid projects funded mainly by other Australian government agencies before the establishment of ACIAR. Because of the difficulty of disaggregating the impact of these antecedent projects from the impact of the ACIAR-funded projects, the assessed impacts of this cluster of industrial plantation domestication projects includes the impact of all of the projects, irrespective of source of funding.

Another five industrial plantation projects (FST/1995/110, FST/1997/035, FST/1995/124, FST/2000/123 and FST/2003/048) will be referred to as the *industrial plantation protection projects*, because their aim was, essentially, to protect plantation productivity and profitability from disease and pest threats.

The remaining project (FST/1996/182) does not fit neatly into any of the above categories, as it was a small part of a much larger worldwide movement to develop a scientific basis for certification and verification of environmentally and socially responsible forestry. It will be referred to as the *industrial plantation enhancement project*.

In the remainder of this report, each section will contain separate subsections for each of the above cognate clusters of projects.

2 The projects

Motivation

The widespread deforestation of 'natural' tropical rainforests in Indonesia and elsewhere gave rise to a variety of problems in many developing countries. These problems included adverse changes in catchment hydrology, accelerated erosion, ecosystem degradation, loss of wildlife habitat and local shortages of fuelwood and timber. Consequent changes, such as burning animal manures as substitute fuel rather than using them as a fertiliser on food crops, reduced food production. Such changes not only depressed living standards directly, but also commonly had serious indirect consequences.

Plantation and farm forestry were often seen as ways to counter these problems, and to meet the needs for fuelwood, fodder, building material and other forest products, as well as a growing demand for pulpwood feedstock for paper production. In particular, plantations of Australian trees have been established in many developing countries in the tropics. They provide social, economic and environmental benefits by helping to meet needs for forest products, and for forest services such as soil stabilisation, carbon sequestration and preservation of biodiversity.

For the agroforestry projects, there were two particular problems in the drier and poorer regions in Indonesia's eastern islands that led to their conception. One problem was developing shortages of fuelwood and timber due to deforestation, burning and overgrazing. The second was a serious decline in exports of sandalwood oil and its by-products for reasons that included administrative and land management deficiencies, overexploitation, poor silvicultural practices and severe regeneration problems. These sandalwood exports had been, after coffee, the region's second-largest source of export income, earning US$500,000 in 1985.

In WA, there were comparable problems of declining production from the stands of native sandalwood in the south-west of the state due to heavy exploitation and regeneration issues. At the same time, the abundant water resources from the Ord River dam in the north of the state presented an opportunity for the development of a new sandalwood industry, provided that various production challenges with the silviculture of sandalwood in a different environment could be overcome.

During the course of the first project, and before planning started on the follow-on project, the abovementioned problems in ENT were exacerbated by a devastating outbreak of psyllid insects in 1986–87 that wiped out most stands of *Leucaena leucocephala*. This local forage and timber tree was a critically important component of the subsistence agricultural system, but one that proved to be susceptible to attack by an insect pest. As a result, it was realised that new provenances of multipurpose trees that had at least some resistance to insect pests and also were adapted to the difficult-to-handle alkaline soils of the region needed to be found.

While locally important, these problems were quite small scale and largely limited to one region of Indonesia, albeit a poor one with a high priority for development. As already mentioned, problems stemming from large-scale deforestation of native tropical and subtropical rainforest to meet the growing need for forest products, and especially demand for industrial pulpwood, are of much greater magnitude and significance for Indonesia as a whole. Severe and multidimensional problems of this type require big solutions.

In response to problems of deforestation, plantations of Australian trees have been successfully established in many developing countries to deal with the demand for forest products. Although the choice of species to plant has sometimes been less than ideal, they often form an important component of a growing agroforestry industry. Many are highly adaptable and grow rapidly when the water supply is good. They perform well on infertile sites and can cope with wide variations in climate.

Globally, *Eucalyptus* has become the most extensively planted hardwood genus, and there are now more than 13 million hectares (ha) of eucalypts planted worldwide (FAO 2001), but there are also other Australian hardwoods, in particular, species of the genus *Acacia*, that are widely planted in tropical and subtropical plantation forestry. There are, in addition, many more Australian trees in agroforestry settings or scattered plantings. This domestication of Australian hardwoods, including both *E. globulus* and other temperate *Eucalyptus* species in Australia, and tropical *Eucalyptus* and *Acacia* species in a number of developing countries, has been one of the more impressive success stories of Australian forestry research.

Given the great diversity among species and provenances of Australian hardwoods, there was considerable potential for domestication of Australian trees to help meet economic, social and environmental needs in Indonesia for industrial wood, domestic building material, fuelwood, soil stabilisation and non-wood products. A number of rapidly growing *Acacia* species thrive in diverse tropical environments, including arid and saline areas, many yield excellent fibre pulp as well as firewood, and some produce high-quality timber suitable for furniture manufacture. To a greater or lesser extent, many species fix atmospheric nitrogen, making them valuable in mixed-cropping systems, and some can be vegetatively propagated. Midgley and Turnbull (2003) estimated that worldwide there were about 2 million ha of acacias in plantations, of which about 1.2 million ha were in Indonesia.

A significant problem of deforestation in parts of Indonesia, particularly in some of the Sumatra and Kalimantan lowlands, has been the widespread degradation of native forest ecosystems into low productivity areas such as the *Imperata* (*alang-alang*) grasslands. *Imperata* grass is very aggresive at lower fertility levels, so it competes very effectively with almost all other plants after forest or long fallow (bush) clearance, and is often linked to a loss of soil fertility and reduced crop yields (Turvey 1995). In the humid, tropical lowlands of Asia, the *Imperata* grasslands are a serious problem and a legacy of widespread deforestation of natural tropical rainforest. They represent a vast, underutilised natural resource.

Owing at least in part to plantation forestry research projects funded by ACIAR and other organisations, *Acacia mangium* has been proven to be highly effective in restoring very large areas of *Imperata* grasslands to productive land use. Its success is due to the ease with which it can be established and its extremely vigorous growth, as well as to its tolerance of low nutrient status and very acidic soils, and relative freedom from diseases. As a result, it has the ability to quickly shade out weed competition, including *Imperata* grasslands. Hence, *A. mangium* has become a major reforestation species in Indonesia, with the potential to improve agrarian livelihood opportunities.

However, as is often the case, new problems arise when there are large changes to complex ecosystems. Following the widespread establishment of plantations of *A. mangium* and other Australian hardwood species, Australian forest scientists were quick to realise that the sustainability of these plantations might be threatened by the emergence of pests and diseases. In recognition of the need to be proactive in tackling this issue, ACIAR has funded a sequence of industrial plantation protection projects. Following three small initial projects to ascertain whether there was in fact a serious threat from insect pests and/or foliar, stem and root fungal pathogens, research on fungal heartrot and rootrot was identified as the most immediate and pressing priority for ACIAR to fund.

At the 1992 Earth Summit in Rio de Janeiro, the urgent task of how to save the world's forests while ensuring that they continue to provide timber, food and a living for those who depend on them, was recognised in a call for more authoritative forestry knowledge. This led to the creation, in 1993, of the Center for International Forestry Research (CIFOR) by the Consultative Group on International Agricultural Research (CGIAR). ACIAR and other Australian agencies played an instrumental role in the establishment of CIFOR and, among other things, provided some support for a CIFOR-led project to enhance management of industrial pulpwood plantations as part of a global movement to encourage more sustainable management of forests worldwide.

Funding

Starting in 1987, the total direct investment by ACIAR in the 12 plantation forestry projects nominated for this study was nearly A$10 million in nominal terms. Furthermore, before ACIAR assumed responsibility for the SAT project in 1993, two 5-year cycles of the 'Seeds of Australian trees for developing countries' (SAT) project from 1983 to 1993 had already been funded by the Australian Agency for International Development (AusAID) (formerly the Australian International Development Assistance Bureau; AIDAB) at a nominal cost of approximately A$3.4 million. As it would be impossible to separate the contributions of the first two AusAID-funded SAT projects from the subsequent ACIAR-funded SAT and DAT projects, this subset of the industrial plantation domestication projects is treated as a single entity in this study and, for heuristic convenience, referred to as the Australian trees projects. Thus, the total funding for the 12 projects assessed in this impact study was about A$13.3 million in nominal terms.

Some of these projects involved collaboration with other countries besides Indonesia. For instance, the Australian trees projects were multicountry projects in which Indonesia was only one of many partners, and there was a flow of information in several directions from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Tree Seed Centre hub that assisted other countries in the development of their plantations. It is clear from previous impact assessment studies, such as that by Fisher and Gordon (2008), that substantial benefits accrued to other countries (e.g. Vietnam) from these projects. Participants from other countries also attended the ACIAR-sponsored workshops on tropical acacias where information was exchanged. In addition, Indonesian plantations might have benefited from technology 'spill ins' from other countries such as Malaysia and India, as well as contributing to spillovers to countries such as Vietnam and China. Other examples of multinational projects include four small projects partly funded and managed by CIFOR, three of which were pest and disease surveys, and one was on sustainability indicators.

In this impact assessment study, only those impacts that have accrued, or are likely to accrue, to Indonesia and Australia have been estimated. Hence, when calculating measures of return on investment in plantation forestry research, only part of the total cost has been ascribed to estimated economic impacts where the research also involved other countries. The proportions of total research costs attributed to impacts in Indonesia and Australia have, unavoidably, been based on subjective judgments, because there is no objective basis for assessing such an allocation.

In constant 2009 Australian dollars, the total value of ACIAR investment in plantation forestry research attributed to Indonesia and Australia was estimated to be about A$7.7 million. Annual values by project cluster are detailed in Table A1 in Appendix 2, and are depicted in Figure 1. Figure 2 illustrates the cumulative cost of this investment, again in 2009 Australian dollars.

In addition to ACIAR's direct investment, co-contributions were made by the Australian commissioned organisations, as well as by Indonesian and other partner institutions. The principal commissioned organisations were the WA Department of Conservation and Land Management (CALM); the Australian Tree Seed Centre (ATSC) and CSIRO Forestry and Forest Products; CIFOR; the University of Tasmania; and CSIRO Sustainable Ecosystems. Indonesian collaborating institutions included the Forest Research and Development Agency; Institut Pertanian Bogor; PT Musi Hutan Persada (MHP); Gadjah Mada University, Center for Forest Biotechnology and Tree Improvement; the Forest and Nature Conservation Research and Development Center; PT Riau Andalan Pulp and Paper (RAPP); PT Arara Abadi (AA); and the University of Sriwijaya. Contributions by Australian commissioned organisations and by Indonesian partner institutions were estimated to total nearly A$16.4 million in nominal terms, of which nearly A$6 million in nominal terms, or more than A$8 million in 2009 Australian dollars, were attributed to the possible generation of benefits in Indonesia and Australia. Other organisations collaborated in some projects and often provided in-kind contributions.[2]

[2] In addition, other external collaborating institutions included:
Outside Australia: Australian Volunteers International; Canadian International Development Agency; Centre for International Research for Agronomic Development (CIRAD Forêt); German Agency for Technical

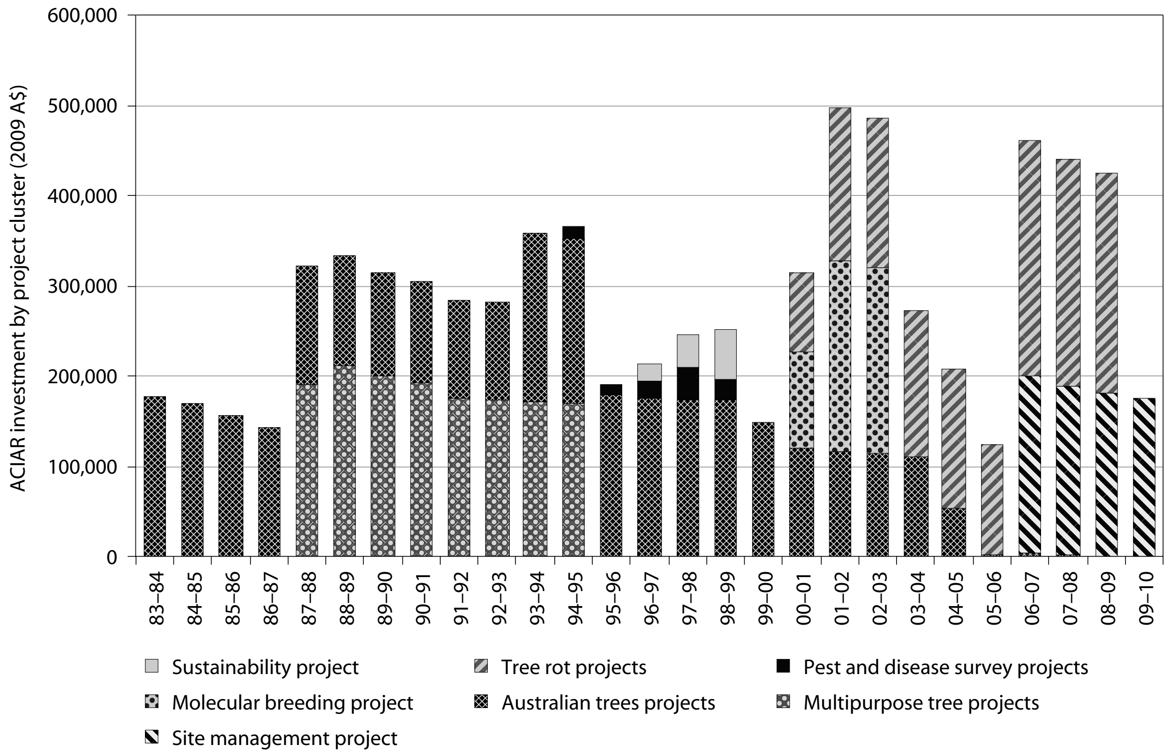

Figure 1. ACIAR investment (in 2009 A$) in Indonesian plantation forestry research, by project cluster and year

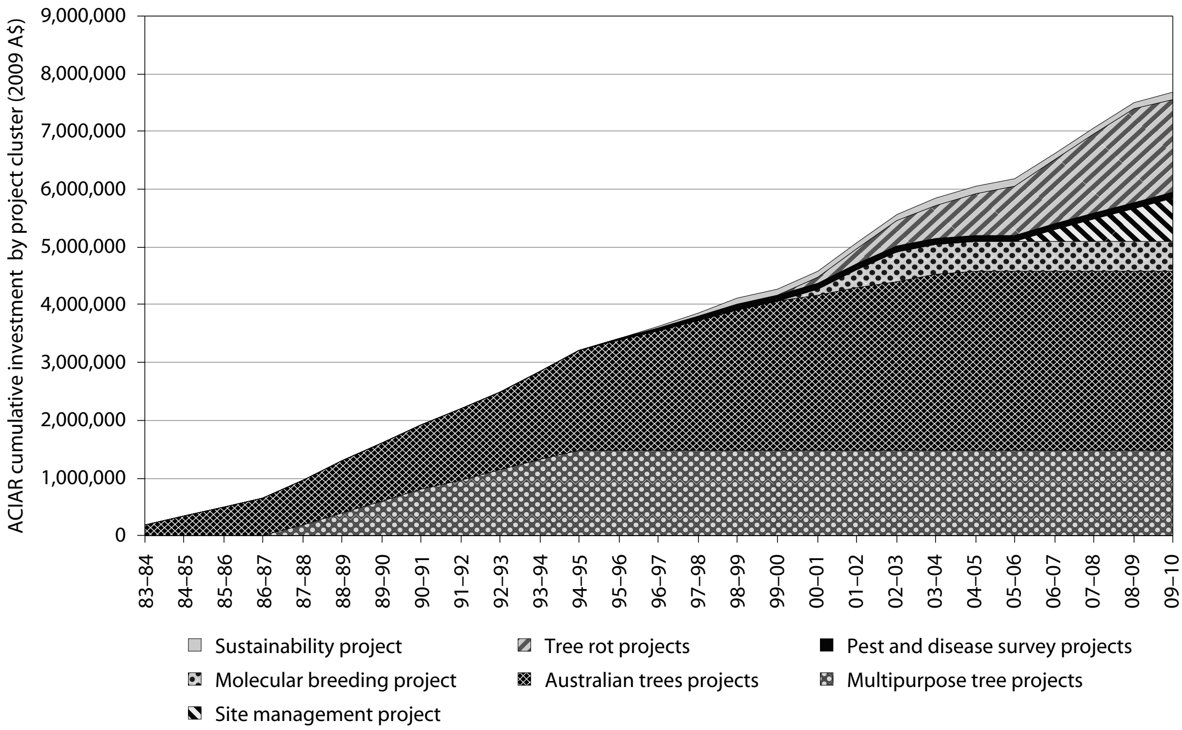

Figure 2. ACIAR's cumulative investment (in 2009 A$) in Indonesian plantation forestry research, by project cluster

For many projects, there were also significant complementary investments in related projects by other agencies. They included AusAID, the Food and Agriculture Organization of the United Nations (FAO), the Danish International Development Agency (DANIDA), Australia's CSIRO, the Japan International Cooperation Agency, Malaysian Sabah Forest Industries Sdn. Bhd. and the Thailand Royal Forest Department. In other cases, a key input to the ACIAR project was intellectual capital generated by large, related multinational studies funded by other agencies. For instance, while project FST/2004/058 involves research on only water and nutrient management in Indonesian and Australian plantations, it is indirectly supported by a large co-investment a in CIFOR-coordinated international network of research projects on site management and productivity in tropical plantation forests.

Estimated funding levels attributed to Indonesia and Australia for total ACIAR plus complementary investments by project cluster are detailed in Table A2 in Appendix 2. In constant 2009 Australian dollars, the total value of all investment in plantation forestry research attributed to Indonesia and Australia was estimated to be about A$20.7 million. The annual and cumulative values in 2009 Australian dollars by project cluster are illustrated in Figures 3 and 4, respectively.

Objectives

This section of the report provides an overview of the objectives for each consolidated cluster of projects.

Cooperation (GTZ); World Agroforestry Centre (ICRAF); The Global Network for Forest Science Cooperation (IUFRO); Papua New Guinea (PNG) Forest Research Institute; PNG Department of Forests; landowners in PNG; United States Agency for International Development; CARE Australia; Plan International; and World Vision

Within Australia: Forestry Tasmania; Queensland Department of Primary Industries; CSIRO Forest Biosciences; Australian Low Rainfall Tree Improvement Group (Joint Venture Agroforestry Program); Farm Forestry Seed and Information Support Project (Australian Department of Agriculture, Fisheries and Forestry); forestry research agencies in all states; CSIRO Division of Entomology; Centre for Forest Tree Technology; landowners and forest managers in Queensland; Great Southern Plantations; and Gene Technics.

Appendix 1 gives details of the stated objectives of individual projects.

The agroforestry projects

The agroforestry projects were:

- FST/1986/013 Fuelwood and sandalwood silviculture in eastern Indonesia
- FST/1990/043 Multipurpose tree and sandalwood silviculture in Indonesia.

The objectives of the agroforestry projects were, in essence, to:

- increase the productivity of smallholder mixed-farming systems by facilitating the introduction of adapted Australian multipurpose tree species into ENT, and by supporting the development of seed nurseries for propagating selected species of superior provenances to overcome intensifying shortages of fuelwood, timber and forage due to deforestation and burning
- enable the development of sandalwood plantations in both West Timor and Australia by research on sandalwood establishment and management, and conduct of provenance trials to explore possible genetic improvement in both productivity and oil content.

The industrial plantation domestication projects

The industrial plantation domestication projects were:

- AusAID-funded 'Seeds of Australian trees for developing countries' (SAT) projects
- FST/1993/118 Seeds of Australian trees
- FST/1998/096 Domestication of Australian trees for reforestation and agroforestry systems in developing countries
- FST/2000/122 Application of molecular marker technologies for genetic improvement of forest plantation species in Indonesia and Australia
- FST/2004/058 Realising genetic gains in Indonesian and Australian plantations through water and nutrient management.

The overarching aim of these projects was to improve the genetic potential of plantations of Australian trees

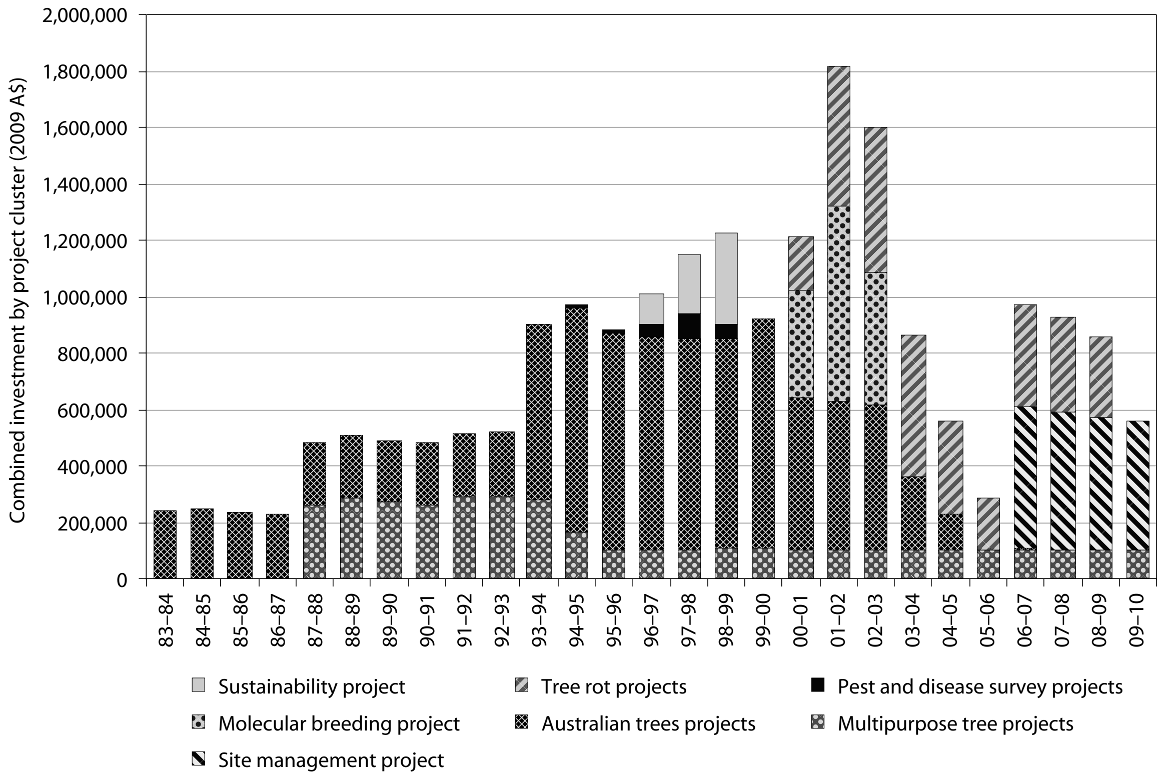

Figure 3. Total investment (in 2009 A$) in Indonesian plantation forestry research, by project cluster and year

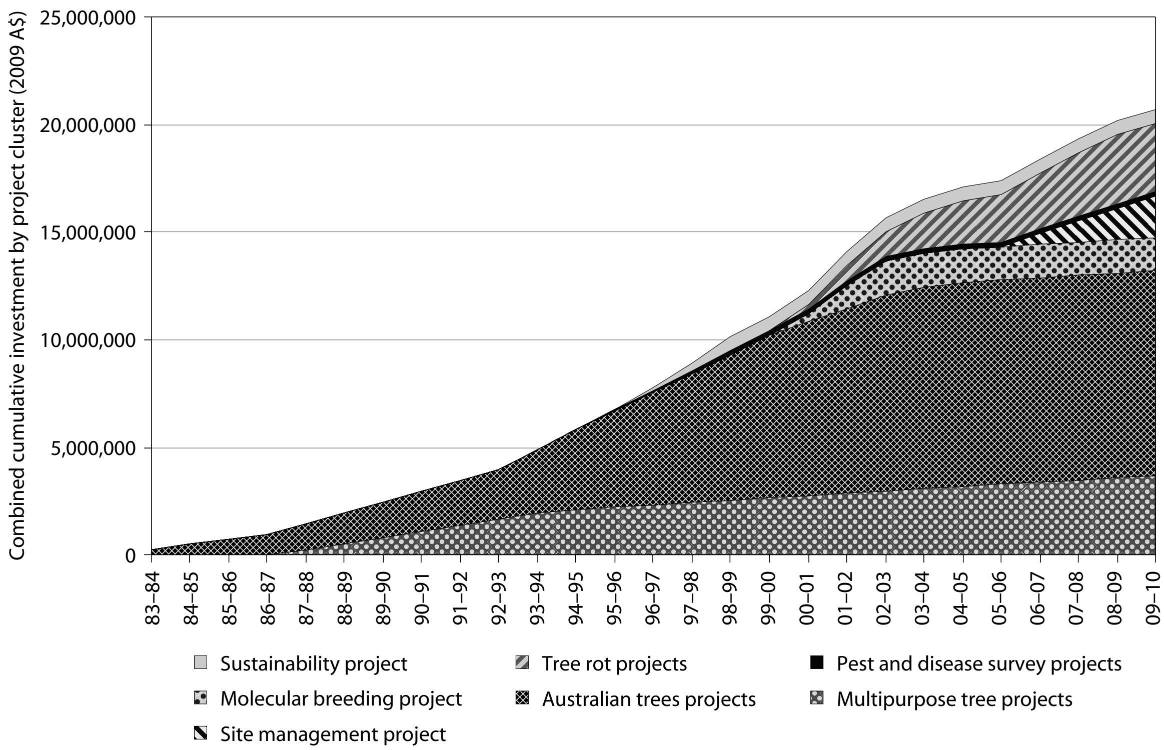

Figure 4. Cumulative total investment (in 2009 A$) in Indonesian plantation forestry research, by project cluster

in Indonesia and Australia (and elsewhere), and to enhance realisation of that potential by:

- selecting Australian hardwood tree species and provenances of proven superior performance for particular sites and environments
- developing and maintaining provision of certified seed
- supporting establishment of in-country seed orchards and mass production of genetically improved planting stock of selected Australian tree species
- providing technical advice on establishment and management of plantations of Australian tree species
- improving the efficiency of tree breeding programs through the development and application of molecular breeding techniques
- improving profitability and sustainability of acacia plantations in Indonesia and Australia by better site management
- expanding the involvement of smallholder farmers and communities in plantation forestry so they can benefit from using wood production as a new source of income.

The industrial plantation protection projects

The industrial plantation protection projects were:

- FST/1995/110 and FST/1997/035 Fungal pathogens as a potential threat to tropical acacias
- FST/1995/124 Potential insect threat to plantations of acacias and eucalypts in tropical Asia
- FST/2000/123 Heartrots in plantation hardwoods in Indonesia and South-East Australia
- FST/2003/048 Management of fungal rootrot in plantation acacias in Indonesia.

The overall objective of this cluster of projects was to protect and preserve gains in plantation productivity against the threat of losses from pests and diseases by:

- identifying the principal threats to Australian hardwood tree plantations from insect pests
- identifying the principal threats to plantations of tropical acacias from fungal pathogens
- developing cost-effective control options for heartrot and rootrot in plantations of *Acacia* spp. and *Eucalyptus* spp.

The industrial plantation enhancement project

The industrial plantation enhancement project was:

- FST/1996/182 Testing and developing criteria and indicators for sustainable management of tropical plantation forests.

Its objective was to contribute to the creation of scientific knowledge to underpin the extension, to plantation forestry in the Indonesian tropics, of a system of accreditation of sustainable forest management.

Outputs

In this report, research and development (R&D) outputs are categorised as either capacity building or technical. In general, the latter are outputs (or deliverables) from R&D that are more or less ready for immediate uptake or adoption, while the principal potential use of capacity-building outputs is typically as inputs to further research or other intellectual endeavour. Hence, while uptake of technical outputs by end users can have outcomes that have quantifiable, near-term economic impacts, the pathways from uptake of capacity-building outputs to eventual economic impacts are normally much less direct.

Capacity-building outputs are sometimes referred to as institutional strengthening, and can include new knowledge or intellectual capital development, human capital development such as the acquisition of either specific technical or generic skills, and physical capital development, such as scientific equipment, laboratories, experimental trial sites or other physical research infrastructure.

Planned outputs for each cluster of ACIAR projects, and the extent to which they were achieved, are discussed in Appendix 1. All projects were assessed to have produced capacity-building outputs that had had at least some positive impacts in both Indonesia and Australia. No attempt was made to collect evidence of uptake of capacity-building outputs, as assessment of uptake of new knowledge would have gone beyond the scope of this study. The available evidence on uptake of achieved technical outputs, based predominantly on project reports, interviews with project leaders and anecdotal evidence, is reviewed in Appendix 1.

It is clear from evidence about uptake of achieved technology outputs from the ACIAR plantation forestry projects that two project clusters either have had, or are likely to have, very large impacts that can be reliably quantified at this stage. Very large impacts in Indonesia have already been realised from the Australian trees projects, and prospective future benefits will almost certainly be even larger. While significant benefits have yet to be realised in Australia from the agroforestry projects, prospective future benefits are likely to be very large, albeit not nearly as large as those from the Australian trees projects.

Table 1 summarises conclusions about the current impacts of projects.

Table 1. Conclusions about significant positive impacts in Indonesia and Australia from uptake of technology outputs from ACIAR plantation forestry projects

Project/s	Impacts in	
	Indonesia	**Australia**
Multipurpose trees projects	0	Y
Australian trees projects	Y	NI
Molecular breeding project	0	0
Sustainability project	0	0
Pest and disease survey projects	0	0
Heartrot project	NI	NI
Rootrot project[a]	TE	TE
Site management project	TE	TE

Key:
0 = no evidence of uptake/impact
NI = insufficient information available to quantify benefits
TE = too early to reliably assess
Y = benefits estimated in this study.
[a] This impact indicator is based on information gathered in 2009. There is now evidence to suggest uptake of outputs from the rootrot project in Sumatra.

3 Outcomes, impacts, and realised and prospective benefits

The review in the previous chapter of each cluster of ACIAR plantation forestry projects found that most completed projects did deliver most or all planned outputs, but that only some of the projects generated technology outputs that could be adopted. There is compelling evidence of widespread uptake of technology outputs for two project clusters, namely the agroforestry projects in Australia and the Australian trees cluster of projects in Indonesia. Most of this chapter is devoted to estimation of the magnitude of economic benefits from these two cases. For the latter case, there are also possible environmental and social impacts that are discussed in the penultimate section of the chapter, although no attempt has been made to make quantitative estimates of these impacts.

Estimation of the size of benefits from the agroforestry and the Australian trees projects requires elucidation of the most plausible impact pathway under what will be termed the consequential scenario, as well as explicit consideration of the counterfactual scenario.[3] In the following sections, for each of the two project clusters, the background to plantation development is discussed first, followed by more detail about the technology output package, the impact on plantation productivity and profitability, and the scale of uptake.

3 In other publications, the consequential scenario is often referred to as the 'With R&D scenario', and the counterfactual scenario as the 'Without R&D scenario'.

The impact in Australia of the agroforestry projects

Background on sandalwood plantations

Sandalwoods range in size from tall shrubs to large trees. Some species can reach a height of 20 metres at maturity. The wood is highly valued because the tree contains unique aromatic oils in the heartwood, butt and roots, and is sometimes described as one of the world's most valuable timbers. In Asia, sandalwood oil is highly prized for its aromatic properties and presumed therapeutic value. Inhalation of the oil vapour is said to aid relaxation, and relieve stress and asthma, and the oil is believed to have antibacterial, antimicrobial and anti-inflammatory properties. The scented wood has uses in scented tobacco, incense and joss sticks, a mouth freshener known as 'pan masala', and carved ornamental furniture. In the West, it is a key ingredient used to stabilise scents in premium high-priced perfumes, and also is used in aromatherapy and fragrant body-care products.

The heartwood of the sandalwood tree contains most of the oil, so it is the volume and oil content of the heartwood that largely determine the value of sandalwood. Generally, heartwood starts to develop when the tree is about 10 years of age, with its proportion progressively increasing with age after that time. Indian sandalwood (*Santalum album*), which is found naturally in the Indian subcontinent, is the most valuable sandalwood species because it produces the highest average oil content. Prices for its timber have escalated rapidly in recent years in response to growing demand and a decline in available supplies due to overexploitation of natural stands in the traditional producing countries such as India, Indonesia and several Pacific islands. While synthetics have substituted for some lower-value end uses, they are inferior as an agent to stabilise scents in perfumes, and there is also a strong preference for natural products in traditional markets where cultural attachment is important.

Technology output package

Many sandalwood species, including *S. album*, are root hemiparasites that extract water and nutrients from host plants. Hence, establishing sandalwood plantations is a much more complex challenge than for most tree species because both sandalwood and pre-established host plants have to be grown first in nurseries before planting out. Moreover, for plantations to be highly productive, Indian sandalwood is typically established on mounds in rows, together with a pot-host, then transferred to an intermediate host, and later moved to at least one long-term host. The fact that *S. album* needs a series of different host plants at various stages of its life cycle if it is to grow vigorously and be ready to harvest at a relatively young age greatly complicates the task of establishing and growing stands of sandalwood.

In Australia, the projects succeeded in developing reliable establishment techniques for plantations of Indian sandalwood in West Timor, and in the Ord River Irrigation Area (ORIA) in the Kimberley region of WA. By the last years of the project, operational-scale establishment survival figures of 90% were being achieved in WA, and plantation management methods had been developed to make high-productivity plantations possible. These technology outputs from the research projects were the critical enabling inputs taken up by plantation forestry companies when, some time later, they created a new plantation forestry industry in the Kimberley region.

Over a period of little more than 20 years, this industry has evolved from the first trial plantings to a commercial enterprise attracting large-scale private investment, and is now a significant part of the crop mix in the ORIA. By November 2005, nearly 2,000 ha of commercial sandalwood plantations were growing in the area, and being added to by further annual plantings of well over 200 ha. Harvesting is expected to commence soon.

A related capacity-building output was a series of irrigated sandalwood plantation trials dating back to 1987 that were set up by the project team, and continue to be maintained by the WA Forest Products Commission. These are the oldest stands of *S. album* in Australia, and potentially are of great value for the industry as the only source of older trees that can be harvested to provide information on yield potential from the commercial sandalwood plantations in the ORIA.

The impact pathway for uptake of technical outputs from the agroforestry projects is depicted in Figure 5.

Observed and projected plantation area

Without the critical enabling inputs from the research projects—in particular, proven and reliable techniques to establish and grow plantations of Indian sandalwood on the ORIA—there would be no sandalwood plantation industry in the area today. This then is the counterfactual scenario with respect to benefits to Australia from the agroforestry projects. Hence, the area already planted to *S. album* in the ORIA, plus the area of likely future plantings, is an effective measure of the uptake of technology from these projects under the consequential scenario.

Although there were limited previous trial plantings of *S. album* dating back to the start of the ACIAR projects, the commercial plantation industry effectively began in 1999, and has been funded almost entirely by investors in managed investment scheme (MIS) products. Most plantations are intensively managed irrigated operations that incur high costs in the expectation of achieving superior growth rates and reaping high returns. Current plans are to harvest each MIS plantation when the *S. album* planting is 15 years old, even although further delaying harvest would most likely improve heartwood and oil content, and might achieve higher profits. However, delayed harvesting is unlikely to ensure the early returns to the investor that are required by undertakings in MIS product disclosure statements and associated taxation rulings. Consequently, lower heartwood and oil content from such short-rotation plantations will not fetch the same returns as older *S. album* grown in India.

As can be seen from Table 2, plantings have increased considerably in more recent years. Two MIS companies, namely Tropical Forestry Services Ltd (TFS) and

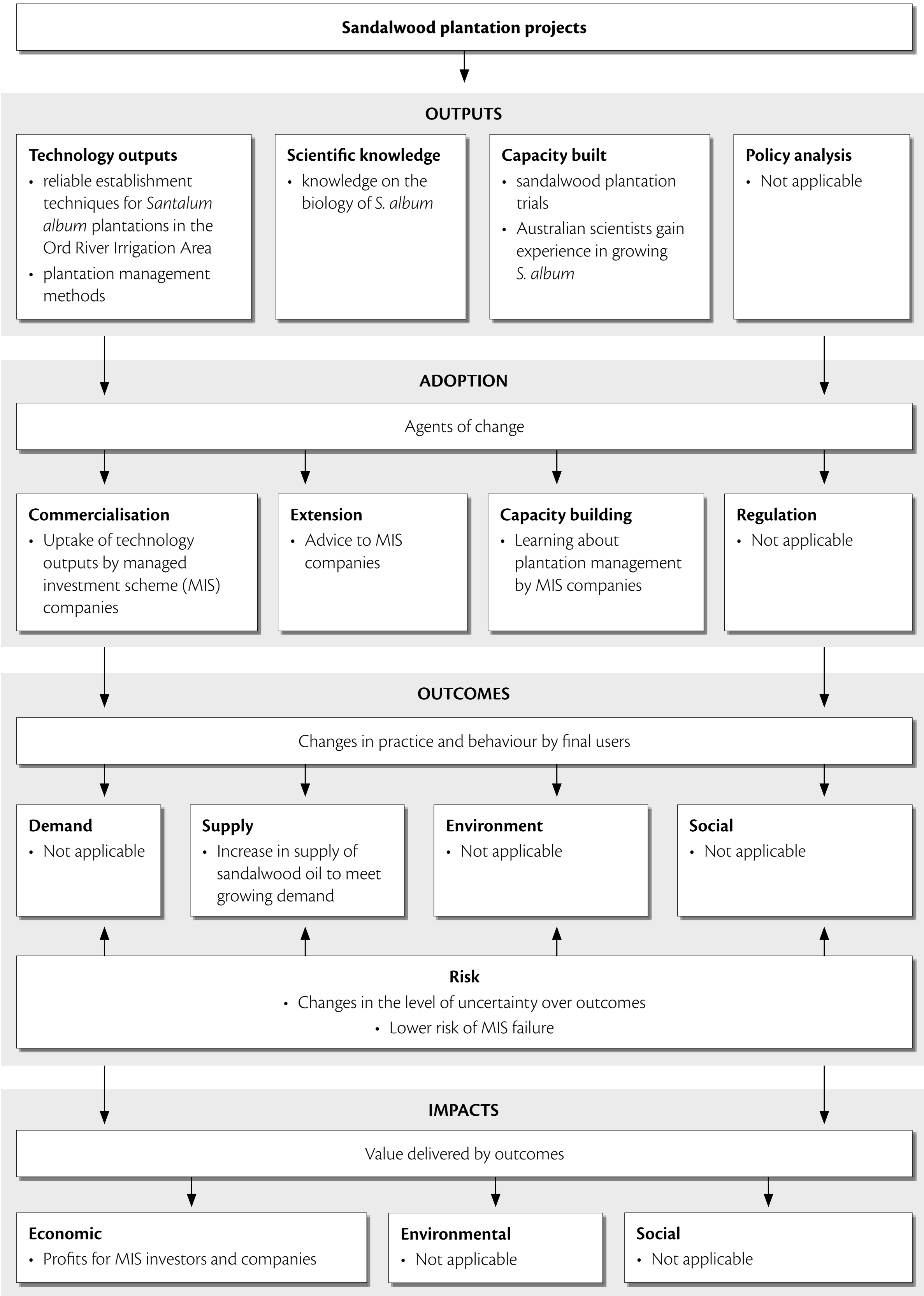

Figure 5. Impact pathway for uptake of technical outputs from the agroforestry projects

Table 2. Annual plantings of *Santalum album* in the Ord River Irrigation Area

Year	Area (ha)
1999	197
2000	118
2001	153
2002	146
2003	127
2004	57
2005	399
2006	557
2007	660
Total to end of 2007	2,414

Source: McKinnell (2008, p. 25)

Integrated Tree Cropping Ltd (ITC), owned and/or managed approximately 1,200 ha and 900 ha, respectively, of the nearly 2,500 ha planted by 2007, with the balance in the hands of private investors.

For the next few years, these plantings are likely to continue as long as the companies involved can compete favourably for available land and water, and as long as MISs continue to receive favourable tax treatment. In the longer term, further expansion will depend on the supply of new sources of suitable land with access to irrigation, and is likely to be constrained if there are further delays to the opening of the second stage of the ORIA.

McKinnell (2008) estimated future output of oil and spent pulp from the ORIA by assuming that planting continues from 2008 onward to 350 ha/year, while harvesting commences in 2014, and all plantations are clear-felled at age 15 years. He followed the predictions of the Rural Industries Research and Development Corporation (RIRDC) in Australia that heartwood would yield 8 tonnes (t)/ha and 3% oil content at age 15 years. He predicted that peak production from *Santalum album* plantations in the ORIA will result in more than 5,000 t of spent *S. album* pulp entering the market at more or less the same time as a projected similar lumpy harvest outturn from *S. spicatum* (a species native to the area) tree farms in southern WA (McKinnell 2008, p. 26). While marketing the oil is unlikely to be a problem given probable further declines in production from native sandalwood in India, it is more problematic whether the market can absorb this quantity of pulp, and at what price.

Based on more recent evidence, the projections in the WA Sandalwood Industry Development Plan 2008–20 seem too conservative. Specifically, whereas McKinnell (2008) assumed annual plantings of only 350 ha/year from 2008 onward, plantings in 2006 and 2007 were 557 and 660 ha, respectively. Moreover, TFS has reported[4] that plantings in 2008 and 2009 were 558 and 813 ha, respectively, and that total land planted by 30 June 2009 by TFS alone was 2,555 ha. In addition, the company still has 2,600 ha of suitable land available for sandalwood, plus up to a possible further 3,725 ha in reserve, and planned to plant a further 1,025 ha in 2010.

These levels of additional sandalwood plantings are not sustainable if ORIA stage two does not proceed, and at least one company[5] is planning to establish new plantations in Queensland. Nevertheless, another company is actively pursuing further additions to its land bank in the ORIA, and most industry experts agree that there is still scope for the area of sandalwood plantation in ORIA stage one to expand to a ceiling of about 7,500 ha. Figure 6 plots plantings to date plus future plantings projected in this study as the basis for estimating benefits.

Figure 7 illustrates the corresponding projected future production levels of sandalwood oil and pulp used in this study that were calculated using the same predicted parameter values as McKinnell (2008) for heartwood yield and percentage oil content.

Estimated benefits from the agroforestry projects

Conceptually, the application of standard welfare (economic surplus) analysis to estimate the economic impacts of the development of a sandalwood plantation industry on the ORIA is simple. Figure 8 depicts the outcome in the world sandalwood market from uptake of the technology outputs from the agroforestry projects. Under the counterfactual scenario, Australia produces QS_0, consumes QD_0 and exports the

4 See TFS (2009) and TFS ASX media release 2008, 'TFS closes MIS following strong investor response, initiates non-MIS sales and secondary market for the first time'

5 ITC media release, 18 June 2008, 'ITC announces sandalwood development strategy stage one completion'

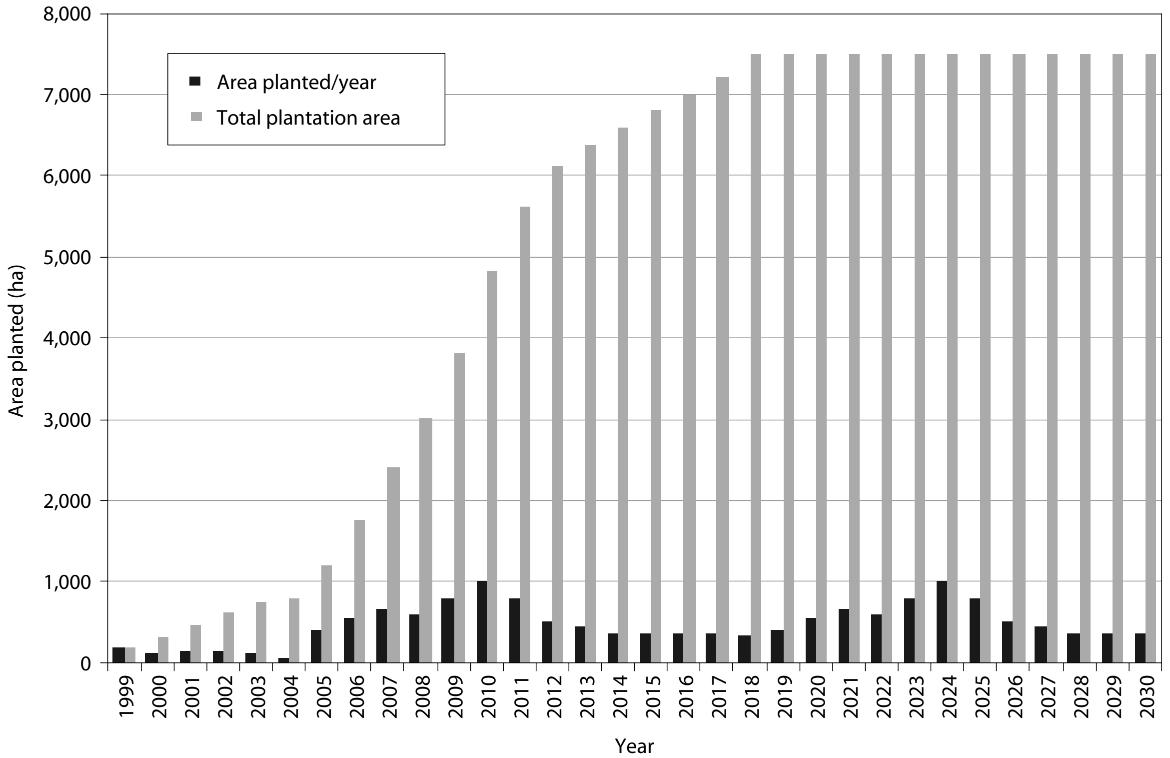

Figure 6. Current and projected areas of sandalwood plantations in the Ord River Irrigation Area, Western Australia

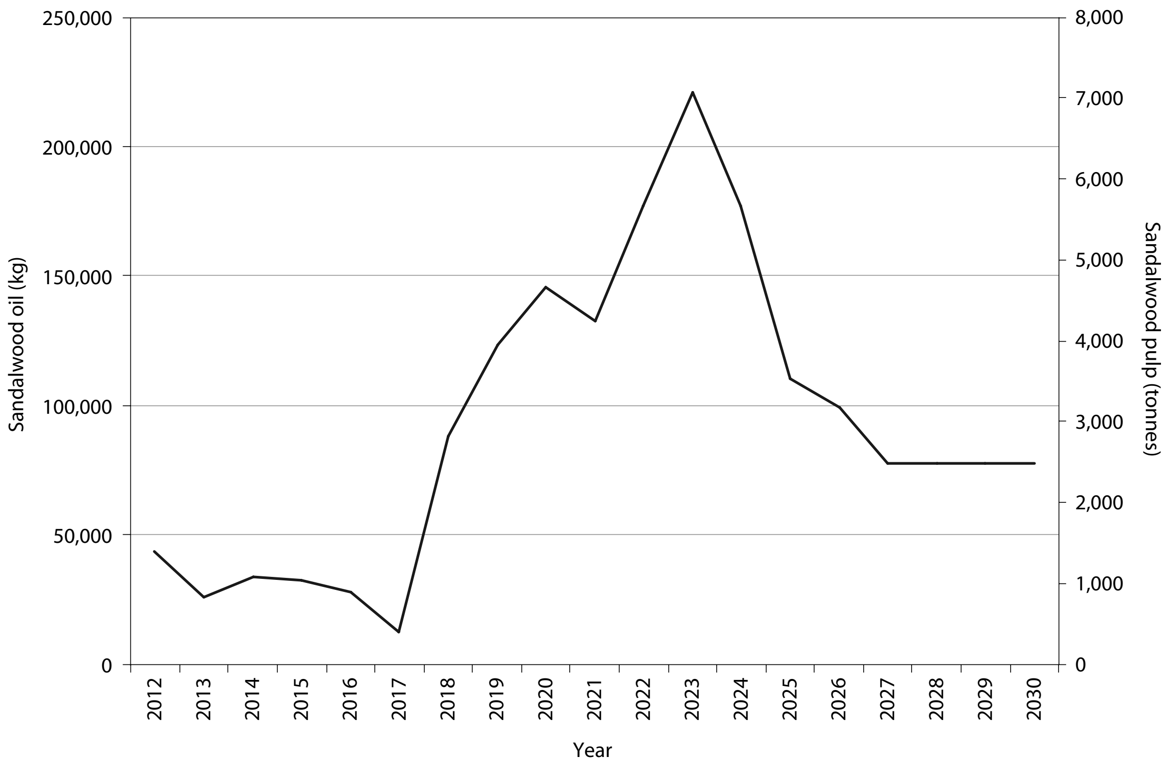

Figure 7. Projected production levels of sandalwood oil and pulp in the Ord River Irrigation Area, Western Australia, 2012–30

difference at a price of P_0 to the rest of the world. In the consequential scenario, the Australian supply curve is at S_1 rather than S_0 and, as a result, Australian production, consumption and exports are all larger, at QS_1, QD_1, and QS_1–QD_1, respectively, while the rest of the world imports QS_1–QD_1 at the lower world price of P_1.

The changes in producer and consumer surplus welfare impacts illustrated in Figure 8 are labelled in Table 3. Clearly, consumers in Australia and the rest of the world are better off, because they consume more at a lower price. The sandalwood plantation producers in the ORIA also are better off, given that there is no production under the counterfactual scenario. The losers are other producers, including Western Australian harvesters of wild *S. spicatum,* Australian investors in *S. spicatum* plantations in southern WA and producers in the rest of the world.

However, there are significant impediments to employing this analytical framework. The fact that the supply of sandalwood from the ORIA plantations will far exceed domestic demand, and consequently that most output will ultimately be exported, either before or after processing, is not of itself a problem, but the lack of data on supply and demand in the world market is a major problem. The following statement from the WA Sandalwood Industry Development Plan 2008–20 (McKinnell 2008, p. 27) is typical of virtually everything that is written about the world market for sandalwood:

> … the likely annual global sandalwood output is probably about 6500 tonnes/year. While there are no definitive market survey data to confirm it, it is generally believed that the real supply and demand is far higher than this.

One reason for the data deficit is commercial secrecy, but a more important one is the size of trade in black-market sandalwood. India is estimated to produce approximately 1,000 tonnes per annum of 'legal' sandalwood, but illegal harvesting is thought to be much greater, possibly as much as an additional 3,000–4,000 tonnes per annum (AAG 2006).

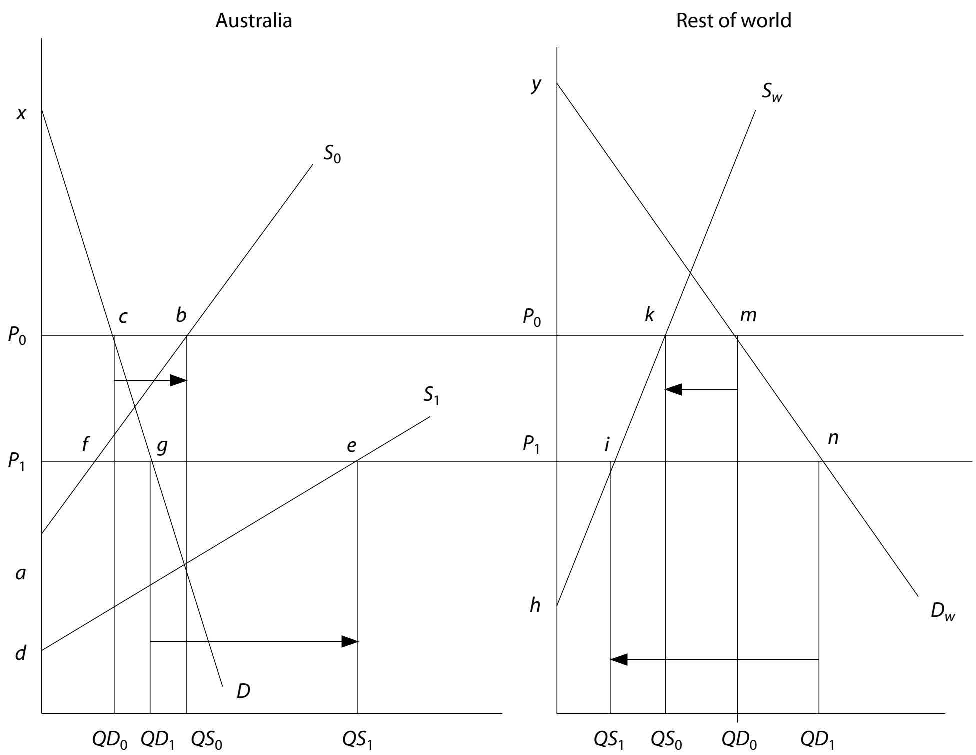

Figure 8. Outcomes in the world sandalwood market from uptake of agroforestry project technology outputs in Australia. See text and Table 3 for explanation of symbols.

Table 3. Areas of producer and consumer surplus depicted in Figure 8 consequential on uptake of agroforestry project technology outputs in Australia

		Without R&D	With R&D	Change
Producer surplus	ORIA plantations	0	*defa*	+ *defa*
	Other Australian producers	abP_0	afP_1	$-P_1fbP_0$
	All Australian producers	abP_0	deP_1	+ *defa* $- P_1fbP_0$
	Rest of world (ROW) producers	hkP_0	hiP_1	$-P_1ikP_0$
Consumer surplus	Australian consumers	xcP_0	xgP_1	$+ P_0cgP_1$
	ROW consumers	ymP_0	ynP_1	$+ P_0mnP_1$

The sizes and characteristics of markets for sandalwood end products, such as sandalwood oil, incense sticks, pan masala etc. are equally obscure. The market for the last two products is reportedly price sensitive, but the rapid increases in sandalwood oil prices in recent years due to supply shortages suggest that the market for oil for use in high-end perfumes is quite inelastic. In any case, there are no credible estimates of either supply or demand elasticities for sandalwood in either Australia or the rest of the world on which to base estimates of relevant measures of consumer and producer surplus.

So far as could be determined, Australia is the only country to have established large areas of sandalwood plantations capable of producing significant and sustainable quantities of sandalwood (AAG 2006, p. 3). Plantations of *S. spicatum* that have been established in southern WA will influence supply under both scenarios, but plantations of *S. album* in the ORIA will influence supply only under the consequential scenario. The former is an important determinant of future prices under both scenarios, because supplies from native-grown stocks in the rest of the world are forecast to continue to decline at a rapid rate, and supplies from production of wild *S. spicatum* from the WA rangeland resource will at best stay steady. Under the counterfactual scenario, increasing supplies from plantations of *S. spicatum* are probably at least 10 years away, and so may or may not offset an increasing gap between consumer demand and world supply, and consequent further increases in prices.

Further complicating the analysis are the twin facts that there is a time lag of about 15 years between establishment of a plantation and its ultimate harvest, and that all of the commercial sandalwood plantations in the ORIA have been established and are being managed by MIS companies. Because of the time lag between incurring costs and receiving proceeds from sale of harvested product, it is necessary to track, year by year, the area planted, so as to predict annual flows of costs and benefits under the consequential scenario. In addition, commercial-in-confidence issues restrict access to some data.

For the above reasons, it proved impracticable to apply conventional economic surplus analysis to estimate the component impacts of the agroforestry projects. Instead, a somewhat different approach was required. Setting aside for the moment the gains in producer surplus to ORIA plantation producers, it is a matter of simple geometry to show from Figure 8 that the net gains to the rest of the world, depicted by the area $(P_0mnP_1 - P_1ikP_0) = ikmn$, must exceed the loss to other Australian producers net of any gains in Australian consumer surplus, depicted by the area $(-P_1fbP_0 + P_0cgP_1)$.[6] It follows that an estimate of the gains in producer surplus to ORIA plantation producers must underestimate global net economic surplus from uptake of the technology outputs from the agroforestry projects. Furthermore, so long as predicted plantation yields are actually harvested, and expected prices are realised, the direct beneficiaries of development of sandalwood plantations in the ORIA are investors in the MISs, who generally include

6 Net gains to the rest of the world = $ikmn > ((P_0 - P_1)^* km)$. The area depicting the loss to other Australian producers (P_1fbP_0) and the area depicting gains to Australian consumer (P_0cgP_1) share the common area (P_0czfP_1), so the net loss = $(bcz - fgz)$, which must be less than $((P_0 - P_1)^* km)$.

large numbers of small investors, and shareholders of the MIS companies. Hence, any credible estimate of non-tax benefits to investors will underestimate the aggregate producer surplus from establishment of these plantations.[7]

The costs of establishing, managing, harvesting and sale of cleaned sandalwood logs from MIS plantations in the ORIA were taken from the TFS Sandalwood Project 2009 product disclosure statement (TFS 2009). The principal fees charged to MIS investors are an establishment fee of $74,250/ha for the initial cost of preparing the land, the supply and planting of the seedlings, and lease and management fees for the first year. In subsequent years, investors are charged annual land lease plus management fees of $7,920/ha. Obviously, the revenue from these fees is intended to not only cover the 'real' costs of plantation establishment, management and harvesting, but also the not inconsiderable costs of the MIS, together with profits for shareholders in the MIS company. These costs will be used in this study even although they probably overstate true social costs because, by doing so, estimated benefits will tend to be underestimated.

The critical determinants of economic returns from the sandalwood plantations in the ORIA are the yield of heartwood harvested, its oil content and the price obtained for sandalwood oil. Other sandalwood products, such as the yield of sapwood, the price for sandalwood pulp after oil has been extracted, and the market for other parts of the tree such as the nuts, will at best make a minor contribution to overall returns, and are ignored in this report.

While there is considerable uncertainty about all three primary variables, some evidence on oil content is available on which to base predictions. In 2004, at age 14 years, 20 Indian sandalwood trees from trial plots established by the ACIAR projects were sampled for total oil yield. In a press release, FPC (2006) reported that:

> The trees contained approximately 34% heartwood at 30 cm, and 29% heartwood at 100 cm. The mean total extractable oil yields were 2.9–3.4% from chips, and 1.8–2.0% from cores. These oil readings are approximately half that obtained from mature trees aged over 50 years growing in India, which have an average oil yield of 5–7%.

With all commercial plantations still in the development stage, expected heartwood yields are more uncertain. Yields depend on, among other things, environmental factors such as location and soil type, and on biotic and abiotic stress factors, as well as on the irrigation regime and management techniques. There also are significant risks involved in growing sandalwood plantations in tropical areas due to storms, fungal diseases, weeds and creepers, and insect pests, that could reduce tree survival rate to 85%, as well as lower heartwood yields. Another threat to sandalwood plantations in the ORIA is rising watertables, although the likelihood that this will cause damage is remote because an extensive drainage system is in place.

In the product disclosure statement for the TFS Sandalwood Project (TFS 2009, p. 20), the following assumptions were made to impute yield:

- Lot size is 0.167 ha.
- The tree survival rate is at least 85%, which equates to 72 trees per lot available for harvest.
- The yield of heartwood per tree is 25 kg in year 13 and 27.5 kg in year 14.
- Twenty per cent of the trees are harvested in year 13, and 80% in year 14.

Thus, the prediction is that heartwood yield will be 1,950 kg of sandalwood per 0.167 ha lot, which equates to 11.67 t/ha. As the prospectus points out, however, realised yields may vary significantly due to factors outlined above.

Based on discussions with the Forest Products Commission, Clark (2006, p. 9) estimated that the yield of heartwood containing 3% oil would be 8 t/ha, and this estimate is used in this study. As noted above, yields of sapwood have been ignored because of its low value relative to that of heartwood.[8]

Predicting future sandalwood oil prices is very difficult too, because commercial secrecy and unofficial trade

7 This assertion is based on the fact that there are two principal potential beneficiaries of the sandalwood plantations. One group is the investors in the MISs, the other is the shareholders in the MIS companies. In the report, the estimates of non-tax benefits to investors include the former, but not the latter.

8 AAG (2006) quotes prices of legally sourced Indian sandalwood between $30,000 and $85,000 per tonne, with sapwood prices ranging from only $1,000 to $2,500 per tonne.

in sandalwood make it virtually impossible to obtain reliable information about international supply and demand. Currently, India dominates the supply of *S. album* to the international market, although Australia is also a major player with harvests of up to 2,500 t of mostly Western Australian sandalwood (*S. spicatum*) every year. It has been estimated that India currently produces approximately 1,000 t/year of 'legal' *S. album*, but unofficial harvesting might account for an additional 3,000–4,000 t/year. According to the Australian Agribusiness Group (AAG 2006, p. 2):

> Current world market demand for Sandalwood is thought to be around 5,000–6,000 tonnes per year, with this figure incorporating demand for a number of different products, sourced from a variety of Sandalwood species.

In recent years, international prices for high-quality sandalwood oil have continued to increase because unofficial and unsustainable harvesting of wild trees has resulted in declining world supply at the same time that demand has continued to grow. Figure 9 shows that sandalwood oil prices have more than trebled during the past decade. While synthetic substitutes have become available on the market, the fact that their price is much lower suggests that they are an inferior alternative to natural sandalwood oil, and are unlikely to have a major impact on future prices.

What's more, as a popular ad says, 'oils ain't oils'. For instance, there are known differences in the chemical composition of oil from different *Santalum* spp., and there also may be differences between trees of different ages, as well as between wild versus plantation-grown trees. Furthermore, it is arguable that attempts by the Indian Government to regulate sandalwood exports have created a black market and corrupted world trade. In a recent article, Forbes India (2009) stated that the price of oil from legally procured Indian sandalwood is R1–1.5 lakh[9]/kg, while the price of oil from smuggled, illegally harvested Indian sandalwood is R65,000/kg. Notably, it was claimed that Australian sandalwood oil, presumably from lower quality *S. spicatum*, sells for only R30,000/kg, which equates to about A$700/kg of oil.

Arguably, the greater threat in the medium term to continued high prices is likely to come from Australia, because Australia's supply of sandalwood is predicted to increase substantially. In a few years time, the ORIA *S. album* plantations as well as *S. spicatum* plantations in southern WA will come on line and start to be harvested. As a result, Australia is virtually assured of at least rivalling, and probably eclipsing, India as the world's largest supplier of sandalwood oil and timber. While there is a significant risk that this increased supply will result in a downward pressure on future sandalwood prices, this may not eventuate if production in India continues to decline.

The other pertinent price data often referred to in MIS publicity are prices paid at the Tamil Nadu Forestry Department auctions for *S. album* heartwood. Figure 10 illustrates how prices for high-quality *S. album* heartwood have soared in recent years. Heartwood has recently been traded at prices above A$100,000/t, albeit in only small quantities.

Further compounding the risks surrounding the price to be paid for *S. album* heartwood from ORIA sandalwood plantations is the fact that the cost of extracting oil is unknown. What is known is that *S. album* grown in ORIA plantations will be harvested at about 14 years of age, while the typical age of *S. album* harvested from wild stands in India is closer to 50 years. As a result, both the heartwood yield per tree and the oil content from the ORIA sandalwood plantations will be significantly lower than the yields from Indian *S. album*. Consequently, it seems very likely that extraction costs will be somewhat higher, and heartwood prices will be correspondingly lower, even if the extracted oil realises the same price per kg.

To sum up, the oil price has fluctuated between US$1,500 and US$2,000/kg for nearly 5 years. Future upside pressure will come from almost certain further declines in the supply of 'wild' Indian sandalwood, as well as from a fall in the value of the United States (US) dollar, while virtually the only downside will come from increased supplies from Australian sandalwood plantations, most of which will not come onto the market until after 2020.

Taking all the above into account, it was decided to base calculation of sandalwood benefits on a sandalwood oil price of US$1,500/kg, and yield on the RIRDC estimate that *S. album* plantations will yield 240 kg of oil per ha. If revenue from sapwood and heartwood pulp is disregarded on the ground that it at least

9 A lakh (100,000) rupees (R) = approximately A$2,325.

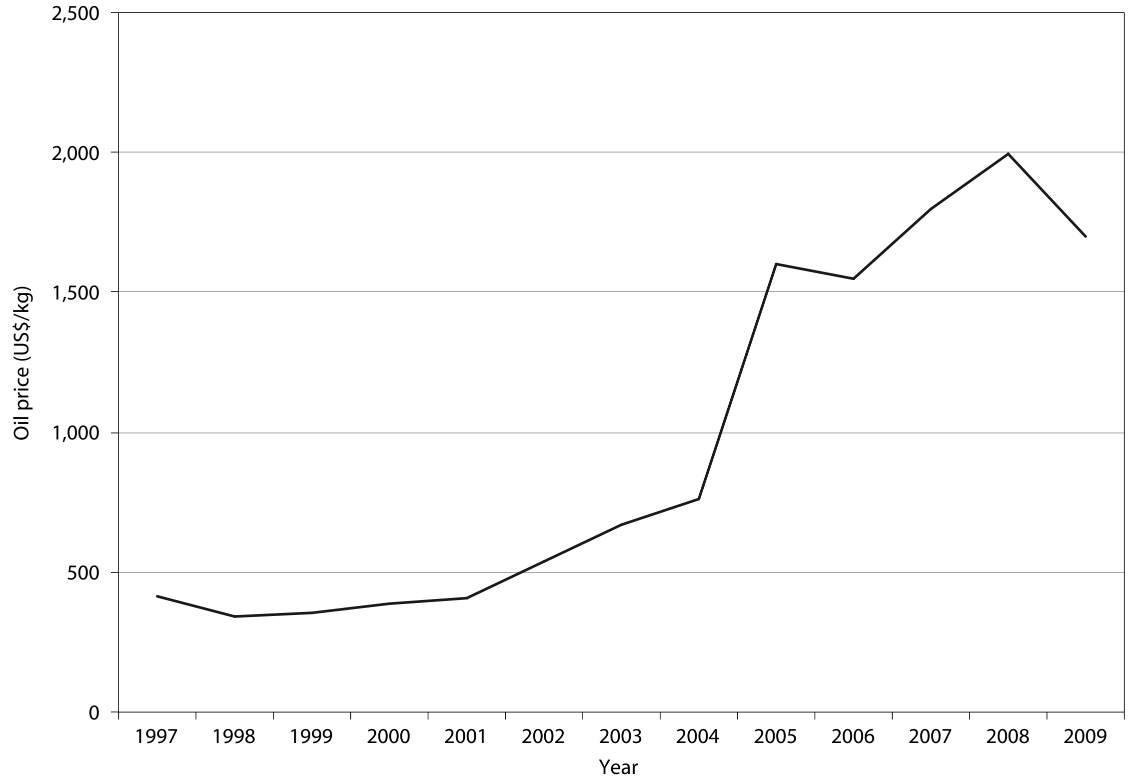

Figure 9. Indian sandalwood oil prices. Source: The Public Ledger

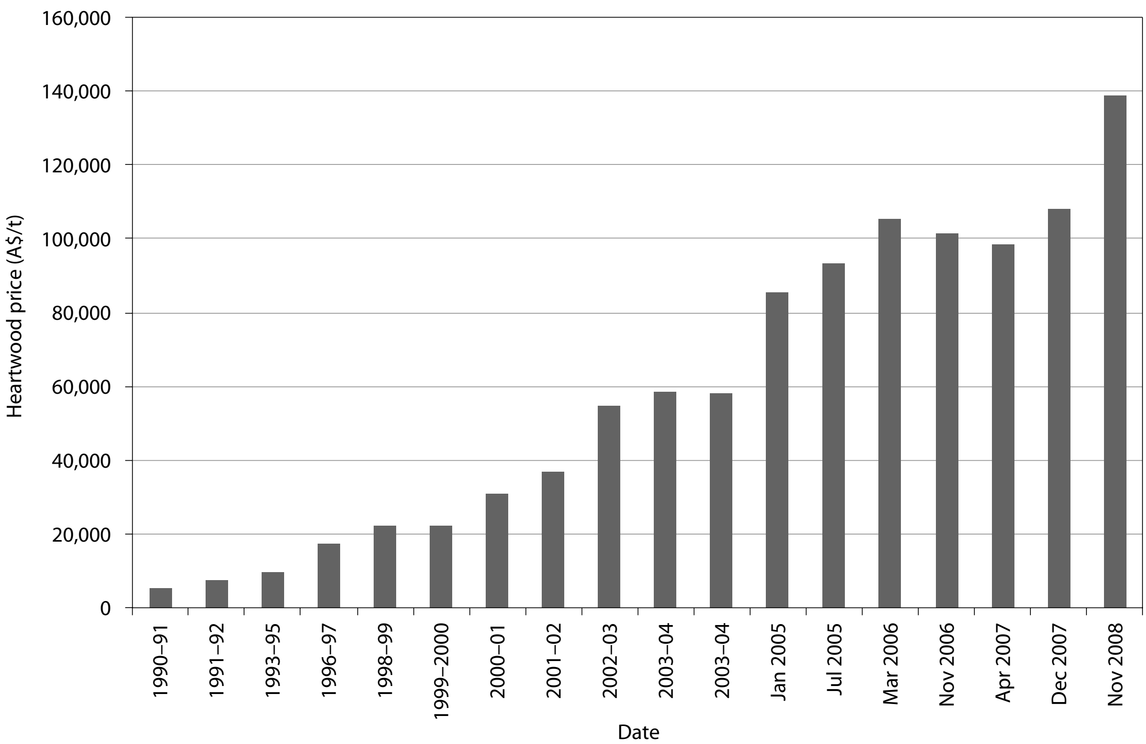

Figure 10. Sandalwood heartwood auction prices. Source: Tamil Nadu Forestry Department

offsets extraction costs, then these values equate to a heartwood price of A$47,872/t, which is less than half recent auction prices for Indian *S. album.* Hence, the projected revenue at harvest is $363,830/ha, which equals 8 t/ha times A$47,872/t, less 5% sales and marketing costs. Table 4 sets out the budget for 1 ha of a single rotation expressed in constant 2009 Australian dollars. Notably, in constant dollars, the expected net present value (NPV) per ha of any rotation at the beginning of the year in which it is commenced is calculated to be A$27,033.

At this stage, the benefits from the ORIA sandalwood plantations are prospective rather than realised, because none of the commercial sandalwood plantations have been harvested yet, and the first harvests are unlikely before 2013. Furthermore, significant areas probably will not be harvested before 2020 at the earliest.

The estimated NPV of prospective benefits is calculated by multiplying the area planted in each year by the NPV/ha per rotation at the start of that rotation, compounding or discounting each year's value to the measurement year of 2009–10 and, finally, summing across years. The resulting estimate of PV of total prospective benefits is greater than A$776 million, which exceeds, by a considerable margin, the investment of less than $37 million by ACIAR, its partners and other agencies in all of the collaborative projects on plantation forestry in Indonesia and Australia.

The impact of the Australian trees projects in Indonesia

Background on Indonesian pulpwood plantations

Indonesia was once a forest-rich country with some of the most extensive, diverse and valuable forest resources in the world. However, more than 40% of the forest resources existing in 1950 have since been cleared, and the remaining natural forests are threatened with rapid and increasing rates of destruction. Much of this deforestation was due to a political and economic system that encouraged exploitation of forests for political ends and personal gain (World Bank 2006, pp. 2, 7, 43). Starting in the 1960s, the then governing 'New Order' regime allowed harvesting of the country's forest for more than three decades in a way that conferred benefits on a privileged few and caused substantial loss of the forest estate. During the 1980s and 1990s, the regime played a pivotal role in the development of Indonesia's wood-processing industry. Lucrative logging concessions covering more than half the country's total forest area were allocated to powerful business groups and individuals in a way that allowed illegal logging and overexploitation of tropical rainforests to flourish with little regard for long-term sustainability of production.

One beneficial outcome has been that Indonesia's forestry sector has made a significant contribution to gross domestic product, foreign exchange, government revenue and employment for several decades. Until recently, forest harvesting, processing into wood-based products, and processing into pulp and paper products has contributed 3–4% of national gross domestic

Table 4. Sandalwood plantation budget (in constant 2009 A$/ha) for a single rotation for the consequential scenario

Items	Time	Units	A$/ha
Establishment costs	Year 0		74,250
Annual management costs	Years 1–13		7,920
Harvesting costs	Year 14		15,996
Heartwood yield (t/ha)		8	
Heartwood price (A$/t)		47,872	
Revenue	Year 14		363,830
Net present value/ha per rotation at start			27,033

product to the economy (World Bank 2006, p. 64). However, most of the benefits have been captured by a small group of powerful people, despite the fact that the legal framework of Indonesia relating to the use of forest lands to produce economic products and benefits also provides that these lands and benefits be shared equitably for the benefit of all Indonesians.

Due largely to government policies, as well as to timber availability and market forces, the Indonesian wood-processing industry has grown rapidly since 1980, and its structure has evolved in a dynamic manner. For a time, Indonesia's forestry sector was a world leader in round wood production, and was the world's top plywood exporter by the early 1990s, but uncontrolled expansion of timber-processing industries in the 1980s and 1990s created excess processing capacity despite many years of overharvesting and deforestation of natural tropical rainforests.

Figure 11 depicts how the three primary wood-processing subsectors have evolved over time in Indonesia. Before 1980, log production dominated the sector, and almost all forestry activities were in logging and sawmills until the early 1980s. Sawn wood production experienced rapid growth from 4.8 million m^3 in 1980 to a peak of 10.4 million m^3 in 1989, followed a few years later by a sharp decline to 1.5 million m^3 by 2006 (CFPS 2009).

Production of plywood added more value to the timber inputs and also grew rapidly, from 1 million m^3 in 1980 to 9.7 million m^3 in 1997. By the mid 1980s, plywood had replaced sawn wood as the dominant subsector. By 2006, however, Indonesia's plywood production had fallen to 4.8 million m^3 as producers experienced difficulty sourcing large-diameter logs, due to resource depletion and recession in some export markets (CFPS 2009). From 2004 to 2006, exports of plywood and sawn timber fell by 55% and 40%, respectively, and nearly one-third (800,000) of the estimated 3 million people working in the forestry sector lost their jobs between 2002 and 2006 (Obidzinski and Chaudhury 2009).

Of more relevance to this study has been the aggressive expansion of Indonesia's pulp and paper industries, to the point where the value of pulp and paper exports exceeded the value of plywood exports by 2002. Again, a small number of well-connected businessmen gained concessions to make use of natural forests to feed the rapid growth in capacity of their pulp mills although, as described below, there was also a requirement to establish industrial forest plantations to provide a more sustainable supply of fibre in the long run. Coupled with subsidised loans and tax breaks, this enabled a rapid growth of the pulp and paper processing sector from 0.5 million t in 1989 to 5.7 million t in 2006 (CFPS 2009, p. 28).

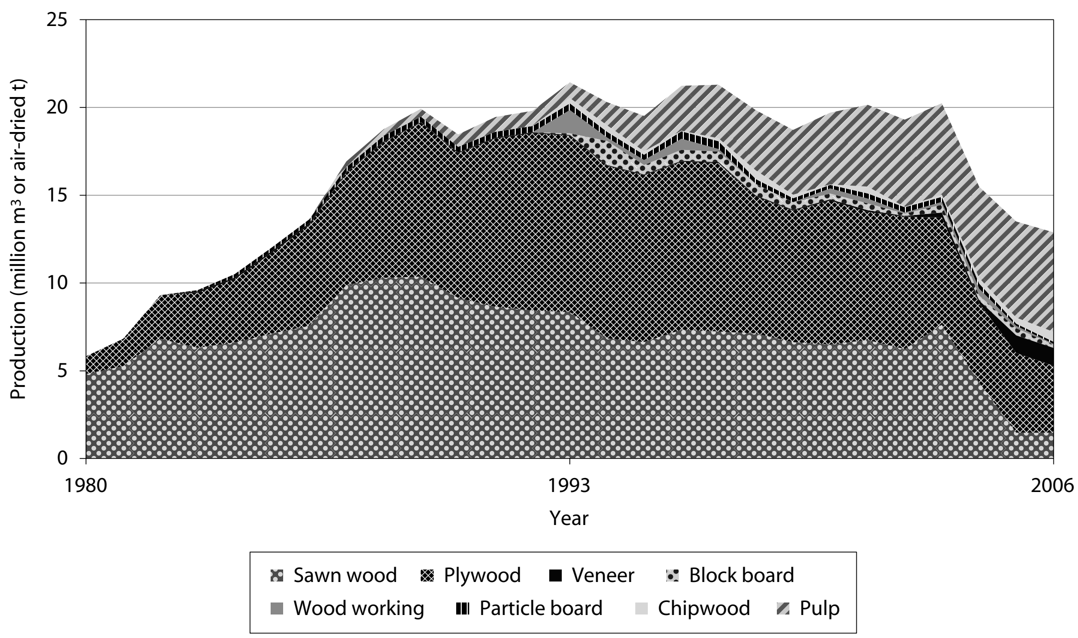

Figure 11. Wood product production in Indonesia, 1980–2006. Source: CFPS (2009, p.74)

The pulp and paper sector is now the fastest growing consumer of timber, and so far has relied mainly on fibre from clear-felling of conversion forest.[10] However, it has created a demand for wood fibre that cannot be met by sustainable management of the current forest resource base. Furthermore, although Indonesia is now among the world's top 10 producers of pulp and paper, massive debts incurred to develop this sector continue to strain Indonesia's financial system (see Setiono 2007).

As noted above, government policies have been instrumental in shaping this evolution of the wood-processing sector. In the early 1980s, the Ministry of Forestry (MOFR) was created to control use and access rights on the vast majority of Indonesia's land. Development of the forest industry was shaped by tightly controlling and restricting rights to forest harvest licences, rights to process and export logs, and by subsidies for so-called value-added processing. Regulatory policies that reinforced government control over rent appropriation included (CFPS 2009, p. 26):

- a monopoly on the export and sale of plywood
- a log export ban (1980 to 1992)
- the sawn wood export tax imposed in November 1989
- the prohibitive log export tax enacted in June 1992 in lieu of the lifted ban on log exports
- subsidised credit from state or group-owned banks
- tax advantages for capital investments.

These policies helped to assure the flow of timber to the processing sector at depressed domestic prices, so that it could be processed and exported at global prices for high profits. Since the MOFR also controlled collection of royalties and reforestation fees from forest concessionaires—the major source of direct and authorised rent extraction—a few timber magnates were able to capture Indonesia's forest industry (World Bank 2006, p. 41).

In the more recent reform era, many elements of this system have been gradually dismantled (e.g. the plywood monopoly and vertically linked harvesting and processing), partly due to international pressures and conditions on borrowed funds following the financial crisis. However, the legacy of this system still influences the political economy, business practices and attitudes of many forest sector operators (World Bank 2006, p. 40). Moreover, as part of the effort to boost the Indonesian economy, more than half of forest land claimed by the state is still allocated to commercial activities, licensed as concessions to corporate conglomerates engaged in forest exploitation, or scheduled for conversion to industrial timber plantations, agricultural enterprises or other uses.

For some time, the Government of Indonesia has recognised the need to dramatically increase the supply of timber from forest plantations to secure the long-term survival of the forestry sector, and to create a turnaround in the wood-processing sector. Starting in about 1990, the Department of Forestry (DepHut) launched the Industrial Timber Plantation, or Hutan Tanaman Industri (HTI), program. This is an ambitious scheme to develop 2.3 million ha of industrial forest plantations by 2000 and 10.5 million ha by 2030 (Arisman and Hardiyanto 2006) to reduce the pressure on the country's natural forest resources by substituting fibre supplied from plantation forests to meet the wood supply needs of the pulp, plywood and other solid wood industries in the medium to long term. While the first of these targets has not been met, and the second is unlikely to be met, recent estimates of the area of industrial forest plantations are as much as 2.5 million ha (Arisman and Hardiyanto 2006). In an attempt to ensure compliance, existing pulp industry and Forest Concession Right (Hak Pengusahaan Hutan, HPH) licence holders were forced to develop HTI projects[11] and continued issuance of annual felling permits was tied to participation in the HTI program (Thorp 2005).

Initially, HTI companies that were either 100% state-owned (Swakelola), or joint ventures between state-owned PT Inhutani companies and private-sector partners,[12] were also given a further huge incentive to develop plantations because they were able to access government-managed interest-free loans to cover plantation development costs. The sting, however, came with the subsequent cancellation of this policy in 2000, an event that left many HTI companies with only

10 Clearance forest is forest that is designated, under a licensing system, for clearance and permanent conversion to another form of land use.

11 According to Thorp (2005), more than 228 licences were issued by 2005.

12 As opposed to HTI companies that were 100% privately owned, such as Sinar Mas Forestry and RAPP.

partly developed plantations and a negative cash flow due to lack of capital to develop new plantations and of markets for existing plantation production. Some have since ceased operations, some have sought to restructure the loans as they become payable, and others have been bought out by private-sector partners. Despite such problems, there has been rapid growth of industrial pulpwood plantations from a very low base in 1990.

Technology output package

The impact of the Australian trees projects funded primarily by AusAID and ACIAR has been one of the most successful development-assistance outcomes of Australian forestry science to date. In Indonesia, the demonstrable impact on productivity and profitability of industrial pulpwood plantations can be attributed almost entirely to uptake of technology outputs from these projects. These outputs included improved planting stock based on proven site-specific selection of species and provenances of Australian hardwood tree species, most notably, superior provenances of *A. mangium,* but also including *Acacia crassicarpa* and *Eucalyptus pellita*. However, high and sustainable levels of production from tree plantations also require good practice across a range of forestry disciplines, and improved germplasm was complemented by an associated extension package about how best to grow the trees with good silvicultural practices and plantation management to increase productivity and protect soil nutrition and water resources (Nambiar and Brown 1997). As an example of how superior genetics and silvicultural improvements complement each other, when *A. mangium* was first planted in Malaysia as a firebreak, it produced single-stem trees, but when it was planted on sites in Indonesia cleared by burning, it typically produced multiple stems/trunks. As a consequence, the practice of singling was developed which, when used with improved germplasm, resulted in much higher productivity than previously achieved. The resulting impact on plantation productivity and profitability was due to uptake of all components of the innovation package. Other complementary outputs included greatly improved seed orchard management, as well as associated knowledge and training.

It is only 30 years since the first introduction of *A. mangium* into South Sumatra, during which time the natural variation within the species has been assessed, breeding programs established, molecular marker technologies applied, silvicultural studies completed, growth and yield studied, and wood and fibre properties determined. As a result, it has gone from being a virtually unknown tree to a major commercial plantation species for pulp and paper in South-East Asia. How such rapid domestication of a tree species was achieved needs to be recounted[13] in some detail to understand the significance of the contribution of the cluster of industrial plantation domestication projects to Indonesian industrial plantation forestry.

Acacia mangium occurs naturally in northern Queensland, the Western province of Papua New Guinea (PNG), and some eastern Indonesian provinces. Seed from a single tree at Mission Beach, Queensland, was introduced into Sabah, Malaysia, in 1966, and subsequently provided the germplasm for the first use of *A. mangium* as a commercial plantation species when it was employed for successful reforestation of *Imperata* grasslands in 1976. In 1979, it was introduced from Sabah into Subanjeriji, South Sumatra, for use in a field trial to examine the potential for rehabilitation and reforestation of large areas of *Imperata* grasslands, where it emerged as the most promising species in terms of adaptability and growth, albeit of poor form. The contributions, if any, of the predecessors of the Australian trees projects to the initial introduction of *A. mangium* into Sabah, and then Indonesia, are not clear. In this report, it will be assumed that there was no contribution, and hence that the above developments also form part of the counterfactual, or without R&D, scenario.

In 1980, seed from four provenances of Queensland's Cairns region were imported, and are referred to as the Subanjeriji local land race. Initially, seed from very few provenances was available, and little was known about the genetic variability of *A. mangium,* or which provenances should be used for plantation development. In 1982, seed collected from Indonesian locations was also planted in Subanjeriji, but growth was poor. The Subanjeriji provenance seed stands were used as seed production areas managed by PT Inhutani I., and produced seedlings for reforestation programs and plantation development throughout Indonesia during the 1980s.

In the 1980s, the then CSIRO Division of Forest Research, with FAO support, organised several expeditions to the humid tropics of Australia, Indonesia

13 The following is a condensed account taken mainly from Arisman and Hardiyanto (2006).

and PNG (Turnbull et al. 1983; Skelton 1987; Searle 1989; Gunn and Midgley 1991) to systematically explore the natural distribution of *A. mangium* and other *Acacia* species, and to assemble comprehensive collections of acacia seed and botanical material. Subsequently, seed of *A. mangium* from these collections, together with seed collected by the Directorate-General of Forestry, Indonesia, was used for large-scale provenance trials in many parts of Indonesia, to examine the patterns of genetic variation in growth rate, tree form and the extent of genotype × environment interactions (Harwood and Williams 1992).

The results of these trials indicated that seed from Far North Queensland (FNQ), PNG and Muting Irian Jaya provenances grew better than Subanjeriji local land race germplasm from the Cairns region of Queensland (Arisman and Hardiyanto 2006).

This seed of better genetic quality from other provenances was gradually introduced into Indonesian industrial pulpwood plantations during the 1990s as it became available. More efforts to broaden the genetic base of *A. mangium* were also undertaken in the early 1990s by introducing seed from a large number of provenances of PNG, FNQ and Muting. Further collections of seed were also made by a number of institutions, including the ATSC, Gadjah Mada University and several forestry companies, and improved seed with a broader genetic base became generally available for operational plantations in the mid 1990s (Hardiyanto 1998).

Large-scale development of *A. mangium* plantations followed, including the establishment of substantial seed production areas and seed orchards during the 1990s. Partly because of its strong growth combined with impressive adaptability to a wide variety of environments, and partly because pulp processed from *A. mangium* has excellent properties for paper making (Clark et al. 1991) that are comparable with or better than those of *Eucalyptus* species, this tree has been the primary species planted in Indonesian industrial pulpwood plantations, and now is the leading tree species in forestry programs in Indonesia.[14] However, other Australian hardwood species also have been domesticated, and large areas of industrial pulpwood plantations have also been planted to *A. crassicarpa* and *E. pellita*, among others.

The domestication of *A. crassicarpa* from a virtually unknown tree in the wilds of FNQ and New Guinea has been even faster. ATSC made the first research seed collections in FNQ in 1981 and PNG in 1982. By 1990, ATSC had sent out over 500 research seedlots to research partners in South-East Asia and China. The pulping and paper-making qualities of *A. crassicarpa* were demonstrated shortly thereafter, and the species had shown excellent survival and vigour in trials across a range of sites in the humid tropics by 1993 (Midgley 2000).

Within a few more years, *A. crassicarpa* had become a significant resource for the pulp industry in Indonesia, with more than 40,000 ha of commercial plantations established on Sumatra by 2000, primarily on highly organic peat-land soils that have a low pH and are occasionally waterlogged (Midgley 2000). While *A. crassicarpa* can have lower yields on these wetlands than *A. mangium* yields on dryland, it has a higher wood basic density and similar pulp yield, so it has become the species of choice on soils prone to seasonal waterlogging where *A. mangium* performs poorly. It also is a major commercial plantation species for pulp and paper in other parts of South-East Asia (Midgley and Turnbull 2003).

Most of the HTI companies have adopted at least some of the technology outputs from the Australian trees projects, and the biggest and the best of them have also taken advantage of capacity built by the projects. While these projects involved the domestication of many species of Australian trees and provided access to seeds of improved germplasm for many countries, the HTI plantations have been planted almost entirely with just three species, namely *A. mangium*, followed by *A. crassicarpa* and *E. pellita*. Estimates of the total area of these industrial pulpwood plantation forests vary, but probably close to 1.5 million ha will have been planted by next year to Australian hardwood tree species provided either directly or indirectly by the industrial plantation domestication projects.

Notwithstanding the fact that the combined elements of the innovation package were jointly important for plantation productivity improvement, it is almost inevitable that evidence of uptake of new technology embodied in improved germplasm is more readily available than is evidence about uptake of new

14 It also predominates in several other Asian countries (Awang and Taylor 1993; Turnbull et al. 1998).

knowledge. Eko Hardiyanto (pers. comm., 2009) estimated that of more than 1.2 million ha of industrial pulpwood plantations in 2008, 70% was planted to *A. mangium*, 20% to *A. crassicarpa* and most of the remainder to *E. pellita* and other *Eucalyptus* species.

In addition to numerous reports and other publications, compelling evidence that Australian forestry research provided key technology inputs for the development of the Indonesian industrial pulpwood plantations comes from data on dispatches of Australian hardwood tree species from ATSC over the past 25 years. For over 40 years, ATSC has been a national seedbank and research centre for source-identified seed of Australia's trees and shrubs. Managed by CSIRO, it collects seed from wild populations and, in addition, sources genetically improved seed from in-house domestication and improvement programs. Internationally, ATSC plays an important role by storing and conserving proven provenance seed of important Australian taxa. It also supplies high-quality, fully documented tree seed for purchase by both domestic and overseas researchers and commercial customers.

Data on seed dispatches from ATSC provides evidence on the extent to which the development of large commercial pulpwood plantations in Indonesia was based on purchases of seed of Australian *Acacia* species and, to a much lesser extent, of *Eucalyptus* species, that originated from the industrial plantation domestication projects. Figure 12 illustrates the number of individual seedlots of *Acacia* and *Eucalyptus* species dispatched from ATSC from 1983 to 2008, to Indonesian customers, to Australian customers and to all other overseas countries. Figure 13 shows the same basic data expressed as a percentage of total seedlots dispatched to each destination in each year.

It can be seen that the number of seedlots dispatched to Australian customers was the largest single destination in virtually every year. This is consistent with an assessment that Australian domestic work accounted for nearly 50% of ATSC's effort (Drielsma et al. 1997, p. 4). Nevertheless, Indonesian customers purchased large numbers of seedlots for about 10 years from 1989 and, in 1997, such purchases accounted for nearly 30% of all seedlot dispatches of *Acacia* and *Eucalyptus* species. After about 2000, however, purchases by Indonesian customers of seedlots from ATSC declined to quite small numbers as the capacity of the large industrial plantation companies to produce improved tree germplasm from their own R&D programs came to supplant ATSC as the main source of seedling supply for new rotations.

While most seedlots dispatched by ATSC were small parcels of seed for research purposes, ATSC also sold larger quantities of seed at commercial rates to commercial customers, including plantation companies in Indonesia, and a different picture is revealed in Figure 14, which shows the weight of seed dispatched rather than the number of seedlots.

In terms of weight of seed sold, it is clear that Indonesia was by far the biggest customer of ATSC for the decade of the 1990s. In fact, for a few years in the 1990s, seed sales to Indonesia provided ATSC with about 34% of revenue from all sources, including funding both from ACIAR for the SAT project, and from AusAID (Drielsma et al. 1997, p. 4). From Figure 15, it can be seen that sales of seeds of *Acacia* and *Eucalyptus* species to Indonesian plantation companies accounted for an extraordinary 90% or more of the total weight of *Acacia* and *Eucalyptus* seed dispatched from ATSC for 4 years from 1995.

Figure 16 illustrates the species composition of numbers of seedlots dispatched to Indonesia from ATSC. Werren (1991, p. 107) notes that the source of seed for the establishment of the original *A. mangium* plantations came from the first generation of seed orchards in Subanjeriji, South Sumatra, managed by PT Inhutani. Starting in 1979, these stands were planted using bulk seeds of Queensland and Indonesian provenances, but PNG provenances were not represented. Although 1983 was the first year for which records are now available of seedlots dispatched by ATSC to Indonesia, it is unlikely that any significant number of seedlots was dispatched earlier than 1983. Hence, it is unlikely that the pulpwood domestication projects made any significant contribution to the first generation of *A. mangium* plantations established before about 1990.

In Figure 16, it can be seen that numbers of seedlots of *Acacia* and *Eucalyptus* species were dispatched in 1983 and 1984. They were presumably used to establish some of the second generation of *A. mangium* stands at Subanjeriji in 1985. However, it was during the period from 1987 to 1999 that the greatest numbers of seedlots of *Eucalyptus* and *Acacia* species were dispatched.
In a recent survey of ATSC clients, S. Midgley (pers. comm., 2009) found that six Indonesian clients,

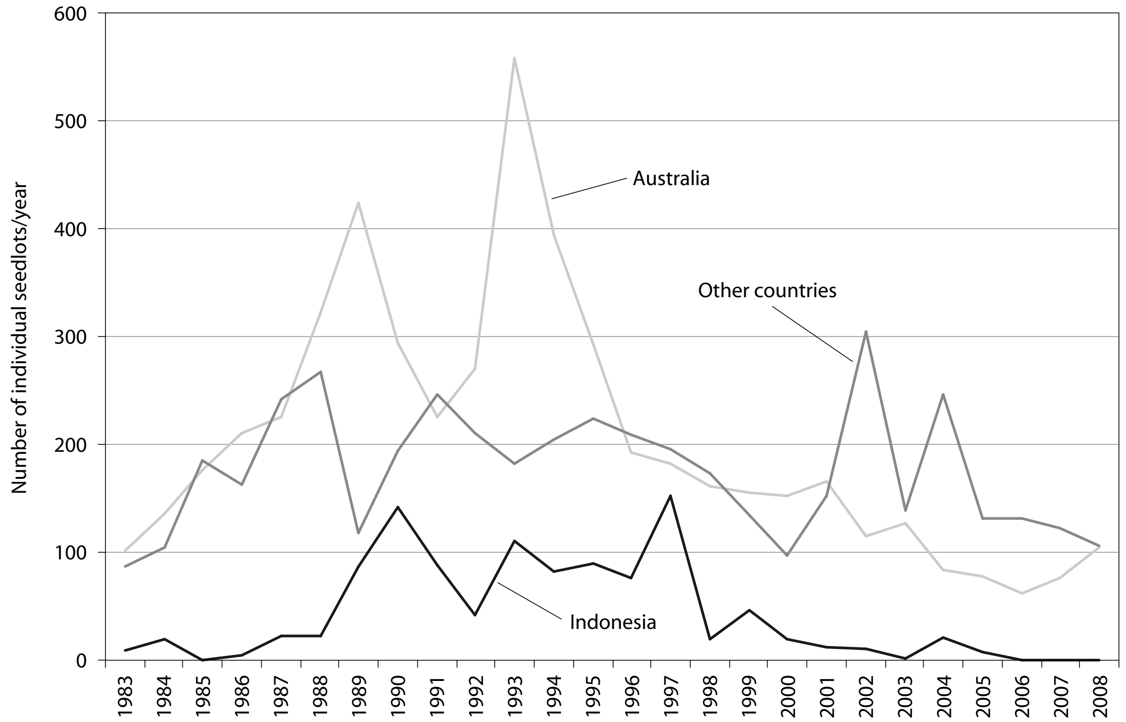

Figure 12. Numbers of seedlots of *Acacia* and *Eucalyptus* species dispatched from the Australian Tree Seed Centre (ATSC), by destination and year. Source: Economic Research Associates analysis of data provided by ATSC.

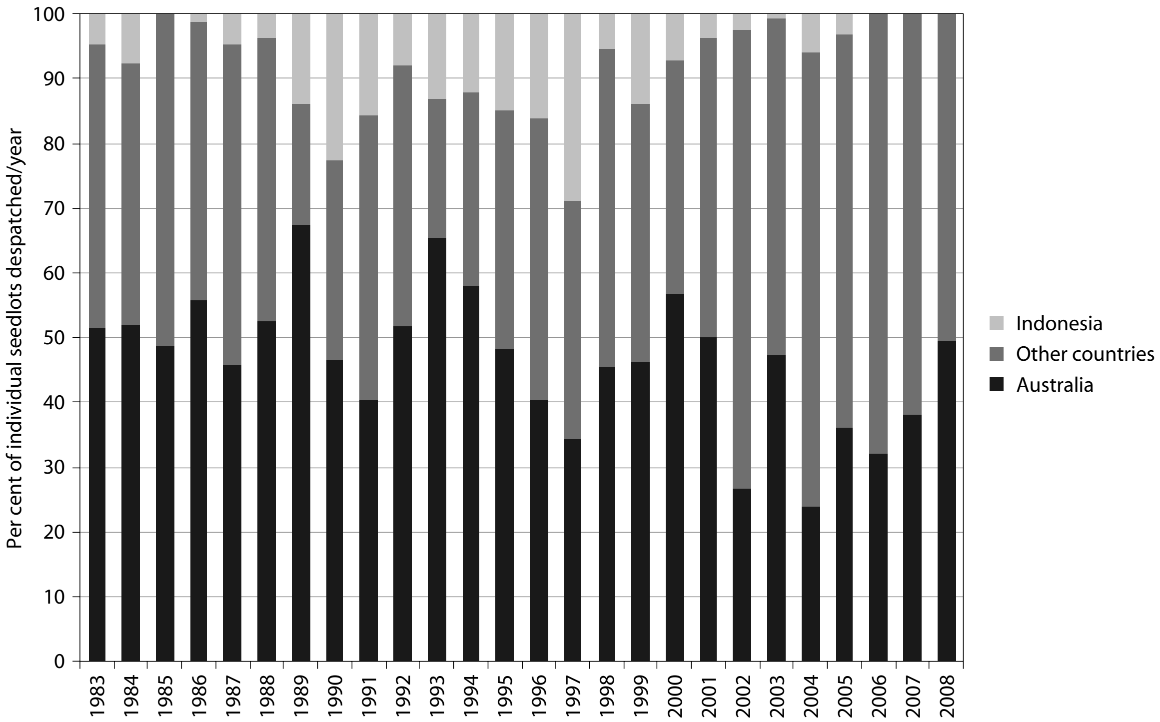

Figure 13. Percentage of *Acacia* and *Eucalyptus* seedlots dispatched from the Australian Tree Seed Centre (ATSC), by destination and year. Source: Economic Research Associates analysis of data provided by ATSC.

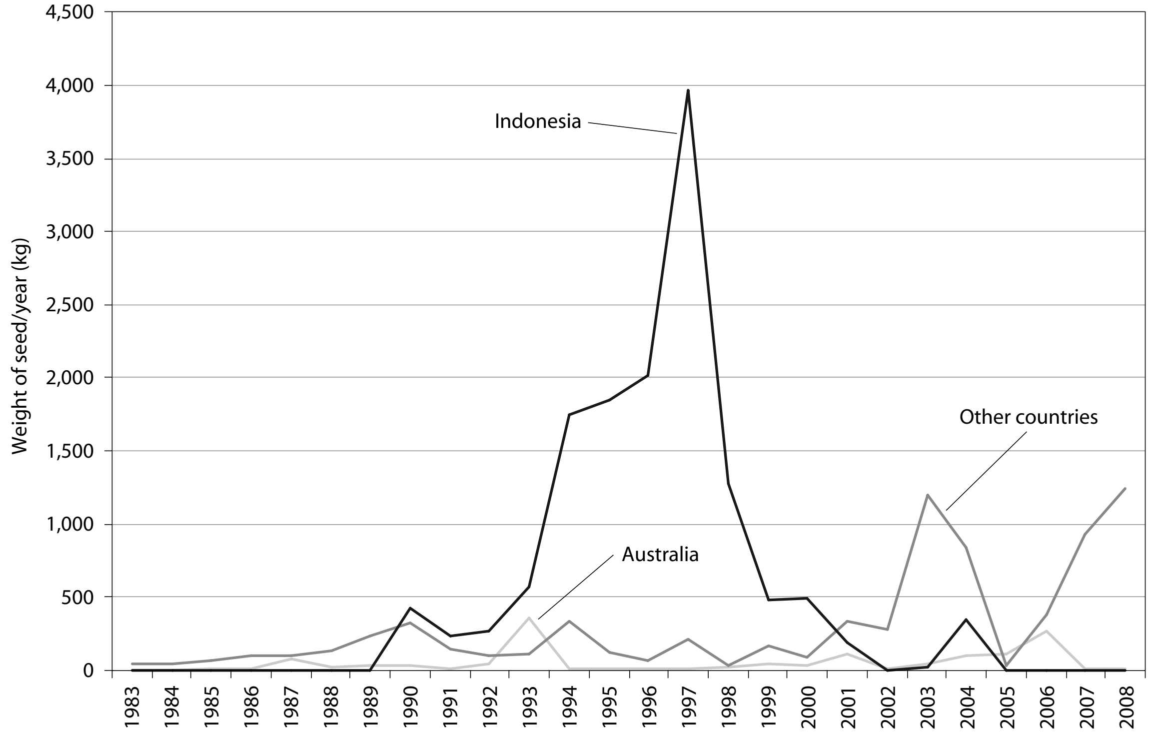

Figure 14. Weight (kg) of seed dispatched from the Australian Tree Seed Centre (ATSC), by destination and year. Source: Economic Research Associates analysis of data provided by ATSC.

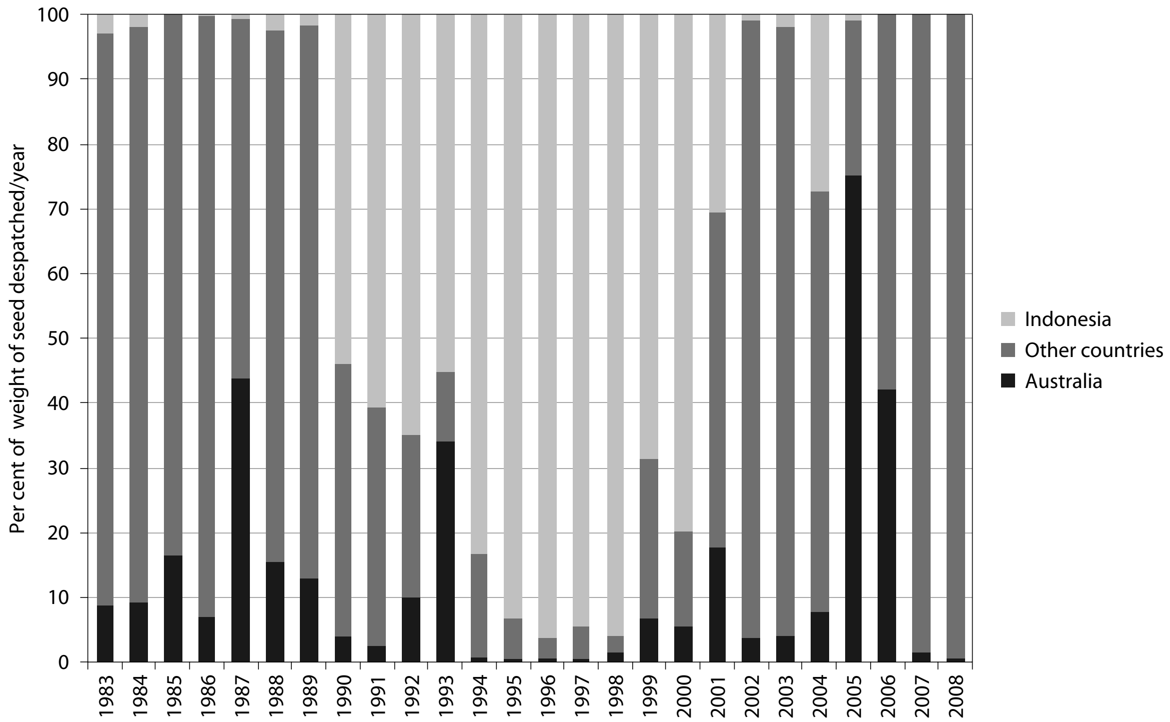

Figure 15. Proportions (%) of seed by weight dispatched from the Australian Tree Seed Centre (ATSC), by destination and year. Source: Economic Research Associates analysis of data provided by ATSC.

including most of the major industrial plantation companies, a government research agency and a university, received between 93 and 469 individual tree seedlots for use in tree improvement programs. Hence, outputs from the pulpwood domestication projects clearly contributed to the tree improvement programs of Indonesian plantation companies by providing a diverse range of Australian hardwood tree germplasm.

Most seedlots dispatched by ATSC comprised only small quantities of seed for research purposes. Figure 17 shows aggregate weights of seed dispatched to Indonesia by species. In contrast to the data on number of seedlots for research, seed dispatched to Indonesia during the 1990s is dominated by bulk seedlots of *A. mangium* and *A. crassicarpa* imported by plantation companies to establish their own seedling seed orchards and/or plant new rotations.

Again, the disparity between, on the one hand, large numbers of seedlots containing small quantities of seeds for research purposes and, on the other, small numbers of seedlots containing relatively large quantities of seeds for commercial purposes, explains the apparent inconsistency between the two measures of composition of seed species dispatched by ATSC to Indonesian customers. This is revealed most clearly in Figure 18, which shows the average weight per seedlot by species and year dispatched to Indonesia from ATSC. All of the dispatches of large bulk seedlots are either of *A. mangium* or *A. crassicarpa*. According to industry experts, approximately 90% of Indonesian industrial forest plantations are planted to these two species, although recently one large company has switched, in most of its new rotations, to planting a fast-growing clone of *E. pellita* with improved resistance to rootrot disease.

The main benefit from adopting the technology innovation package is improved plantation productivity, which is a multidimensional concept. The most commonly used measure of plantation productivity is the growth rate, given in terms of the mean annual increment (MAI) in m^3/ha/year. For any given year, this is calculated by dividing the merchantable volume of harvestable timber by the age in years of the plantation. While the key determinant of MAI is rate of growth of forest biomass, tree form (e.g. stem straightness and frequency of multiple leaders) can also influence the

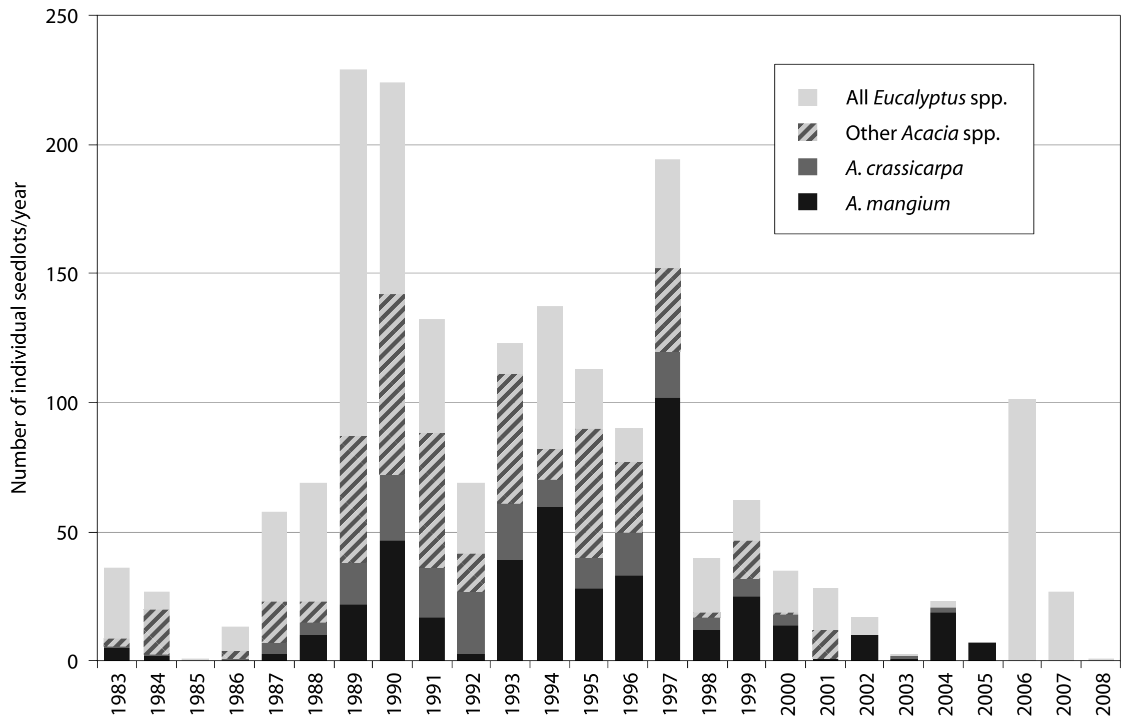

Figure 16. Number of seedlots dispatched to Indonesia from the Australian Tree Seed Centre (ATSC), by species and year. Source: Economic Research Associates analysis of data provided by ATSC.

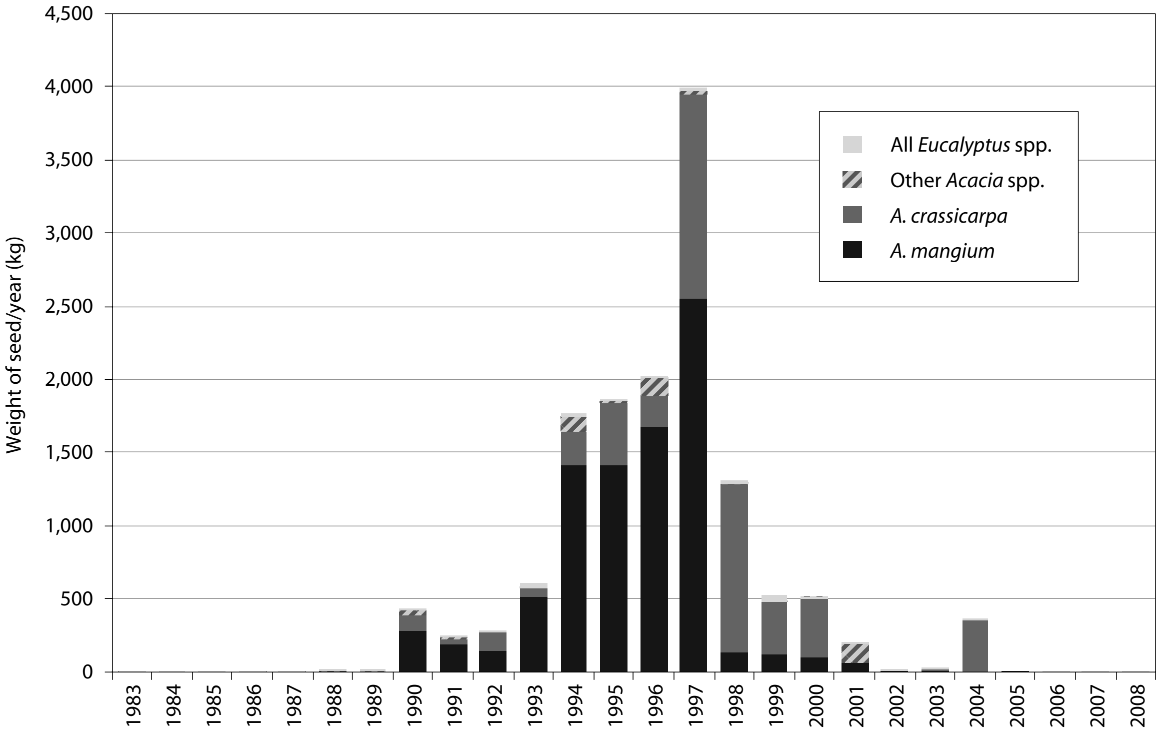

Figure 17. Weight (kg) of seed dispatched to Indonesia from the Australian Tree Seed Centre (ATSC), by species and year. Source: Economic Research Associates analysis of data provided by ATSC.

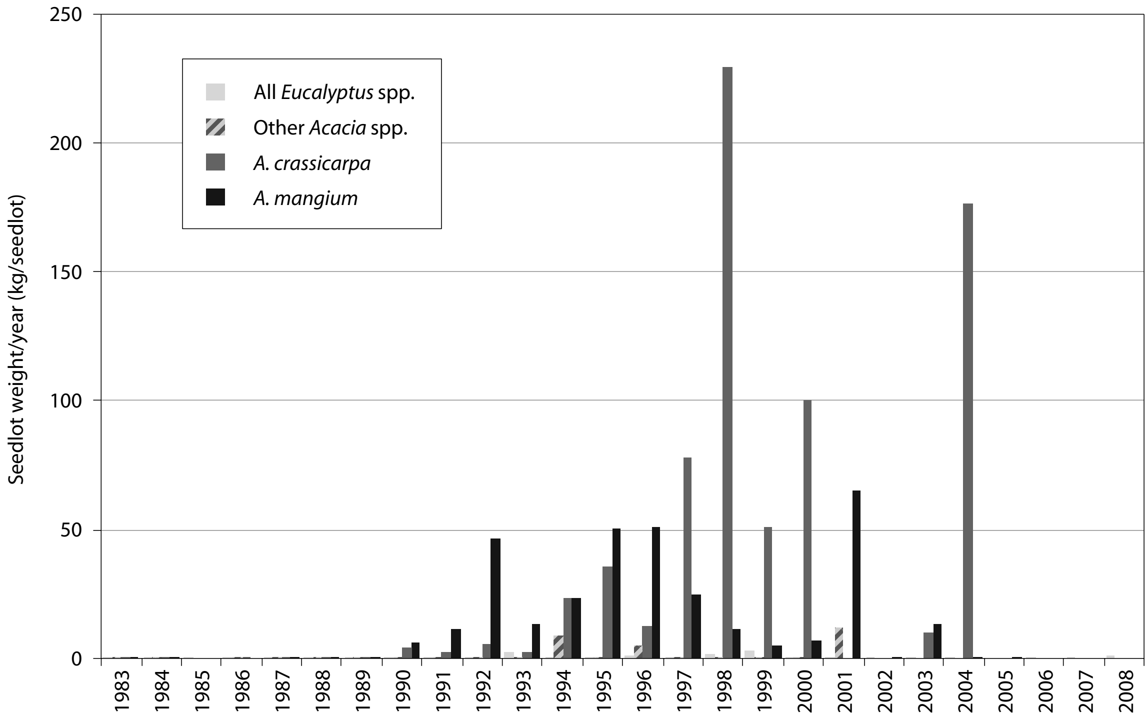

Figure 18. Weights (kg) of seedlots dispatched to Indonesia from the Australian Tree Seed Centre (ATSC), by species and year. Source: Economic Research Associates analysis of data provided by ATSC.

proportion of biomass that is 'merchantable'. Tree form can also influence losses during harvesting, transport and chipping, as well as transport cost, while wood properties such as density and fibre yield also influence the ultimate amount of saleable pulp.

To estimate the economic benefits from the Australian trees projects, a consequential scenario and a counterfactual scenario had to be specified in considerable detail. Plantation productivity and profitability can change from one rotation to the next, so the analysis needs to track the area planted, by year, to first, second, third and subsequent generation rotations. The impact pathway for uptake of technical outputs from the Australian trees projects is depicted in Figure 19.

The consequential scenario

Although it was known by the early 1980s that *A. mangium* grew well in the tropics on poor-quality podsolic soils, and was effective in rehabilitating *Imperata* grassland, significant uptake of research outputs from the Australian trees projects did not occur until about 1990, when considerable areas of HTI plantations were established and planted with *Acacia* and, to a lesser extent, *Eucalyptus* species of Australian origin. The 1990s was also the time when researchers in the Australian trees projects had largely completed the exploration phase of the domestication process, and were actively investigating optimal propagation and silvicultural techniques in close collaboration with staff of some of the largest HTI companies in Indonesia. Subsequently, Indonesian plantation companies established sophisticated tree-improvement programs to support large-scale industrial plantings of *A. mangium*, *A. crassicarpa* and *E. pellita*.

Information on the best provenances of *A. mangium* to plant at different sites was not available until the mid 1990s. Exploration of the natural distribution of *A. mangium*, and systematic collection of seed, took place mainly between 1980 and 1990 (Gunn and Midgley 1991), and it was not until the early 1990s that extensive provenance trials incorporating this material were established to examine the patterns of genetic variation in growth rate, stem straightness and frequency of multiple leaders, and the extent of genotype × environment interactions (Doran and Skelton 1982). Results from these trials, summarised by Harwood and Williams (1992), revealed that survival and growth rates of trees sourced from FNQ, PNG and Muting (Irian Jaya) were significantly superior to trees of the Subanjeriji land race. PNG provenances consistently grew fastest, closely followed by the Claudie River provenance from FNQ, with those from the Cairns region, further south in Queensland, clearly slower. The MAI of the best provenances commonly exceeded that of the base case by 30–40% (Arisman and Hardiyanto 2006).

However, until about 1995, virtually all *A. mangium* pulpwood plantations established in Indonesia had to use seedlings from the so-called Subanjeriji land race, which was derived from the first three seedlots brought from Sabah in 1979, seedlots from four provenances of the Cairns region of Queensland imported in 1980, plus seed collected shortly thereafter from several sites in Indonesia. Selected seedlings from the Subanjeriji provenance stands were used for reforestation programs and plantation development all over Indonesia during the late 1980s, but production ceased in 1995 when seed of better genetic quality from other provenances became available (Arisman and Hardiyanto 2006). Seed production areas and seedling seed orchards were established with seeds from FNQ, PNG and Muting, for mass production of *A. mangium* seedlings and, after about 1996, better genetic quality seed to populate new plantation areas became widely available. From this time, significant gains in MAI were possible simply by planting seed of wild populations from selected known localities (S. Midgley, pers. comm., 2009).

Although domestication of *A. crassicarpa* did not start until much later than for *A. mangium,* seed collections from Queensland and PNG took place at much the same time. By 1993, the species had been shown to have excellent survival and vigour at various trial sites across the humid tropics, and its suitability for pulp and paper making had been demonstrated (Midgley 2000). Within a few more years, *A. crassicarpa* was the species of choice to plant on highly organic, low pH peat-land soils that are subject to waterlogging, where *A. mangium* performs poorly. It is now a significant resource for the pulp industry in Indonesia, with more than 40,000 ha of commercial plantations established on Sumatra by 2000 (Midgley 2000).

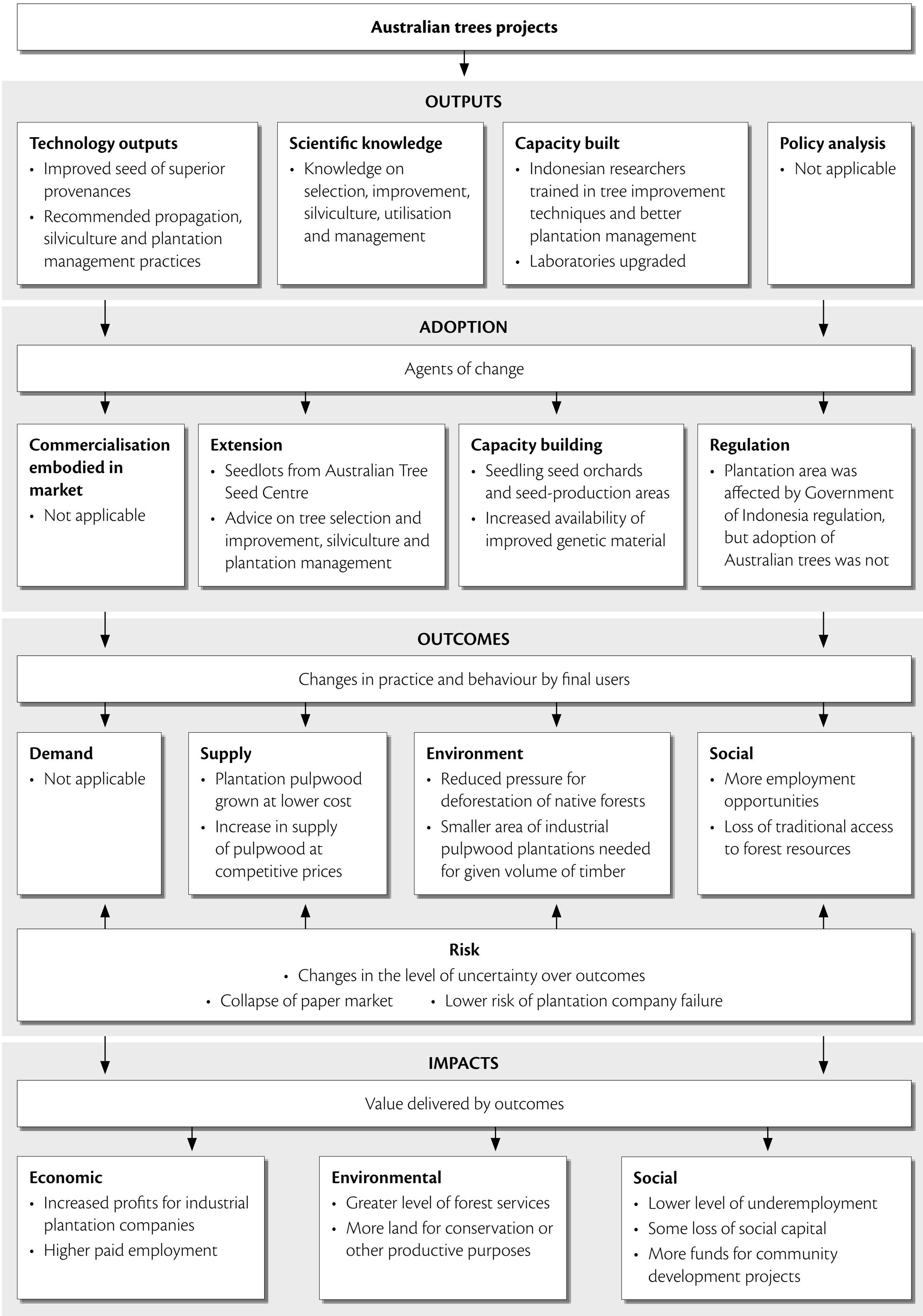

Figure 19. Impact pathway for uptake of technical outputs from the Australian trees projects

Plantation profitability parameters

Some of the technology outputs from the Australian trees projects, such as improved germplasm and better propagation and silvicultural practices, became available only progressively, over a period of more than a decade. As a result, the impact from uptake of project outputs on plantation growth rates, and on the duration of rotations, evolved during the course of the consequential scenario. This has had a significant impact on the quantity and timing of harvested timber, and on improvements in plantation productivity and profitability between rotations and over time.

Conversely, there also are several disparate reasons why plantation productivity might decline over time and/or between subsequent rotations. Genetic deterioration from inbreeding, and negative selection, sometimes from a suboptimal initial introduction based on informally collected seed (Harwood 2005), are possible sources of declining plantation productivity between rotations. Other likely reasons for declining productivity from one rotation to the next can be fire, a build-up of pests and diseases, and/or a decline in the level of basal nutrients and an incidence of other forms of site degradation.

There are no credible statistics on levels of plantation productivity achieved, or even of operational-scale growth rates for *A. mangium*, *A. crassicarpa* or *E. pellita*. The choice of parameter values to use in determining plantation productivity and profitability had therefore to be based on extensive consultation with industry experts and inferences drawn from experimental data from provenance trials.

Since HTI plantations established before 1996 had to rely on essentially the same germplasm that would have been available under the counterfactual scenario, the main consequence of uptake of technical information on superior propagation and silvicultural practices was a somewhat faster growth rate, estimated to be 25 m^3/ha/year, and a slightly shorter rotation period of 9 years. Subsequently, following uptake of improved germplasm that became widely available from 1996, the growth rate in first-rotation plantings was assumed to increase to 30 m^3/ha/year[15] and harvesting to take place after 8 years. Table 5 sets out details of these parameters for subsequent rotations, of other parameter values that determine plantation productivity for each rotation and funds flows used to calculate profitability.

Observed and projected plantation area

While the rapid evolution of a very large industrial plantation forest sector in Indonesia based mainly on Australian hardwood species is undisputed, it is extremely difficult to obtain reliable information about such basic 'facts' as the current extent of productive pulpwood plantations, let alone the area planted by year by species. Moreover, much of the evidence that is publicly available is often contradictory and contentious. For instance, Obidzinski and Chaudhury (2009) noted:

> In 2005, government figures on what were said to be established HTI plantations ranged from 1.5 to 2.5 million hectares. In the same year, FAO (Food and Agriculture Organization) claimed there were 3.3 million hectares of such plantations in Indonesia … In 2006, the Ministry of Forestry stated there were 3.03 million hectares of established timber plantations in the country …

Although about 5.96 million ha of land have been allocated for conversion to fast-growing pulpwood plantations, the World Bank (2006) estimated that only 1.83 million ha, or 31% of this allocated area, had been planted by 2006, and that, due to the Asian financial crisis, forest fires, poor management or abandonment over the years, less than half of these lands are performing well in producing timber. Industrial reforestation also has failed to meet expectations, and reported reasons include land-use conflicts, top-down approaches, inadequate attention to technical requirements (species selection, maintenance), corruption and lack of clear objectives for plantation establishment (Barr 2001). Besides requiring adequate soil fertility and topography, pulp plantations also need to be close to processing facilities or ports to be financially viable, and have to compete with oil palm and other uses for suitable land (Casson 2000; Barr 2001). Nevertheless, most plantation companies still have significant additional land areas available to expand their plantations.

Many industry insiders believe that the planted area actually producing timber may be less than the officially quoted figures (World Bank 2006, p. 77), and dispute government claims that the current annual planting rate of industrial timber plantations (HTI) is 400,000 ha.

[15] Midgley and Turnbull (2003, p. 92) cite annual wood volume increment of over 30 m^3/ha at favourable sites.

Table 5. Key parameter values and funds flows by rotation for the consequential scenario

Rotation generation		**1st**	**1st**	**2nd**	**3rd**	**4th**
Year of planting		<1996	≥1996	≥1996	≥1996	≥1996
Number of years/rotation		9	8	7	7	7
Expected mean annual increment (MAI)[a]	m^3/ha/year	25	30	27.8	27.2	27.6
Pulp from delivered timber[b]	air-dry tonne (ADT)/ha	47.78	56.30	45.63	44.68	45.40
Pulpwood equivalent price[c]	A$/ADT of pulp	320	320	320	320	320
Funds flow by year of rotation (A$/ha)[d]						
1		–2,400	–2,640	–2,640	–2,640	–2,640
2		–800	–880	–880	–880	–880
3		–800	–880	–880	–880	–880
4		–800	–880	–880	–880	–880
5		–800	–880	–880	–880	–880
6		–800	–880	–880	–880	–880
7		–800	–880	–6,018	–5,944	–6,001
8		–800	–6,856	19,621	19,215	19,525
9		–6,495	24,213			
10		20,545				
Net present value at the start of the rotation (A$/ha)		1,732	4,199	2,860	2,638	2,808
Amortised annual present value (A$/ha)		244	650	494	456	485

[a] Relative to 1st generation rotations planted post 1996; MAI for 2nd, 3rd and 4th generation rotations based on productivity gain due to superior genetics and silviculture of 5%, 10% and 20%, respectively, as well as productivity losses due to rootrot of 10%, 15% and 20%, respectively, and productivity losses due to site decline of 2%, 3% and 4%, respectively.

[b] Based on wood density of 420 kg/m^3, yield of 50% and harvesting/transport/chipping losses of 9% for rotations planted before 1996; and 450 kg/m^3, 51% and 8%, respectively, for rotations planted thereafter.

[c] Based on average implicit price for Indonesian pulp imports for 2008–09 of US$711/ADT, from FAO statistics; average exchange rate for 2008–09 of A$1=US$0.744; and Economic Research Associates' estimate that the cost of pulpwood/ADT of pulp is 45% of total pulp production costs.

[d] Based on:
- establishment costs of $2,000/ha/rotation for rotations planted before 1996, and $2,200/ha/rotation for all rotations planted thereafter
- annual maintenance and operating costs of $400/ha for rotations planted before 1996, and $440/ha/rotation for all rotations planted thereafter
- annual overheads costs of $400/ha for rotations planted before 1996, and $440/ha/rotation for all rotations planted thereafter
- harvesting fixed costs of $2,000/ha/rotation, plus variable costs of $20/$m^3$ of merchantable volume of timber harvested
- revenue/ha/rotation equal to delivered pulp × pulpwood equivalent price of A$320/ADT received AFTER end of year of harvesting.

Reliable industry sources consulted during the course of this study estimated the total area of industrial pulpwood plantations in 2008 to be between 1.2 and 1.5 million ha. This makes the prediction of future plantation forest production to be discussed below an even more problematic exercise.

A key reason for the lack of dependable statistics is that many plantations are privately owned and operated by very large corporate conglomerates which, until now, have sourced fibre for pulp and paper mills from both industrial plantations and logging concessions in natural rainforests. Much information about the operations of these corporate conglomerates is commercially confidential. Furthermore, the extent to which they rely on deforestation of tropical rainforests rather than production from industrial plantations to supply their mills is a very sensitive topic because exploitation of the former is so great an environmental issue.

According to Werren (1991, p. 107), the first industrial-scale *A. mangium* plantations in Indonesia were established in the early 1980s, mainly in Sumatra; but by 1988 only about 13,000 ha had been planted. This area was not included when calculating economic impacts from the Australian trees projects because it is unlikely that there was noteworthy uptake of project outputs during the 1980s.

Government statistics on industrial plantation forest development for the years 1989–90 to 2006, as set out in Table 6, were the only official time series of planting statistics available at the time of drafting this report. Calculation of the magnitude of uptake to date of technology outputs from the industrial plantation domestication projects was based on the data on the annual areas planted to industrial pulp plantations (HTI-pulp) in the second column of Table 6. Although the wood species planted on areas under HTI-pulp are listed as including *Pinus*, *Eucalyptus*, *A. mangium*, Meranti, Sungkai and *Gmelina melina arborea*, it is clear from other evidence cited below that virtually all of this area has been planted to *Acacia* and *Eucalyptus* species originally sourced from Australia. Equally, while it is possible that some of the areas listed in the other columns may have been planted to industrial pulpwood plantations growing *Acacia* and *Eucalyptus* species, these areas have been disregarded in this study.

To derive from the data in Table 6 estimates of aggregate area in industrial pulpwood plantations at any point in time, it needs to be recognised that the duration of a single rotation for such plantations is typically about 7–8 years. Hence, much of the area planted in the early years would have been harvested well before the end of the time series, and presumably replanted to second- or even third-rotation forest. As discussed above, there are several reasons why the productivity of first-rotation industrial plantation forests may differ significantly from the productivity of subsequent rotations, so it is important to be able to estimate the proportions of such plantings that are first, second or subsequent rotations.

For the consequential scenario involving industrial pulpwood plantations planted to Australian-sourced *Acacia* or *Eucalyptus* spp., and also employing related technology outputs from the industrial plantation domestication projects, estimates of annual areas planted to date to first, second and subsequent rotations have been calculated based on the following assumptions:

- The total annual area actually planted from 1990 to 2007 inclusive equals the areas in the HTI-pulp column in Table 6 for industrial pulpwood plantation forest development.
- The duration of first-rotation forests planted before 1996 was 9 years, but only 8 years for first-rotation forests planted from 1996 onwards. Hence, subject to the constraint below:
  - first-rotation forests planted before 1996 would be harvested at the end of year t+8; and replanted to second-rotation forests in year t+9; and so on subsequently
  - first-rotation forests planted in 1996 and later years would be harvested at the end of year t+7; and replanted to second-rotation forests in year t+8; and so on subsequently.
- The duration of second and subsequent rotations was 7 years.
- If the total area actually planted in any given year is less than the area harvested in the preceding year, then the land used longest for plantation forest would be used first for the next rotation.

The results of these calculations for the consequential scenario are presented in Figure 20, and form the basis for the calculation of realised benefits.

It can be seen from Figure 20 that the aggregate area of industrial pulpwood plantations was calculated to peak at about 1 million ha in 2000, then declined for several years following a lull in new plantings in the late 1990s due to the Asian financial crisis and changes in government support for plantation development. By 2007, the aggregate was calculated to be slightly less than 799,000 ha, made up almost entirely of second-rotation forest, and only minimal areas of first- and third-rotation plantations.

The biggest imponderable in estimating the ultimate economic impact of the Australian trees projects is the future level of annual plantings by pulpwood plantation companies (including both replanting harvested plantation areas plus any increase in total area planted to industrial pulpwood plantations).

The World Bank (2006, pp. 63–71) has argued that Indonesia is at a transition point in forest policy, and that it is now widely accepted that, because of past forest destruction, the current size of Indonesia's wood-processing industry cannot be sustained without serious intervention. Production forest lands are now more than two-thirds depleted, including one-quarter that is completely deforested. The remaining forests are incapable of sustained production at current levels and, in future, will be capable of producing only lower quality timber. Because the industrial demand for timber far exceeds the available sustainable supply from natural forests and existing plantations, the MOFR has recognised that there is an urgent need to create new timber supplies for the future, and has developed a plan for industrial restructuring, salient points of which are outlined below.

Table 6. Statistics on area (ha) of industrial plantation forest development in Indonesia for the years 1989–90 to 2006

Year	HTI-pulp	Carpentry	Crops—mainstay	HPHTC	HT—self management crops	Total
1989–90	29,160	102,495	–	–	–	131,655
1990–91	65,661	104,213	–	–	–	169,874
1991–92	104,222	109,769	–	–	–	213,991
1992–93	83,962	150,891	–	–	–	234,853
1993–94	113,066	188,646	71,895	–	–	373,607
1994–95	117,940	100,873	77,973	–	–	296,786
1995–96	162,200	103,000	61,248	–	–	326,448
1996–97	172,320	123,897	94,324	–	–	390,542
1997–98	100,883	77,184	88,542	–	2,500	269,109
1998–99	82,604	52,366	45,536	–	2,072	182,578
1999–2000	85,744	51,749	–	–	1,169	138,662
2000–01	58,152	21,597	–	–	2,569	82,317
2001–02	56,299	10,673	–	–	500	67,472
2002–03	87,614	13,873	–	1,121	15,900	118,508
2003–04	100,497	18,755	–	1,456	3,983	124,691
2004–05	112,714	19,200	–	–	–	131,914
2005–06	142,598	20,527	–	–	–	163,125
2006–07	200,169	31,785	–	–	–	231,954

Source: Directorate General of Forestry Production Development website at <http://74.125.153.132/translate_c?hl=en&sl=id&u=http://www.dephut.go.id/Halaman/Buku-buku/2007/strategis07/II3-II4.pdf&prev=/sea>, accessed 24 August 2009

Note: HTI = industrial timber plantations; HPHTC = forest concession mixed crops; HT = timber plantation.

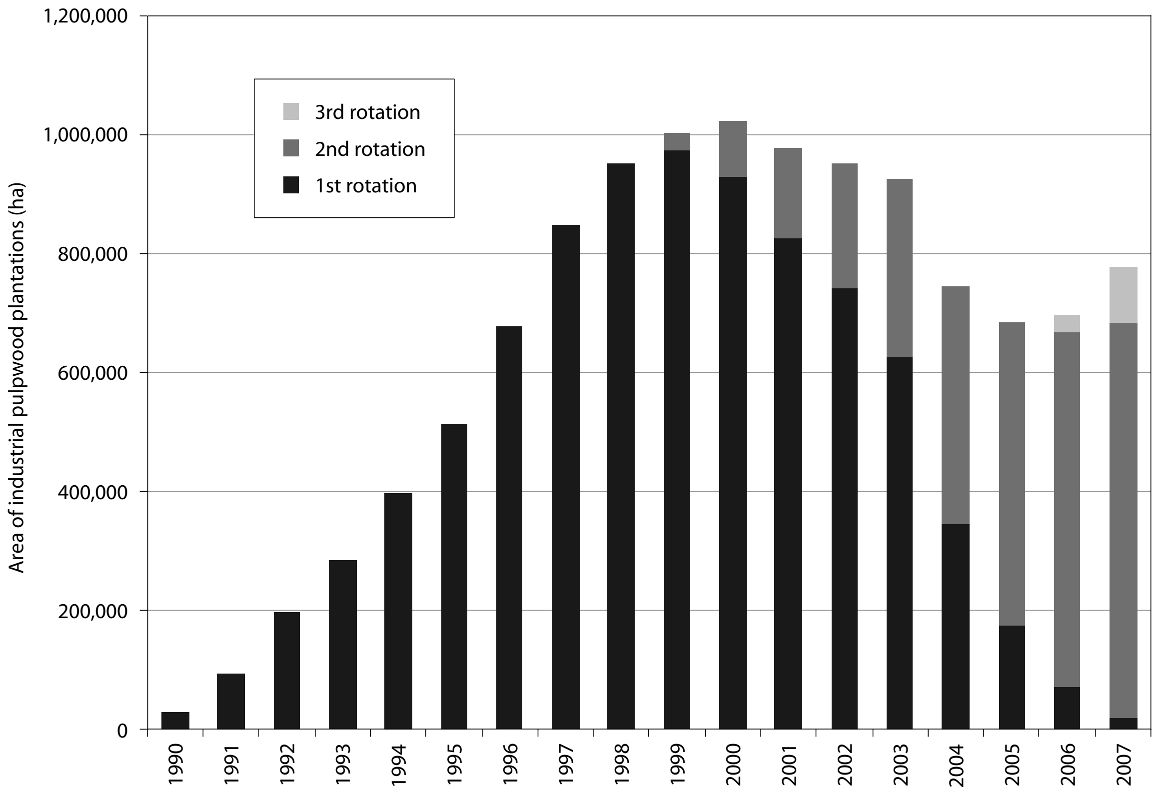

Figure 20. Annual industrial plantation plantings of first-, second- and third-rotation forests in Indonesia, inferred for the consequential scenario from official statistics on annual total area actually planted from 1990 to 2007

The latest Government of Indonesia forest policy involves very ambitious targets for growth of industrial plantations. The aim is to stimulate investment in 9 million ha of new industrial timber plantations in Indonesia by 2016, and thereby switch entirely to plantation-based forestry to produce a permanent solution to the timber supply–demand disparity (Obidzinski and Chaudhury 2009, p. 80). While massive investment in the expansion of all types of plantations is planned, it will be necessary to more than treble the current area of industrial pulpwood plantations if these targets are to be met.

The MOFR believes that it will be able to achieve its objectives by taking advantage of favourable global trends and by creating a number of incentives, such as:

- simplified application procedures for plantation concession permits that will be valid for up to 100 years
- a tax exemption for the first 8 years of operations
- plantation investors being allowed to use available natural timber stock on their plantation concessions as collateral for bank loans, or as raw material for mills
- government funding for timber plantation development from over $5 billion in the Funding Body for Forest Development.

However, there is considerable doubt about the extent to which these targets will be achieved in the future because actual plantation areas to date have fallen well short of previous less-ambitious targets.

Some recent predictions are contained in the 2009 Indonesia Forestry Outlook Study by the Center for Forestry Planning and Statistics (CFPS 2009). In this study, experts from various fields of forestry analysed, in conjunction with MOFR officials, the current state of Indonesian forests and helped to develop probable growth scenarios for an Indonesia Forestry Outlook to 2020. The four scenarios developed were labelled: socioeconomic development stalls (S1), unsustainable growth (S2), low-growth development (S3) and sustainable development (S4). For each scenario, the starting point was an area of 1.9 million ha of pulp plantations in 2006 that grew to 2.6 million ha in 2020 under scenarios S1 and S3, or to 3.3 million ha in 2020 under scenarios S2 and S4. Table 7 sets out the assumptions about annual increment to area planted, total area planted and pulp production under each of the four scenarios.

A conservative approach to projecting future areas of industrial pulpwood plantations was taken in this study, starting with the above estimate that the aggregate planted area in 2007 was less than 800,000 ha, rather than the level of about 2 million ha assumed in the 2009 Indonesia Forestry Outlook Study (CFPS 2009). Next, because future levels of plantings are so uncertain, and because there are serious doubts about the likelihood of achieving the target levels of aggregate industrial pulpwood plantation area projected in the Outlook Study S4 scenario, projected future annual aggregate plantings were based on a conservative outlook involving future annual pulpwood plantation plantings that would increase from about 200,000 ha in 2007 to 300,000 ha in 2009, then remain at that level in perpetuity.

The estimated annual areas planted to first, second, third and subsequent rotations for this conservative outlook are depicted in Figure 21. It can be seen that the aggregate area of industrial pulpwood plantations would reach between 2.5 and 3.0 million ha under this conservative outlook. If these plantations were well managed, then they should be capable of sustainably producing between 50 million m^3 round wood equivalent (RWE) and 60 million m^3 RWE. The Center for Forestry Planning and Statistics (CFPS 2009, p. 6) states that installed capacity of the pulp industry currently is 29 million m^3 RWE, so this capacity could be doubled even if only the conservative outlook for future plantation expansion were achieved.

The counterfactual scenario

There are two possible counterfactual scenarios about how the Indonesian industrial pulpwood plantation sector would have developed if outputs from the Australian trees projects, such as improved Australian hardwood tree species and associated advances, had not been available. One is that growth of the area of industrial forest plantations would have been much slower and not as extensive. The second is that the growth and extent of the industrial plantation sector would have been very similar to what has happened, and is projected to happen, but that plantation productivity would have been lower because second-rate germplasm would have been planted and inferior practices used to establish and manage the plantations. It is clear from the background to the development of HTI plantations described above that this development was driven primarily by Government of Indonesia development priorities and policies, and that the area planted would have been much the same even if outputs from the Australian trees research projects had not been available. Consequently, this study assumes the second of the two counterfactual scenarios outlined above.

Under this counterfactual scenario, the HTI companies would initially have had to rely for many years on unselected wild genetic material of very poor quality to establish their *A. mangium* plantations. Germplasm that would have been available would have included the first seedlots imported from Malaysia in 1979 by Government of Indonesia staff, and local Indonesian provenances collected from Sidei (Manokwari), Seram and Sanga-sanga by Indonesian researchers in 1982. It also is doubtful if the four provenances of *A. mangium* from the Cairns region that were an important component of the Subanjeriji land race would have been imported in the absence of the collaborations between Australian and Indonesian researchers established during the Australian trees projects. The inferior growth rates of the available material were demonstrated in the 1982 provenance trials at Subanjeriji and Benakat.

Also absent would have been access to Australian and other technical expertise to assist in setting up seedling seed orchards and seed production areas, or to investigate improved methods to establish and manage plantations, including propagation and silvicultural practices. Thus, the first-rotation trees would have been slow growing, and would have probably taken 10 years to be ready for harvest. It is arguable, however, that plantation establishment and operating costs would have been somewhat lower than for the consequential scenario.

Table 7. Annual and total areas planted, and pulp production, for the four scenarios in the 2009 Indonesia Forestry Outlook Study, over the period 2007–20

Scenario			2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
S1	Extra area planted	'000 ha	75	90	90	90	90	90	90	90	0	0	0	0	0	0
	Total area planted	'000 ha	1,975	2,065	2,155	2,245	2,335	2,425	2,515	2,605	2,605	2,605	2,605	2,605	2,605	2,605
	Production	million m^3	7.2	7.7	10.9	13.3	12.6	14.6	16.2	11.4	11.2	13.8	15.5	14.4	16.3	17.9
S2	Extra area planted	'000 ha	150	180	180	180	180	180	180	180	0	0	0	0	0	0
	Total area planted	'000 ha	2,050	2,230	2,410	2,590	2,770	2,950	3,130	3,310	3,310	3,310	3,310	3,310	3,310	3,310
	Production	million m^3	7.7	8.6	12.1	14.8	14.4	16.4	17.9	16.0	15.5	17.9	19.3	17.9	19.8	21.4
S3	Extra area planted	'000 ha	75	90	90	90	90	90	90	90	0	0	0	0	0	0
	Total area planted	'000 ha	1,975	2,065	2,155	2,245	2,335	2,425	2,515	2,605	2,605	2,605	2,605	2,605	2,605	2,605
	Production	million m^3	7.2	7.7	10.9	13.3	12.6	14.6	16.2	11.4	11.2	13.8	15.5	14.4	16.3	17.9
S4	Extra area planted	'000 ha	150	180	180	180	180	180	180	180	0	0	0	0	0	0
	Total area planted	'000 ha	2,050	2,230	2,410	2,590	2,770	2,950	3,130	3,310	3,310	3,310	3,310	3,310	3,310	3,310
	Production	million m^3	7.7	8.6	12.1	14.8	14.4	16.4	17.9	16.0	15.5	17.9	19.3	17.9	19.8	21.4

Source: CFPS (2009, p. 51)

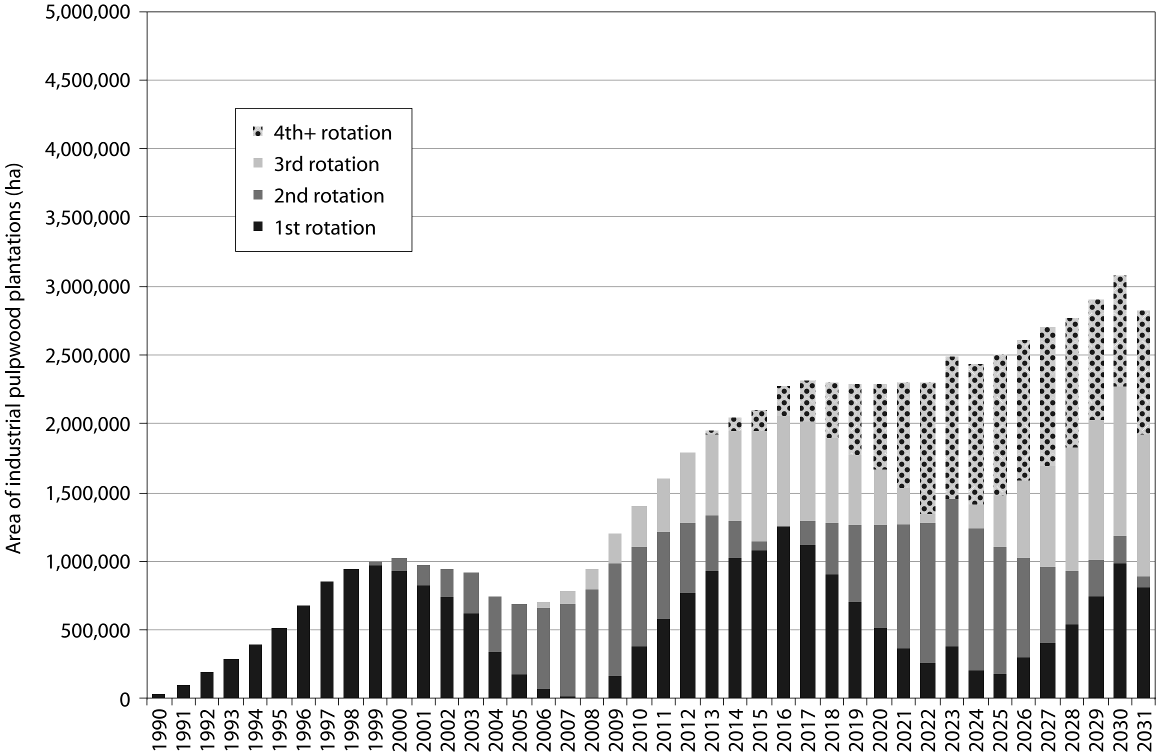

Figure 21. Estimated annual industrial plantation area of first-, second-, third- and fourth-rotation forests for the consequential scenario if future plantings increase to 300,000 ha/year

Plantation profitability parameters

Based on widespread consultation, it was conjectured that first-rotation growth rates would have been 22 m^3/ha/year, which is only 12% lower than the MAI for first-rotation plantations established before 1996 in the consequential scenario. On the other hand, harvesting and transport losses would have been higher due to poor tree form. Details of other parameter values for the counterfactual scenario that determine plantation productivity for each rotation, and funds flows used to calculate profitability, are set out in Table 8.

Inferred plantation areas

For the counterfactual scenario, in which industrial pulpwood plantations do not have access to technology outputs from the industrial plantation domestication projects, estimates of annual areas planted to date to first- and second-rotation forests, and subsequent rotations, have been calculated based on the following assumptions:

- The annual total area actually planted from 1990 to 2007 inclusive equals the areas in the column for HTI-pulp in Table 6 for industrial pulpwood plantation forest development.
- The duration of first-rotation forests was 10 years. Hence, subject to the constraint below, first-rotation forests planted in year *t* would be harvested at the end of year *t*+9; and replanted to second-rotation forests in year *t*+10; and so on subsequently.
- The durations of second, third and fourth rotations were 9, 8 and 7 years, respectively, due to 'learning by doing'.
- If the actual total area planted in any given year is less than the area harvested in the preceding year, then the land used longest for plantation forest would be used first for the new rotation.
- Under the conservative outlook, future annual aggregate plantings would increase from about 200,000 ha in 2007 to 300,000 ha in 2009, then remain at that level in perpetuity.

Table 8. Key parameter values and funds flows by rotation for the counterfactual scenario

Rotation generation		1st	2nd	3rd	4th
Number of years/rotation		10	9	8	7
Expected mean annual increment (MAI)[a]	m^3/ha/year	22	23.3	25.4	27.0
Pulp from delivered timber[b]	Air-dry tonnes (ADT)/ha	46.20	45.56	46.60	44.39
Pulpwood equivalent price[c]	A$/ADT of pulp	320	320	320	320
Funds flow by year of rotation (A$/ha)[d]					
1		−2,400	−2,400	−2,640	−2,640
2		−800	−800	−880	−880
3		−800	−800	−880	−880
4		−800	−800	−880	−880
5		−800	−800	−880	−880
6		−800	−800	−880	−880
7		−800	−800	−880	−5,922
8		−800	−800	−6,178	19,091
9		−800	−6,214	20,041	
10		−6,360	19,591		
11		19,868			
Net present value at the start of the rotation (A$/ha)		502	1,327	1,969	2,570
Amortised annual present value (A$/ha)		65	187	305	444

[a] Relative to 1st generation rotations; MAI for 2nd, 3rd and 4th generation rotations based on productivity gain due to superior genetics and silviculture of 20%, 40% and 60%, respectively, as well as productivity losses due to rootrot of10%, 15% and 20%, respectively, and productivity losses due to site decline of 2%, 3% and 4%, respectively.

[b] Based on wood density of 420 kg/m^3, yield of 50%, and harvesting/transport/chipping losses of 10% for 1st generation rotations; 430 kg/m^3, 50% and 9%, respectively, for 2nd generation rotations, 440 kg/m^3, 51% and 8%, respectively, for 3rd generation rotations, and 450 kg/m^3, 51% and 8%, respectively, for 4th and subsequent generation rotations.

[c] Based on average implicit price for Indonesian pulp imports for 2008–09 of US$711/ADT, from FAO statistics; average exchange rate for 2008–09 of A$1=US$0.744; and Economic Research Associates' estimate that the cost of pulpwood/ADT of pulp is 45% of total pulp production costs.

[d] Based on:

- establishment costs of $2,000/ha/rotation for 1st and 2nd generation rotations, and $2,200/ha/rotation for 3rd, 4th and subsequent generation rotations
- annual maintenance and operating costs of $400/ha for 1st and 2nd generation rotations, and $440/ha/rotation for 3rd, 4th and subsequent generation rotations
- annual overheads costs of $400/ha, for 1st and 2nd generation rotations, and $440/ha/rotation for 3rd, 4th and subsequent generation rotations
- harvesting fixed costs of $2,000/ha/rotation, plus variable costs of $20/$m^3$ of merchantable volume of timber harvested
- revenue/ha/rotation equal to of delivered pulp times pulpwood equivalent price of A$320/ADT received AFTER end of year of harvesting.

The estimated annual areas planted to first, second, third and subsequent rotations for the counterfactual scenario are presented in Figure 22. Note that, in contrast to the consequential scenario in which aggregate area of industrial pulpwood plantations is projected to plateau at about 3.0 million ha by the year 2030, for the counterfactual scenario the aggregate plantation area peaked at about 2.8 million ha in 2020, before declining to less than 2.5 million ha by 2031. The explanation for this discrepancy is the different lengths of the forest rotations between the two scenarios. Because the average length of rotations of plantations in the counterfactual scenario is greater than for the consequential scenario, for the same rate of annual planting a greater area of trees will remain in the ground at any given future date.

Estimated benefits from the Australian trees projects

Indonesia is a net exporter of pulp, but accounts for less than 5% by value of trade in pulp (FAO 2010), so although global demand for pulp might be somewhat inelastic, demand for Indonesian exports will be highly elastic. As a result, an increase in supply of fibre to pulp mills due to uptake of technology outputs from the Australian trees projects will have minimal effect on pulp prices, and any gain in consumer surplus will be negligible.

The Indonesian market for pulp is depicted in Figure 23. S_0 is the supply curve for the counterfactual scenario, and S_1 that for the consequential scenario. Economic surplus equals the difference between producer surplus of $P_{01}cd$ for the consequential scenario and $P_{01}ab$ for the counterfactual scenario. Both supply curves are drawn as becoming increasingly inelastic due to pressure to conserve forest land and competition from other land uses.

Data availability for pulp production and trade are much better than for sandalwood, but prices paid by pulp mills for plantation timber are not generally available due to commercial secrecy. In any case, to capture all the benefits from the superior provenances of trees that became available after 1996 in the consequential scenario, it was necessary to compute the production of pulp because these improved trees had somewhat better yield and density, and hence delivered more pulp for a given volume of harvested timber.

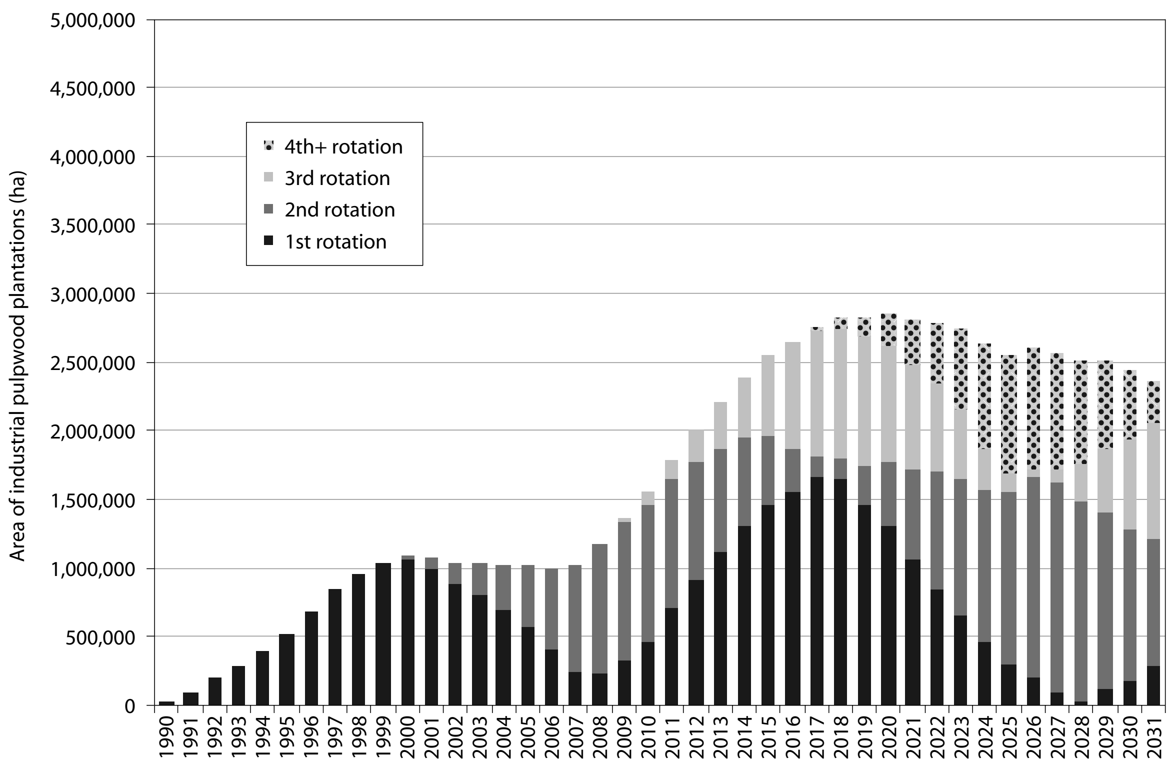

Figure 22. Estimated annual industrial plantation area of first-, second-, third- and fourth-rotation forests for the counterfactual scenario if future plantings increase to 300,000 ha/year

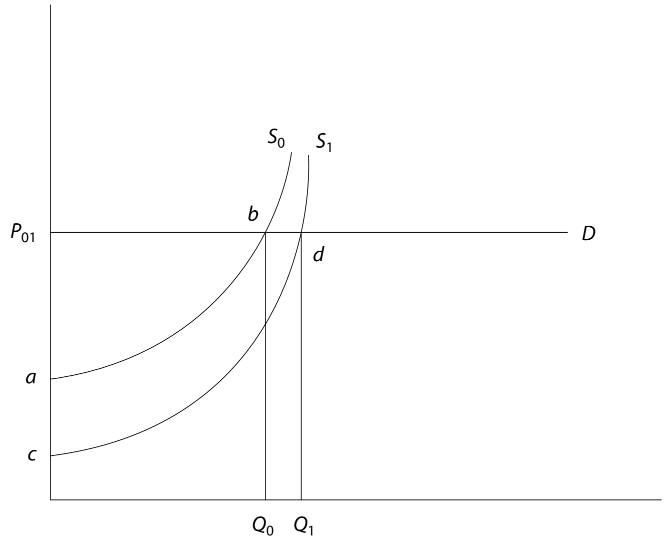

Figure 23. Outcomes in the world pulp market from uptake of technology outputs from the Australian trees projects in Indonesia

Furthermore, differences between the two scenarios in the duration and productivity of successive rotations made it even more important to track the area planted and harvested on a year-by-year basis to predict annual flows of costs and returns. For the consequential scenario, the total area of the plantation estate at any point in time consists of areas of trees of different age. In any year, the area for each age group is multiplied by net returns per ha for trees of that age. Summing across age groups gives the net return in that year. The counterfactual scenario is treated similarly. The difference between the consequential and counterfactual scenarios in each year gives a stream of net returns representing the net benefits from the ACIAR technology. Note that this approach only approximates the area of surplus gain identified in Figure 23.

Annual financial returns from establishing the conjectured area of industrial pulpwood plantations were estimated separately for each scenario by multiplying the area planted each year to each rotation by the corresponding cost per ha for the year of planting and subsequent years, and by the estimated return in the year of harvest for that rotation. Economic benefits from the Australian trees projects were then calculated by subtracting one set of annual funds flows from the other.

While almost all of the area of industrial pulpwood plantations has been planted to *Acacia* and *Eucalyptus* species of Australian origin, that alone is not sufficient evidence of complete uptake of the technology outputs on all plantations. Compelling evidence of uptake of project outputs by three major industrial pulpwood plantations companies was provided by project documentation, and in meetings held with Australian and Indonesian researchers who collaborated on the projects, as well as with Indonesian government officials, and with company staff. Confidential data on forestry plantation areas by company in 2008 were provided to the author by industry sources during a field trip. The three largest plantation companies, namely RAPP, AA and MHP, all of which were directly involved with one or more of the Australian trees projects, controlled 1,380,000 ha of an estimated total plantation area of 1,736,284 ha. This suggests that uptake of project outputs benefited at least 67% of total plantation area, given the likelihood that there was at least partial uptake on some of the plantations controlled by other companies. However, there also was evidence that many smaller plantation companies were not well managed (World Bank 2006, p. 77) and may not have adopted all, or even any, of the project outputs. Furthermore, even for the large companies, plantation management was sometimes poor in the early years, with the result that not all of the potential productivity gains might have been realised. Accordingly, estimated benefits were calculated on the basis of a very conservative assumption that there was full uptake of project outputs on only 50% of aggregate plantation area.

The technology outputs from the Australian trees projects are enduring innovations for which the benefits relative to the counterfactual scenario will continue in perpetuity. If these outputs were to become obsolete due to being displaced by even better technologies, then plantation productivity and profitability for the consequential scenario would constitute the baseline for measuring benefits of the new innovation.

Some of the benefits have already been realised because the plantations have been harvested and the timber delivered to pulp mills. Future benefits will come from harvesting trees already planted but not yet ready to harvest, and from plantations that will be planted and later harvested. The estimates of realised benefits reported below recognise only the value of fibre harvested by the end of 2009, and do not impute any value to standing timber already planted but not yet harvested, even although costs incurred to the end of 2009 for plantations of standing timber are included in the estimate. This is a very conservative approach, and the reported estimate of realised benefits is a lower bound to possible values that could be calculated if the value of standing timber were also recognised. No such problem arises for measures including future benefits, because such benefits continue indefinitely.

The present value of realised benefits up to the end of 2009 from the Australian trees projects was calculated to be $3,842 million, which far exceeds the present value of the less than $37 million total investment by ACIAR, its partners and complementary investments by other agencies in all of the Indonesian plantation forestry projects evaluated in this study. The distribution of fund flows by year that underpin this estimate are illustrated in Figure 24. The amounts are given in Table A3 in Appendix 3. Note that fund flow values for 1990 to 1996 were zero because during this period the plantation areas were identical for both the consequential scenario and the counterfactual scenario and no pulpwood was harvested.

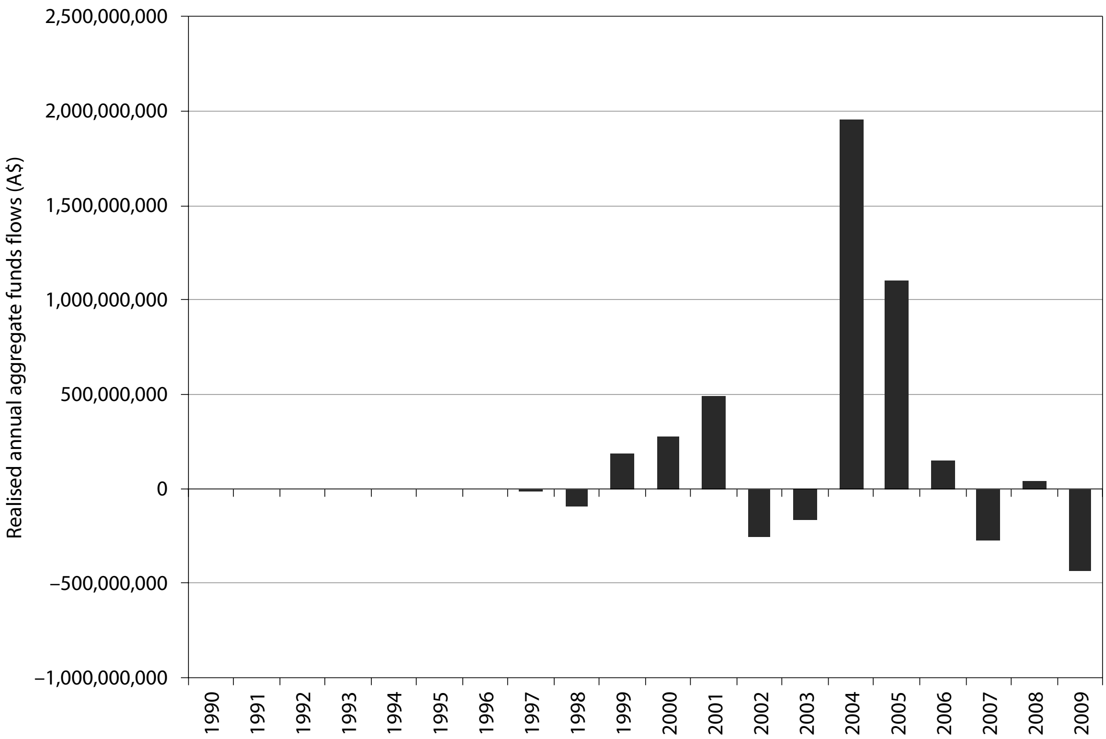

Figure 24. Realised annual aggregate funds flows arising from the Australian trees projects to the end of 2009

The present values of all estimated benefits for the Australian trees projects are set out in Table 9, together with the total estimated investment by ACIAR and other agencies in these projects. Despite the huge magnitude of these benefits, the development of industrial plantations to supply fibre to large pulp mills is a contentious issue. Some critics argue that industrial pulpwood plantations have adverse environmental impacts, others criticise alleged undesirable social impacts, and there is widespread concern about the inequitable distribution of the benefits.

Table 9. Estimated present value of benefits and costs (2009 A$ million) of the Australian trees projects

Benefits			Costs
Realised	Prospective	Total	
3,842	14,134	11,148	19

Environmental, social and poverty impacts of industrial pulpwood plantations

Obviously, industrial pulpwood plantations growing *A. mangium* and other Australian hardwood tree species are monocultures that lack the biodiversity of natural rainforests. Equally, there is no doubt that much of the supply of fibre to the rapidly developing pulp and paper mills in Indonesia to date has come from logging natural forests rather than from harvesting of sustainable industrial plantations. It is also true that the Government of Indonesia granted forest concessions to large plantation companies as part of a package of incentives that was provided to stimulate plantation development.

These associated facts have led to claims that development of industrial plantations has been one of the causes of deforestation, with consequent loss of biodiversity and emergence other forms of environmental degradation. Such claims ignore the fact that deforestation preceded plantation establishment, as most plantations are established on land classified as secondary forest. Moreover, given the history of the development of the timber industry in Indonesia, the plausible counterfactual scenario to development of the industrial pulpwood plantations is that the natural forests would still have been logged, leaving the land as either badly degraded forest or, worse still, as unproductive non-forest land such as *Imperata* grasslands.

With regard to estimated benefits of the Australian trees projects, the relevant counterfactual scenario is one where development of the industrial pulpwood plantations would have happened in much the same way as has actually happened, except that productivity and profitability of the plantations would have been lower than has been the case. Relative to this counterfactual scenario, it is hard to see how these research projects could have had significant adverse environmental impacts.

Moreover, looking to the future, the Government of Indonesia has recognised that further development of industrial pulpwood plantations to ensure a sustainable supply of plantation-grown fibre sufficient to satisfy the demand from existing and future pulp and paper mills is the only feasible way to reduce logging pressure on natural rainforest. Accordingly, it plans substantial increases in the area of plantation forests. If these plantations are more productive, have shorter rotations and grow faster, then the total area of industrial pulpwood plantations needed to supply any given volume of timber will be less than for the counterfactual scenario. The Government of Indonesia also decreed that, from 2009, pulp and paper mills must source all of their fibre supplies from industrial plantations. It is too early to know how effectively this decree will be implemented.

What is already clear, however, is that the large industrial pulpwood plantation companies have invested significant funds in the development of certification and authentication systems for timber delivered to their mills. By such measures, they are gaining certification from organisations such as the Indonesian Ecolabelling Institute (Lembaga Ekolabel Indonesia; LEI) and the Forest Stewardship Council that their operations comply with chain-of-custody protocols and do not use timber from illegal logging. In addition, they have declared moratoria on plantation development in areas of high conservation value forests within their concessions, and profess to have developed systems of forest management that will mitigate deterioration of fragile ecosystems, such as peat-land forests that have been heavily affected by uncontrolled drainage from abandoned canals.

More generally, these companies claim to employ broadly based business models to manage their operations on a sustainable basis that balances social and economic development with the conservation of biodiversity and ecological values. They run professional public relations departments that produce, fairly regularly, environmental and social sustainability reports. In such reports, as well as in press releases and other publications, they highlight activities they are supporting to avoid environmental problems, such as programs to protect endangered species including Sumatran tigers and elephants. They also claim to be following forest management practices that will assist with greenhouse gas reduction and carbon sequestration.

The development of industrial pulpwood plantations has also had various social impacts. Arguably, the most significant positive social impact has been creation of jobs, both directly and indirectly through the procurement of goods and services from local supply chains, as well as induced as a result of the economic activities of those directly or indirectly employed. Many of these jobs require a level of skills, and create a demand for training that is often funded by the plantation companies for its own employees. Hence, some jobs are better remunerated than unskilled employment.

Notwithstanding a degree of scepticism about some of the claims by plantation companies about the level of employment generated,[16] it is indisputable that a significant labour force is required to establish plantations, maintain and manage them, and harvest and transport the timber.[17] Furthermore, because the plantations are located in rural areas of Sumatra and Kalimantan where poverty levels are high, the social impacts of the projects might contribute to poverty reduction. However, some of this labour would also have been employed under the counterfactual scenario, but additional employment will come from higher productivity in the existing plantation area and this will have some impact on the reduction of poverty. Conversely, if the new management techniques consequential on uptake of project outputs are more labour intensive, then more labour might be employed per hectare, thus offsetting a larger plantation area under the counterfactual scenario.

Another social impact has been mitigation of land-use conflicts. Previously, tensions between plantation companies and local communities due to a poorly defined land tenure system were suppressed under the New Order regime. However, these tensions have subsequently erupted into numerous land-use conflicts that at times have disrupted plantation operations and stopped the establishment of new plantations. Unlike the employment and poverty impacts, land-use conflicts for the consequential scenario should be lower if less land is needed for industrial pulpwood plantations to supply a given volume of timber.

In any case, at least the major industrial pulpwood plantation companies have taken initiatives to build partnerships with local communities, and have implemented a number of social benefit programs in recent years. Specific initiatives have included investments in programs that promoted educational opportunity, supported community culture, provided greater access to health care and raised the quality of life in villages surrounding their operations. Presumably, the capacity of the companies to fund such initiatives depends in part on their profitability, so research projects that raise plantation profitability should have a positive effect on this form of social impact.

Possible impacts of industrial plantation protection projects

These projects produced an impressive range of capacity-building outputs, but so far few technology outputs ready for adoption by end users. Normally, it takes many years for uptake of capacity-building outputs to become evident, but it is already clear in this case that knowledge gained during the heartrot project has had impacts in the form of avoided losses. Specifically, the findings from this study have led ACIAR, as well as project members, to reorganise priorities for future research. These findings have

16 For instance, in an Asia Pulp and Paper (APP) media release (2009), it was claimed that 37 jobs are created for every 100 ha of plantation developed. A much more modest number of 'around 35 permanent new jobs are created for every 100,000 ha the company plants' was quoted by the CEO of APRIL in a talk to a symposium on certification during Pulp Week 2007.

17 For instance, in a social footprint assessment for APP Indonesia, Environmental Resources Management (2009) reported that the pulpwood production plantations operated by Sinarmas Forestry and its partners employed 5,382 permanent employees and 372 contract workers, of whom 24% were recruited from local communities, and the total annual cost of wages was US$15,497,957.

contributed too to decisions by plantation companies in Indonesia and Australia to reverse earlier operational plans. Estimation of the magnitude of such benefits is even more problematic than cost–benefit analysis of uptake of technology outputs, because specifying the counterfactual scenario is even more speculative than usual. Consequently, the discussion below merely seeks to outline some of the considerations that might influence the size of such benefits.

In summarising the proceedings of a workshop on 'Heartrot and rootrot in tropical acacia plantations', Potter et al. (2006) concluded that future research to manage heartrot needs to focus on alternative host species that demonstrate an inherent resistance to the disease rather than on the pathogen because *A. mangium* is a species that appears very susceptible to heartrot. As a result, the incidence of heartrot on some sites will exclude the sustainable production of *A. mangium* for its solid-wood values. The focus of research has now shifted to rootrot, a disease that is a much more serious threat to industrial pulpwood plantations. There also was some evidence of uptake of such knowledge by stakeholders from industry and government. For instance, some pulpwood plantation companies have abandoned plans to extend the rotation length of parts of their plantation to produce sawlogs for solid-wood products (MHP, pers. comm., 2009).

In Australia, investigations to explain the factors that determine decay development and spread have focused on *Eucalyptus nitens* plantations in Tasmania. An important result was that all decay columns in pruned trees were confined to the knotty core and the amount of clear wood without decay increased over time (Beadle et al. 2008). In other words, this species actually limits pruning decay into clearwood after pruning. The results of these studies informed the industry that the risk of pruning decay, about which they were concerned, was low in species such as *E. nitens* (C. Mohammed, pers. comm., 2009), thereby enabling the industry to implement pruning practices to maximise plantation productivity.

The most adoption-ready technology output from the heartrot project was a set of recommended pruning practices to mitigate damage from heartrot. As already noted, most acacia plantations in Indonesia produce wood for pulp and paper production only. While stem- and heartrot fungi can affect pulp yield and market acceptability, in practice pulpwood plantation companies have largely avoided this potential problem by harvesting early (i.e. in less than 8 years), while the volume of wood affected, if any, is small. Hence, there is no reason for these companies to adopt uneconomic pruning practices, and they will continue to produce timber exclusively for pulp because *A. mangium* is very susceptible to decay from pruning wounds.

However, this avoidance strategy is not an option for plantations growing *A. mangium* for higher value solid-timber production. Not only does production of marketable solid wood for sawn timber require more-mature trees that are at much greater risk of severe stem defects and extensive heartrot, but green pruning to remove persistent branches is also an important practice that contributes to optimal tree size and form and high rates of recovery of merchantable timber.

There are a few Indonesian plantation companies that have mature plantations of *A. mangium,* but do not have sales agreements with pulp mills. These plantations conceivably could benefit from the findings of the ACIAR-funded heartrot research because short rotations and/or minimal pruning are not an option. At best, however, uptake of recommended pruning practices to mitigate damage from heartrot will be limited to this small number of industrial plantations that might be able sell harvested trees for sawn timber. Nevertheless, while it is possible that a small part of the *A. mangium* plantation estate in Indonesia might benefit from strategies to reduce the severity of the heartrot problem, it is difficult to ascertain the area of these plantations, and information on sawlog volumes available is particularly unreliable.

Of the existing acacia plantation resources, Thorp (2005) notes that 80% are affiliated to existing pulp mills and that, although a small proportion of the harvest might be suitable for sawn timber production, none of the largest pulp companies are currently interested in use of such logs for timber production. Most of the remaining 20% of large acacia plantations were established for planned pulp mills that are yet to be built, and currently are not affiliated to any existing pulp mills. While these unaffiliated plantations are the main potential source for acacia timber at present, the only high-volume market for logs at present is for pulpwood.

Thorp (2005) identified 16 potential acacia sawlog suppliers as possible partners in the International Finance Corporation's Program for Eastern Indonesian SME Linkages (Pengernbangan Usaha; PENSA) Sustainable Supply Chain Linkages program, which aims to develop supply chains from sustainably managed acacia plantation companies to furniture manufacturers. Based on ease of wood transport logistics, availability of mature plantations and experience of sawlog production, four geographically proximate plantations in East and South Kalimantan were rated as the 'most likely suppliers' of sawlogs for the foreseeable future. If 50% of the potential volume from this cluster of plantations were milled, then sawlog production could be 83,000 m^3 of logs per year, which would suffice to meet about 5% of the Indonesian furniture industry's timber consumption.

However, while there is a significant profit premium from selling sawlogs rather than pulpwood, currently there is little demand for acacia sawn timber due to the availability of high-quality, low-cost natural forest timber from outside Java, plus teak and mahogany from plantations on Java. In addition, future demand for acacia sawn timber may be limited by its reputation for being difficult to work with, and because sawmilling, kiln drying and other quality issues are still being investigated. In addition, the major pulp producers are committed to taking over many of the unaffiliated acacia plantations to supply their expanding pulp industries, which may lead to much of the potential supply of sawlogs identified by Thorp being redirected to pulp mills. Hence, it was concluded that almost all production timber from *A. mangium* plantations will continue to be consumed by pulp mills, and that use of acacia by local sawmills will remain a small niche industry for the foreseeable future. This might explain why no evidence was found of uptake by Indonesian plantation companies of research outputs from the heartrot project.

Lastly, the possibility of a serendipitous impact in Australia from the heartrot project needs to be mentioned. Some of the research staff who worked on the ACIAR project are now employed by Australian hardwood forest companies, and are responsible for plantation management, including the timing and intensity of pruning. While uptake of recommended pruning practices is not considered necessary to mitigate heartrot damage in *E. nitens* plantations, knowledge gained during the project has been used to devise pruning practices to optimise timber production (D. Wiseman, pers. comm., 2009). No attempt has been made to quantify this benefit because the plantation area involved is small, and there is a lack of evidence about the extent of modifications to pruning practices that can be attributed to the ACIAR project, and about consequential outcomes, as it will still be many years before the trees are harvested.

4 Review and conclusions

Starting in 1987, ACIAR has invested in a series of collaborative research projects between Australian and Indonesian scientists, with the aim of improving plantation forestry in both countries. The present value of the direct investment by ACIAR in the 12 projects assessed in this study that contributed to the possible generation of benefits in Indonesia and Australia is $14.74 million. In addition to ACIAR, many other agencies also invested in these projects. The commissioned organisations were CALM, ATSC and CSIRO Forestry and Forest Products, CIFOR, the University of Tasmania and CSIRO Sustainable Ecosystems. Details of Indonesian project partners and other agencies involved are described under funding in Chapter 2 of this report. The present value of the combined investment by ACIAR, its partners and other agencies was estimated to be $37 million.

In Table 10, total investments are broken down by clusters of projects that have similar aims and outcomes. Consequential benefits were estimated for the two clusters where there was clear evidence of uptake of technology outputs from the projects. For the other project clusters in Table 10, the reasons for not estimating benefits are classified as one of:

- no evidence of uptake/impact
- insufficient information available to quantify benefits
- too early to reliably assess.

The largest investment, approximately 50% of the total, was in the Australian trees projects cluster. Initially funded from 1983 by AusAID, then by ACIAR from 1993 for more than another decade, uptake of technology outputs by Indonesian industrial pulpwood plantations from this series of projects has yielded extraordinary returns on this investment. Based on conservative assumptions both about the proportion of plantation area benefiting from uptake of project outputs, and about future rates of planting of industrial pulpwood plantations, the present value of realised benefits to date is estimated to be A$3,842 million, and the present value of total benefits A$11,148 million.

Several factors contributed to these very large benefits. First, the area of the Indonesian industrial pulpwood plantations grew rapidly from less than 100,00 ha in 1990 to about 1 million ha by 2000 and, if the plans of the Government of Indonesia are even partly realised, will continue to grow rapidly to a peak of at least 3 million ha, and possibly as much as 5 million ha. The impetus for this growth during the 1990s was due almost entirely to government policy and, arguably, would have taken place at much the same rate had outputs from the Australian trees projects not been available.

Second, uptake of the technology package from the Australian trees projects enabled very significant gains in plantation productivity and profitability. In particular, improved provenances of Australian hardwood tree species, most notably *A. mangium,* but also including, among others, *A. crassicarpa* and *E. pellita,* were markedly superior to any of the alternatives available at the time, in terms of increased growth rates, shorter rotations, improved tree form and increased pulp yield. For instance, relative to productivity of first rotations on non-adopting plantations, adoption of the technology package in first rotations after 1996 was calculated to increase volume of merchantable wood per hectare per year by 39%, pulp yield per hectare per year by 52% and the amortised NPV per year from a single rotation by as much as 900%.

Third, due largely to such huge initial advantages in plantation productivity and profitability, early uptake of the Australian trees technology packages was rapid and

Table 10. Present value of investment and benefits (2009 A$ million) for ACIAR plantation forestry project clusters

	Present value of investment		Present value of total benefits	
	ACIAR only	All sources	Indonesia	Australia
Multipurpose trees projects	3.71	7.57	0	766.48
Australian trees projects	7.06	19.40	11,148.00	NI
Molecular breeding project	0.77	2.28	0	0
Sustainability project	0.20	1.13	0	0
Pest and disease survey projects	0.19	0.40	0	0
Heartrot project	1.18	2.99	NI	NI
Rootrot project	0.84	1.16	NI	TE
Site management project	0.80	2.07	TE	TE
Total	14.74	37.00	11,148.00	766.48

Note: 0 = no evidence of uptake/impact; NI = insufficient information available to quantify benefits; TE = too early to reliably assess.

extensive. While the advantage of the Australian project packages was substantially reduced for subsequent rotations, the technology provided the foundation for ongoing R&D by most Indonesian plantation companies. Although only anecdotal evidence is available on the extent of uptake of technology from the Australian trees projects, a conservative assumption was made in this study that it was adopted on only 50% of total plantation area.

Perhaps the magnitude of the estimated returns from uptake of outputs from the ACIAR projects are best set into some perspective by comparing them with gross returns from the industrial pulpwood plantation sector. Unfortunately, there are no official published statistics on the value of pulpwood plantation production. However, using the same assumptions used to estimate NPV of total ACIAR project returns of A$11,148 million, it was estimated[18] that the NPV of total pulpwood production over the same time frame was A$131,900 million. In other words, estimated R&D returns were less than 10% of the value of gross production. Although unusually big, this proportion is plausible given the extraordinarily large gains in plantation productivity and profitability enabled by uptake of technology outputs from the Australian trees projects.

The next largest investment was in the multipurpose trees projects, which accounted for 20% of the total investment by ACIAR and other agencies. Widespread uptake of the technology outputs from these two projects enabled the development of an irrigated sandalwood plantation industry in the ORIA. Benefits from this outcome have yet to be realised, because so far only small-scale trial plots have been harvested, but commercial-scale harvesting of the *S. album* resource should commence in about 4 years time. It is estimated that benefits with a present value of A$766 million will be generated from these projects.

Outputs to date from the remaining 27% of the investment in plantation forestry research have been mainly in capacity building, for which further investment would be needed to yield technology outputs ready for adoption by end users. For instance, the only output from the sustainability project was publication of a book recording knowledge about sustainability criteria and indicators for plantation forests. Such knowledge may have contributed to the development of forest product accreditation schemes that many people hope will help protect threatened natural forests. However, this particular project was a very small cog in a very big wheel, and no evidence was found that the knowledge it produced was instrumental in establishing forest product accreditation schemes. It also is not clear yet whether the forest product accreditation schemes that have been established will achieve the desired outcomes.

18 Estimate by Economic Research Associates based on the same assumptions used to estimate ACIAR project returns.

The cluster of five pest and disease projects, which accounted for about 12% of the total investment in plantation forestry research assessed in this study, provides an example where there is evidence of uptake of knowledge. Findings from the early survey projects were subsequently used in investment decisions by ACIAR and research partners to fund, first the heartrot project, then the rootrot project.

The heartrot project did produce some adoption-ready technology outputs but, with the benefit of hindsight, it seems likely that uptake will be minimal. Virtually all *A. mangium* plantations in Indonesia will continue to avoid serious heartrot problems by keeping rotations short and harvesting trees solely for pulp production. Consequently, potential uptake will be limited to a few small plantations that will have to overcome strong competition in markets dominated by more popular plantation timbers such as teak and mahogany. In Australia, it was found that *E. nitens*, the species being researched, was not as susceptible to heartrot as had originally been thought.

By contrast, rootrot is regarded almost universally as a very serious problem threatening productivity throughout the industrial pulpwood plantation industry in Indonesia. However, it is also a particularly intractable problem and it remains to be seen whether cost-effective rootrot control options can be developed that will be economic for industrial pulpwood plantations to adopt.

The site management project also was not complete at the time of writing and it is too early to forecast the technology outputs that this project will produce, or the extent to which they will be adopted and lead to impacts.

The overall findings from this study are summarised in Table 11, which shows the estimated present value of benefits already realised, as well as total predicted benefits under a conservative outlook for further industrial plantation development in Indonesia. Also included in Table 11 are the present value of the total investment in the plantation forestry projects assessed in this study, the overall NPV, the benefit:cost ratio and the internal rate of return.

Apportioning total benefits between the various sources of investment is always problematic and often controversial. The normal method of doing so is to attribute benefits on the basis of cost shares. On this basis, $1,307 million of the present value of realised benefits to date from the ACIAR plantation forestry projects could be attributed to ACIAR. It is projected that the present value of total benefits attributable to ACIAR could eventually be as much as $4,746 million. Arguably, this might be an underestimate, because it was considered doubtful by some participants in the development of commercial sandalwood plantations in the ORIA that there would have been any such development had ACIAR not funded the agroforestry projects. By contrast, the CSIRO Division of Forest Research clearly played a pivotal role in generating the benefits from the Australian trees projects and, had ATSC not been created and developed, it is doubtful that Australian hardwoods would have been domesticated and their seed made available widely for plantation development. Nevertheless, AusAID and ACIAR were significant, albeit not the only, funding sources for ATSC. Furthermore, without this funding, the operations of ATSC might have been largely focused on Australian plantation development and, at best, uptake of technology packages from the Australian trees

Table 11. Summary measures of returns from ACIAR plantation forestry projects

	Realised benefits	All benefits
Present value of benefits (2009 A$ million)	3,281	11,914
Present value of all costs (2009 A$ million)	37	37
Net present value (2009 A$ million)	3,244	11,877
Benefit:cost ratio	89	322
Internal rate of return[a]	54.3%	54.4%

[a] The internal rate of return (IRR) for realised benefits is almost identical to that for all benefits because cash flows are the same from 1982 to 2010, and it is the cash flows during these early years that have by far the greatest influence on the IRR.

projects in countries such as Indonesia would have been much diminished.

Observations on the successful ACIAR investment in plantation forestry research in Indonesia include the following:

- The majority of the investment, about 70% of the total, has already produced technology outputs that have been very extensively adopted and have generated substantial impacts and impressive returns on ACIAR's investment.
- Unfinished projects may also produce technology outputs that are adoption ready and are likely to generate significant impacts.
- With the exception of the investment by ACIAR in the two early multipurpose trees projects, the focus of all of the projects assessed in this study was on improving or maintaining productivity and profitability in the industrial pulpwood plantations in Sumatra and, to a lesser extent, Kalimantan. Due mainly to government policy during the 1990s, the area of these industrial pulpwood plantations grew from less than 100,00 ha to about 1 million ha by 2000 and, even when based on conservative assumptions, is projected to expand further to a steady state of nearly 3 million ha.
- The uptake of Australian hardwood tree species, most notably superior provenances of *A. mangium,* but also including, among others, *A. crassicarpa* and *E. pellita,* in industrial pulpwood plantations has been one of the most successful outcomes of Australian forestry research. In particular, uptake of the technology package from the Australian trees projects increased tree growth rates, reduced the duration of rotations, improved tree form and increased the yield of pulp. As a result, the pulp yield per hectare per year from first-rotation plantations that adopted the technology package after 1996 was calculated to be 52% greater than that achieved on non-adopting plantations. Notwithstanding the likelihood that similar technology packages eventually would have been developed and adopted by Indonesian plantation companies, thereby eroding almost all of this productivity advantage, the first-mover advantage generated very large returns.
- Most of the science that produced these very large impacts in Indonesia was low tech. Research that enabled development of commercial sandalwood plantations in the ORIA was also relatively low tech. On the other hand, there has been a lack of uptake of outputs from projects such as that researching molecular marker technologies for genetic improvement of forest trees, which involved high-tech and high-cost science.
- Despite these successful outcomes, plantation forestry is a relatively long-term investment, and even short-rotation forestry as practised in the Indonesian industrial pulpwood plantations takes 7 years to yield positive cash flows. It also is an enterprise with some risks associated with fire, disease and pest threats. Therefore, research outputs that lead to significant productivity or quality improvements increase the profitability of the forestry enterprise and can reduce some of the risks associated with the long investment cycle of plantation forestry.
- There is little doubt that the benefits from the Australian trees projects have been inequitably distributed, with the majority of the benefits going to the large plantation company owners, and that the contribution to poverty alleviation may have been comparably small. Nevertheless, while it is difficult to prove, it seems that the benefits to the rural poor in Sumatra and Kalimantan probably outweigh the combined cost of the investment by ACIAR and other agencies.
- The research in the agroforestry projects that enabled development of commercial sandalwood plantations in the ORIA also was relatively low tech, but again seems certain to generate significant impacts. Most of these benefits will be captured by investors in MISs and/or by shareholders in MIS companies, although Indigenous people are likely to benefit from increased employment associated with the harvesting of the sandalwood in the next few years.

Appendix 1 The projects—history, objectives and outputs

History

Since at least 1985, ACIAR has funded research on developing and improving tropical plantations of Australia's unique genetic resource of hardwoods. In 1987, ACIAR started funding 20-plus collaborative forestry projects between Australian and Indonesian scientists. For some, the aim was the development of agroforestry based on multipurpose trees, but for most the aim was to improve plantation forestry in both countries. The scope of 12 key studies included the domestication of Australian trees for reforestation and agroforestry, silvicultural practices, control of fungal and insect pathogens, development of sustainable management systems and the application of molecular marker technologies for genetic improvement of forest plantations.

In addition to *Eucalyptus*, our most important genus, ACIAR projects in Indonesia have concentrated mainly on selected *Acacia* species with the potential for rapid growth in a wide variety of environments, including arid and saline areas. As well as thriving at many sites, most species of these trees fix atmospheric nitrogen to a greater or lesser extent, making them valuable in agroforestry and mixed-cropping systems. While the first projects on Australian tropical acacias were in countries other than Indonesia, the process of selecting acacias for higher productivity than traditionally achieved in the tropics laid the foundation for improvements to the commercial potential of tropical plantation forestry in many countries including, in particular, Indonesia.

Little could be discovered about the history of the agroforestry projects beyond the fact that there was concern among some scientists about the degradation of the natural resource base of multipurpose trees in eastern provinces of Indonesia. Traditionally, multipurpose trees provided the foundation for an integrated agroforestry system that underpinned moderately productive subsistence farming.

The history of industrial plantation domestication projects stretches back many years to the establishment of the Australian Tree Seed Centre (ATSC) in 1962. The centre is now part of CSIRO.[19] The impetus for the creation of ATSC was a formal request from the Food and Agriculture Organization of the United Nations (FAO) to set up a seed centre with the objectives:

- to assemble and disseminate technical information on *Eucalyptus* species most suitable for wood production and for sheltering field crops, for use in countries outside Australia
- to assist in the procurement of seeds of *Eucalyptus* species suitable for use in countries outside Australia
- to conduct research in genetics of *Eucalyptus* and in tree breeding for improved varieties.

Nevertheless, the initial focus was primarily domestic, and for the first few years, ATSC was funded primarily by CSIRO. According to Byron (1992), the charter of ATSC subsequently was expanded to include all Australian genera of useful woody plants, from small

19 The initial establishment was by predecessor organisations within the Forest Research Institute.

shrubs to tall trees. From 1966, FAO also provided modest financial support in recognition of the additional workload required to service a growing number of international requests for seeds and technical advice that was beyond CSIRO's normal mandate or resources.

In 1979, AIDAB (now AusAID) started to support ATSC as a componenadt of Australia's development assistance activities to developing countries within its mandate. Later, support was formalised by providing funding of $589,000 for the 'Seeds of Australian trees for developing countries' (SAT) project from 1983 to 1988. The broad aim of this project was to provide germplasm and technical assistance, including training, to developing countries to establish research trials to evaluate which species and provenances of Australian tree species were most likely to be productive and ecologically sustainable under local conditions.

After a favourable review in 1987, a significantly enlarged project was funded for a further 5 years from July 1988 to June 1993 with a total budget of $2.8 million. The revised mandate was to:

- cover all developing countries, but with special emphasis on the least developed
- focus on a range of end uses additional to timber production
- provide greater emphasis on training and technical assistance to complement the supply of seeds.

Following another favourable review that recommended ACIAR take over responsibility for this project, ATSC, by then part of the Forestry and Forest Products division of CSIRO, was commissioned to continue Phase 3 of the SAT project with funding from ACIAR of around $600,000 per year for a further 5 years from July 1993.

Other recommendations of the review that were accepted included:

- broadening the scope of activities to include other Australian species besides those of the four main genera (*Eucalyptus*, *Acacia*, *Casuarina* and *Grevillea*) with applications in Asia
- addressing problems of species–site compatibility (semi-arid, alkaline and saline sites, *Imperata* grasslands)
- undertaking work relating to root symbionts with a view to propagation and distribution as part of the seeds/information package
- increasing advisory and training services, particularly with respect to species selection in general and in-country seed production
- increasing monitoring and follow-up activities for species performance and effectiveness of training.

Some of these recommendations were taken up some years later in subsequent projects in the industrial plantation domestication cluster of cognate projects.

In 1998, the SAT project was extended for one more year pending preparation of a proposal for a further 5-year project with modified objectives. The new 'Domestication of Australian trees for reforestation and agroforestry systems in developing countries' project, commonly referred to as DAT, was funded for 5 years until the end of 2004. Lastly, a small extension was funded in 2006–07, mainly to ensure a service function of continued supply of certified lots of high-quality seeds of eucalypts, acacias, melaleucas and casuarinas to country partners for research studies on species suitability, species–site matching and establishment of seed orchards, seed production areas and genetic gains trials.

Hence ATSC, SAT and DAT have been a more or less continuous series of development-assistance projects supporting the international use of Australian forest genetic resources for more than 40 years. However, unlike most ACIAR projects, SAT and DAT were multicountry reactive projects that responded to thousands of specific individual requests for assistance from many countries.

During the 1990s, there was growing recognition of a number of impediments not only to achieving further gains in potential plantation productivity and profitability, but also to preserving the initial productivity gains from the introduction of certified genetically improved seed of Australian hardwood species of proven superior provenances.

For instance, by the end of the SAT project, it was recognised that inbreeding and negative selection in seed orchards with restricted genetic diversity were limiting potential gains in plantation productivity, and even resulting in genetic deterioration in plantations of

Australian hardwood species. Concurrently, the rapidly developing science of molecular biology seemed to offer the prospect of a sophisticated solution to this problem. This led, among other things, to the initiation of ACIAR project FST/2000/122 involving the application of molecular markers to genetic improvement of Australian hardwood plantation species.

There also was growing recognition that some of the potential gains in plantation productivity were not being realised due to poorly adapted plantation management practices. This led to the development of the current ACIAR project FST/2004/058, which aims to realise the potential of genetic gains in plantation productivity through better adapted water and nutrient management.

However, arguably the greatest threat to preserving and further improving plantation productivity was, and remains, the possibility of large production losses from attack by pests and diseases. Starting in 1995, ACIAR has funded a cluster of industrial plantation projects in response to this threat. The first three projects, FST/1995/110, FST/1995/124 and FST/1997/035, funded limited-scale surveys to scope the incidence of various insect pests and fungal pathogens, and to assess the severity of the potential threats to tree growth and plantation productivity from prevalent pests and diseases. Based on the findings from these preliminary studies, ACIAR subsequently decided to fund the two projects, FST/2000/123 and FST/ 2003/048, on fungal heartrot and rootrot in Australian plantation hardwoods, but principally in plantation acacias in Indonesia.

Lastly, ACIAR contributed to an international movement to foster more sustainable forest management by funding FST/1996/182. This so-called industrial plantation enhancement project on criteria and indicators for sustainable management of tropical plantation forests was managed in collaboration with the recently established CIFOR.

Objectives

The stated objectives of each project for each cluster of projects are reported in this section.

The agroforestry projects

FST/1986/013 – Fuelwood and sandalwood silviculture in eastern Indonesia

1. To assemble germplasm of a range of Indonesian and exotic tree species which can satisfy East Nusa Tenggara (ENT) requirements for fuelwood and/or forage.
2. To test the adaptability and growth of these species on a range of soil types in ENT in the seasonally dry regions.
3. To improve the research capabilities of Indonesian researchers in ENT.
4. To assist Indonesia in obtaining basic silvicultural information needed to underpin a program for regeneration of the sandalwood industry in ENT.

FST/1990/043 – Multipurpose tree and sandalwood silviculture in Indonesia

1. Assist BPK to define a group of multipurpose trees (MPTS) for fodder, fuel and small poles adapted to the soil types and climate of West Timor and Sumba Island.
2. Commence a research program into cultural methods for selected MPTS to produce the outputs required by small farmers in ENT.
3. Develop a reliable establishment technique for sandalwood plantations in ENT and the Kimberley region of WA.
4. Continue sandalwood silvicultural research, including the selection of plus trees in West Timor.
5. Support the conservation of germplasm of other commercial sandalwood species outside Australia in secure reserves or seed production areas.

The industrial plantation domestication projects

FST/1993/118 – Seeds of Australian trees (SAT) project

1. To provide certified seeds to developing-country institutions so that they may establish seed orchards.
2. To provide developing-country institutions with up-to-date information on selection, improvement, silviculture and management of plantations.
3. To provide training courses for recipients of seeds.

FST/1998/096 – Domestication of Australian trees for reforestation and agroforestry systems in developing countries

Service objectives:

1. To improve clients' access to Australian forest genetic resources.
2. To ensure clients have current information on selection, improvement, silviculture, utilisation and management.
3. To increase clients' knowledge and skills on selection, improvement, silviculture, utilisation and management.

Research objectives:

1. To identify key factors for improved seed orchard management.
2. To improve management in existing seed orchards in two countries.
3. To establish new seed orchards in two countries.
4. To assess, through genetic gain trials, the additional productivity and value obtained in four selected countries by using seed orchard rather than unimproved alternative seed sources.

FST/2000/122 – Application of molecular marker technologies for genetic improvement of forest plantation species in Indonesia and Australia

In Indonesia:

1. To develop and implement molecular procedures to determine parentage of selections in open-pollinated families derived from mini-breeding arboreta or seed orchards.
2. To determine levels of inbreeding and gene flow within a commercial seed orchard of *A. mangium.*
3. To generate fullsib crosses through a mini-breeding arboretum in field trials.
4. To identify, on a pilot scale only, areas of severe phyllode rust occurrence, and assess the scope for application of quantitative trait loci (QTLs) to select for resistance in acacias.

In Australia:

1. To confirm QTLs for rooting and frost tolerance in hybrid families of *E. grandis* × *E. globulus.*
2. To develop marker-aided selection strategies for multiple traits for application in molecular hybrid breeding through selection of superior breeding lines using markers associated with QTLs for use in the next generation of breeding.
3. To transfer experimental procedures and marker-aided selection strategies developed for *E. grandis* × *E. globulus* hybrids and for *A. mangium* × *A. auriculiformis* molecular hybrid breeding in Indonesia and elsewhere in South-East Asia.
4. To enhance scientific and technical skills of Indonesians to make optimum use of molecular technology in forest tree breeding.

FST/2004/058 – Realising genetic gains in Indonesian and Australian plantations through water and nutrient management

1. To quantify the role of site edaphic properties and phosphorus in realising gains from deployment of genetic gain across sites, and to develop appropriate management strategies for maximising productivity and economic value.
2. To develop a capacity to predict potential productivity of *A. mangium* in relation to site factors in Indonesia and Australia.
3. To evaluate economic benefits of improved management in outgrower schemes.
4. To develop practical tools to support improved management.

The industrial plantation protection projects

FST/1995/110 – Fungal pathogens as a potential threat to tropical acacias

To conduct a disease survey of tropical acacias in native trial stands and operational plantings in India, Malaysia, Thailand, Indonesia and Australia, to provide an indication of the potential of fungal pathogens as limiting factors to tree growth and productivity and to assess the relative importance of individual pathogenic fungal species.

FST/1995/124 – Potential insect threat to plantations of acacias and eucalypts in tropical Asia

To gather data about current pests and the severity of their occurrence in plantations of Indonesia, Malaysia, Thailand and Vietnam to enable forest managers to identify, assess, and handle pests, and to contribute to setting priorities for further research.

FST/1997/035 – Fungal pathogens as a potential threat to tropical acacias

To prepare a publication reporting the results of disease surveys of tropical acacias in native stands, trials and operational and social forestry plantings, to assess the potential of fungal pathogens as limiting factors to tree growth and productivity, and to assess the relative importance of individual fungal species.

FST/2000/123 – Heartrots in plantation hardwoods in Indonesia and South-East Australia

1. To assess the incidence of root- and heartrots in different Indonesian environments.
2. To establish the relationship between silvicultural practices, especially singling multistemmed trees and pruning of *A. mangium*, with the incidence of heartrot in Indonesian plantations.
3. To establish the relationships, in different environments, between *A. mangium* provenances, *A. crassicarpa* and *A. mangium* × *A. auriculiformis* hybrids, and eucalypts selected for other traits such as leaf pathogen/insect resistance and form (single stemming and small branch diameter), and the incidence/risk of heartrot in pruned and non-pruned stems.
4. To develop DNA-based methods coupled with traditional taxonomical and pathological methods to identify and characterise fungi causing rot (in the absence of fruiting bodies) in acacias and eucalypts and detect their presence in symptomless wood as an aid to the above objective.
5. To provide guidelines to assist plantation managers in Indonesia to reduce heart- and rootrot incidence in plantations.
6. To provide revised selection criteria for tree improvement projects in Indonesia to reflect outcomes of the research.
7. To transfer technology by staff exchange, training courses and postgraduate training, report and guideline preparation, and dissemination of project results to end users (private forest industry companies, sawmillers).

FST/2003/048 – Management of fungal rootrot in plantation acacias in Indonesia

1. To identify the causal agent(s) of rootrot disease and characterisation of their field biology. This information will provide direction for the development of effective biological control agents and the realisation of the potential benefits from options for chemical control.
2. To investigate factors that influence root-disease distribution. These factors will include soils, topography, aspect and rainfall and will be based on a similar investigative process being used in hoop pine plantations in Queensland. It will also consider changes in leaf and crown level morphology and physiology that will be used to provide advice on early detection and response to disease development.
3. To develop and apply cost-effective rootrot control options for the outgrower sector.

The industrial plantation enhancement project

FST/1996/182 – Testing and developing criteria and indicators for sustainable management of tropical plantation forests

1. To develop methods to identify scientifically sound and cost-effective criteria and indicators (C&I) for sustainable management of plantation forests.

2. To identify scientifically sound and cost-effective C&I relevant to the sustainable management of plantation forests at selected sites in collaborating countries.
3. To validate C&I identified by the project.

Capacity-building and technical outputs

This part of the appendix is subdivided into separate sections for each cluster of ACIAR projects. Within each section, planned capacity-building outputs are first outlined, followed by discussion of the extent to which planned outputs were achieved and whether there were also any serendipitous outputs.

The second part of each section deals with technical outputs, starting with planned outputs and the extent to which they were achieved, and whether any serendipitous outputs were realised. Lastly, the available evidence on uptake of achieved technical outputs is reviewed. With the exception of the two detailed impact assessments in Chapter 3, assessment of achievement and uptake of planned outputs was based predominantly on project reports, interviews with project leaders and anecdotal evidence.

The agroforestry projects

Planned capacity-building outputs from the two agroforestry projects included the following:

1. improved capacity of Indonesian scientists in ENT to carry out research into cultural methods for selecting MPTS required by small farmers in ENT
2. publications in English and Bahasa Indonesia reporting new scientific knowledge about performance of a large number of Australian MPTS in ENT gained from results of species and provenance trials
3. publications in English and Bahasa Indonesia reporting new scientific knowledge about proven propagation practices to enable seed orchards to produce quantities of selected MPTS for ENT smallholders to grow as part of traditional mixed-farming systems
4. trial sites created for ongoing evaluation of species and provenances of, and cultural methods for, MPTS
5. publications in English and Bahasa Indonesia reporting new scientific knowledge about reliable techniques for establishment and ongoing management of sandalwood plantations in ENT and the ORIA
6. secure reserves or seed production areas of alternative commercial sandalwood species outside Australia to support the conservation of sandalwood germplasm
7. a network of sandalwood researchers established through the publication of a *Sandalwood Research Newsletter*.

While some planned institutional-strengthening outputs were achieved for this cluster of projects, due to a combination of project implementation problems, others were not achieved. These included such things as the failure to have a signed memorandum of understanding with the Indonesian Ministry of Forestry, and unfavourable weather conditions in several years of the project. Moreover, as far as could be determined, there has been little if any utilisation in Indonesia of the capacity created by these projects since their completion.

- Institutional strengthening achieved included considerable enhancement of the capacity of BKP to carry out research into cultural methods for selecting MPTS required by small farmers in ENT; plus formal training for one BPK staff member who gained a Masters degree in natural resource management, and several BPK staff who completed a short training course in statistical methods.

  There has been no known utilisation of project-specific skills built during the projects. All of the Indonesian staff associated with the projects who acquired project-specific research skills in forestry science reportedly moved to other locations and/or organisations shortly after completion of the projects. Consequently, it is highly unlikely that the project-specific skills built by the projects were gainfully employed in future years.

  Some of these human-capacity-building outputs are generic skills acquired from the formal training components, and it is probable that such skills proved useful to the individuals involved, although it has not been possible to determine if these staff were actually able to utilise some generic skills, such as training in statistical analysis. However, as is the case for all ACIAR projects, there is a strong prima facie presumption that generic skills will have been utilised no matter where former project participants end up working.

- Significant new knowledge about performance of MPTS in ENT was gained from species and provenance trials, as well as knowledge about proven propagation practices to enable seed orchards to produce quantities of MPTS seed. A novel finding from the trial results was the demonstrated importance of inoculation with a suitable strain of *Rhizobium* when evaluating the performance of *Acacia* species. However, it seems that little of this knowledge was reported in publications in either English or Bahasa Indonesia. Furthermore, for reasons to be discussed below, no evidence was found that this knowledge built by the projects about ways to improve agroforestry systems in ENT by growing improved varieties of MPTS has been utilised to any significant extent.
- While trial sites were established to enable ongoing evaluation of species, provenances and cultural methods of MPTS, much of this essential infrastructure built during the projects has been allowed to degrade through lack of resources, and/or has been destroyed by fire, weeds and depredation.
- One of the more impressive outputs from the projects was more than 20 publications on the biology of sandalwood, including an improved understanding of its genetic variation in Timor, and on reliable techniques for the establishment and management of sandalwood plantations in the ORIA, and to a lesser extent in ENT. However, while there is demonstrable evidence of large-scale uptake of this knowledge in the ORIA, there is no evidence of any utilisation in ENT. There also seems to have been limited utilisation of new knowledge about genetic variation in sandalwood to support the conservation of germplasm of other commercial sandalwood species, and the projects did not establish secure reserves or seed production areas outside Australia to support the conservation of sandalwood germplasm. However, as a result of the projects, CALM had the advanced knowledge of sandalwood silviculture and technical capacity to establish genetic conservation stands of *S. album*.
- Last, but not least, the *Sandalwood Research Newsletter* was an initiative conceived by the ACIAR project team, when the founding editor was a research officer employed by the ACIAR projects and based in the ORIA. First issued in 1993, the newsletter continues to be published. Its aim is to raise awareness about *Santalum* species by the distribution of international scientific literature to:
  - promote *Santalum* species conservation
  - stimulate *Santalum* species plantation establishment
  - increase *Santalum* species research
  - increase *Santalum* species literature exposure.

Planned technical outputs from the two agroforestry projects included:

1. an extension package of recommended MPTS to plant on specific soil types and climatic regions of ENT to address critical resource shortages of fuelwood, timber, and fodder for villagers in West Timor and eastern Sumba
2. established seed orchards utilising proven cultural methods for production of improved MPTS planting stock
3. reliable operational-scale establishment techniques for sandalwood plantations in West Timor, and in the ORIA in the Kimberley region of WA.

In Indonesia, only some of the planned technical outputs were achieved due to a variety of technical and administrative difficulties, including problems in locating and accessing suitable representative experimental trial sites on forest land, technology issues with production of high-quality seedlings and unfavourable weather conditions. Even more disappointing was the virtually complete lack of uptake of achieved outputs in Indonesia, due at least in part to lack of commitment and extension effort both by government agencies and non-government organisations (NGOs).

By contrast, in Australia, all of the planned technical outputs were achieved despite some delays in making an appointment of a sandalwood research officer in WA.

- An extension package of recommended species of superior, better adapted MPTS to plant in ENT was produced, but there has been virtually no observed uptake in Indonesia of this technical output. Initially, NGO groups working to improve farmer practices in Sumba took up the results of field trials that identified suitable MPTs adapted to the soil types and climate of Sumba to tackle critical resource shortages of fuelwood and fodder, but these efforts were not sustained because of shortages of resources, administrative problems and staff movements.

  More than 5 years after these projects finished, another ACIAR project (AS2/2000/157 – Leucaena management in West Timor and Cape York) commenced in West Timor to introduce improved cultivars of MPTS, including a productive and psyllid-resistant leucaena hybrid. For this project, it was again deemed necessary to establish seed orchards and on-farm research/demonstration sites of MPTS in selected target villages, indicating that similar outputs from the earlier projects had not persisted.

- Seed orchards utilising an effective direct-seeding regime for the establishment of improved MPTS germplasm of *Sesbania grandiflora* and *Acacia auriculiformis* were developed during the life of the projects, but fell into disuse when the projects finished because of a failure to have a signed memorandum of understanding with the MOFR, and consequent lack of funds for protection and maintenance of these sites.

- In Australia, the projects succeeded in developing reliable establishment techniques for sandalwood plantations, and establishment survival figures of 90% were being achieved at Kununurra by the last 2 years of the project. The uptake of such outputs by plantation forestry companies that have established a new forestry industry in the Kimberley region of WA based on Indian sandalwood (*Santalum album)* has been discussed in detail above.

- No comparable success in developing sandalwood establishment techniques was achieved in Indonesia due to lack of resources and contractual problems.

- Establishment of a program to conserve and develop remaining genetic resources of *S. album* in ENT was hindered by the unwillingness of the Indonesian MOFR to supply germplasm of Indonesian sandalwood for research in Australia.

Uptake of achieved outputs has been substantial, and is evident in the thousands of hectares planted to *S. album* that were established and are being managed with technology outputs developed by the agroforestry projects. A more detailed assessment of the significant contribution made to the development of a sizeable sandalwood plantation industry in the ORIA is provided in Chapter 3 of this report.

The industrial plantation domestication projects

As discussed above, the ACIAR-funded SAT and DAT projects grew out of earlier development-assistance projects run by ATSC that supported the international use of Australian forest genetic resources as part of Australia's aid program. As a result, the characteristics of the outputs that evolved were heavily influenced by the services provided in response to thousands of specific individual requests for assistance from many countries, rather than by formally planned outputs as is more common for most ACIAR projects.

Planned capacity-building outputs from the cluster of industrial plantation domestication projects included:

1. an extensive body of new knowledge about the most productive species and provenances of *Eucalyptus*, *Acacia*, and other Australian genera prominent in tropical plantation forestry, such as *Casuarina*, *Grevillea* and *Melaleuca,* gained from international species and provenance trials
2. training and technical advice on the domestication and best use of Australian tree and shrub species
3. an international network of depositories of superior, certified germplasm of Australian hardwood species derived primarily from seed collection expeditions made by ATSC staff and collaborators
4. a network of trained scientific researchers within the Asia–Pacific region

5. a recording system and database to help improve client access to germplasm information on species and provenance performance
6. new knowledge about molecular markers for *A. mangium* in Indonesia, such as
   - DNA fingerprints of selected lines and their parents
   - extent of inbreeding, gene flow and pollen contamination in seed orchards
7. training the staff of the Center for Forest Biotechnology and Tree Improvement (CFBTI) to perform microsatellite screening and genetic analysis of molecular marker data
8. an established clonal mini-breeding arboretum and identified valuable seed collections for future breeding to strengthen the institutional capacity of the CFBTI to carry out a new strategy for further research and advanced tree breeding
9. new knowledge about molecular markers for *Eucalyptus globulus* in Australia, such as QTLs for rooting ability and frost tolerance to be used as selection tools for these traits
10. superior lines for eucalypt breeding programs
11. increased level of understanding of water and nutrient management of *A. mangium* plantations in Sumatra
12. increased level of understanding of water and nutrient management of *A. mangium* plantations in Tiwi Islands
13. staff with postgraduate degrees from Australian universities.

The following section discusses the achievement and utilisation of built capacity for the industrial plantation domestication projects, focusing mainly on the early Australian trees projects and on project FST/2000/122. It is premature to assess uptake of built capacity outputs from project FST/2004/058 because it is still in progress.

- Government research agencies and the larger private plantation companies in Indonesia now have well-established in-country progeny testing and breeding programs and seed orchards and, in some cases, clonal propagation programs for mass-production of genetically improved planting stock. This extensive tree improvement infrastructure is based on selected superior provenances of key Australian tree species, and is delivering improved planting stock and underpinning substantial gains in plantation productivity.
- Up-to-date information on selection, improvement, silviculture and management of plantations has been disseminated.
- There is a network of forest scientists trained in the selection, improvement, silviculture and management of plantations.
- TREDAT, a recording system and database on tree performance incorporating a large body of data from trials on species and provenance performance of Australian tree species to help improve client access to germplasm information, has been established.
- The principal capacity-building output achieved from project FST/2000/122 – 'Application of molecular marker technologies for genetic improvement of forest plantation species in Indonesia and Australia' – was the transfer of sophisticated tree-breeding technology. All primers and available information for the 33 microsatellite loci for acacias were transferred to the molecular laboratory at the CFBTI and microsatellite assays were optimised.
- Four Indonesian staff at the CFBTI were trained to conduct microsatellite screening and to analyse molecular marker data and interpret the results. Other planned outputs to strengthen the institutional capacity of the CFBTI, such as establishing a clonal mini-breeding arboretum, were not achieved due to unanticipated technical problems.
- In Australia, a genetic linkage map for the hybrid eucalypt pedigree was constructed, and several QTLs for rooting of stem cuttings and frost tolerance were located.

The new knowledge gained from research using microsatellite markers showed that they are sufficiently powerful to efficiently monitor inbreeding and pollen contamination in seed orchards, and to provide quality control in Indonesian breeding programs of *A. mangium*. However, analysis of sampled data revealed the possibility of significant problems in genetic trials of *A. mangium* in Indonesia that could have serious implications for breeding programs. Since completion of the project, it seems that little has been done to further investigate this possible problem. Furthermore, research found no significant relationship between the degree of genetic relatedness of *A. mangium* parents and the performance of their progeny. If this result is confirmed by further research, it questions whether molecular marker assisted breeding could have a vital role in making *A. mangium* breeding programs in Indonesia more effective.

Nevertheless, the R&D departments of some of the larger industrial pulpwood plantation companies continue to utilise the built capacity of the CFBTI to carry out molecular marker analysis for them under contract as part of their tree improvement programs. For instance, there is ongoing construction of genetic linkage maps for other species such as *E. pellita,* but to date there has been little uptake of other capacity-building outputs from the project, such as specific microsatellite loci for acacias.

In Australia, the lack of uptake of project outputs can be attributed at least in part to the subsequent decision by CSIRO to discontinue further genomics research, which removed a key driver for further development of this technology. Given the discontinuation of several state government based tree-breeding programs, and a lack of interest to date in molecular marker assisted tree breeding by private plantation companies, it is most unlikely that there will be any uptake of these outputs to develop more efficient methods for selecting frost tolerance traits in breeding programs.

There were no planned technical outputs from project FST/2000/122. Planned technical outputs from the other industrial plantation domestication projects included:

1. a ready supply of source-identified certified seeds and seedlings of priority species of Australian hardwood trees to set up provenance trials and for other research, and to enable mass-production seed orchards to be established
2. expert advice, and practical manuals for seed orchard management in developing countries to enable collaborators to maximise quantity and genetic quality of seeds and seedlings produced of priority species
3. extension packages of recommended propagation and silvicultural practices for industrial pulpwood plantations of Australian hardwood tree species
4. a decision-support system and practical operations manual in Bahasa Indonesia to improve site-specific water and nutrient plantation management of *A. mangium* plantations in Sumatra
5. a decision-support system and adapted practical operations manual to improve site-specific water and nutrient plantation management of *A. mangium* plantations in the Tiwi Islands.

The uptake of technical outputs achieved by the early industrial plantation domestication projects has been spectacular, and has been discussed in detail above. As noted above, there were no technical outputs from project FST/2000/122, and it is premature to assess uptake of technical outputs from project FST/2004/058 because it is still in progress.

The industrial plantation protection projects

New knowledge as outlined below was the only planned output from the first three 'survey' projects in this cluster:

1. preliminary knowledge about the identity and significance of insect pests in native and plantation stands of tropical plantation forestry
2. preliminary knowledge about the identity and significance of foliar and stem fungal pathogens in native and plantation stands of tropical plantation forestry
3. published workshop proceedings on the status of pathogenic fungal diseases of tropical acacias
4. a reference collection of pathogenic fungal diseases of tropical acacias.

Planned capacity-building outputs from the heartrot and the rootrot projects were as follows:

1. better knowledge about
   - the incidence of root- and heartrots in different environments
   - the relationship between silvicultural practices and the incidence of heartrot in Indonesian plantations in varied environments

- variations in the incidence of root- and heartrots between *A. mangium* provenances, *A. crassicarpa* and *A. mangium* × *A. auriculiformis* hybrids
- variations in the incidence of root- and heartrots and between eucalypts selected for traits such as leaf pathogen/insect resistance and form
- the relationship between alternative control options for rootrot and the incidence of rootrot in Indonesian plantations of *A. mangium*

2. molecular techniques to identify and characterise fungi causing rot in acacias and eucalypts, and to detect their presence in symptomless wood
3. Indonesian scientists gaining new skills by undertaking postgraduate studies or training courses
4. institutional strengthening of the CFBTI to upgrade capacity to carry out DNA sequencing and mycological research
5. a network of involved stakeholders that embraces end users (private forest industry companies, sawmillers etc.) as well as Indonesian and Australian scientists and Indonesian government officials who are better informed about project results due to staff exchange, training courses and postgraduate training
6. improved capacity of scientists in selected industrial plantation companies to understand the threat posed by heartrots and rootrots, and about possible management options that might mitigate these threats
7. technical information sheets written in Bahasa Indonesia for use by company extension officers to deliver information to outgrowers to maximise the impact of the research in the community forestry sector
8. workshop proceedings and scientific papers for a broader audience.

In the discussion below, an assessment is made of how many of the planned capacity-building outputs were achieved.

- The collection of knowledge by the first 'survey' project about the incidence of then current insect pests, as well as the severity of their occurrence in forest plantations in Indonesia, was severely curtailed by civil disturbance that destroyed most of the project infrastructure, and also caused the evacuation of personnel of the ACIAR project and collaborating aid agencies.[20] Nevertheless, sufficient information was obtained to decide that the immediate threat of serious damage by insect pests to tropical plantation forests in Indonesia was less than that from fungal pathogens. The uptake of this output by ACIAR influenced its future funding priorities within the cluster of possible future industrial plantation protection projects.
- The primary achieved output from the other two 'survey' projects was published in workshop proceedings on the status of pathogenic fungal diseases of tropical acacias, including a literature review, preliminary knowledge about susceptibility of different species and provenances to the most common pathogenic fungal diseases, and knowledge about the presence of pathogenic fungi in selected seed collections of tropical acacias. Based on the knowledge in this output, ACIAR decided to fund a project on heartrots in plantation hardwoods in Indonesia and south-eastern Australia, and subsequently decided to fund a follow-up project on management of fungal rootrot in plantation acacias in Indonesia.
- Knowledge from the other two 'survey' projects was incorporated in a manual of diseases of tropical acacias in Australia, South-East Asia and India that has become a standard reference source on foliar and stem fungal pathogens, including leaf spots, shoot blights, stem cankers, heartrot and gall rusts, in tropical plantation forestry.
- Institutional strengthening of the Indonesian CFBTI to upgrade capacity to carry out DNA sequencing and mycological research has been very successful in building on earlier assistance from other ACIAR projects, as well as aid from the Japan International Cooperation Agency. The CFBTI now carries out analyses on a contract basis for private plantation forestry companies as well as government agencies concerned with conservation of natural forest.

20 This was a multicountry project and planned outputs were, in general, largely achieved in the other collaborating countries.

- Several hundred new genetic sequences for fungal isolates were added to the Fungal Sequence Database. Uptake of this knowledge within the project's research program enabled direct detection of fungi from symptomless or rotten wood, thus increasing the likelihood of identifying unknown fungi, particularly those isolated from roots, wood or symptomless wood, without needing to locate a fruiting body.
- New knowledge gained during the heartrot and rootrot projects was documented in many publications covering, among other things:
  - the incidence of root and heartrots in different Indonesian environments
  - techniques for molecular identification of heartrot and rootrot in *A. mangium*
  - discovery that there are at least three causal agents of rootrot, and not just *Ganoderma* sp. as originally thought
  - the relationship between silvicultural practices and the incidence of heartrot in Indonesian plantations is varied in different environments
  - variations in the incidence of root- and heartrots between *A. mangium* provenances, *A. crassicarpa* and *A. mangium* × *A. auriculiformis* hybrids
  - variations in the incidence of root- and heartrots and between eucalypts selected for various traits
  - the relationship between alternative control options for rootrot and the incidence of rootrot in Indonesian plantations of *A. mangium*.
- Laboratory and field manuals in both English and Bahasa Indonesia were prepared for plantation managers, researchers and technical staff who attended a workshop on rot diseases in *Acacia* plantations. Technical information sheets to assist with molecular identification of decay fungi, and on how to survey for heartrot and rootrot, also were prepared and widely distributed to stakeholders.
- Six staff of FORDA received postgraduate or other training in Indonesia and/or in Australia.
- The capacity of scientists in selected industrial plantation companies to understand the threat posed by heartrots and rootrots, and about possible management options that might mitigate these threats, was improved.
- A network now exists of involved stakeholders that embraces end users (private forest industry companies, sawmillers etc.) as well as Indonesian and Australian scientists and Indonesian government officials who are better informed about project results due to staff exchange and training courses. As a result, exchange of technical information between plantation companies has improved considerably.

For reasons explained above, the following planned technical outputs relate to only the heartrot and rootrot projects:

1. an extension package of recommended guidelines for silvicultural practices to assist plantation managers in Indonesia and Australia to reduce heartrot incidence in plantations
2. an extension package of recommendations for revised selection criteria for tree improvement projects in Indonesia to mitigate development of heartrot
3. an extension package of recommended cost-effective rootrot control options for the outgrower sector
4. a simple decision-support system for the management of rootrot disease in *A. mangium* that will include:
   - a site-rating system to rank the potential for disease outbreak
   - prescriptions for ground-based detection and monitoring of rootrot disease
   - technical recommendations for inter-rotation intervention strategies.

Only the heartrot project was complete when this study was undertaken, so it is still too early to say whether some technology outputs from the rootrot project will be achieved. For instance, the efficacy and cost-effectiveness of various rootrot control options were still being evaluated at the time of writing this report, but so far none have been proven to be cost-effective, and they are therefore unlikely to be adopted. Hence, the discussion below focuses mainly on the extent to which planned outputs from the heartrot project were achieved.

1. For the use of plantation forest managers, an extension package comprising a technical information sheet in both Bahasa Indonesia and

English of recommended pruning practices to mitigate development of heartrot was produced by the project team.

2. Technical information sheets written in Bahasa Indonesia about the principles of rootrot disease management and the deployment of intervention strategies to reduce rootrot disease in *A. mangium* (e.g. early detection and intervention, risk avoidance, and silvicultural, chemical and biological management strategies such as the use of biological agents to treat freshly cut stumps) have been distributed to the outgrower sector.
3. A recommendation was made to Indonesian plantation companies to integrate planting-hole preparation with biological control application and management solutions such as stem injection of systemic fungicides on high-value assets such as seed orchards to mitigate rootrot problems.
4. The planned development of a simple model reflecting disease incidence/severity that integrates the health of a tree's direct neighbours into an index has yet to be completed and distributed to stakeholders.

The industrial plantation enhancement project

1. The only planned capacity-building output from this project was new knowledge about methods to identify and validate criteria and indicators for sustainable plantation forest management. This was achieved in the form of a book entitled 'Criteria and indicators for sustainable plantation forestry in Indonesia' published by CIFOR.
2. No technical outputs were planned, and none have been achieved.

Appendix 2 Details of project costs

Table A1. Annual investments (in 2009 A$) by ACIAR in plantation forestry research

Year	Australian trees[a]	Multi-purpose trees[b]	Disease and pest surveys[c]	Sustain-ability[d]	Molecular breeding[e]	Tree rot[f]	Site manage-ment[g]	All projects
1983–84	178,291	0	0	0	0	0	0	178,291
1984–85	169,996	0	0	0	0	0	0	169,996
1985–86	156,813	0	0	0	0	0	0	156,813
1986–87	143,534	0	0	0	0	0	0	143,534
1987–88	132,418	190,492	0	0	0	0	0	322,910
1988–89	121,948	211,327	0	0	0	0	0	333,274
1989–90	115,501	200,155	0	0	0	0	0	315,656
1990–91	111,411	193,067	0	0	0	0	0	304,479
1991–92	109,245	175,790	0	0	0	0	0	285,035
1992–93	107,896	173,619	0	0	0	0	0	281,516
1993–94	186,106	172,202	0	0	0	0	0	358,308
1994–95	183,362	169,663	12,834	0	0	0	0	365,859
1995–96	178,808	0	12,447	0	0	0	0	191,255
1996–97	176,273	0	18,357	18,660	0	0	0	213,290
1997–98	173,809	0	36,201	36,798	0	0	0	246,809
1998–99	173,809	0	23,409	55,096	0	0	0	252,315
1999–2000	149,149	0	0	0	0	0	0	149,149
2000–01	120,967	0	0	0	106,669	87,200	0	314,836
2001–02	117,626	0	0	0	210,328	169,583	0	497,537
2002–03	114,851	0	0	0	205,365	165,582	0	485,797
2003–04	111,591	0	0	0	0	160,882	0	272,473
2004–05	53,867	0	0	0	0	154,473	0	208,340
2005–06	2,897	0	0	0	0	122,133	0	125,031
2006–07	5,535	0	0	0	0	261,661	194,351	461,546

Table A1. (continued)

Year	Australian trees[a]	Multi-purpose trees[b]	Disease and pest surveys[c]	Sustain-ability[d]	Molecular breeding[e]	Tree rot[f]	Site manage-ment[g]	All projects
2007–08	2,641	0	0	0	0	251,129	186,528	440,299
2008–09	0	0	0	0	0	243,815	181,095	424,910
2009–10	0	0	0	0	0	0	175,821	175,821
Present value (5% compound)	7,061,918	3,714,539	190,990	195,503	765,198	2,015,800	796,604	14,740,553
Percentage of total	48	25	1	1	5	14	5	

[a] AusAID; FST/1993/118; FST/1998/096; FST/2005/054
[b] FST/1986/013; FST/1990/043
[c] FST/1995/110; FST/1995/124; FST/1997/035
[d] FST/1996/182
[e] FST/2000/122
[f] FST/2000/123; FST/2003/048
[g] FST/2004/058.

Table A2. Combined annual investments (in 2009 A$) by ACIAR, project partners and other agencies in plantation forestry research

Year	Australian trees[a]	Multi-purpose trees[b]	Disease and pest surveys[c]	Sustain-ability[d]	Molecular breeding[e]	Tree rot[f]	Site manage-ment[g]	All projects
1983–84	246,856	0	0	0	0	0	0	246,856
1984–85	247,537	0	0	0	0	0	0	247,537
1985–86	239,877	0	0	0	0	0	0	239,877
1986–87	230,123	0	0	0	0	0	0	230,123
1987–88	222,044	260,532	0	0	0	0	0	482,576
1988–89	222,431	289,027	0	0	0	0	0	511,458
1989–90	219,170	273,748	0	0	0	0	0	492,918
1990–91	219,605	264,055	0	0	0	0	0	483,660
1991–92	223,372	291,846	0	0	0	0	0	515,218
1992–93	228,552	295,387	0	0	0	0	0	523,939
1993–94	620,456	282,740	0	0	0	0	0	903,196
1994–95	788,098	169,663	16,723	0	0	0	0	974,484
1995–96	768,524	101,362	16,219	0	0	0	0	886,105
1996–97	757,630	102,923	44,963	108,105	0	0	0	1,013,621

Table A2. (continued)

Year	Australian trees[a]	Multi-purpose trees[b]	Disease and pest surveys[c]	Sustain-ability[d]	Molecular breeding[e]	Tree rot[f]	Site manage-ment[g]	All projects
1997–98	747,041	104,529	88,668	213,188	0	0	0	1,153,427
1998–99	747,041	107,665	50,968	319,199	0	0	0	1,224,872
1999–2000	814,085	108,415	0	0	0	0	0	922,500
2000–01	537,457	106,382	0	0	381,324	187,391	0	1,212,554
2001–02	522,614	106,547	0	0	693,587	493,485	0	1,816,233
2002–03	510,282	107,154	0	0	469,119	514,351	0	1,600,906
2003–04	259,949	107,236	0	0	0	499,751	0	866,936
2004–05	125,481	106,053	0	0	0	331,960	0	563,495
2005–06	2,897	104,210	0	0	0	178,661	0	285,768
2006–07	5,535	102,518	0	0	0	362,035	505,876	975,964
2007–08	2,641	101,344	0	0	0	338,837	485,515	928,336
2008–09	0	101,344	0	0	0	288,323	471,373	861,040
2009–10	0	101,344	0	0	0	0	457,644	558,988
Present value (5% compound)	19,397,167	7,570,575	398,070	1,132,642	2,276,400	4,149,511	2,073,481	36,997,845
Percentage of total	52	20	1	3	6	11	6	

a AusAID; FST/1993/118; FST/1998/096; FST/2005/054

b FST/1986/013; FST/1990/043

c FST/1995/110; FST/1995/124; FST/1997/035

d FST/1996/182

e FST/2000/122

f FST/2000/123; FST/2003/048

g FST/2004/058.

Appendix 3 Annual costs and benefits from investment in plantation forestry research

Table A3. Annual costs and benefits (2009 A$ million) from investment in plantation forestry research

Year	Total Investment	Multipurpose trees benefits[a]	Australian trees benefits	Net benefits
1983	−246,856	0	0	−246,856
1984	−247,537	0	0	−247,537
1985	−239,877	0	0	−239,877
1986	−230,123	0	0	−230,123
1987	−482,576	0	0	−482,576
1989	−511,458	0	0	−511,458
1990	−492,918	0	0	−492,918
1991	−483,660	0	0	−483,660
1992	−515,218	0	0	−515,218
1993	−523,939	0	0	−523,939
1994	−903,196	0	0	−903,196
1995	−974,484	0	0	−974,484
1996	−886,105	0	0	−886,105
1997	−1,013,621	0	−6,488,000	−7,501,621
1998	−1,153,427	0	−96,413,900	−97,567,327
1999	−1,224,872	−14,627,250	187,891,655	172,039,532
2000	−922,500	−10,321,740	276,144,528	264,900,288
2001	−1,212,554	−13,855,050	486,551,940	471,484,336
2002	−1,816,233	−14,547,060	−254,259,548	−270,622,840
2003	−1,600,906	−14,292,630	−162,258,244	−178,151,780
2004	−866,936	−10,100,970	1,951,325,075	1,940,357,168

Table A3. (continued)

Year	Total Investment	Multipurpose trees benefits[a]	Australian trees benefits	Net benefits
2005	−563,495	−35,945,910	1,100,078,640	1,063,569,235
2006	−285,768	−50,837,490	145,553,261	94,430,003
2007	−975,964	−62,896,680	−273,056,272	−336,928,916
2008	−928,336	−63,668,880	37,996,759	−26,600,458
2009	−861,040	−83,270,880	−431,617,107	−515,749,027
2010	−558,988	−104,456,880	−363,516,364	−468,532,232
2011	0	−97,526,880	408,530,609	311,003,729
2012	0	−81,587,880	185,609,302	104,021,422
2013	0	−11,751,884	247,227,668	235,475,784
2014	0	−34,435,193	672,542,100	638,106,907
2015	0	−23,821,251	1,381,419,259	1,357,598,009
2016	0	−27,871,767	−822,253,451	−850,125,218
2017	0	−36,246,769	887,533,905	851,287,136
2018	0	−61,727,694	1,384,808,528	1,323,080,834
2019	0	52,920,011	511,661,384	564,581,395
2020	0	97,397,609	1,089,474,517	1,186,872,126
2021	0	126,392,500	575,356,827	701,749,327
2022	0	109,502,272	1,053,832,259	1,163,334,531
2023	0	165,803,030	−1,453,569,459	−1,287,766,429
2024	0	222,103,787	725,413,558	947,517,345
2025	0	165,803,030	−290,363,072	−124,560,043
2026	0	81,351,894	888,633,294	969,985,187
2027	0	67,276,704	−67,347,541	−70,837
2028	0	39,126,326	−419,245,337	−380,119,012
2029	0	39,126,326	794,305,945	833,432,270
2030	0	2,740,538,473	5,437,989,484	8,178,527,958
Present value (5% compound)	−36,997,845	$766,481,973	11,147,828	11,877,312

[a] Due to the longer duration of sandalwood plantation rotations, it took longer for the replanting cycle to approach a steady state, so financial flows were projected to 2044, and then capitalised thereafter before taking present value in 2031.

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1	Centre for International Economics 1998.	Control of Newcastle disease in village chickens	AS1/1983/034, AS1/1987/017 and AS1/1993/222
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3	Centre for International Economics 1998.	Establishment of a protected area in Vanuatu	ANRE/1990/020
4	Watson A.S. 1998.	Raw wool production and marketing in China	ADP/1988/011
5	Collins D.J. and Collins B.A. 1998.	Fruit fly in Malaysia and Thailand 1985–1993	CS2/1983/043 and CS2/1989/019
6	Ryan J.G. 1998.	Pigeonpea improvement	CS1/1982/001 and CS1/1985/067
7	Centre for International Economics 1998.	Reducing fish losses due to epizootic ulcerative syndrome—an ex ante evaluation	FIS/1991/030
8	McKenney D.W. 1998.	Australian tree species selection in China	FST/1984/057 and FST/1988/048
9	ACIL Consulting 1998.	Sulfur test KCL–40 and growth of the Australian canola industry	PN/1983/028 and PN/1988/004
10	AACM International 1998.	Conservation tillage and controlled traffic	LWR2/1992/009
11	Chudleigh P. 1998.	Postharvest R&D concerning tropical fruits	PHT/1983/056 and PHT/1988/044
12	Waterhouse D., Dillon B. and Vincent D. 1999.	Biological control of the banana skipper in Papua New Guinea	CS2/1988/002-C
13	Chudleigh P. 1999.	Breeding and quality analysis of rapeseed	CS1/1984/069 and CS1/1988/039
14	McLeod R., Isvilanonda S. and Wattanutchariya S. 1999.	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008 and PHT/1990/008
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23	McLeod R. 2003.	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011 and AS2/1993/001
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26	Mullen J.D. 2004.	Impact assessment of ACIAR-funded projects on grain-market reform in China	ANRE1/1992/028 and ADP/1997/021
27	van Bueren M. 2004.	Acacia hybrids in Vietnam	FST/1986/030
28	Harris D. 2004.	Water and nitrogen management in wheat–maize production on the North China Plain	LWR1/1996/164
29	Lindner R. 2004.	Impact assessment of research on the biology and management of coconut crabs on Vanuatu	FIS/1983/081
30	van Bueren M. 2004.	Eucalypt tree improvement in China	FST/1990/044, FST/1994/025, FST/1984/057, FST/1987/036, FST/1988/048, FST/1996/125 and FST/1997/077
31	Pearce D. 2005.	Review of ACIAR's research on agricultural policy	
32	Tingsong Jiang and Pearce D. 2005.	Shelf-life extension of leafy vegetables—evaluating the impacts	PHT/1994/016
33	Vere D. 2005.	Research into conservation tillage for dryland cropping in Australia and China	LWR2/1992/009 and LWR2/1996/143
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35	Raitzer D.A. and Lindner R. 2005.	Review of the returns to ACIAR's bilateral R&D investments	
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38	ACIAR 2006.	Future directions for ACIAR's animal health research	
39	Pearce D., Monck M., Chadwick K. and Corbishley J. 2006.	Benefits to Australia from ACIAR-funded research	AS2/1990/028, AS2/1994/017, AS2/1994/018, AS2/1999/060, CS1/1990/012, CS1/1994/968, FST/1993/016 and PHT/1990/051
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45	Turnbull J.W. 2007.	Development of sustainable forestry plantations in China: a review	
46	Monck M. and Pearce D. 2007.	Mite pests of honey bees in the Asia–Pacific region	AS2/1990/028, AS2/1994/017, AS2/1994/018 and AS2/1999/060

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48	Longmore C., Gordon J. and Bantilan M.C. 2007.	Assessment of capacity building: overcoming production constraints to sorghum in rainfed environments in India and Australia	CS1/1994/968
49	Fisher H. and Gordon J. 2007.	Minimising impacts of fungal disease of eucalypts in South-East Asia	FST/1994/041
50	Monck M. and Pearce D. 2007.	Improved trade in mangoes from the Philippines, Thailand and Australia	CS1/1990/012 and PHT/1990/051
51	Corbishley J. and Pearce D. 2007.	Growing trees on salt-affected land	FST/1993/016
52	Fisher H. and Gordon J. 2008.	Breeding and feeding pigs in Vietnam: assessment of capacity building and an update on impacts	AS2/1994/023
53	Monck M. and Pearce D. 2008.	The impact of increasing efficiency and productivity of ruminants in India by the use of protected-nutrient technology	AH/1997/115
54	Monck M. and Pearce D. 2008.	Impact of improved management of white grubs in peanut-cropping systems	CS2/1994/050
55	Martin G. 2008.	ACIAR fisheries projects in Indonesia: review and impact assessment	FIS/1997/022, FIS/1997/125, FIS/2000/061, FIS/2001/079, FIS/2002/074, FIS/2002/076, FIS/2005/169 and FIS/2006/144
56	Lindner B. and McLeod P. 2008.	A review and impact assessment of ACIAR's fruit-fly research partnerships—1984 to 2007	CS2/1983/043, CS2/1989/019, CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225, CS2/1997/101, CS2/1998/005, CS2/2003/036, CP/1997/079, CP/2001/027, CP/2002/086, CP/2007/002, CP/2007/187, PHT/1990/051, PHT/1994/133, and PHT/1993/87
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59	Chupungco A., Dumayas E. and Mullen J. 2008.	Two-stage grain drying in the Philippines	PHT/1983/008, PHT/1986/008 and PHT/1990/008
60	Centre for International Economics 2009.	ACIAR Database for Impact Assessments (ADIA): an outline of the database structure and a guide to its operation	
61	Fisher H. and Pearce D. 2009.	Salinity reduction in tannery effluents in India and Australia	AS1/2001/005
62	Francisco S.R., Mangabat M.C., Mataia A.B., Acda M.A., Kagaoan C.V., Laguna J.P., Ramos M., Garabiag K.A., Paguia F.L. and Mullen J.D. 2009.	Integrated management of insect pests of stored grain in the Philippines	PHT/1983/009, PHT/1983/011, PHT/1986/009 and PHT/1990/009
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65	Martin G. 2010.	ACIAR investment in research on forages in Indonesia	AS2/2000/103, AS2/2000/124, AS2/2001/125, LPS/2004/005, SMAR/2006/061 and SMAR/2006/096
66	Harris D.N. 2010.	Extending low-cost fish farming in Thailand: an ACIAR–World Vision collaborative program	PLIA/2000/165
67	Fisher H. 2010.	The biology, socioeconomics and management of the barramundi fishery in Papua New Guinea's Western Province	FIS/1998/024
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