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Mixed-methods impact assessment of sandalwood research in Vanuatu

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Mixed-methods impact assessment of sandalwood research in Vanuatu

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Sustineo Pty Ltd

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The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. ACIAR operates as part of Australia's international development cooperation program, with a mission to achieve more productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

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Foreword

The international partnerships that underpin research supported by the Australian Centre for International Agricultural Research (ACIAR) aim to improve the productivity and sustainability of agricultural, forestry and fisheries systems in partner countries. Through this research Australia contributes to improving food security, food system resilience and the livelihoods of smallholder farmers in the Indo-Pacific region. Importantly, this research also helps improve the Australian agricultural innovation system, with flow-on benefits to rural industries and regional communities.

Sandalwood (*Santalum* spp.) is a high-value, low-volume, non-perishable forest product sought by international markets for its highly fragrant oil and heartwood. There are 16 species distributed across India, Indonesia, Pacific Islands and Australia. The high demand for sandalwood, coupled with lack of plantations, has led to a steady decline of wild sources of various sandalwood species.

The species *S. austrocaledonicum* is native to Vanuatu and has been an important commodity for traders since the 1800s. This long history of wild harvest has led to a decline in wild stocks and the need to conserve genetic resources. Since the 1990s, research-for-development programs and regulation and policy approaches have strived to promote sustainable development of the forestry sector, including plantation production of sandalwood.

ACIAR has supported sandalwood research activities in Vanuatu in close collaboration with the Vanuatu Department of Forests (VDoF) since 2002. The first project identified genetically superior seeds and improved planting techniques, which in turn increased smallholder farmers' access to seeds and improved plantation establishment. ACIAR has contributed about A$2 million to four completed sandalwood projects in Vanuatu. This investment was augmented by partner contributions and the program was implemented by researchers from James Cook University and staff of the VDoF.

The full impact of research-for-development work in agriculture, forestry and fisheries is realised over decades and cannot be properly evaluated when the research first takes place. For more than 30 years, ACIAR has systematically undertaken independent impact assessment studies of its portfolio of research activities. These evaluations have consistently found high returns on investment, reflecting the quality of Australian agricultural science and our partnership model, which ensures a high level of engagement with in-country partners, and a high level of adoption of research results.

This ex-ante impact assessment of ACIAR-supported sandalwood research in Vanuatu analyses the situation around seven years prior to harvest of the first significant volumes of plantation-grown sandalwood in Vanuatu. Accordingly, estimated economic benefits are projections. This analysis suggests that almost two decades after the first project was initiated, the overall impact of the investment is positive, with a benefit:cost ratio on ACIAR investment exceeding 5 to 1. Ultimate economic impacts will be further enhanced by favourable market policies. The impact on institutional and smallholder capacity is reported to be clear, positive and enduring.

Andrew Campbell
Chief Executive Officer, ACIAR

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Abbreviations

A$	Australian dollar
ACIAR	Australia Centre for International Agricultural Research
CITES	Convention on the International Trade of Endangered Species of Flora and Fauna
IRR	internal rate of return
ha	hectare
kg	kilogram
m	metre
NPV	net present value
PHAMA	Pacific Multicultural and Agricultural Market Access Plus Program
RAPID	research and policy in development
SPRIG	South Pacific Regional Initiative on Forest Genetic Resources
SWOT	strengths, opportunities, weaknesses, and threats
t	tonne
US$	United States dollar
VDoF	Vanuatu Department of Forests
VT	vatu (Vanuatu currency)

Summary

Sandalwood is a high-value, non-perishable forest product with the potential of providing incomes and livelihoods for rural communities.

The Australia Centre for International Agricultural Research (ACIAR) has supported sandalwood research activities in Vanuatu for more than 15 years, in close collaboration with the Vanuatu Department of Forests (VDoF).

Sandalwood is native to Vanuatu, yet a long history of wild harvest has seen a decline in wild stocks, and a need to develop plantation systems to conserve the genetic resources and deliver income opportunities for smallholders.

Under the ACIAR forestry program, these projects have supported research that has led to the identification of genetically superior seeds, and increased smallholders' access to seeds and planting techniques.

Since the mid 2000s, there has been a significant increase in sandalwood plantations by smallholders in Vanuatu, which are due to come into production in the next few years. This is expected to lead to improvements in domestic processing and increased export volumes, providing an opportunity for smallholders to increase their annual incomes through the sale of sandalwood products.

ACIAR investment in sandalwood in Vanuatu has focused on expanding understanding of planting techniques, disseminating knowledge and, more recently, establishing farmer-to-farmer knowledge exchange processes to continue production.

This impact assessment draws from three previous reports that assessed the impacts of sandalwood activities at a point in time (Harrison and Karim 2016; Walker 2015). It uses field data collected in 2018 to update the current and likely benefits of sandalwood production in Vanuatu. The assessment was designed to integrate cost–benefit analysis and qualitative methods to determine the current and potential future impact of planted sandalwood activities supported by ACIAR in partnership with VDoF.

The integration of these methods provides an example of how impact assessments can assess both the economic returns and non-quantifiable impacts of research investments. The objectives of this impact assessment were to:

- estimate the financial viability of sandalwood for smallholders
- estimate the overall economic benefits of sandalwood to Vanuatu
- identify the impacts of technical products on knowledge, capacity and industry.

The focus of this impact assessment is on two major ACIAR projects on sandalwood genetics and plantation projects:

- 'Identification of optimum genetic resources for establishment of local species of sandalwood for plantations and agroforests in Vanuatu and Cape York Peninsula' (FST/2002/097)
- 'Development and delivery of germplasm for sandalwood and whitewood in Vanuatu and northern Australia' (FST/2008/010).

Two complementary ACIAR-supported small research activities, which focused on environmental and socioeconomic factors, serve as context to this assessment:

- 'Sandalwood inventory' (FST/2006/118)
- 'Socio-economic constraints to smallholder sandalwood in Vanuatu' (FST/2007/057).

This impact assessment was done about 7 years before the first harvest of sandalwood grown with the support of the ACIAR projects.

The data used are based on site visits to smallholder and large-scale plantation sites in Efate and Tanna over a 10-day period in September 2018. We conducted 34 interviews with VDoF staff, licence-holders and smallholders. The interview guide included socioeconomic as well as qualitative open-ended questions. This enabled respondents to openly discuss their perceptions of opportunities and challenges related to sandalwood production, and allowed them to communicate their understanding of the market and planting practices.

Quantitative farm level data were collected from interviews and from secondary sources, and used to calculate the economic impacts of research investments.

The assessment found that the overall impact of ACIAR investments was positive. There was a clear, positive and enduring impact on institutional capacity and smallholder capacity.

Even under worst-case scenarios, the economic impact for smallholder farmers is expected to be positive. But the social analysis of the policy context identified that future policies will play a critical role in maximising returns to smallholders. This relates to the transparency of prices and alternative policy systems that allow for public auctioning of heartwood.

Economic impacts

The analysis of economic impacts and returns suggests that growing sandalwood is an attractive proposition for smallholders and industry in Vanuatu. This impact assessment conservatively estimated that, of the reported 100,000 seedlings distributed during the ACIAR projects, 50% can be attributed directly to ACIAR.

It is assumed that, at 18 years, these individual trees will yield 30 kg of heartwood. We estimate that 70% of production will come from 1-ha farms, 25% from 7-ha farms, and 5% from a single large 200-ha plantation.

Based on these assumptions, and considering ACIAR expenditure of A$1.9 million (A$2.3 million in 2018 constant dollars), we calculate a positive net present value (NPV) of A$3.8 million, and an internal rate of return (IRR) of 13%, equating to a benefit:cost ratio of 5.7:1.

Based on a mix of field observations and previous studies, we can conclude that, for an individual producer who is not concerned about the amount of ACIAR funding, the NPV is $33,951, with a 22% IRR.

We also carried out sensitivity analysis, and modelled how NPV would vary depending on mortality rate, opportunity cost, heartwood yields, and farm gate price variations. Even in the worst-case scenario, we estimate sandalwood is still profitable, with a NPV of A$14,878. This analysis was carried out using a conservative farm gate price of A$12.50/kg, as we expect prices to likely fall when plantations become ready for harvesting.

Social and environmental impacts

Interviews with smallholders, industry, and VDoF staff demonstrate the contributions that ACIAR projects have made towards building an understanding and awareness of planting techniques, as well as government capacity to conduct forestry research and extend services to smallholders. The research projects have had demonstrable impacts on institutional and smallholder capacity.

Improved institutional capacity was shown through the increased experience and knowledge of sandalwood growing, extension, and harvesting skills during the projects. Both projects also supported the employment of VDoF foresters in working with Australian researchers during the project and supporting farmers in establishing seedling systems.

Smallholder capacity has been developed through the extension and knowledge services in maintaining a sandalwood plantation. Smallholders held traditional and family knowledge on sandalwood growing and harvesting due to the native nature of the tree. But before the ACIAR research, their sandalwood was largely harvested from the wild, and, if planted, it was done in an ad hoc manner.

The publication, *Vanuatu sandalwood—Growers' guide for sandalwood production in Vanuatu* (Page et al. 2012d), produced as part of the projects, has led to greater awareness of the use of hosts to optimally grow sandalwood, and the use of spacing techniques to maintain a plantation. The guide provided information on how to establish nurseries in smallholder farms, and field visits confirmed that nurseries are established in some villages and that informal seedling distribution and sales exist.

The growers' guide and the active role of VDoF in disseminating sandalwood planting techniques has permeated through rural systems in Vanuatu, with different community groups growing sandalwood for community or educational purposes.

While it has been beyond the scope of ACIAR project investments to influence policy, it remains an important external factor that might determine the ultimate impact on smallholder incomes.

The policy context of Vanuatu emerged as an important factor that might determine the equitable distribution of economic benefits in the future that arise from sandalwood investments. Issues of transparency in heartwood sales and an understanding of the market and prices are key to allowing producers to optimise their returns.

New auctioning systems are being proposed, but it remains unclear how they will be implemented before planted sandalwood enters the market. Understanding how alternative systems operate—for example, through public tendering—might offer Vanuatu a greater opportunity for smallholders to understand market behaviour.

This impact assessment is an ex-ante analysis of the potential economic benefits of two ACIAR projects—FST/2002/097 and FST/2008/010—and captures the state of knowledge and policy context of sandalwood in Vanuatu at this point in time.

Future assessments of sandalwood projects will benefit from better understanding of adoption rates, which were difficult to determine, and clarity on oil and heartwood yields from ACIAR seedling distributions.

Any future impact assessments could also seek to explore how gender dynamics unfold at household levels, and the difference in labour between men, women and young adults in sandalwood planting, harvesting and selling, to understand impacts on gender.

1 Introduction

The ACIAR forestry program has supported more than 100 research projects in Australia, Africa, South and South-East Asia and the Pacific (Bartlett 2016). Australian aid has supported research activities in the Vanuatu forestry sector since the 1990s, when the South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) program enabled workshops and initial research into the potential of forestry activities and products to improve Pacific livelihoods.

Since 2002, ACIAR has contributed about A$2 million of nominal research costs towards four completed sandalwood projects in Vanuatu (excluding partner contributions to project investments). These projects have been implemented largely by researchers who were based at James Cook University at the time, and staff of the Vanuatu Department of Forests (VDoF). Two major projects have been completed with a focus on sandalwood genetics and plantation establishment:

- 'Identification of optimum genetic resources for establishment of local species of sandalwood for plantations and agroforests in Vanuatu and Cape York Peninsula' (FST/2002/097)
- 'Development and delivery of germplasm for sandalwood and whitewood in Vanuatu and northern Australia' (FST/2008/010).

Two additional small research activities provided insight into the environmental and socioeconomic context of this assessment:

- 'Sandalwood inventory' (FST/2006/118)
- 'Socio-economic constraints to smallholder sandalwood in Vanuatu' (FST/2007/057).

Through these projects, ACIAR supported the identification of genetically superior seeds, and increased smallholders' access to seeds and planting techniques.

Since the mid 2000s, there has been a significant increase in sandalwood plantations by smallholders in Vanuatu, and these are due to come into production in the next few years. This is expected to lead to improvements in domestic processing and increased export volumes, providing an opportunity for smallholders to increase their annual incomes through the sale of sandalwood products (ACIAR 2018).

ACIAR investments in sandalwood have focused on expanding the understanding of planting techniques, disseminating knowledge, and, more recently, on establishing farmer-to-farmer knowledge exchange processes to continue producing Vanuatu sandalwood.

To date, there have been documented socioeconomic benefits to smallholders from sandalwood activities (Page et al. 2010a; Page et al. 2012b). Using data from wild plantations and stocks, these studies found that 1 ha planted with 833 stems in a rotation of 15–20 years had a 2012 net present value (NPV) of US$21,785.

The studies found that sandalwood is most profitable to smallholders when integrated into existing garden and mixed cropping systems. Other ACIAR analysis by Harrison and Karim (2016), based on a single 2-ha farm model, found that the NPV at an 18-year harvest was A$20,495 when growing in an agroforestry system with cocoa and sweetpotato. These analyses indicate that sandalwood has the potential of being a profitable activity for smallholders in Vanuatu.

While previous studies have presented optimistic scenarios for the potential benefits of sandalwood plantation, they have been based on limited sites or on wild harvest data. These studies have also focused solely on quantitative returns to smallholders, and have not assessed the impacts of ACIAR knowledge products or the policy context that enables or inhibits the distribution of benefits to smallholders.

To overcome these gaps, this impact assessment was designed to integrate quantitative modelling and qualitative analysis to determine the current and potential future impacts of planted sandalwood activities supported by ACIAR in partnership with the VDoF.

The objectives of this impact assessment were to:

- estimate the financial viability of sandalwood for smallholders
- estimate the overall economic benefits of sandalwood to Vanuatu
- identify the impacts of technical products on knowledge, capacity and industry.

To deliver on these objectives, we drew on two methods papers published as part of the ACIAR Impact Assessment Series:

1. We drew from Davis et al. (2008) to model the financial viability of a smallholder farm, and to estimate the NPV and internal rate of return (IRR) of ACIAR investments.
2. We integrated the knowledge systems and research and policy in development (RAPID) framework to determine how research outputs have been salient, legitimate and credible to the sandalwood policy context in Vanuatu (Davila et al. 2016).

The focus of this impact assessment is on two major ACIAR projects on sandalwood genetics and plantation projects—FST/2002/097 and FST/2008/010. The complementary ACIAR-supported projects, which focused on environmental and socioeconomic factors, serve as context to this assessment.

This impact assessment was done about 7 years before first harvest of sandalwood grown with the support of the ACIAR projects. The data used in this assessment are based on site visits to smallholder and large-scale plantation sites in Efate and Tanna over a 10-day period in September 2018. We conducted 34 interviews with VDoF staff, licence-holders and smallholders.

The interview guide included socioeconomic and qualitative open-ended questions. This enabled respondents to openly discuss their perceptions of opportunities and challenges related to sandalwood production and allowed them to communicate their understanding of the market and planting practices.

The next section provides an overview of sandalwood as an internationally traded, high-value, non-perishable forest product. We introduce the different sandalwood species and the context of sandalwood production in Vanuatu. We then provide an ecological and socioeconomic overview of sandalwood in Vanuatu, and outline the methods and frameworks used in this impact assessment.

In Chapter 2, we summarise the investments from ACIAR and partners in the relevant projects, as well as the reported impacts from previous project reviews and assessments.

In Chapter 3, we present the farm level and national models showing the projected economic benefits of sandalwood.

Chapter 4 draws from the qualitative data to present vignettes of impacts on knowledge systems and capacity, and sets the policy context that might enable or inhibit realisation of future impacts.

In Chapter 5, we distil the implications of this study for future sandalwood activities in Vanuatu and mixed-methods impact assessments.

1.1 Sandalwood overview

Sandalwood (*Santalum*) is a high-value, low-volume, non-perishable forest product that is in demand in international markets (Page et al. 2012c). There are 16 different species, distributed across India, Indonesia, Pacific Islands and Australia (Harbaugh and Baldwin 2007).

The high market value of sandalwood stems from the highly fragrant oil and heartwood, used for ornamental products or powdered for incense production. The high demand of sandalwood, coupled with lack of plantations, has led to a steady decline of wild sources of various sandalwood species (Gillieson et al. 2008; Page et al. 2012b).

In relation to international trade of sandalwood, no *Santalum* species are currently listed in the Convention on the International Trade of Endangered Species of Flora and Fauna (CITES). *S. album* is the only commercial species listed under the International Union for Conservation of Nature Red List of Threatened Species as vulnerable.

Reduction of wild stocks, long rotations and ongoing demand for oils and heartwood make sandalwood a valuable forest product for communities in South Asia and the Indo-Pacific.

The majority of the world's legally harvested sandalwood is supplied by Australia, using Australian sandalwood (*Santalum spicatum*). Indian sandalwood, grown in India and Indonesia, is considered the most valuable species, due to high heartwood oil concentrations.

Six other species are sold commercially, and, up until the 1980s, the majority of Indian sandalwood came from wild stocks, including both legal and illegal harvesting. The complex host requirements and failures of pure sandalwood plantings prevented a plantation industry from developing up until the 1980s.

Wild harvests have dominated the supply of sandalwood products to markets by core countries (Table 1). Currently, there are no specific global regulations governing the trade of sandalwood.

Table 1 Countries producing sandalwood for market distribution

Country	Overview
India	Historically dominant exporter of Indian sandalwood from wild sources, harvesting about 1,000 t legally, and about 4,000 t illegally per year. Status of plantations remains unclear.
Indonesia	Significant producer of Indian sandalwood from wild sources. The Provincial Forestry Service estimates a 50% reduction of wild trees between 1987 and 1997. The low uptake of plantation means there is unlikely to be high output of sandalwood from Indonesia in the next 20–30 years.
Timor-Leste	Native Indian sandalwood has been heavily exploited, declining from 30 t to 7 t between the 1960s and 1994.
China	Plantations of Indian sandalwood have been established since the mid 2000s, planting about 60,000 seedlings per year. It is expected that much of these will meet domestic demand.
Australia	Large-scale investments have been responsible for expanding Indian sandalwood production. Planted land has increased from 50 ha in 1999 to 20,000 ha in 2016.

Source: Page et al. 2012b

While Vanuatu sandalwood (*S. austrocaledonicum*) has a unique scent and market offering, it could be substituted in the market by Indian sandalwood, depending on consumer understandings of the difference between the products. Table 1 presents Indian sandalwood plantations, which could compete with the local Vanuatu variety when it is harvested and exported.

To overcome the rapid decline of wild sandalwood harvests, research, industry and policy sectors began identifying opportunities to develop plantations, notably in the Indo-Pacific region.

In the 1980s, Australia became a global leader in plantation-based sandalwood, through the development of research into host species and regulatory standards (Statham 1990). Other countries in the Indo-Pacific had yet to develop plantation-based sandalwood industries, largely due to:

- the long-term rotation of the species
- restrictive policies
- competition between commodity and food production
- impacts of fires and natural phenomena
- higher value of other forest products (Page et al. 2012c).

Unlike Australia, Indo-Pacific countries had little experience and capacity in establishing plantations and nurseries, and in identifying suitable hosts. They also lacked the documented technical knowledge in growth rates, oil characteristics, and managing sandalwood plants.

Sandalwood has distinct attributes that make it a favourable commercial produce for Pacific islands—notably, its suitability to growing in the Pacific environment, the high value of the heartwood, and the non-perishable nature of the product, which simplifies storage and transport requirements.

In 1996, Australia began a comprehensive research-for-development program into sandalwood, to expand sandalwood knowledge, and plan for a reduction in wild harvests. AusAid's SPRIG ran until 2006, and invested US$4.5 million in Fiji, Samoa, Vanuatu, Tonga and Solomon Islands. SPRIG aimed to promote ecologically sustainable development in the forestry and natural resources sector across the Pacific.

In 2002, ACIAR funded the project FST/2002/097 to begin filling the technical knowledge gaps on sandalwood genetics in Vanuatu, building from networks and links established through SPRIG.

1.2 Sandalwood in Vanuatu

Vanuatu is an archipelagic nation in the Pacific with a population of 250,000, distributed evenly throughout 14 major islands. About 75% of the population live in rural areas. Agriculture employs 98% of the rural population, and produces 73% of export earnings.

In 2000, the forestry sector contributed to 11% of total exports, declining to 3% in 2007, mainly due to reduced access to timber resources. The decline in timber resource is attributed to the overharvesting of wild stocks, including sandalwood.

A 1997 National Forest Policy sets sustainable yield for native forests at 63,000 m^3. Total timber production peaked in 1999 at 40,000 m^3, dropping to 11,000 m^3 due to the departure of the largest timber exporter in the late 2000s.

To overcome the decline of the industry and overharvesting of wild resources, there has been sustained interest and support for developing plantation-based forest products from donors and domestic government agencies. Native and high-value products—such as whitewood and sandalwood—have remained a focus, building from knowledge established in 1990s programs.

Sandalwood is naturally occurring in Vanuatu and has been an important commodity for the country since the 1800s. The native species is *S. austrocaledonicum*. It has grown naturally in the wild, predominantly in the western parts of Santo and Erromango, and in lesser quantities on Tanna, Aniwa, Aneityum, Efate and Malekula (Gillieson et al. 2008).

ACIAR funded an assessment of wild stocks of *S. austrocaledonicum* under project FST/2008/116, which produced the wild distribution map in Figure 1.

Between the 1820s and 1850s, Australian merchants traded sandalwood to consumers in China (Shineberg 1967). After this period, the trade was sporadic, with a small commercial industry emerging in the 1970s. The lack of regulation on harvesting in the 1980s increased concerns over the reduction of wild populations, leading to a moratorium in 1988–1991.

After the moratorium, the first set of regulatory standards were established in 1997, with the *Management and Control of Sandalwood Trade and Exports Order*. Under this policy, sandalwood merchants were required to hold a licence to purchase sandalwood, and submit monthly purchase totals to official registers.

In 1992–1996, Far North Timber Sales entered the trade, sourcing about 20–25 t from Dillons Bay in Erromango (Gillieson et al. 2008).

Figure 2 shows the estimated volumes of heartwood harvested from wild stocks in Vanuatu. In the early 2000s, there were five buyers in the industry, harvesting a total quota of 130 t from all islands within Tafea, Malekula and Santo. Export markets for Vanuatu included Australia, China, Hong Kong and India.

The main form of exports in the 2000s came in the form of oil by-products, oil, chops, logs and spent biomass. In the early 2010s, only one company (South Pacific Sandalwood Ltd) was processing sandalwood oil and scents, which they still sell in the local market (at Summit Estate) and to a few customers overseas. During the mid 2010s, the Pacific Provender company distilled essential oils from a range of timber products (Daily Post 2015).

For smallholders, choosing to plant sandalwood is likely to be as a form of additional income or saving strategy for the future, rather than as a main income source. Vanuatu is among a small group of countries where the traditional economy, otherwise known as a subsistence economy, is more important for providing livelihoods than the cash economy (Regenvanu 2010).

Smallholders in Vanuatu still work with traditional, low technology farming practices, which have been passed on through generations (Walter and Lebot 2007). While the integration of trees into farming systems can bring dual conservation and income benefits to landscapes and farmers, the time lag associated with seeing returns from forestry-related investments might reduce the motivation and desires of smallholders to invest and maintain trees in agricultural landscapes (Lasco et al. 2014).

In traditional subsistence economies, like the majority of Vanuatu, where day-to-day incomes are marginal, and used for immediate educational or health needs, the time lags associated with maintaining plantations are an inevitable barrier to developing a forestry plantation.

This indicates that the success of forest plantations will depend on:

- the extent to which it fits within existing agricultural practices
- expected benefits motivating smallholders continue to manage plantations into the future.

1.2.1 The Vanuatu sandalwood value chain

The Vanuatu sandalwood value chain is made up of largely smallholder farmers growing sandalwood in small plots of about 2 ha.

Figure 3 shows an overview of the sandalwood value chain in Vanuatu. The value chain is supported largely by smallholder farmers, who grow the majority of planted sandalwood in Vanuatu.

Domestic processing into oils is minimal, with one small distillery operating in Efate. Tabi et al. (2015) report that planting activities have resulted in about 550 ha of smallholder plantings and 150 ha of commercial plantings.

Larger farmers produce a smaller portion of the supply on land areas of about 7 ha. But these large plots are spread out throughout the islands, and land is often customary, with labour shared between village and family members. The largest plantation in Vanuatu is South Pacific Sandalwood plantation of about 200 ha in Efate.

Sandalwood trees are harvested and prepared for heartwood sales by farmers, and then sold to licence-holders who sell the commodity to international buyers. Licence-holders apply for the total number of tonnes they plan to sell every year, and VDoF issues a licence annually. The current structure of the value chain prevents smallholders from selling directly to end buyers, requiring licence-holders to act as middle people in the value chain.

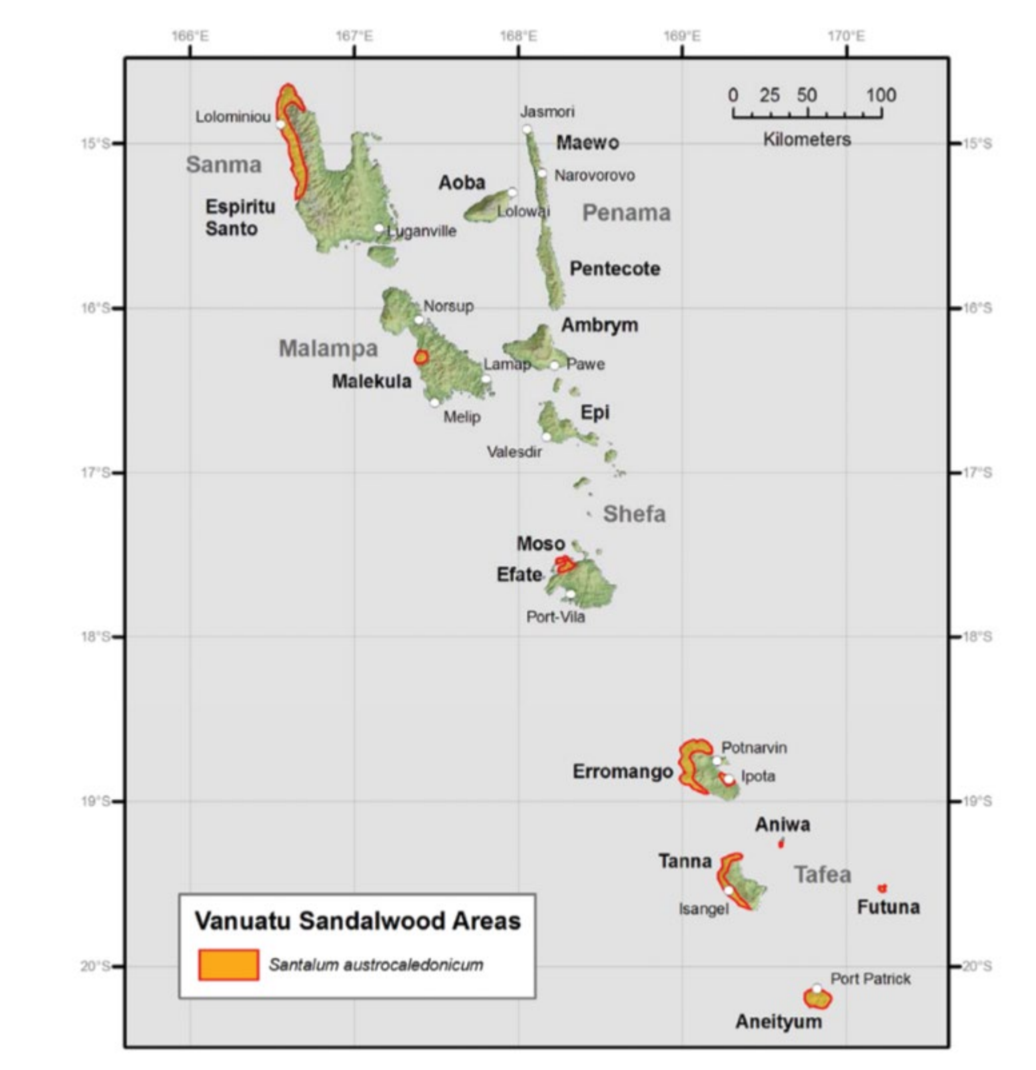

Figure 1 Distribution of wild *Santalum austrocaledonicum* in Vanuatu
Source: Gillieson et al. 2008.

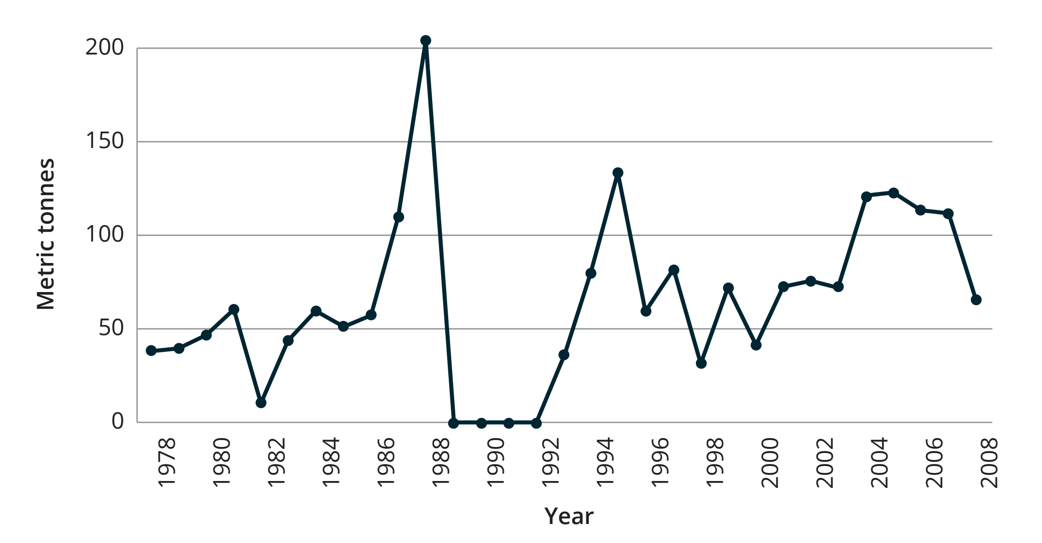

Figure 2 Volumes of heartwood harvested from wild sandalwood in Vanuatu
Source: Gillieson et al. 2008.

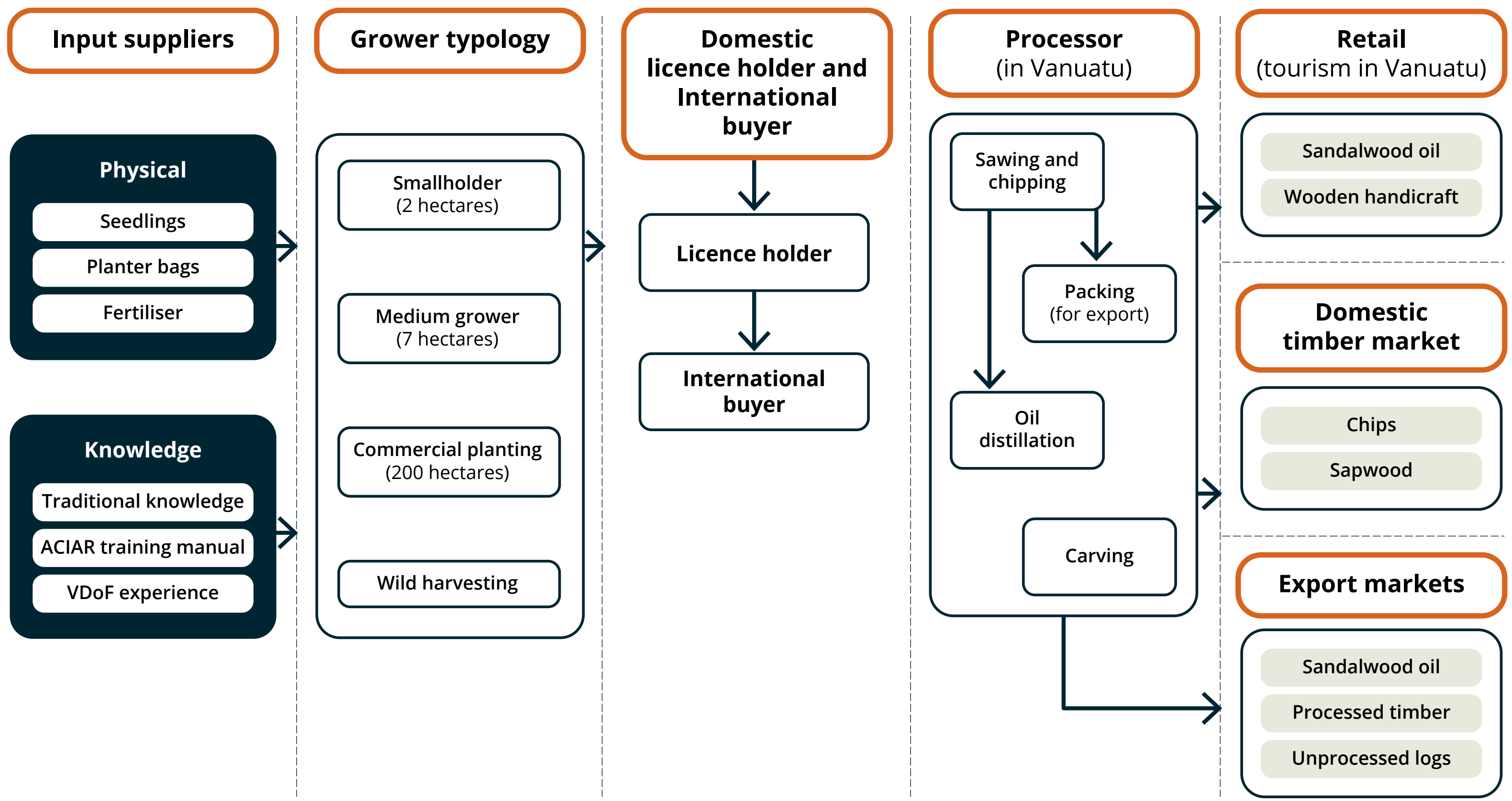

Figure 3 The Vanuatu sandalwood value chain

1.3 Sandalwood ecological context

Sandalwood is a hemi-parasitic species—it requires another species as a host to absorb nutrients via root connections. This makes it amenable to mixed-species systems and can be planted with other species commonly planted by smallholders in the Pacific, such as cocoa and citrus (Harrison and Karim 2016).

This differentiates sandalwood from other cash crops that often require clearance of native forest for planting, as it can be integrated into existing forests. Vanuatu sandalwood provides many of the ecological functions of other endemic trees, including carbon sequestration, erosion prevention, watershed protection, and supporting local biodiversity (Da Silva et al. 2016)

Vanuatu sandalwood is grown in customary smallholder farms of about 2 ha, often within inter-cropped agricultural systems. These systems include various crops rotated throughout the year, providing a diversity of products for households. Planting sandalwood within these existing systems is beneficial for both smallholders and for sandalwood productivity.

For smallholders, the integration of tree production into existing agricultural systems comes at minimal cost, and is unlikely to require further land clearing. The production in existing systems can reduce the incidence of resource disputes, as ownership of trees is less likely to be challenged than for wild trees (Page et al. 2012c).

Access to seed has traditionally been through using 'mother trees' in the wild, where farmers harvest seeds and plant them. The sparse and rare nature of wild trees makes access to seed and seedlings a key determinant in increasing plantations in the country.

Determining the quality of the oil and heartwood of different species is critical to maximising the benefits of planting sandalwood. Project FST/2002/097 sought to identify and propagate 'superior genetic material' (Page et al. 2010b). Preliminary molecular genetic analysis was reported in Page et al. (2005), and failed to find any genetic markers that were related to oil yield. But this research did find evidence of high homozygosity and potential risk of inbreeding depression.

There is no evidence in the literature for the heritability of oil yield, with oil yield being determined by environmental factors, rather than genetic. Anecdotal evidence suggests that oil yield of this species might vary due to local edaphic and climatic conditions (for example, higher oil/heartwood yield from trees growing on relatively shallow, gravelling and dry slopes) (Page et al. 2012b).

Despite research into the phenotypic variation in heartwood and essential oil of Vanuatu sandalwood (Page et al. 2010b), the relationship between genetic and environmental determinant of oil yields is yet to be clarified.

Previous research into oil quality determinants has suggested that sandalwood oil (a terpene) is a response to environmental stress, particularly disease (Murphy et al. 2010). Well-watered trees growing quickly on deep and fertile soils might not yield heartwood and oil as expected compared with wild harvested trees of similar age or size.

To date, there are only two published papers on the yield of oil from planted sandalwood, in this case Indian sandalwood (*Santalum album*) growing in northern Australia (Brand et al. 2007; Brand et al. 2012). The studies found that, as expected, that young (small) sandalwood trees generally have very little heartwood, and that the yield of heartwood and oil from large trees is highly variable.

Given uncertain knowledge on oil and heartwood quality yields from planted sandalwood, predicting possible yields from sandalwood plantations is highly uncertain.

Heartwood, the other major high-value product from a sandalwood trees, has been more commonly harvested and traded in Vanuatu. Smallholders have traditionally harvested wild sandalwood and 'cleaned' the tree for heartwood. This activity is ongoing, and heartwood remains the main exported sandalwood product in Vanuatu.

1.4 Sandalwood economic context

The economic potential of the sandalwood tree relates to both its scented wood and high oil content. Sandalwood oil is a key component in many perfumes, medicines and cosmetics; the wood is used for woodcarving and handicrafts; and its sawdust is used to produce incense for religious ceremonies (Shineberg 1967).

While total available sandalwood for world markets is declining, the price is increasing, at A$3,000–A$16,500/t of heartwood, and A$4,500/kg of oil. This price is expected to grow 6% per year for the foreseeable future (UNCTAD 2016).

Global demand for sandalwood is estimated to be about 5,000–6,000 t/year (Page et al. 2012b). This sustained price increase has been driven by the decline in supply, partially attributable to the wild harvesting of sandalwood, which has depleted natural reserves.

International demand for sandalwood is increasing in line with growing consumer preferences for natural ingredients in cosmetics and the expansion of Asian consumer markets (Page et al. 2012b). Given that demand is already outstripping supply, this is driving price rises and providing economic incentives for greater harvests (Dhanya et al. 2010; Page et al. 2012b).

Sandalwood can offer a long-term saving strategy for farmers, and provide income when harvested periodically when ready. A study into the most profitable methods to grow sandalwood found that mixing it into existing food gardens is likely to yield higher returns (Page et al. 2010a; Page et al. 2012b). Previous studies found that 1 ha planted with 833 stems in a rotation of 15–20 years has a benefit:cost ratio of 2.14:1, and an NPV of A$30,000 (it is not clear from the source material whether this figure is based on 2010 or 2011 values).

The study also identified that sapwood production is not economically competitive, as it has a low farm gate price of A$1,000/t and is harvested at 7 years. Given the potential high value of hardwood and oil, sandalwood could provide a long-term saving strategy for smallholders (Page et al. 2012c).

In Vanuatu, it is estimated that the average annual harvest of 80 t of hardwood will quadruple by 2030, given the uptake of planted sandalwood throughout the country (Page et al. 2012b). In this study, we assume tripling of harvest from 80 t to 240 t.

The exotic location, cultural production context, and recognition of a high-quality produce make Vanuatu sandalwood potentially competitive in future markets (Page et al. 2012c). Supporting the expansion of sandalwood plantations are the ongoing knowledge extension services provided by the VDoF, and smallholders' increasing ability to germinate seeds and establish rural orchards in their villages.

A single oil distillery processes oils to sell largely to international tourists. But heartwood provided by smallholders at farm gate prices to licence-holders is the main way products are sold from sandalwood plantations.

1.5 Mixed-methods approach

ACIAR has published a series of impact assessment frameworks and methods that can be used to determine how research partnerships have delivered on social, economic and environmental outcomes and sustained impacts. From these frameworks, Davis et al. (2008) provides a comprehensive benefit:cost tool that enables consistent impact assessment of agricultural projects.

This guideline offers researchers a structure for:

- capturing adoption of new technologies
- capturing various market and production costs and benefit variables
- calculating investment returns to research, including NPV, benefit:cost ratio and IRR under different scenarios.

Complementing this, the framework developed by Davila et al. (2016) offers an analytical tool for examining how ACIAR research has enabled salient, credible and legitimate knowledge products that are suitable for the developmental and policy context of partner countries.

Throughout this assessment, we combine these frameworks, as part of a mixed-methods approach to identifying the impacts of ACIAR sandalwood projects in Vanuatu.

1.6 Theoretical foundations for mixed-methods impact assessments

The nature of forestry systems means that yields cannot be calculated until the specific species is ready for harvest. For ACIAR, this means that quantifiable economic project impacts are difficult to empirically test until initial products make it to markets.

But ACIAR projects also have partnership and knowledge-based activities embedded throughout the projects, and these can have less empirically observable, but relevant, impacts on both Australian and partner researchers and communities.

One way of framing these different types of impacts from projects and their relevant agricultural commodities is to approach impact assessment with an acknowledgment of how different data can be used to document various project impacts.

Figure 4 presents these different types of data that can contribute to various impact stories. In the figure, we propose that impact observations and measurements can fall both within positivist or constructivist ways of understanding observations and how the world operates.

Positivism relates to understanding the world through observations of measurable entities, allowing a clear testing of a hypothesis or problem to produce a set of definite results. On the other hand, constructivist methods acknowledge that there is more than one reality, and rather the world is interpreted differently by people as they are exposed to their changing environments and contexts.

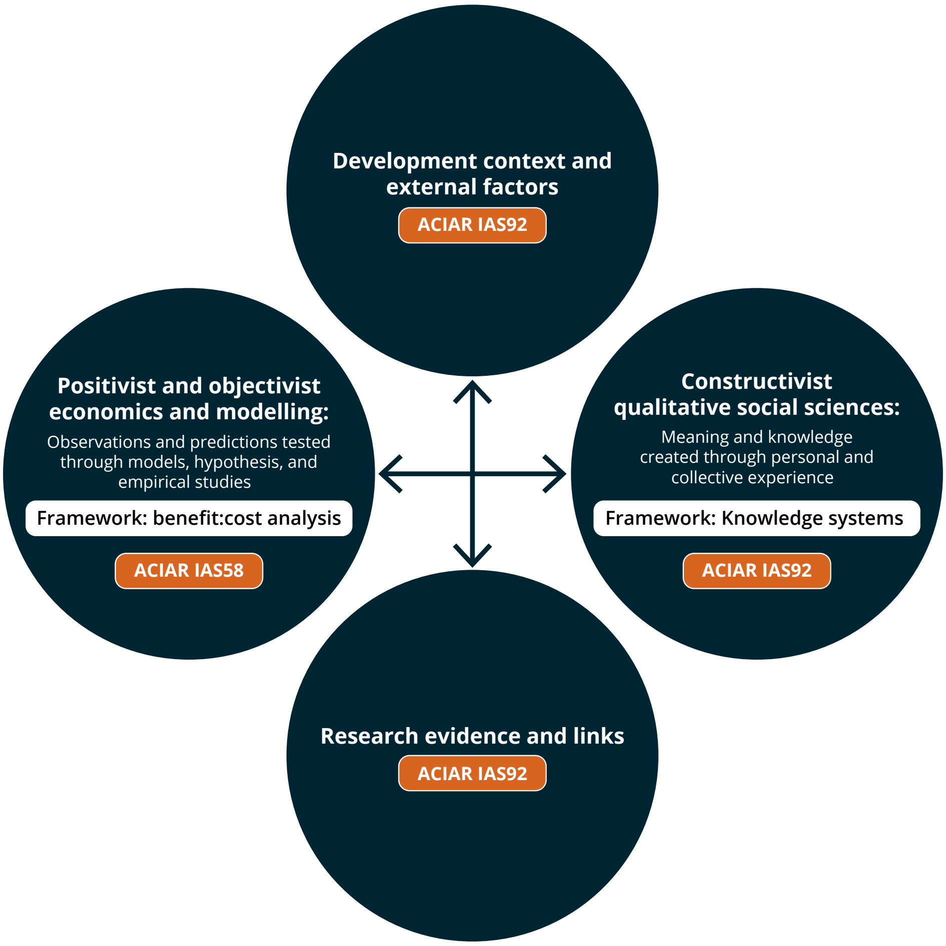

Figure 4 Synergies between quantitative and qualitative frameworks for impact assessment

In smallholder context, a constructivist analysis would seek to understand how smallholder experiences of productivity are shaped by their exposure to education, markets or environmental change, for example. These experiences then shape how someone reacts and makes decisions in their immediate environment.

This distinction between positivist and constructivist epistemologies is important for understanding how the different impact assessment frameworks in ACIAR publications can be implemented, using different quantitative or qualitative methods, leading to different data to document project impacts. Ultimately, these different methods tell different parts of the story.

Quantitative methods under the positivism side of the diagram are essential for documenting the economic returns to smallholder or partners. Given the ACIAR focus mostly remains on the smallholder farm, these quantifiable metrics are important for planning future investment or calculating how smallholders would benefit from research project. But these economics impacts do not operate in a value-free vacuum—they form part of dynamic interpersonal knowledge exchange processes, and changing developmental contexts.

The right side of the diagram proposes that qualitative methods provide insights into how knowledge is exchanged between different research producers and users, and how it is translated to end beneficiaries, often smallholder farmers.

Finally, regardless of whether impact is being sought to be measured in either qualitative or quantitative terms, it needs to be situated within the changing development context in which ACIAR operates, and the linkages made during the research process. The arrow in the middle draws from the research to policy framework developed in IAS 92.

In mixed-methods impact assessments, it is important to situate the economic analysis or qualitative findings, or both, within the wider national and international context of the impact assessment.

While the two methods have different theoretical foundations, quantitative and qualitative data are usually collected and analysed in a deductive way. This is done to look for changes in behaviours and practices in the models or qualitative stories, to answer the specific impact assessment questions.

Inductive analysis—where the data reveal insights not originally built into the impact assessment—is most likely to take place when unintended benefits are identified during the assessment process.

Throughout this impact assessment, our team worked across the different economic and knowledge-based frameworks developed by ACIAR. The types of questions and analysis offered by the different frameworks enable researchers to ask questions that look for different types of impacts across the positivist to constructivist spectrum.

1.7 Data collection

The two frameworks were integrated through the field work and the interview guides. The limited economic data on sandalwood price and production from Vanuatu meant that interviews were required to confirm the current costs of production and market prices of sandalwood in Vanuatu.

The interviews also provided an opportunity to discuss non-economic factors that are related to impact, such as use of extension services, use of training manuals, application of skills, and changes in policy.

At the core of this blended approach to impact assessment is the reality that reliable quantitative data in geographically dispersed countries like Vanuatu are very difficult to obtain with confidence.

The use of interviews and engaging with local knowledge networks working in the sandalwood value chain allowed our team to capture, qualitatively, the current market behaviour and use of sandalwood products. This qualitative data were then organised in Excel to create a general template of the different:

- costs of production
- current heartwood yields
- farm gate and market prices offered
- planting rates for individual farmers.

Interview notes were used to identify wider themes around the quality of knowledge and use of research outputs by different stakeholders in the value chain. We used desktop literature and interview themes relating to policy context in Vanuatu to determine how possible policy shifts influence the long-term impacts of the projects being assessed.

In the concluding chapter, we present a table building from both the impact assessment guidelines (Davila et al. 2016; Davis et al. 2008) and linking them to the findings from this study.

The sandalwood context outlined in this chapter presented the three major products that can be obtained from sandalwood: sapwood, oil and heartwood. Previous studies indicate that sapwood is not economically viable due to its low market price. Oil is high value, but Vanuatu has only one small distillery, making the processing and exporting of oil a challenge.

Determining oil yields from currently planted sandalwood is also highly uncertain, making it difficult to determine possible yields from current plantations. Heartwood yields are more commonly understood in Vanuatu, as it is the main product sold from sandalwood trees by smallholders. Heartwood has been harvested by smallholders and sold by licence-holders for decades, largely based on wild trees.

As a result, this impact assessment focuses only on heartwood yields, as they are the most salient to the Vanuatu context at the point of data collection and analysis.

Our team designed a question guide that sought to capture both quantitative and qualitative data from key informants. We interviewed 34 people from four sectors: research, policy, farm and industry. Table 2 presents the breakdown of these stakeholders. Appendix 1 presents the interview guide used.

A field trip was conducted over a 10-day period in September 2018 to Efate and Tanna. Interviews with government and licence-holders were held in Port Vila, and interviews with smallholder and large producers were held on-farm.

We conducted the interviews in Bislama, with the support of an experienced research staff from Vanuatu. The quantitative data were organised in a spreadsheet while the qualitative data were summarised thematically, following the knowledge systems and RAPID framework.

Chapters 3 and 4 present the detailed analysis and findings for the quantitative and qualitative analysis. The next chapter summarises ACIAR projects reviewed for this impact assessment.

Table 2 Key informants interviewed in this impact assessment

Key informant group	Number of people interviewed	Link to ACIAR sandalwood projects
Policy	3 (in group format interview)	Involved in project research and extension activities
Farmers and licence-holders	30	Small, medium and large producers growing sandalwood
Research	1	Involved in project research and extension activities

1.8 Economic modelling assumptions

For individual producers of sandalwood, the economics of production are complicated by a long-time horizon. In contrast to annual crops, such as melons, sandalwood producers are likely to need to wait 15–30 years before they can reap the benefits of their initial investment. This has several implications for modelling the future returns of sandalwood plantations:

- There is great uncertainty over the future output prices. Output prices have doubled in recent years to reach A$4,500/kg for high-quality oils. For heartwood, the reported Vanuatu price is A$12.50/kg (VT1,000). These prices can fluctuate widely, and uncertainty needs to be considered when determining the viability of the industry.
- Discount rates determine the extent to which producers are motivated to harvest early.
- The risk of tree loss or damage needs to be factored in, as it is a threat in Vanuatu. Growth and yield relationships need to be considered, as it is unclear how different ages and weight of heartwood lead to different oil yields.
- The opportunity cost faced by smallholders is considered to capture the alternative land uses for smallholders.

For the economic analysis, we compartmentalised producers into three categories, consistent with the previously described typologies. These were:

- smallholder farmers, working on mixed agricultural land of about 1 ha (this was the most common category, and was also used in previous analysis in Harrison and Karim 2016)
- medium-scale producers, working on land of 7 ha
- a single large-scale plantation of 200 ha.

Smallholder production is expected to supply the majority of heartwood in the future.

The uncertainty of yield and adoption data required us to carry out the analysis with some major assumptions (Box 1).

Limitations of the analysis presented in the partial equilibrium model centre around attribution. We know 100,000 seeds have been distributed but we assume only 50% of these can be attributed to ACIAR activities. We also assume that 100,000 is about the limit of seeds that were planted. This represents a threefold increase in production (see Section 3.2.2). All data collection and analysis were conducted during 2018 and early 2019 and, to the best of our knowledge, the projected impacts have not changed since that time.

Box 1: Assumptions made for the modelling in this assessment

a. ACIAR nominal research expenditure of A$1,914,693 (A$2.53 million in constant 2018 dollars) relates to projects FST/2002/097 and FST/2008/010.
b. About 100,000 seedlings have been or will be planted, and half of these can be attributed to ACIAR activities.
c. We assume that all the 100,000 trees are planted in 1 year and harvested 18 years later.
d. Forgone revenue is a modest A$75/ha/year.
e. Economies of scale benefit larger properties.
f. Yields are 30 kg/tree.
g. The farm-gate price for sandalwood heartwood is A$12.50/kg. This is the lowest price recommended by VDoF for low-grade heartwood.

Young sandalwood trees planted among undergrowth vegetation on a farm, at Tanna, Vanuatu.

2 Research investments

In the 1990s, as awareness of sandalwood demand increased, research and government agencies in Australia and the Indo-Pacific saw the opportunities for developing plantation-based sandalwood industries.

In 1990, the East-West Centre Symposium in Hawaii reported on the emerging knowledge of sandalwood species in the Pacific (Hamilton and Conrad 1990). This was followed in 1991 by an ACIAR-funded symposium on sandalwood conservation at the XVII Pacific Science Congress (McKinnell 1993).

A study, funded by AusAID in 1996 under SPRIG, developed a strategy for the conservation, management and better use of the genetic resource of sandalwood in the Pacific. The outcome of the SPRIG program led to the support of recommendations to establish planting programs, exchange germplasm and study genetic structure of sandalwood.

These recommendations and local efforts in Vanuatu to extend the work by the Vanuatu Chamber of Commerce seedling program led to ACIAR supporting project FST/2002/097.

A survey of oil content, quality and superior genetics was able to determine the types of species best suited to be planted in Vanuatu that had the potential of yielding high quality oil.

Through planting trials, capacity building activities and technical scientific papers, the project concluded that further information was required in wild sandalwood stocks and the socioeconomics of sandalwood production.

To fill this knowledge gap, ACIAR commissioned two small research activities. The first (FST/2006/118) provided an inventory of wild sandalwood stocks in Vanuatu. Based on field data on four islands, the research estimated wild stocks to be at 2,010 t, and 80 t in non-surveyed islands. The project supported planting initiatives as a way of protecting wild populations.

The second (FST/2007/057) analysed the socioeconomic constrains for developing sandalwood plantations in smallholder systems. Since FST/2002/097, there had been an increase in the establishment of planted resources in village communities. But there was a lack of sustained expansion of planting practices. FST/2007/057 sought to understand the socioeconomic impediments to the deployment of the resources and knowledge produced during SPRIG, FST/2002/097 and FST/2006/118.

As awareness of the possible value of planted sandalwood increased in Vanuatu, so did demand for seeds, planting bags and technical services.

Building on the knowledge from the previous three projects, ACIAR supported FST/2008/010 to establish plantations and support community incomes and national royalties for the national government.

The project used previous knowledge to establish a seed orchard to improve seed quality and establish plantations. About 100,000 seedlings were distributed throughout the country (2008–2012)—the most reliable adoption figure available for the projects. The project resulted in:

- seven formal orchards being established
- a cold storage facility being developed in Port Vila
- a farm with species from all but one island being established
- a series of capacity building workshops and training manuals being delivered.

The establishment of grafted seed orchards has been replicated across seven sites throughout the country.

2.1 Sandalwood projects in Vanuatu assessed

Table 3 summarises the sandalwood projects in Vanuatu relevant to this impact assessment.

Table 4 summarises small research activities that delivered contextual information to inform further sandalwood planting projects.

Figure 5 shows the visual timeline of ACIAR investments and counterfactual activities.

Table 3 List of relevant ACIAR-supported projects in sandalwood in Vanuatu

Project	Budget	Title	Objectives	Agencies involved	Major outputs
FST/2002/097	ACIAR: A$988,091 Partners: A$314,538 Total: A$1,037,040	Identification of optimum genetic resources for establishment of local species of sandalwood for plantations and agroforests in Vanuatu and Cape York Peninsula	• To describe the variation in oil content and quality, and other traits in natural populations of sandalwood in Vanuatu and Queensland. • To develop and implement tree domestication strategies for Vanuatu and Queensland, to ensure that future plantings of sandalwood are of high-yielding trees producing high sandalwood oil. • To provide scientific and technical training to build the capacity of local staff, and to disseminate and implement project findings.	VDoF, James Cook University, Queensland Forestry Research Institute	• Publications • Planting trials
FST/2008/010	ACIAR: A$1,298,710 Partners: A$415,310 Total: A$1,714,020	Development and delivery of germplasm for sandalwood and whitewood in Vanuatu and Northern Australia	• To advance the whitewood genetic improvement program in Vanuatu. • To advance the Vanuatu sandalwood genetic improvement program. • To establish the basic elements of a sandalwood genetic improvement program in northern Queensland.	James Cook University, VDoF	• Publications related to sandalwood production • Distribution of 100,000 sandalwood seedlings across 12 islands • Establishment of seed conservation farm • Establishment of 6 seed orchards, replicating 18 superior seeds twice • Learning field trip to Western Australia to determine strengths and weaknesses for the industry

Table 4 Small research activities on additional sandalwood inventory and socioeconomic context

Project	Budget	Title	Objectives	Agencies involved	Major outputs
FST/2006/118	ACIAR: A$84,475	An inventory of wild sandalwood stocks in Vanuatu	• To provide a rough inventory of wild sandalwood stocks in Vanuatu, stratified geographically and by size class.	James Cook University, VDoF	• Comprehensive estimate of wild sandalwood stocks in Vanuatu
FST/2007/057	ACIAR: A$149,000	Socioeconomic constraints to smallholder sandalwood in Vanuatu	• To determine the feasibility and profitability of the sandalwood plantation industry to smallholders and other participants. • To provide alternative strategies for financing of planting activities by smallholders, including participation as out-growers to larger industry investors. • To present marketing options for sandalwood, including by-products from sapwood. • To define government policy initiatives required to facilitate the development of the industry. • To develop a promotion strategy and information package for current and potential growers and investors.	James Cook University, VDoF	• Publications • Growers' manual

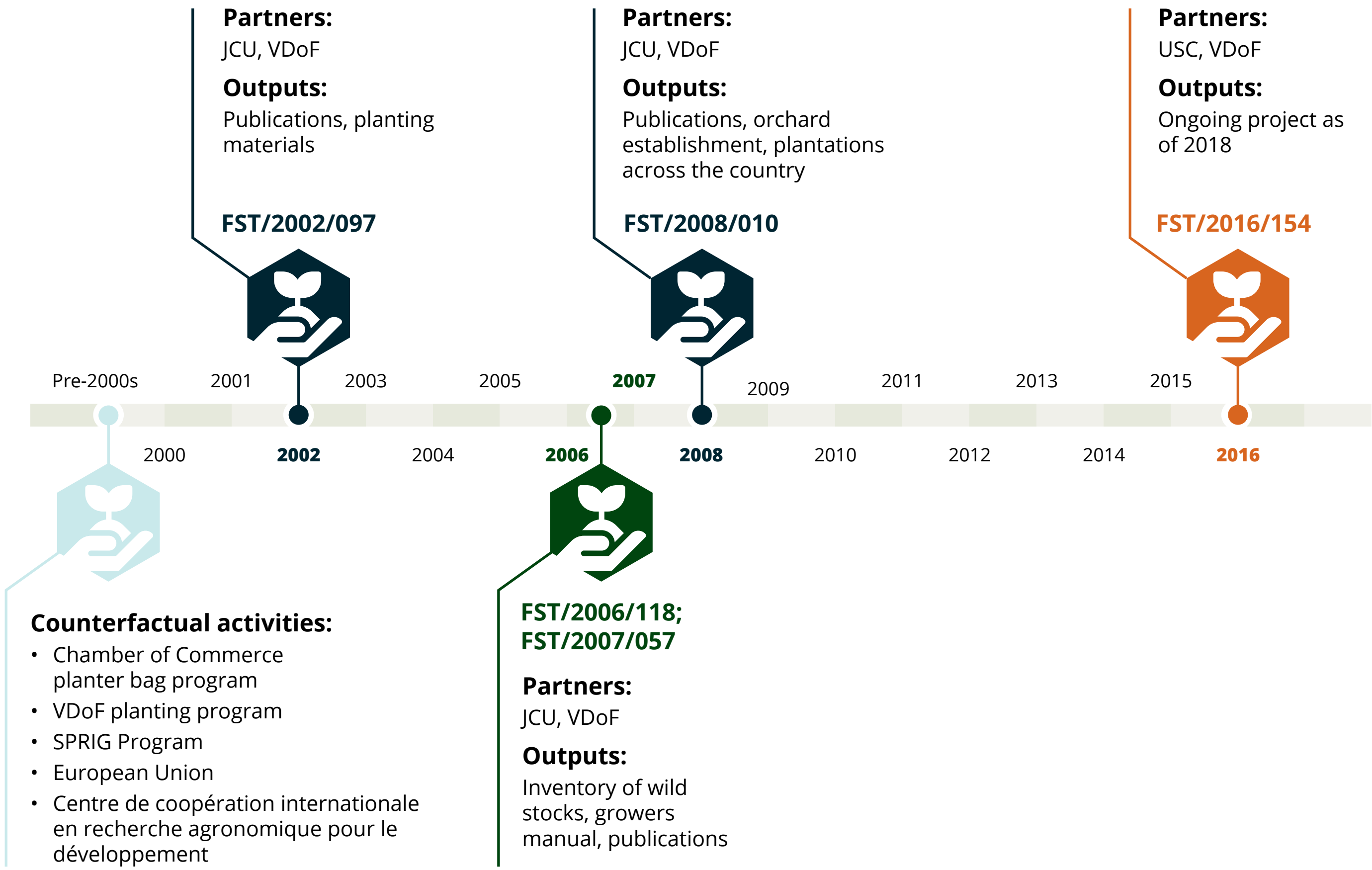

Figure 5 Sandalwood investments by ACIAR and other donors in Vanuatu

2.2 Reported impacts before the impact assessment

The project teams for FST/2002/097 and FST/2008/010 documented their perceived impacts of both projects in the final reports (Table 5).

The scientific contributions of FST/2002/097 related to the identification of links between morphology and oil quality. The research identified genetic material and composition of sandalwood suitable for the Vanuatu conditions.

The environmental contributions related to the initiation of plantation trials in smallholder plots as an alternative to wild harvesting. Social and capacity impacts were reported to relate to local staff technical understanding of sandalwood genetics and planting techniques, and to stronger understanding of strategies to disseminate planting skills to smallholders.

Reported economic impacts included a fivefold increase in southern islands and twentyfold increase in northern islands for seeds to establish plantations.

The impacts of FST/2008/010 identified in the final report were framed to directly build from FST/2002/097. The reported impacts of scientific data, as captured in 2012 in final reporting, related to floral phonology data and understanding of the factors that influence the success of planted seeds.

Environmentally, the project was reported to establish nurseries throughout the country, and supported the distribution of genetically superior seeds throughout the country. Social and capacity impacts reported related to the extension of the sandalwood growers' guide (Page et al. 2012d) and support for establishing plantations during 2008–2012.

The external review by Walker (2015) of FST/2008/010 captured some of the impacts the knowledge and extension activities have had on Vanuatu:

> *'Vanuatu sandalwood seed resources developed under this project, and enhanced awareness and knowledge promoted via release of the Sandalwood Handbook, are having a significant impact on the capacity of island communities to break into this potentially lucrative rural industry.'*

The report recommended exploring the approach of equity injection being implemented by other donors in Erromango to industry, to determine whether the approach could be extended to Tanna.

As part of the Western Australia trip conducted under FST/2008/010, sandalwood experts from VDoF conducted a strengths, opportunities, weaknesses, and threats (SWOT) analysis for sandalwood production in Vanuatu in 2015 (Table 6).

This analysis provides a baseline of how stakeholders perceived the enablers and inhibitors to marketing the planted sandalwood during ACIAR projects. This impact assessment conducted 3 years after the SWOT analysis provides an opportunity to gauge how the industry and governance arrangements within the domestic sandalwood value chain can enable or inhibit long-term positive economic impacts from planting activities.

The various reviews and publications associated with ACIAR-funded sandalwood projects show that there have been changes in knowledge and practices during project implementation.

The nature of forest products means that changes in knowledge and capacity might occur during and immediately after project completion, but economic impacts will occur in the future. The impact pathway in Figure 6 summarises impacts across economic, social and environmental domain for projects FST/2002/097 and FST/2008/010.

Table 5 Summary of impacts of FST/2002/097 and FST/2008/010 as reported in final reports

Impact area	Impacts in final reports for each project
FST/2002/097	
Scientific	• Findings of a link between morphology and oil quality. • Finding that, at the time, the industrial plantings were using genetic material that leads to high oil qualities. • Information that can lead to the development of near infrared scanning technology to evaluate oil quality.
Environmental	• Planted sandalwood to reduce harvesting of wild resource.
Capacity and knowledge	• Training of local staff on establishing nurseries, agroforestry, plantings. • Improved capacity of VDoF to implement sandalwood improvement strategy. • Higher awareness of the state of the resource and potential for future improvement. • Increased VDoF awareness of the need to promote planting. • Reported high confidence to provide training after workshops.
Social	• Women's church groups involved in planting. • Increased awareness of the need for ex situ conservation sandalwood plantings and a germplasm exchange program.
Economic	• Reported increase in demand for seed and seedling, fivefold in the south and twentyfold in the north. • Development of a nursery industry in all islands with natural sandalwood. • Future planting of improved plants can increase value of plantings. • Increased plantings.
FST/2008/010	
Scientific	• Floral phenology data, which are important for understanding the factors that influence success of seeds. The information can be used by plant breeders to determine the floral characteristics that affect controlled pollination. • Reproductive biology information published.
Environmental	• Established 880 trees in Navota Farm, South Santo. This represents sandalwood populations from all islands except Efate. This site is conserving genes. • Seed storage facility installed to have seeds available when they are scarce. • About 300 grafted sandalwood plants produced at the grafted seed orchards at several sites. • Findings that Malekula and Santo provenances are worth exploring further.
Capacity and knowledge	• Distribution of 2,400 copies of the sandalwood growers' guide (Page et al. 2012d) in Vanuatu. This guide is important for establishing and maintaining sandalwood plantings. • An extension DVD and kit produced. • In-house training to increase VDoF capacity. • Training in northern islands was well attended and received. It led to the creation of the Wunmaho Sandalwood Growers Association.
Economic and social	• Navota farm is harvesting sandalwood seeds by local landowners. • Establishment of five grafted seed orchards in northern islands—these communities had previously been left out from sandalwood planting activities. • Unclear impact in Tagabe—no evidence of distribution of seeds.

Table 6 SWOT analysis for sandalwood production in Vanuatu

Strengths
• Vanuatu sandalwood is recognised in the marketplace as a very high-quality product. • Vanuatu has marketing advantages associated with its location and traditional way of life. • Vanuatu sandalwood has rapid growth and heartwood development compared with other species, particularly *S. spicatum*. • Smallholder farmers have a capacity to grow sandalwood trees. • Vanuatu has a genetic improvement program aimed at ongoing improvements.
Opportunities
• There is a clear market for oil, and Vanuatu sandalwood generally produces a very high-quality oil. • The prices paid to landowners in Vanuatu can be increased in line with current market prices. • Tribal/fair trade marketing of sandalwood can demonstrate a chain of custody from farmer to consumer to add value. • A sandalwood oil library can be used to identify origin of sandalwood. • Improvement in productivity and product quality can be achieved by improving silviculture—growing products (silviculture) instead of growing trees (wild). • Industry restructure including single point marketing of sandalwood can attract a greater number of international buyers to Vanuatu.
Weaknesses
• The Vanuatu sandalwood industry suffers from fragmentation, with many small producers, making it difficult to access the broader international market. • The legality of sandalwood from Vanuatu is unclear to the international marketplace. • The VDoF has limited resources to adequately administer and regulate the sandalwood trade. • There is a lack of in-country capacity for processing and value adding.
Threats
• Significant volumes of sandalwood will come onto the market from *S. album* plantings in Western Australia. • Trees are sometimes removed illegally, with farmers not being paid. • *S. album* introgression with *S. austrocaledonicum* potentially leads to a reduction in wind firmness and an increase in rotation length due to slowing of heartwood development.

Source: Tabi et. al (2015).

OUTPUTS

Technology outputs
- Optimal varieties
- Seedlings

Knowledge
- Academic publications
- Manuals

Capacity built
- Government and smallholders skills on sandalwood planting

Environment
- Six grafted seed orchards for conserving native species

ADOPTION—NEXT USERS

Smallholders
- Adoption of seedlings
- Some adoption of nursery establishment knowledge
- Increased understanding of host plants
- Plantings by recommended spacing

VDoF staff
- Research writing and technical skills applied in Vanuatu and Australia
- Extension services and knowledge developed

Final users: smallholders, VDoF, large commercial plantings

OUTCOMES AND INTERMEDIATE IMPACTS

Economic
- Economic impacts expected in 18–25 years from planting
- Occasional sales of seeds

Environment and policy
- Seed conservation
- Anecdotal experiences of resilience of native varieties to cyclones
- Active industry groups throughout the country

Knowledge
- Non project end users, such as church and union groups, using knowledge products
- Improved planting techniques
- Increased understanding of nursery establishment
- Knowledge exchanges with Western Australian sandalwood experts
- Ongoing academic publications

Current policy context: smallholders dependent on licensing system to sell heartwood

FINAL IMPACTS

Economic
- General understanding and interest of sandalwood in Vanuatu
- Increased profit to farmers and industry from heartwood sales

Environmental
- Seeds conserved in VDoF facilities
- Orchards conserve native seeds and enable seed distribution

Social
- Increased capacity among VDoF staff
- Large commercial planting employs smallholders throughout the country
- Sandalwood branding as a unique Vanuatu product

Final beneficiaries: smallholders, license holders

Figure 6 Impact pathway for projects FST/2002/097 and FST/2008/010

3 Economic impacts of sandalwood in Vanuatu

This chapter presents economic modelling used to project the potential gains for the sandalwood industry in Vanuatu, and the contributions ACIAR projects have made to these industry gains. The models were created based on a mix of secondary data, previous ACIAR studies into sandalwood economics, and field interviews with smallholders, licence-holders and government officials.

The chapter first lays out the definitions used to develop the models and the assumptions in the analysis, given data fragmentation and uncertainties. We then present analysis for calculating the NPV and IRR, and carry out sensitivity analysis under different scenarios. We conclude the chapter by identifying the long-term price viability, and discuss the influence this might have on the sandalwood industry.

3.1 Economic concepts for this assessment

3.1.1 Discount rates

Future gains need to be discounted back to the present. Producers contemplating a long-term investment would prefer to have the returns sooner than later, and need to be assured of greater returns to make a long-term investment. What the discount rate should be is subject to debate, and there are several rationales for establishing one.

The discount rate is important, and should be acknowledged. At a 3% discount rate, a stand of timber worth A$10,000 in 10 years' time is worth A$7,374 now, and only A$4,670 in 25 years (Figure 7). At 5%, the respective NPVs are significantly less, at A$5,987 and A$2,774.

For sandalwood products, which may take 20 years before maturity, future returns need to be at 2.5 times the initial investment to break even. Intermediate maintenance, such as pruning and fertiliser, need to be taken into account, as they are ongoing costs to smallholders.

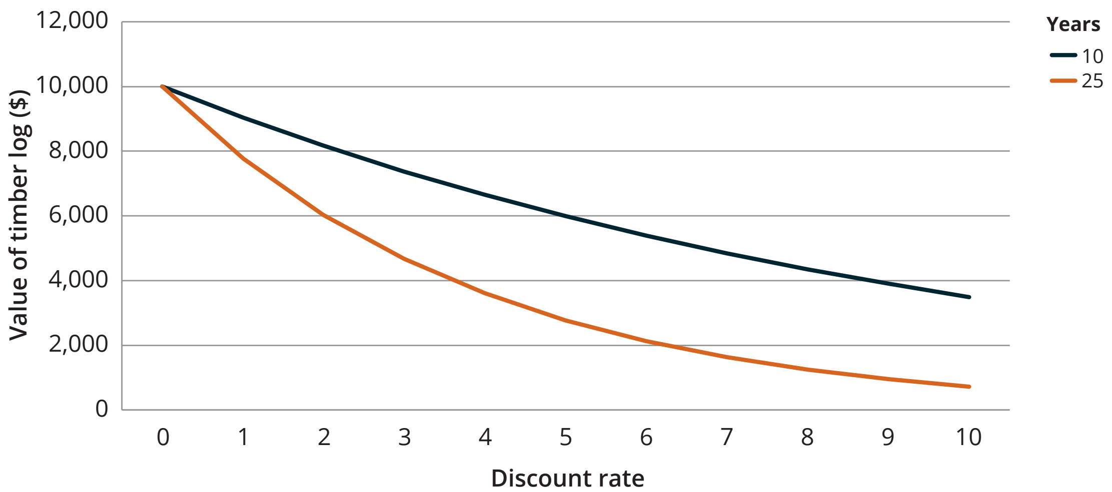

Figure 7 Impact of discount rates on future values, based on a generic timber log of A$10,000 and different time frames

The discount rate influences the optimal rotation length. The higher the discount rates, the greater the incentive to harvest trees earlier to gain the economic benefits. ACIAR impact assessment guidelines recommend the use of a 5% discount rate. As such, we use a 5% discount rate in our analysis.

3.1.2 Risk

A second issue related to the time horizon is the risk of damage or theft. Cyclones represent a potential threat to sandalwood, and this might increase in the future if cyclones increase in frequency or severity. This is documented qualitatively in Chapter 4.

Risk can be covered by insurance, although small producers might need to self-insure in the absence of a reliable insurance market. In this study, we assume a mortality rate of 20% between planting and harvest, based on field interviews and previous studies into sandalwood plantations. This mortality rate is varied at 10%–30% in the sensitivity analysis to present different scenarios for the net present value.

3.1.3 Growth rates

Growth of timber is an important dynamic concept to consider. Young trees grow exponentially, according to a logistic function, but growth slows as they age, as shown in Figure 8.

The Faustmann Rule suggests the optimum time to harvest depends on when the marginal benefits equate with the opportunity costs of waiting (Mitra and Wan Jr 1986). This is where a line from the origin is tangent to the curve. The amount of additional timber produced each year is past its peak, but still positive. But for some timber products, larger trees have greater value, because broader planks can be cut from them. This does not apply for sandalwood, where much of the value comes from essential oils obtained or heartwood carving logs used for aesthetic products.

Following Harrison and Karim (2016), we assume a linear relationship, with yields increasing 5% per year between the ages of 18 and 30. If the growth rate does not exceed the discount rate, there is no economic incentive to harvest later than 18 years.

3.1.4 Yields

Related to growth rate are the yields from sandalwood products. In sandalwood production, the most valuable product is oil—which needs to be distilled—followed by heartwood. This analysis focuses on heartwood only. There is not a direct relationship between the amount of timber (stumpage) and the quantity and quality of the essential oils. Variation in yield is a significant uncertainty in modelling the viability and profitability of a sandalwood plantation.

Our field work confirmed that the domestic oil market is in its infancy in Vanuatu, and the majority of sandalwood returns come from heartwood sales.

Plantation crops are grown under more controlled conditions, in contrast to wild production. These controlled conditions were promoted by ACIAR through the publication, *Vanuatu sandalwood—Growers' guide for sandalwood production in Vanuatu* (Page et al. 2012d). But a research leader indicated that following the controlled conditions in Vanuatu is not critical, given the highly fertile environment in which smallholders grow sandalwood. The growers' guide value lies in its knowledge and capacity to plant hosts and maintain a plantation, as discussed in Chapter 4. It remains unclear whether controlled conditions will lead to higher-quality heartwood and oil outputs.

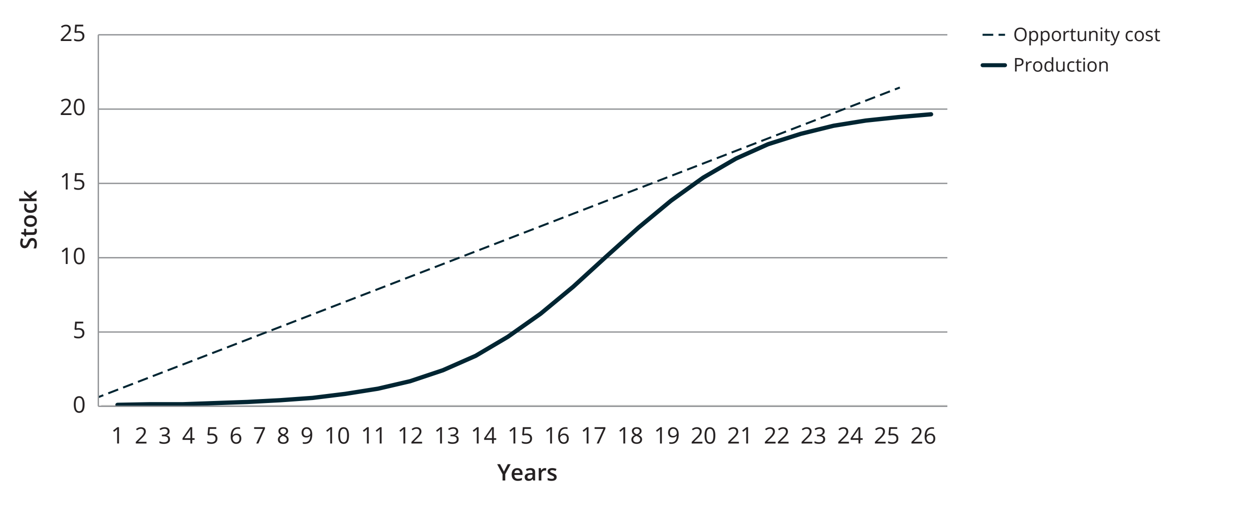

Figure 8 Growth of stock of timber over time

3.1.5 Opportunity cost

Opportunity cost, the loss from not undertaking alternative activities, also needs to be considered. This is income that could be obtained if land, labour and capital had been diverted to other crops, such as producing other timber products, other tree crops like cocoa or coconuts, or annual crops like sweetpotato.

Alternatively, the owner has the option of felling the trees and replanting, as the new trees will grow faster than the old ones. For wild harvest, the opportunity cost is probably low, but this is unlikely to be the case for plantation timber. In Vanuatu, it seems that sandalwood is preferred to other forest products. During the interviews, we were told that mahogany and whitewood were occasionally planted, but the smallholders we visited prioritised sandalwood as the main investment commodity. We assume, based on previous studies, an opportunity cost of A$50/ha (Harrison and Karim 2016). We vary this in the sensitivity analysis.

3.1.6 Government policy

Producers face the uncertainty of the current policy context, which might act as an inhibitor for the industry in the future. At present, the government imposes an export quota on processed sandalwood products, and raw timber cannot be exported at all. The purpose of the quota, which is currently 80 t/year, is to limit harvest of wild trees. As the planted sandalwood begin to come online, this quota is likely going to have to change to enable producers and licence-holders to deliver the product to international markets.

Vanuatu supplies about 2% of the world market, making it reasonable to conclude that changes in supply will not affect export prices received. This assumes that all sandalwood is homogenous and perfectly substitutable. But it is clear that Vanuatu sandalwood is distinct from Indian or Australian product, and offers the country a niche marketing opportunity. The local species, *S. austrocaledonicum*, has been identified as optimal for growing in Vanuatu, and amenable to local environmental conditions.

For this reason, an increase in exports of Vanuatu sandalwood might have a negative effect on prices. Individual producers, largely smallholder farmers, are price takers and have little to no influence over the price of the harvested product.

Factors not considered in this analysis are non-timber values, such as environmental and recreation benefits. These values do not much influence the decisions of individual producers, who are making decisions about plantings. If these external benefits are significant, it might be sound policy for the government to subsidise production. The problem for the government is to put a value on these benefits.

3.2 Methodology and data

Financial modelling involves an assessment of farm-level decision-making on the choice of activities or crops. In this case, the decision to grow sandalwood and the optimal time to harvest are of interest.

This is essentially a gross margin analysis, assuming that fixed costs remain unchanged. Data required from different sites in the field include costs, yields, expected prices and a relevant discount rate.

The scope for alternative use of the land is captured through an estimate of the opportunity cost. Some account is included of the risk that the forest will be damaged or destroyed by cyclones, or otherwise fail to reach maturity. The assumptions for yields and adoption were introduced in Chapter 1 of this report.

Cost data are taken from Harrison and Karim (2016). These data relate to a single 0.2 ha site in 2008, but provide a detailed breakdown of costs. We updated these data, where possible, from a survey of producers and stakeholders conducted in 2018. The interviews done in the field provide estimates of output prices.

We also consider economies of scale that arise from larger plantations. We obtained estimates of yields from producer and stakeholder opinions. Although conservative, these estimates are somewhat speculative, partly because previous trees have been wild, and plantation crops are not subject to stresses that might lead to higher-quality oil.

A characteristic of forestry is that the costs are mainly incurred upfront and the revenues are postponed for many years. The standard approach is to calculate a NPV to bring future benefits back to the present, using an appropriate discount rate.

For a single producer or plantation owner, we estimate:

- initial establishment cost
- year-by-year maintenance costs
- harvesting costs
- expected yields
- final value of the product at the farm gate when sold.

Costs and revenues are expressed in 2018 constant dollars using the gross domestic product deflator (IMF 2017). In addition to being expressed in 2018 dollars, the ACIAR expenditure incurred from 2002 and 2008 is discounted to 2018 to reflect the opportunity costs of these funds. This increases the value of the ACIAR costs.

3.2.1 Formulas

The NPV formula is:

$$NPV = \frac{CF^0}{(1+r)^0} + \frac{CF^1}{(1+r)^1} + \frac{CF^2}{(1+r)^2} + CF^3 (1+r)^3 + \dots + \frac{CF^n}{(1+r)^n} \quad (1)$$

Where:

- CF is cash flow each year
- 'r' is the discount rate, assumed here to be 5% following Davis et al. (2008)
- 'n' is the time to harvest.

If NPV is positive, the plantation is profitable, in that the returns exceed the discount rate, which represents the best alternative investment return available.

We also calculate an IRR, which is essentially the discount rate 'r' that makes the sum of discounted revenues equal the sum of discounted costs.

$$\sum_{i=1}^{n} \frac{R^i}{(1+r)^i} = \sum_{i=1}^{n} \frac{C^i}{(1+r)^i} \quad (2)$$

The investment should be made if IRR exceeds the discount rate. The advantage of this technique is that there is no need to specify the discount rate in advance.

Some analysts prefer a modified IRR, which accounts for differences in the rate of return for cash flows that are reinvested partway through the project. The firm's cost of capital might differ from the initial IRR. This modification doesn't apply here, because all the returns occur at the end of the project.

The discounted revenues and costs can be used to calculate a benefit:cost ratio, which will exceed 1 if NPV is positive.

3.2.2 Approach

Single farm financial analysis provides an estimate of the economic incentive to plant sandalwood, given a fixed output price, or at least, assuming farm production does not affect the price. This is reasonable at a single farm level, but not for an industry.

To show the effects of production and price fluctuations on industry performance, we develop a dynamic multiregion partial equilibrium model. The underlying assumption in the farm financial analysis is that the quantity of output in Vanuatu does not affect international prices, given Vanuatu produces about 2% of global output.

But changes in global production and demand will affect international prices that are received by local producers. International prices are quite variable, depending on variations in supply in India and Australia, and increasing demand in China.

The success of the industry as a whole depends on the adoption rate—that is, how many producers choose to plant the trees. Adoption of sandalwood seedlings is partially available from the VDoF annual reports 2012–17, field interviews, and the data reported by Page et al. (2012b).

Based on these data, we assume 100,000 seedlings have been distributed and planted. Further distribution of seedlings is not built into the modelling, given the uncertainty of frequency and quantity of seedlings distributed. Interviews with smallholders also confirmed that access to polybags to germinate and plant new sandalwood trees is a major barrier, as polybags are both expensive and difficult to obtain.

To put this in context, current production of 80 t could be produced from about 2,700 trees, assuming a yield of 30 kg/tree. Given a 20-year rotation, with 5% of the stock harvested each year, the current stock of trees could be about 50,000. A further 100,000 trees would represent a tripling of steady state output, presenting a reasonable projection.

Finally, there is the issue of attribution to specific ACIAR activities. It is very difficult to determine the counterfactual of what would have happened in the absence of the ACIAR projects.

Table 7 summarises other activities in Vanuatu related to sandalwood or forestry activities. We assume that 50% of the 100,000 seedling plantings can be attributed to ACIAR initiatives. But the available desktop literature and field observations indicate that ACIAR has been a core player, with sustained efforts on sandalwood research and extension services since 2002, and linked to AusAID's initial activities in the 1990s.

Figure 9 shows the counterfactual simulations. The counterfactual is presented as projected sandalwood production using a 'with' ACIAR and 'without' ACIAR simulation.

We know that 100,000 seeds have been distributed, and we assume that half of these can be attributed to ACIAR activities. In the absence of ACIAR contribution, the volume of output might increase from the current value of 80 t to 160 t in 20 years.

Following adoption of ACIAR practices and the planting of a further 50,000 seeds, following a logistic curve, the volume is projected to reach 240 t in 20 years. The ACIAR contribution is the difference between the two curves.

Table 7 Other sandalwood-related investments, 1980–2015

Agency	Year	Overview
CIRAD Forests in the 1980s (French agricultural research funder)	1980s	• Oil quality research
VDoF Vanuatu	1990s	• Co-relation between heartwood and weight research
AusAid: South Pacific Regional Initiative on Forest Genetic Resources	1990s	• Invested in research and development on the quality of sandalwood seed • Initial socioeconomic studies done in 1993–1994 • Initiated gene and seed conservation
Vanuatu Chamber of Commerce	2000s	• In 2003–2007, more than 1.9 million empty nursery polybags were distributed to smallholders (Page et al. 2010a)
European Union	2000s	• Facilitating Agricultural Commodity Trade pilot Project (workshop funding)
Asia–Pacific Association of Forestry Research Institution	2000s	• Workshop support
SPC Land Resources Division	2000s	• Workshop support
New Zealand Aid	2010	• Equity injection model being applied by the private sector to promote sandalwood smallholder plantings on Erromango, with possible link to The Summit/New Zealand Sandalwood Futures Ltd
Asian Development Bank	2011	• Investigating ways of using sandalwood to address barriers to securing finance, a major impediment to enterprise in Vanuatu
Gesellschaft für Internationale Zusammenarbeit (GIZ)	2015	• Coping with climate change in the Pacific region, with an agroforestry focus, and some sandalwood elements

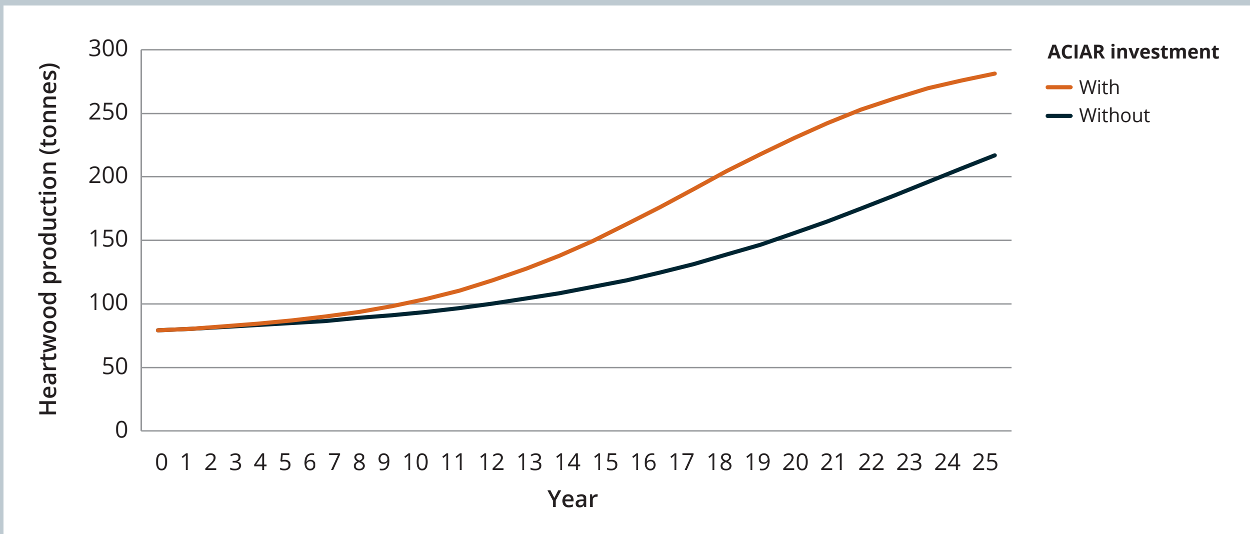

Figure 9 Estimates of heartwood production 'with' and 'without' ACIAR investment over 25 years

ACIAR has been one of the major supporters of sandalwood knowledge and training activities in Vanuatu, but other agencies have supported the industry. In the early 2000s, the European Union reportedly worked on forestry industry projects, with sandalwood as one of the key commodities.

In 2018, the World Bank was supporting a readiness phase for a Reducing Emissions in Reforestation Project, which has provided polybags for planting key forest products throughout the country, including sandalwood. The Pacific Multicultural and Agricultural Market Access Plus (PHAMA) Program, co-financed by the Australian Government, has also provided an opportunity for industry to organise themselves to manage the expected surplus availability of sandalwood in Vanuatu markets by 2025–2030.

While these projects have supported elements of the sandalwood industry, ACIAR-supported research has been the main contributor to improved knowledge on the growing techniques and screening of genetic resources of Vanuatu species.

Costs

Table 8 shows costs data obtained from Harrison and Karim (2016), and updated from survey data. We assume a 1-ha plot, with 5-m spacing between and within rows. This means there are 400 trees/ha.

In the field interviews, smallholders also noted that 400 trees in 1 ha was relatively common practice. But every fifth tree is a host tree, other than sandalwood, with the host tree incurring planting costs, but no yield.

We take the labour use data (time for clearing, fencing, planting, fertilising, watering etc) from Harrison and Karim (2016). Total labour time at establishment is about 260 hours/ha. We have updated the labour cost at A$17/person/day, based on the minimum wage of VT170 (A$2.43) per hour.

Material costs also need to be considered, at:

- A$330 for fencing, depending on the perimeter of the plot, although only half the cost is attributed to the plantation[1]
- A$2.50 for each seedling, or A$800/ha
- A$0.80 per tree for fertiliser, or A$256/ha at planting.

Total capital outlays are A$1,880 for establishing a sandalwood plantation.

Table 8 Planting and maintenance items for sandalwood

Variable	Area/ cost/ time
Area planted to sandalwood (ha)	1
Distance between rows (m)	5
Spacing within rows (m)	5
Planting area perimeter (m)	400
Length of working day (hours)	8
Site clearing time (hours/ha)	35
Fencing labour time (minutes)	36
Share of fencing attributed to sandalwood (%)	50
Number of seedlings planted	320
Fertiliser rate at planting (grams/tree)	50
Hole digging time (minutes/tree)	12
Planting fertilising/mulching time (minutes/tree)	5
Planting and watering time (minutes/seedling)	10
Tree mortality rate after planting (%)	20
Infilling time (minutes/tree)	8
Total labour time, plantation establishment (hours)	260
Weed control labour, year 1 (minutes/tree)	15
Weed control labour, year 2 (minutes/tree)	10
Weed control labour, year 3–7 (minutes/tree)	5
Fertiliser rate, years 1–4 (gram/tree)	50
Fertiliser labour, years 1–4 (minutes/tree)	2
Pruning labour, year 5 (minutes/tree)	10
Pruning labour, year 10 (minutes/tree)	15
Tree protection, year 8 on (minutes/tree)	5
Number of trees harvested	256
Root lifting and cleaning labour, year 18 (hours)	3
Tree felling, bucking and debarking, year 18 (hours/tree)	2
Sapwood chipping time, year 18 (hours/tree)	1
Total harvest labour, year 18 (hours/tree)	6

Sources: Harrison and Karim (2016) and authors' estimates.

1 We assume plots are square, which minimises the perimeter. The formula is 4*sqrt(ha*10,000), as there are 10,000 m^2 to the hectare.

Table 9 summarises the operating costs for smallholders growing sandalwood. Modifying Harrison and Karim (2016), we assume the opportunity costs is A$75/ha. This is what the land could be rented out for if it was not planted out to sandalwood. Costs include:

- weed control, at A$708/ha in the first 7 years
- fertiliser, at A$177 in the first 4 years
- pruning, at A$283/ha in years 5 and 10
- other tree protection costs, at A$623/ha from year 8 onwards.

After 18 years, the total expected operating costs are A$3,142/ha, before harvest and transport costs are considered. Harvesting a single tree can take about 6 hours, and transporting costs are about A$5 per tree. This amounts to A$4,544/ha if the trees are cut at age 18. The cost rises somewhat for later years. So, at the time of harvesting, total costs are expected to be about A$9,566/ha (Table 9).

Table 9 Cost summary per hectare

Type of cost and age of tree	A$
Capital costs, year 0	1,880
Operating costs, years 1–18	3,142
Harvesting costs, year 18	4,544
Total costs	**9,566**

Source: Authors' calculations.

Yields

Farm gate revenue depends on yields and prices. Farmers sell direct to licensed buyers who buy the whole tree, taking into account the expected yield of heartwood, carving timber, sapwood and fuel wood. Farmers might also sell seeds, and those with the skills to germinate seed, sell seedlings in local markets and to other farmers. Each tree yields about 0.1 kg of seeds, but there is a limited market.

Heartwood yields are the highest value item farmers can get from the trees, as it is what they can sell in the market. Heartwood yields can be about 30 kg per tree, but this can rise to 70 kg under good conditions.

We conservatively assume the yield is 30 kg/tree after 18 years. A mortality rate of 20% is assumed, due to cyclones, pests, disease, theft and other causes. It is assumed that there is a linear relationship between age and yield.

Prices

The heartwood price that farmers expect to receive is A$12.50/kg (VT1,000/kg). Revenue per tree at age 18 is A$375. So, revenue per hectare is A$96,000, taking into account the likely mortality and with every fifth tree being a host tree.

These prices are based on the lowest recommended price for poor quality heartwood, as identified by the VDoF. We used a conservative price lower than the recommended price, as some farmer interviews expressed low prices being offered at farm gate. The recommended prices for heartwood by VDoF are:

- first grade heartwood—VT4,000/kg
- second grade heartwood—VT3,000/kg
- third grade heartwood—VT2,000/kg.

Prices received by farmers reflect the international price of sandalwood oil. This is currently thought to be as much as US$4,500/litre, although evidence is anecdotal, and based on press reports, as opposed to a transparent and well-functioning auction market.

It is clear that prices vary a great deal, perhaps by 50% in the extreme, meaning prices might double from trough to peak, or halve on the way down. In our sensitivity analysis, we assume farm gate prices may vary 25% up and down.

3.3 Net present value and internal rate of return for smallholder plantings

Using the formula outlined earlier, with a 5% discount rate, and our best estimates of yields and prices, as well as operating, maintenance and harvesting costs as outlined previously, we calculate a positive NPV and IRR as shown in Table 10. This represents returns for the individual producer, and does not account for ACIAR expenditure.

We considered how this NPV and IRR would differ as opportunity costs, mortality rates, yields and prices changed. To build this into the model, we conducted sensitivity analysis of different scenarios. We assume:

- opportunity cost might vary A$25 around the standard estimate of A$75/ha
- remaining variables might each rise or fall by 25% with a:
  - mortality rates range of 15%–25%
  - yields range of 22.5–37.5 kg/tree
  - farm gate prices range of A$9.40–A$15.60/kg.

Table 10 Financial calculation for 1-ha sandalwood plot, not including ACIAR expenditure

Criterion	Value
NPV	$33,951
IRR	21%

Source: Authors' calculations.

We then combine the best and worst-case scenarios, with each variable at the bottom or top of the range. Table 11 shows the results for a 1-ha property.

In the worst case, the NPV is A$14,878. This means sandalwood is still profitable even in the most unlikely circumstances. In the best case, also unlikely, the NPV more than doubles to A$60,504.

Table 11 Sensitivity of NPV to variations in mortality, yields and prices

Scenario	$
Base scenario	33,951
High mortality, low yields and prices (worst scenario)	14,878
Low mortality, high yields and prices (best scenario)	60,504

Source: Authors' calculations.

3.3.1 Sensitivity to opportunity cost

Another way to assess sensitivity to opportunity cost is to identify the break-even point, where the opportunity cost is high enough to reduce the NPV to zero. Under the assumptions made in this analysis, the break-even point is A$2,979/ha/year. This amounts to A$53,622 over 18 years, compared with revenue from sandalwood of A$96,000 in the last year. Discounting brings these two values into line, so their values can be compared in the same year.

3.3.2 Economies of scale

Bigger properties are likely to take advantage of their size, by reducing the cost of weed control, fertilising, pruning and transporting the timber to the farm gate. In addition, the mortality rate is likely to be reduced.

We assume these factors are reduced by 25% on a 7-ha property, and by 50% on a 200-ha property. This reduces cost per hectare from A$9,566 in the 1-ha case to A$8,841 and A$8,183, respectively. Taking into account economies of scale, NPV per hectare is as shown in Figure 10. In the base scenario, NPV rises 9% for the 7-ha property, and 18% for a 200-ha plantation.

But given the nature of agricultural systems in Vanuatu, it is unlikely that large 200-ha farms will develop in the future. One-hectare smallholder plantations are expected to remain the most common sandalwood plantations in the country.

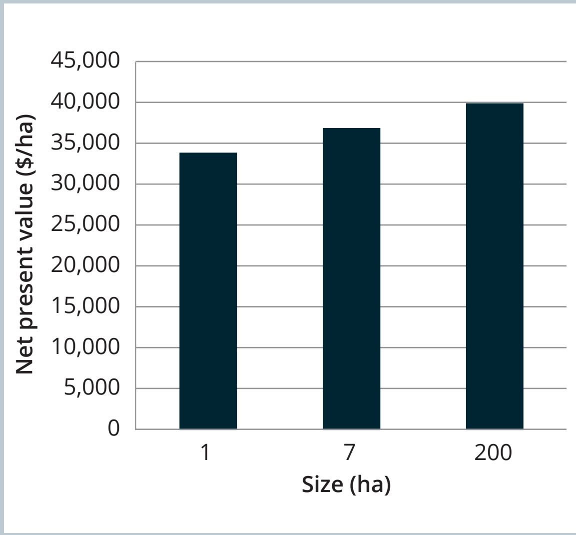

Figure 10 Economies of scale (NPV/ha), base case
Source: Authors' calculations.

3.4 Industry-wide NPV accounting for ACIAR expenditure

The previous sections calculated that individual producers have an economic incentive to produce sandalwood, considering variations in expected prices, yields, mortality and opportunity cost. That analysis did not take into account the A$1.914 million expenditure by ACIAR in projects FST/2002/097 and FST/2008/010, starting in 2002 and 2008.

To calculate the NPV for the industry, we assume the distribution of seeds is as shown in Table 12. Most of the seeds are planted on 1-ha farms, with one-quarter on 7-ha properties. There is one 200-ha plantation that takes up 5% of 100,000 seeds. It is assumed that 50% of the plantings are due to the efforts of ACIAR and that 50% would occur spontaneously in the absence of ACIAR funding or through the support of other agencies.

Table 12 Distribution of seeding, by farm size in Vanuatu

Size	%
1 ha	70
7 ha	25
200 ha	5

Source: Authors' estimates.

Table 13 shows ACIAR expenditure by year, along with spending by farmers, assuming all the seeds were planted in 2002, and revenue is collected when harvested in 2020. The distribution of ACIAR expenditure affects the NPV, the IRR and the benefit:cost ratio.

Taking into account ACIAR expenditure and the distribution of seeds to the different farm sizes, we calculate NPV for the industry of A$3.8 million, ranging from about A$800,000 to A$8 million in the worst and best case. In the base case, as opposed to best and worst, the IRR is 13.2% and the benefit:cost ratio 5.7:1 (Figure 11).

Table 13 Present value flows of benefits and costs and rate of return from FST/2002/097 and FST/2008/010, based on ACIAR funds only

	Total costs	Costs by farmers		Benefits	Net flow
Year	**Constant 2018 A$**	**Constant 2018 A$**	**ACIAR funds A$**	**Constant 2018 A$**	**Constant 2018 A$**
2002	284,726	284,726			(284,726)
2003	48,556	48,556			(48,556)
2004	355,810	38,457	317,353		(355,810)
2005	345,758	28,358	317,400		(345,758)
2006	242,310	28,358	213,952		(242,310)
2007	177,363	37,977	139,386		(177,363)
2008	21,818	21,818			(21,818)
2009	179,349	21,818	157,531		(179,349)
2010	285,957	19,798	266,159		(285,957)
2011	269,537	19,798	249,739		(269,537)
2012	259,604	44,036	215,567		(259,604)
2013	272,676	16,704	255,972		(272,676)
2014	173,540	19,798	153,742		(173,540)
2015	19,798	19,798			(19,798)
2016	19,798	19,798			(19,798)
2017	19,798	19,798			(19,798)
2018	19,798	19,798			(19,798)
2019	19,798	19,798			(19,798)
2020	726,423	726,423		15,328,125	14,601,702
Total	**3,742,419**	**1,455,617**	**2,286,803**	**15,328,125**	
				Net present value	A$3,802,412
				Benefit:cost ratio	5.7:1
				Internal rate of return	13.2%

Sources: ACIAR project documents; authors' calculations.

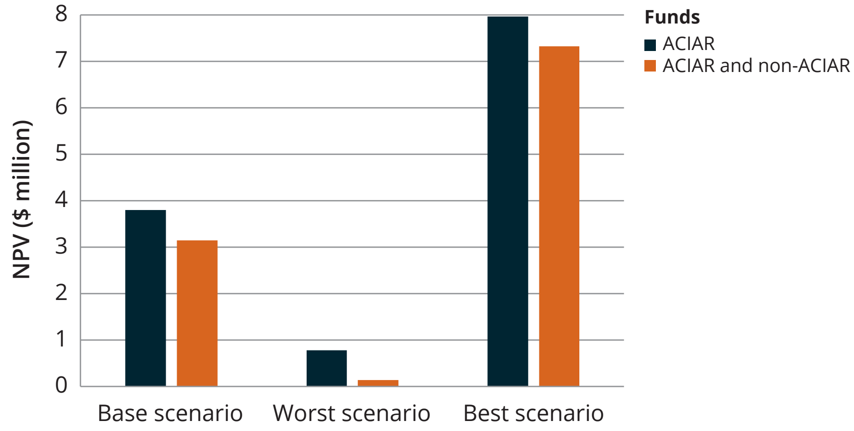

Figure 11 Industry NPV using 2018 constant dollars
Source: Authors' calculations.

So far, we have ignored the contribution of other agencies listed in Table 7, such as VDoF, Asian Development Bank and the European Union. If we also add expenditure by non-ACIAR sources of A$729,847, the NPV falls to A$3.1 million, and the IRR to 11.2% (Table 14).

This assumes the additional expenditure contributed to the 50% uptake we previously attributed solely to ACIAR. So, the NPV and IRR are slightly reduced. But the NPV remains positive in all scenarios, even in the worst case, indicating positive impacts for this project.

It should be noted that the ranges assumed are likely greater than would be realistically experienced. This means that it is unlikely that all producers would experience low yields and high mortality simultaneously, although low prices might affect all producers. But even in a scenario where low prices affect all producers, the NPV is still positive, even taking into account expenditure by non-ACIAR agencies.

Based on a mix of field observations and previous studies, we can conclude that for an individual producer who is not concerned about the amount of ACIAR funding, the NPV is of A$33,951 with a 22% IRR.

We also carried out sensitivity analysis to this analysis, to model how NPV would vary depending on mortality rate, opportunity cost, heartwood yields and farm gate price variations. Even in the worst-case scenario, we estimate sandalwood is still profitable, with a NPV of A$14,878. This analysis was done using a conservative farm gate price of A$12.50/kg, as we expect prices to likely fall when plantations become ready for harvesting.

Overall, taking into account ACIAR expenditure, in this chapter we have calculated a positive NPV of A$3.8 million and an IRR of 13%, equating to a benefit:cost ratio of 5.7:1. Taking into account non-ACIAR expenditure, these estimates drop to A$3.1 million, 11% and 4.5:1, respectively.

These economic impacts demonstrate long-term benefits to the sandalwood industry and smallholders in Vanuatu. Beyond economic benefits, the projects have also delivered impacts on scientific knowledge and capacity, which are explored in Chapter 4.

Table 14 Present value flows of benefits and costs and rate of return from FST/2002/097 and FST/2008/010 and non-ACIAR funds

		Costs			
		Farmers	ACIAR and non-ACIAR funds	Benefits	Net flow
Year	Total costs	Constant 2018 A$	Constant 2018 A$	Constant 2018 A$	Constant 2018 A$
2002	284,726	284,726	-	-	(284,726)
2003	48,556	48,556	-	-	(48,556)
2004	411,030	38,457	372,573	-	(411,030)
2005	553,775	28,358	525,417	-	(553,775)
2006	352,985	28,358	324,627	-	(352,985)
2007	229,727	37,977	191,750	-	(229,727)
2008	21,818	21,818	-	-	(21,818)
2009	228,859	21,818	207,041	-	(228,859)
2010	381,000	19,798	361,202	-	(381,000)
2011	362,146	19,798	342,348	-	(362,146)
2012	354,804	44,036	310,768	-	(354,804)
2013	356,487	16,704	339,783	-	(356,487)
2014	209,723	19,798	189,925	-	(209,723)
2015	19,798	19,798	-	-	(19,798)
2016	19,798	19,798	-	-	(19,798)
2017	19,798	19,798	-	-	(19,798)
2018	19,798	19,798	-	-	(19,798)
2019	19,798	19,798	-	-	(19,798)
2020	726,423	726,423	-	15,328,125	14,601,702
Total	**4,621,051**	**1,455,617**	**3,165,434**	**15,328,125**	-
				Net present value	3,153,746
				Benefit:cost ratio	4.5:1
				Internal rate of return	11.2%

Sources: ACIAR project documents; authors' calculations.

Mixed forest system in Vanuatu.

4 Knowledge systems and RAPID analysis

This chapter presents the qualitative findings from the field trip to Port Vila and Tanna. During the field trip, key informants provided a series of stories and insights related to their exposure to sandalwood research and training activities. This included articulating what they perceived as the challenges and opportunities for the sandalwood industry in Vanuatu.

This section presents thematic qualitative findings that were not easily quantifiable nor captured as benefits in the economic assessment presented in previous sections.

The qualitative insights presented in this chapter provide a complementary insight into how ACIAR-supported projects have enabled knowledge, capacity and industry to work in the Vanuatu socioeconomic and governance context.

Throughout this section, we use the term ‘industry’ inclusively of all stakeholders involved in the production, training of people, licensing, processing and sales of sandalwood in Vanuatu. The themes and quotes presented are centred on issues of knowledge salience, credibility and legitimacy, and are situated in the policy context of sandalwood in Vanuatu.

These themes and policy context form part of the knowledge systems that are supported and developed through research for development activities. These systems are made up of various actors who absorb knowledge products and change practices. In the Vanuatu context, the major actors are smallholder farmers, licence-holders, researchers and government employees.

4.1 Knowledge and capacity impacts

A knowledge system is one where different interest groups share expertise and experiences to produce salient, credible and legitimate knowledge on a particular issue (Clark et al. 2016). In research-for-development projects:

- salience relates to the relevance of the investments to the environmental and socioeconomic contexts of the location of projects
- credibility relates to the quality and value stakeholders receive from knowledge products delivered during research activities
- legitimacy relates to the extent to which stakeholders, including those with less power or ability to participate, are involved in the generation of new knowledge.

ACIAR investments into the genetic and planting aspects of sandalwood were confirmed as being highly salient to the forestry developments in Vanuatu, and to the declining natural resource-base of wild sandalwood. Throughout the field trip, staff from VDoF and industry acknowledged the value that the work of Australian and Ni-Vanuatu researchers had brought to the industry.

One key informant explained how the projects had provided an opportunity to document information on previously undocumented issues, notably the genetic composition, socioeconomic contexts and inventory of wild sandalwood in Vanuatu.

One research sector key informant said that ‘even though the project did not try to stop wild harvesting per se, they provided genetic and wild stock inventory knowledge to document the state of sandalwood in Vanuatu’.

Another key informant involved in sandalwood extension in Vanuatu said the following:

> *ACIAR has been research oriented, allowed us to identify high-quality oils and it has enabled an understanding of harvesting at approximately 15–18 years. Farmers now know that they are growing something they can harvest and benefit from in the future.*

ACIAR research findings have complemented the skills and knowledge held by VDoF officers in Vanuatu. As one staff member noted:

> *ACIAR has helped with seed sharing and distribution throughout the country, and it has allowed us to eliminate any unknowns we had to enable us to work with things we now know. These new known skills and ideas are, for example, optimal spacing and host plants for sandalwood plantations.*

4.1.1 Use of ACIAR knowledge products

The VDoF are involved in extending knowledge produced during the research projects. An example of new users adopting knowledge and implementing practices supported by ACIAR is presented in Box 2, which provides an overview of the knowledge system between VDoF, and Teacher's Union, and smallholder farmers. The insights from key informants in the salience of ACIAR-supported knowledge products provides a snapshot of impacts at this point in time. But there are still unknowns in the sandalwood industry in Vanuatu. A clear unknown remains the relationship between the genetic and environmental determinants that influence oil yields. Oil distilling is not commonly practised in Vanuatu, and the majority of sandalwood is expected to be sold as heartwood.

Despite research into the phenotypic variation in heartwood and essential oil of Vanuatu sandalwood (Page et al. 2010b), the relationship between genetic and environmental determinant of oil yields is yet to be clarified. This remains an area of interest for key informants, and an economic opportunity for the industry in Vanuatu.

Knowledge produced during the research projects has enabled sandalwood activities to be disseminated to different users. During the trip, stakeholders from industry mentioned that they were 'familiar with ACIAR work—we understand the science and how it transfers to growing'.

Teachers' Unions and church groups were reported to be using techniques and knowledge in sandalwood host and spacing techniques, and linked their practices to the exposure to VDoF activities.

4.1.2 Capacity building

Objective 2.4 of FST/2008/010 focused on building capacity to facilitate scaling-up of germplasm delivery systems for sandalwood. The research projects have had impacts on institutional capacity and on smallholder capacity.

Institutional capacity was evidenced through the increased experience and knowledge of sandalwood growing, extension and harvesting skills during the projects. Both projects assessed supported the employment of VDoF foresters to work with Australian researchers during the project and support farmers in the establishment of seedling systems.

During a visit to a farm outside Efate, VDoF staff explained their role in facilitating knowledge and extension to people interested in planting sandalwood. One VDoF staff said 'one of ACIAR's major contributions has been the teaching and informing farmers about sandalwood, notably in regards to spacing, caring and planting. The skills have been transferred from the manuals to the farmers'.

Sandalwood grown with pineapples in the Teachers' Union plantation.

Box 2: Teachers' Union and sandalwood

A 30-minute drive South of Efate, an area of 2 ha with 800 trees can be found among a mixed-crops agricultural landscape. Planted in 2015, this carefully planned plot has sandalwood trees aged 3–5 years planted in a 5 m by 5 m spacing, in a mixed-growing system. Among the taro, pineapples, banana, pawpaw and citrus plants, sandalwood is monitored with the support of the VDoF to use the plot as an economic and pedagogical tool.

Initiated by the Teachers' Union, the VDoF has supported the union to collectively plant and manage the sandalwood plantation. ACIAR planting techniques and skills have been passed on to union growers, who now use the plot to show farmers the value and techniques associated with growing sandalwood.

A field day, run once or twice a year, captures the attention of 50–100 farmers. These farmers get exposed to sandalwood plantations, and are encouraged to plant trees on the land they work on. Seeds and seedlings are provided to those farmers willing to plant sandalwood. University and school students are also engaged through the plot, and exposed to the agroforestry skills needed to maintain sandalwood.

Communication and awareness are critical aspects of this 2-ha plot. The open days communicate the value of waiting for sandalwood to be ready for harvesting, and of the potential returns. The diversity of fruit and vegetables planted with sandalwood are promoted as a value-add and income source during the wait to harvest. While this educational component was not part of the ACIAR project, the knowledge and staff from ACIAR project have contributed to advancing the use of sandalwood in Efate. This demonstrates a transferability of skills and knowledge beyond specific project activities.

The independent review of FST/2008/2010 also documented the high-quality knowledge products and capacity developed among VDoF staff. Walker (2015) discussed this high capacity in relation to the high quality of the work, and the confidence displayed by VDoF staff in facilitating sandalwood workshops and presentations, and in producing written material.

There are limited professional and technical staff at VDoF, and the ACIAR projects have had significant impacts institutionally and for individuals. The projects have allowed staff to advance their scientific and technical skills of sandalwood grafting.

Two staff members were reported by Walker (2015) to have demonstrated a high-quality report and systematic analysis of the impacts of cyclone Pam on different plantations. Walker (2015) also documented the critical thinking abilities demonstrated by VDoF staff as part of their analysis of the 2015 Western Australia field visit, where they identified challenges and opportunities for the Vanuatu sandalwood industry.

Along with written and technical skills, VDoF staff have been able to maintain an active role in using the sandalwood growers' guide to regularly interact with farmers and informally monitor the progress of sandalwood plantation. This was witnessed particularly in Tanna, where smallholders responded positively to the role of VDoF in communicating sandalwood growing techniques.

Smallholder capacity has been developed through the extension and knowledge services in maintaining a sandalwood plantation. Smallholders already held traditional and family knowledge on sandalwood growing and harvesting to the native nature of the tree. But before ACIAR research, their sandalwood was largely harvested from the wild, and, if planted, it was done in an ad hoc manner.

One researcher noted that 'if we have done one thing, it is to raise understanding of the friend tree', relating to the importance of host species that grow well with sandalwood.

Additional capacity skills include understanding of optimal spacing and nursery development techniques.

4.1.3 Learning from the growers' guide

One of the major ACIAR knowledge outputs was the publication, *Vanuatu sandalwood—Growers' guide for sandalwood production in Vanuatu* (Page et al. 2012d). The guide (Figure 12) provides easily accessible written and visual material on the biology of sandalwood, and gives growers an overview of core techniques to successfully germinate, plant and maintain a sandalwood crop.

Figure 12 English and Bislama versions of the sandalwood growers' guide (ACIAR Monograph 151), based on findings from research projects

During the field work in Tanna, we walked with a physical copy of the manual provided by VDoF, and used it to elicit insights from key informants on how they have used and shared information provided by the manual. ACIAR projects also supported a DVD, but this was not widely known about in the field. There were mixed stories on the use of the grower's guide to establish and maintain sandalwood plantations.

One of the major ACIAR-supported activities was to produce and distribute the manual throughout the country. But these activities were not always coupled with extension and training—it became the task of farmer leaders and forestry officers.

In Tanna, smallholders said 'they had seen the manual, and learned from their neighbours about keeping a nursery' in their homes. Another research key informant said that 'while there is some positive farmer-to-farmer knowledge exchange, other farmers choose to withhold knowledge'. Our trip to Tanna demonstrated that farmer-to-farmer exchanges were present, and informed by the techniques in the manual.

In Efate, it was industry from a large plantation that articulated the value of the manual for sandalwood producers. A key informant noted that 'they distributed the manual everywhere, and they even had to have more photocopies made and shipped throughout the islands'. The 2012 manual remains highly accessible to growers throughout the country, due to a mix of dissemination efforts by industry, ACIAR and VDoF staff.

The growers' guide provides examples of how research findings transfer to farming practices. Two core examples of these planting techniques adopted by smallholders were the spacing and the ability to conceptualise hosts. Spacing varied on the farms visited—farmers said they planted at either 3x3 m or 4x4 m spacing between each sandalwood tree.

Farmers in small and large farms discussed this spacing as being learned by observing neighbours or by attending training. This highlighted that while the growers' guide was important as a knowledge source, other factors influence how people source their information.

The guide is printed on waterproof paper, and provides landowners with various technical and visual information on planting and maintaining a sandalwood plantation. In 2015, Walker's review of FST/2008/010 reported that the publication should be updated to include the comparative resistance of *S. austrocaledonicum* to cyclones, which was reported in 2015 by VDoF staff to be 'windfirm'.

Another example of the transfer of research knowledge to smallholder practices was the ability to conceptualise hosts and use hosts for growing sandalwood. The guide presented an overview of what a host is, and the optimal hosts to use during the different life stages of a sandalwood plant.

A researcher noted that 'while the concept of hosts can be scientific, we use the language of a friend plant with smallholders' to communicate the relevance of hosts for the survival of a sandalwood plantation.

During the field work, smallholders discussed using the host plants recommended by ACIAR, notably citrus, cassis (*Leucaenea leucocephala*) and pigeon pea (*Cajanus cajan*).

While Vanuatu's climatic and soil conditions make sandalwood relatively easy to grow, the optimal host plants identified by ACIAR have provided smallholders with knowledge on planting sandalwood systematically within their existing plots. This can reduce pressure on highly depleted wild stocks, and provide an economic opportunity for future income for smallholders planting sandalwood.

The VDoF has remained active in disseminating the value of sandalwood activities to smallholders and to Vanuatu. As reported by Walker (2015), VDoF previously communicated project progress through Radio Vanuatu, notably the dissemination of the growers' guide. ABC Rural disseminated similar stories in 2015 (ABC Rural 2015).

The guide remains highly popular among growers and industry, and is readily recognised by foresters working with sandalwood in Vanuatu.

4.2 Boundary organisations and policy context

The ACIAR approach to agricultural research is centred on partnerships, where Australian and international researchers collaborate to enable social, economic and environmental impacts.

While agricultural research provides tangible products—in this case, seedlings and manuals—they also enable knowledge systems. Knowledge systems are abstract constellations of individual and organisations concerned with using and developing knowledge on a particular topic.

Studies into knowledge systems have revealed that boundary organisations that link together actors are important tools that can leave a lasting legacy on how research knowledge is used and taken up by non-researchers.

The concept of boundary organisations in a policy context was explored in the context of ACIAR research investments by Davila et al. (2016). In that study, they found that such organisations can emerge through collaborative research projects, and influence how research transfers into policy.

Sandalwood projects assessed in Vanuatu did not have explicit objectives targeting the establishment of networks and organisations. But the relatively small Forestry Department, the small number of licence-holders, and knowledgeable forestry officers with an understanding of the location of sandalwood producers enabled high knowledge sharing of sandalwood activities.

For example, Page et al. (2012a) identified that training and extension activities in Santo and Malekula enabled the establishment of a sandalwood growers association in Santo. This organisation has been proactive in establishing woodlots, and enabling producers to supply seeds throughout the country.

Such associations were found to be common throughout the country, and, through the PHAMA program, there is a growing interest in transitioning towards a national Vanuatu Industry Sandalwood Association.

The policy environment and boundary organisations for sandalwood are at a juncture that will determine the extent to which smallholders are substantial beneficiaries from the huge sandalwood interest in Vanuatu. As one key informant said, 'the farmers should be the richest person out of this' and 'farmers need support in motivating them to wait [long enough until] harvest and in understanding the market'.

While it was outside the research objectives to influence policies for sandalwood harvests, the policy context acts as a factor that might determine how economic impacts flow down to smallholders in the future.

Sandalwood harvest policy limits legal export quotas to 80 t/year in Vanuatu—a quota that is reportedly not frequently met. One key informant involved in both production and selling sandalwood to international buyers said that the licensing system presents risks, noting that ‘sometimes licensees struggle to get the heartwood, and they encourage smallholders to harvest early’.

Another producer said that ‘there is a huge risk of losing from the harvest boom in the next 5 years due to the desire to harvest too early’. While the licensing system is expected to remain, alternatives are being proposed by the Vanuatu Industry Sandalwood Association.

Two producers spoke of the need to learn more about the market and how the sandalwood is processed and sold internationally. Similar to the ACIAR-supported Western Australia learning tour, these two key informants discussed the value of increasing market knowledge and extending this to farmers. One key informant highlighted that ‘we want to understand where the product goes internationally, and what it is sold for, to have stronger understanding of prices’.

A policy shift that some key informants noted as critical for enhancing financial benefits to smallholders was the development of an auction system for sandalwood. These ideas have been documented by AECOM (2017), where they argue that an auctioning system can lead to benefits such as:

- increased level of market information and transparency
- simpler and more efficient way of linking producers to buyers
- greater capacity to focus industry regulation
- development of sandalwood log grading standards in Vanuatu.

A key informant also noted that ‘getting the trees accredited, so that they can be tracked, could be part of a new auction system that can help improve benefits to smallholders’.

It remains unclear the extent to which the quota is in the process of being revised to tailor for the current number of trees planted as part of ACIAR projects. The licensing system is an important contextual factor that may inhibit or enable different benefits. It reduces smallholders’ ability to be informed of price behaviour, and reduces their legitimacy in the market as informed agents.

An alternate system based on public tendering, which could operate through the relatively advanced telecommunications infrastructure in the country, might enable smallholders to increase their understanding of prices and market behaviour. While these industry associations continue to grow and change, it is important that policy changes are monitored, as they will likely influence the ultimate return to smallholders.

4.3 Perceptions of climate resilience and environmental impacts

In 2016, tropical cyclone Pam affected Vanuatu, severely damaging urban and rural infrastructure, and agricultural, water and health services. Building the adaptive capacity of rural communities and the ability for agricultural systems to respond to climate shocks will be critical to sustain development outcomes. During our field visit, we confirmed some of the anecdotal reports that *S. austrocaledonicum* had high potential to resist increased weather events.

Walker (2015) reported that:

> *A preliminary assessment completed at Efate during project review (4 months after cyclone Pam) identified only 5/36 grafted Sandalwood trees missing/dead (86% survival), and that cyclone Pam has demonstrated the resilience of* S. austrocaledonicum *but also the need to replicate valuable genetic material across many sites.*

Walker also recommended that future updates to the grower’s guide could provide guidance and information on the merits of *S. austrocaledonicum* and *S. album* in the Vanuatu context, notably in relation to cyclone resistance.

In Efate, smallholders noted that cyclone Pam had impacts on their sandalwood crops, with some farmers losing more than 50% of their trees. But various key informants discussed their understanding of different sandalwood species and the resilience offered by the commonly planted *S. austrocaledonicum*.

One said that ‘the local variety of sandalwood has been more resilient than other varieties—it is a strong small tree that can withstand cyclones’. Smallholders noted the impact the cyclone had on their properties. They also criticised the availability of re-planting opportunities in a post-cyclone context, notably that ‘it has been hard to receive support after the cyclone’, and that ‘polybags prevent us from replanting the trees we lost during the cyclone’.

Despite these challenges, participants confirmed that ACIAR project identification of local varieties as suitable for smallholders has the co-benefit of being resilient to intense weather events.

Cyclone damage of sandalwood crops also enabled industry and farmers to benefit from damaged trees, and extend training opportunities to re-plant sandalwood. For example, one industry key informant noted that 'after cyclone Pam, we went around different islands with the growers' guide to help farmers re-plant and manage their existing sandalwood. This included training in germination and spacing'.

In Tanna, we were exposed to the immediate economic benefits to households from selling sandalwood trees. Tanna was heavily affected by cyclone Pam, and the damage was visible—dense agroforestry systems still had 15-year-old sandalwood trees with bark damage or fully ripped from the soil.

One smallholder farmer said that 'the loss of our trees meant that we could sell them at that point in time to get some income during hard times'. The option of selling the younger heartwood, albeit for potentially lower-than-expected prices, provided smallholders with a quick return in difficult financial circumstances in a post-cyclone context.

Scientific analysis of the adaptive capacity of sandalwood plantations remains scarce. Anecdotal evidence from the field trip indicates that an unintended benefit from establishing sandalwood plantations may be a potential adaptation tool for smallholders.

While the sandalwood projects did not seek to build climate change resilience among smallholders, the anecdotes from the field showed that local varieties were perceived to buffer against weather events.

After intense weather events, the damaged trees also provided immediate income opportunities, as smallholders were able to quickly sell their heartwood. Future sandalwood projects would benefit from further exploring the links between plantations and climate resilience, and look at ways of promoting sandalwood as both a valuable product and possible climate change buffer.

4.3.1 Environmental impacts

A parallel small research activity funded by ACIAR tried to estimate remaining wild stocks of sandalwood in Vanuatu. The research findings estimated that, as of 2006, 290 t of wild stocks were available in Vanuatu, and harvest rates at the time were leading to a rapid depletion in the resource (Gillieson et al. 2008).

Anecdotal evidence from our 2018 field work indicated that it is becoming harder to harvest wild trees, or source seed from 'mother trees' in the wild, with smallholders saying that wild stock was nearly extinct.

At the time of this assessment, it is difficult to determine whether ACIAR research activities have had environmental impacts. In Chapter 3, based on a series of assumptions, we calculate that plantations will supply 240 t of sandalwood in the next 20 years. These trees are likely to be traditional mixed agricultural systems, rather than in wild forests, potentially changing ecosystem function and habitats dependent on wild stocks.

While wild stocks might be depleted, sandalwood is not expected to be fully extinct in Vanuatu, partially due to the sustained efforts since 2002 by ACIAR to establish plantation and shift harvest systems from wild harvest to plantation based.

5 Conclusion

This impact assessment aimed to investigate the impacts of two sandalwood research projects carried out in Vanuatu. The impact assessment focused on the benefits to smallholders, with a focus on calculating the NPV and IRR for a smallholder plantation.

We found that even in a worst-case scenario, with low yields and high mortality rate, sandalwood remains a valuable investment for smallholders. We also found that the skills and knowledge produced during the ACIAR projects have enabled sandalwood practices to be better understood by smallholders and industry.

While sandalwood has been planted throughout the country, the policy environment when harvests come online will play a role in maximising distribution of benefits to smallholders.

This impact assessment built from three previous studies that focused on the socioeconomic potential (Page et al. 2012b), farm viability (Harrison and Karim 2016), and general project impacts at a point in time (Walker 2015).

Our assessment confirms previous studies that indicate the high economic potential for smallholders, but identifies the critical role that the policy environment will play in distributing the benefits. The nature of this ex-ante economic assessments means that the returns to smallholder farms is yet to be realised. But the scenarios and calculations derived from existing and field-collected data indicate that even in a worst-case scenario, there will be substantial economic benefits to smallholders.

If we attribute the 50% uptake of seedlings solely to ACIAR expenditure of A$2.3 million (constant 2018 dollars), we calculate a positive NPV of A$3.8 million and IRR of 13%, equating to a benefit:cost ratio of 5.7:1. This is based on a 5% discount rate.

Subject to the assumptions outlined in Chapter 3, and taking into account total project expenditure by ACIAR and partners of A$3.1 million (constant 2018 dollars) between 2002 and 2014, the project's NPV is A$3.1 million and the IRR is 11.2% after adjusting for inflation and discounting future returns back to the present. This demonstrates a positive return on investments to ACIAR and partners, using a 5% discount rate.

For specific smallholder systems in the worst-case scenario, we estimate sandalwood is still profitable, with a NPV of A$14,878. This analysis was carried out using a rather conservative farm gate price of A$12.50/kg, as we expect prices to likely fall when plantations become ready for harvesting.

It was found that motivations and interests for planting and maintaining sandalwood remain high among different stakeholders. The impacts of ACIAR knowledge products, notably planting techniques and the growers' guide, continue to be perceived as salient, credible and legitimate to the Vanuatu context.

Smallholders remain optimistic about the financial benefits of sandalwood, yet noted the challenges in negotiating adequate prices.

The policy context of Vanuatu emerged as an important factor that might determine the equitable distribution of economic benefits in the future. Issues of transparency regarding heartwood sales, and understanding the market and prices are key to allowing producers to optimise their returns. New auctioning systems are being proposed, but it remains unclear how they will be implemented before planted sandalwood enters the market.

Understanding of how alternative systems operate—for example, through public tendering—might offer Vanuatu a greater opportunity for smallholders to understand market behaviour.

Other Australian Government-supported initiatives, such as PHAMA, have identified how the market structure for sandalwood is likely to influence the benefits to producers (AECOM 2017).

Over the next 5–10 years, it will be important to understand the policy context of Vanuatu to gauge how economic benefits will be distributed throughout the value chain. It will also be important to address what seemed to be a critical shortage of polybags to continue to grow seedlings on farm. Smallholders consistently expressed this as one of the major barriers to planting sandalwood.

While there is high polybag demand, it remains unclear whether these will be supplied in the future.

Sandalwood projects in Vanuatu have had positive impacts on scientific and capacity domains. The various project reports and independent reviews have documented the new knowledge that the research team has produced. Scientific and grey literature now exists on the:

- genetic variations of sandalwood in Vanuatu
- growing techniques required
- socioeconomic dimensions of sandalwood production.

While other donors have also supported some private sandalwood ventures in Vanuatu, ACIAR has been instrumental in enabling the scientific skills required to understand growing techniques and genetic variation of sandalwood in Vanuatu. Table 15 provides a summary of project impacts found in this impact assessment. This assessment is the first independent ex-ante analysis of the potential economic benefits of projects FST/2002/097 and FST/2008/010, and captures the state of knowledge and policy context of sandalwood in Vanuatu at this point in time.

Future assessments will benefit from greater understanding of adoption rates, which were difficult to determine, and clarity on oil and heartwood yields from ACIAR seedling distributions. Any future impact assessments could also seek to explore how gender dynamics unfold at household levels, and the difference in labour between men, women and young adults in sandalwood planting, harvesting and selling, to understand impacts on gender.

Conducting a mixed-methods impact assessment requires teams with the technical understanding of economic modelling and qualitative analysis, and ability to work through integrated frameworks. Throughout this report, we have shown how impact assessments can use the field trips and interviews with project participants and beneficiaries to capture data that allow quantitative and qualitative analysis.

These data can then be used by different team members to distil the measurable and non-quantifiable dimensions of impact.

Davila et al. (2016) proposed links between the ACIAR guidelines for impact assessment and the value-add of knowledge and policy-based analysis of impact.

Table 15 Summary of impacts of sandalwood projects

Impact	Findings from 2018 impact assessment
Scientific	• Scientific advances and understanding of trial sites and experiments remain relevant to major industry producers. • Smallholders report understanding of host concept in some farms.
Environmental	• VDoF cold storage facility are being used and reported to be highly useful for storing and distributing seeds throughout the country. • Large plantation remains active and conserving different species. • There were anecdotal reports of high planting rates in Malekula and Santo.
Capacity and knowledge	• The growers' guide remains a highly salient knowledge product. Smallholders in remote islands associated the guide with changes in behaviour, notably use of hosts and spacing. • The Vanuatu Industry Sandalwood Association and other grower's associations now exist as a way of bringing together industry and producers. • Some smallholders remember training and planting activities, but most seemed to have learned from neighbours.
Economic and social	• It is difficult to determine the number of grafted seed orchards throughout the country. • Entrepreneurial farmers with skills to germinate seed have been doing so and selling them. • Seedling and seed trade is now reportedly common practice. • For an individual producer, NPV for a 1-ha sandalwood plot is estimated to be A$33,951, and IRR is 22%. • Even in a worst-case scenario, the NPV is estimated to be A$14,878, providing positive benefits • Break-even point for 1-ha farm per year is A$2,979. • Considering ACIAR expenditure, the NPV for the industry is A$3.8 million, ranging from A$800,000 to A$8 million under different scenarios. • Even under a worst-case scenario, with low yields and high mortality, the returns remain positive. • The benefit:cost ratio is 5.7:1.

Table 16 Complementary table of impact assessment frameworks and relevance to sandalwood projects

ACIAR guidelines (IAS 58)	Knowledge systems and RAPID framework (IAS 92)	Vanuatu sandalwood case study example
Clearly identify causal links between levels of results.	Key informants identify causality between knowledge products and behavioural changes in the local context.	Key informants discussed the valuable role of ACIAR research, training and outputs in enabling sandalwood practices.
All outputs, intended and unintended should be identified.	Determine emergence of new boundary organisations and linkages previously not in place.	Majority of outputs were identified as intended per project objectives. Unintended outputs, such as the formation of boundary organisations, are evident. These new organisations, however, cannot be fully attributed to ACIAR.
Identify the preconditions and complementary investments required for the results to be realised.	Historical and macro-economic policy contexts are embedded into the analysis.	The context of depleting wild harvesting creates challenges for smallholders to benefit from wild stocks. Findings indicate behavioural shifts towards planted sandalwood systems. Some wild harvesting continues to occur in remote areas.
Always measure change from a baseline (counterfactual) and make this counterfactual explicit.	Historical narratives from key informants determine what other activities have contributed to behavioural change.	There have been other investment supporting aspects of agroforestry systems, notably polybag provisions and workshops on sandalwood biology and planting strategies. To our knowledge, no other donor has invested in supporting seedling distribution at the scale of ACIAR projects.
Make sure opportunity costs are included in assessing impacts.	Consider human resource and financial economic opportunity costs.	Sandalwood remains salient and legitimate for the smallholder context of Vanuatu. Smallholders continue to see the product as beneficial for them. While opportunity costs exist and other commodities are present, such as fruit of mahogany, smallholders articulated interest in sustaining sandalwood practices.
Final users are not always the only beneficiaries.	Allow key informants to determine broader end beneficiaries beyond those in the planned impact pathway.	Final users of technology were identified to be smallholders, who in theory will benefit from the sale of heartwood. The benefits will be determined by the variability of farm gate price and the structure of the market when sandalwood comes online.
Attribution, in the absence of any other information indicating otherwise, is based on research, development and extension cost shares.	Base the attributions on participants' interpretations of connections between project activities and policy developments.	Participants discussed the highly credible and salient knowledge products delivered by ACIAR research, notably the skills in spacing and host selection.
Validate estimates of results and report on the degree of uncertainty in the assessment of impact and benefits.	Focus on specific actions where changes have been made due to project outputs.	Behavioural change seems to be occurring, with emerging seedling and seed trade systems throughout the country. Farm-level plantations have increased, and large plantations are collaborating with smallholders.

Source: Davila et al. (2016).

Table 16 advances the integrated links and shows how the Vanuatu sandalwood case study has provided the evidence-base for expanding mixed-methods impact assessments.

The results in this impact assessment present an initial evidence-base on how mixed-methods impact assessments can be carried out. Figure 13 situates the findings from this impact assessment on the spectrum of the different economic and knowledge-oriented frameworks within the ACIAR impact assessment database.

It shows that the more quantifiable items, such as adoption of seeds, market behaviour, and increase tonnes of sandalwood sit on the left side of the diagram, towards more positivist philosophies.

In a complementary way, the analysis of the policy context, capacity built among VDoF staff and the establishment of demonstration farms align with the more qualitative oriented frameworks.

Our study of sandalwood impacts could have been reported in purely economic results, or purely qualitative narratives. While both of these analyses present valuable components of the impact story, in isolation, they might miss the entirety of benefits from the projects.

While the economic analysis tells us the likely returns to smallholders and industry, it has more difficulty explaining unintended uptake of project ideas by other social groups or the policy implications of the current licensing system.

Contrastingly, a purely qualitative analysis would not have been able to model and estimate the projected economic benefits of this project under various scenarios. Integrating the analysis using the different impact assessment frameworks allowed us to tell a more comprehensive story of impact.

At the core of mixed-methods research is the fact that researchers from different disciplinary backgrounds will have different philosophical ways of capturing data, analysing them, and reporting on them.

This diversity is important, as it allows detailed analysis of the different dimensions of a particular problem. In agricultural research-for-development, which deals with issues from economics, gender, policy and natural resource management, to name a few, understanding how problems and questions are conceptualised is critical for determining the impact of projects.

As illustrated in Figure 13, impact assessments can collect a rich diversity of impacts sitting within a spectrum of quantifiable to non-quantifiable impacts. Designing the assessments to include insights from different disciplines with establish frameworks can guide analysis into the wide range of benefits and impacts agriculture projects can deliver.

Agricultural research-for-development is changing. While the ACIAR 10-year strategy maintains a strong emphasis on research programs concerned with agroeconomic research (ACIAR 2017), the strategic objectives and sustainable development context will inevitably make projects more complex, lengthy and challenging.

The strong focus on partnerships, advances in the use of technology in agricultural systems, and greater embedding of food-producing stakeholders, such as consumers and processors, indicates that the impacts of projects will be embedded across different stages of the value chain.

While some impacts (like changes in productivity) might continue to be measurable through ex-ante and ex-post analysis, other developmental impacts (like changes in gender dynamics or sociocultural change) will take much longer, and will be much harder to identify.

The continued effort of ACIAR impact assessment studies and frameworks presents independent assessors with a suite of tools from different disciplines that can be used to capture these diverse impacts from ACIAR projects.

This impact assessment of sandalwood research in Vanuatu has demonstrated how different frameworks can provide different stories and data on socio, environmental and economic impact, advancing the use of mixed-methods approaches in impact assessment.

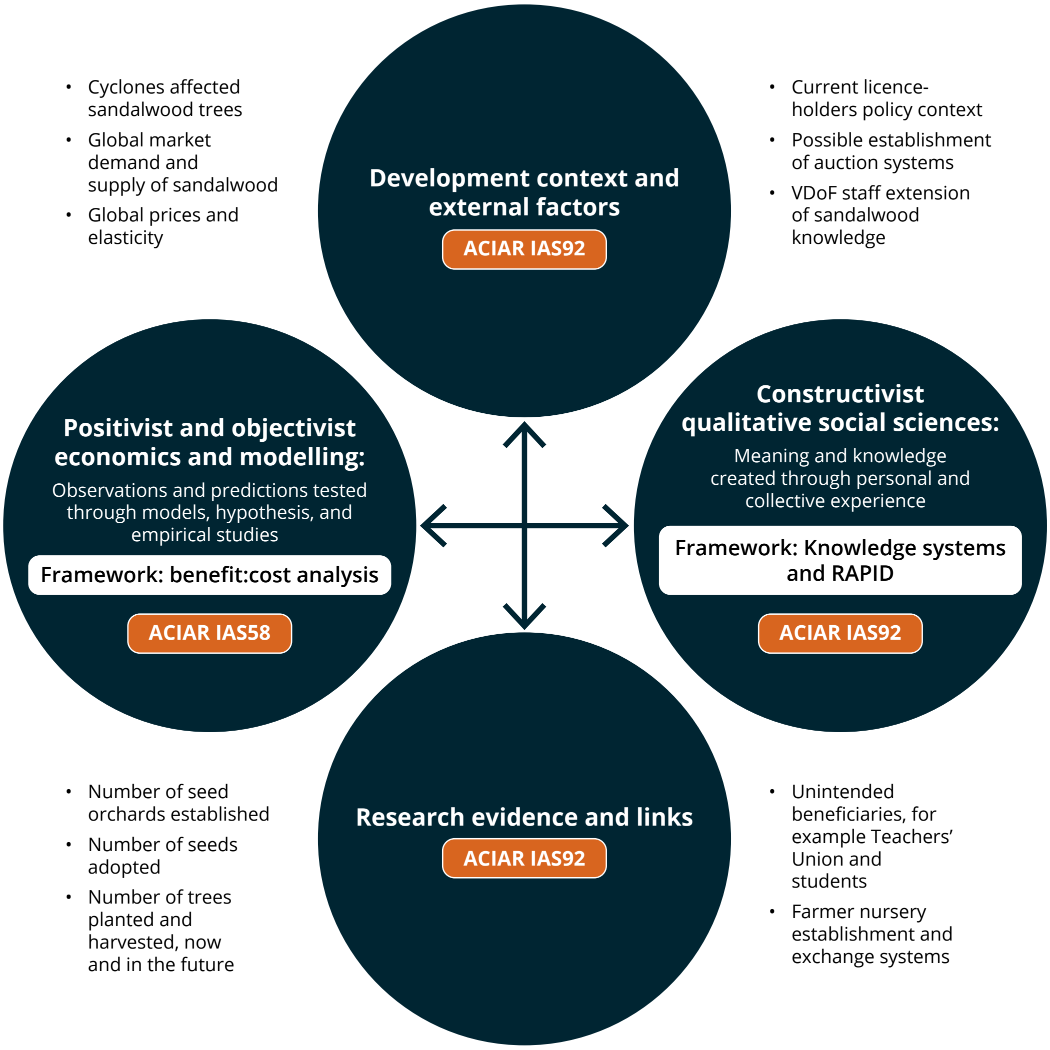

Figure 13 Findings of the impact assessment and where they fit within the mixed-methods framework spectrum

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Appendix 1: Sandalwood impact assessment interview guide

Typology of sandalwood producers

Previous economic studies have looked at different type of smallholder farmers to document the contribution of sandalwood to incomes. These typologies were:

1. smallholder garden with staple vegetables over a 4-year rotation
2. commercial smallholder garden **with** sandalwood interplanted with 4, 15, 20-year rotation
3. sandalwood only with 15 and 20-year rotation
4. sandalwood and sapwood with 7-year rotation.

Part 1: Participant profile

- What organisation do you work for? How long have you been there?
- Please tell us how you/your organisation works with sandalwood.
- Prompt: policy links, boundary organisations, use of up-to-date research, engagement with universities.
- Who are the main other organisations working in sandalwood?
- What has been your engagement with ACIAR sandalwood projects?

Part 2: Sandalwood industry context and history

Guide for VDoF staff

- What has been the role of VDoF in the sandalwood industry? Please explain with some detail.
- Can you please tell us about the role of sandalwood in Vanuatu policy and business?
- Why do you think smallholders choose to plant sandalwood?
- Prompt: ask about subsidies for planting and operation costs.
- What are your experiences of the transition between wild-based to plantation-based systems?
- Are there other commodities that could yield quicker and similar returns to smallholder farmers in Vanuatu?
- Prompt: what is the link to the department of agriculture?
- Can you please tell us about the current sandalwood market in Vanuatu?
- **Quota** history and enforcement. Is the quota going to change?
- Major production regions and perceived productivity of those regions.
- Comment on decline/changes of wild stocks towards plantation-based stocks.
- What have been the government experiences of illegal sandalwood logging?
- Have there been reported cases of between household conflict or tensions in planting sandalwood? If yes, how have these been overcome and what are the drivers behind these tensions?
- What island governments/farmers/industries have shown the most industry in sandalwood plantations?
- What are the main **challenges** for the sandalwood industry in 2018?
- What are the main **opportunities** for the sandalwood industry in 2018?
- How has ACIAR supported sandalwood activities in Vanuatu?
- Have there been other donors or researchers working in sandalwood over the past 15 years? Prompt: please expand and explain the nature of their involvement.

Guide for licence-holders

Additional questions for licence-holders

- Are you exporting wild or planted sandalwood?
  - If wild, how has the resource changed through time? Do you have records of the changes in production and exports between 2002 and 2018?
  - If planted, when were these trees planted, and do you know where the seeds were sourced from?
- How long have you been buying sandalwood from farmers, if any? Expand on:
  - major purchasing islands
  - average tonnes sold per farmer, if any
- Who are the main international buyers?
- Can you please tell us about the domestic processing process for Vanuatu?

On tourism industry

- Are you involved in selling sandalwood products to tourists visiting in cruise ships?
- What are the main shop fronts responsible for selling sandalwood products?
- Where is the heartwood and oil processed or refined in Vanuatu?

Additional questions for smallholders

- What motivated you to plant sandalwood
- If you were not planting sandalwood, what else would you be doing?
  - Is there support for planting other commodities?
- What other sources of farm income do you have?
- What other sources of off-farm income do you have?
- What has been your involvement in ACIAR sandalwood training activities?

Part 3: Economic variables (collected during smallholder site visits)

Site descriptions

1. What species of sandalwood are you growing? (*S. Austrocaldonicum*)
2. What host are you growing sandalwood with?
3. What other crops do you have on your farm?
4. How big is your farm (hectares)?
5. How many people are there in your household?
6. How many sandalwood trees do you have?
7. Do you own your land? If not, what is the land ownership structure?
8. Where do you source your seedling from?
9. How many times have you planted seedlings?

Cost of production

It is important to differentiate between capital costs, occurring in the first period, and operating costs, which occur later.

1. How much does it cost to prepare your land for sandalwood planting?
2. How much does a fence cost to protect your sandalwood?
3. What other infrastructure do you need to plant sandalwood?
4. How many seeds do you plant?
   a. What is the cost of these seeds?
   b. How many do you expect will survive? And why do you think that will be the survival rate?
5. What other planting-related costs are there?
6. Are there other costs associated with planting? Please state.
7. Overall, how much do you estimate planting sandalwood costs you?
   a. Do you receive any subsidy/support for establishing sandalwood?

Operating costs

1. How much revenue have you invested in planting sandalwood site?
2. How much does it cost you to manage any weeds?
3. What is the cost of fertiliser you use on sandalwood?
4. How much does it cost you to prune/maintain your crop?
5. How much does it cost you to protect the planting?
6. Overall, how much does it cost you per year to maintain your sandalwood plantation?
7. How much would it cost you to harvest?
8. How much would it cost you to transport it to the licence-holder? (licence-holder may buy from farm gate).

Adoption rates

1. When did you start planting?
2. How many hectares have you planted over the years?
3. How many of your trees planted have survived?
4. When will you be able to harvest?

Price

1. How many trees have you planted per hectare?
2. What is the price you received for selling 1 kilogram of sandalwood
3. What price do you **expect to receive** 15 years after planting?
4. What price do you **expect to receive** 30 years after planting?
5. Do you know the oil export price?
6. Do you know the hardwood log export price?
7. Do you know the sapwood export price?
8. How do you expect the price to behave in the future?
   a. Prompt: estimate future price
   b. Ask what they are basing the estimates on.

For licence-holders:

1. How much do you buy a tree for from the smallholder producers?
2. How much do you sell a **15-year-old** sandalwood for?
   a. heartwood
   b. oil
   c. sapwood
3. How much do you sell a **30-year** sandalwood for per tonne?
   a. heartwood
   b. oil
   c. sapwood
4. How do you expect the price to behave in the future? What is this based on?
5. Do you expect Australian or other sandalwood entering the market from influencing the price, and how?
6. Can exporters differentiate wild versus plantation products at the export stage?

Yield

15-year questions

1. What is your predicted oil yield?
2. What is your predicted sapwood yield?
3. What is your predicted heartwood yield?

30-year questions

1. What is your predicted oil yield?
2. What is your predicted sapwood yield?
3. What is your predicted heartwood yield?

Opportunity cost

- What are other major commodities being grown in this village/town?
- What is the reason for planting sandalwood and not another commodity?
- What is the type of knowledge/technical/subsidy support for sandalwood compared to other commodities?

Knowledge systems and RAPID questions

Knowledge

- What was the state of knowledge on sandalwood high-yielding varieties and market behaviour in the late 1990s (pre-ACIAR projects)?
- Besides ACIAR, who else has been responsible for enabling sandalwood knowledge in Vanuatu?
- What knowledge did people use to base decisions on harvesting wild stock?
- To what extent is there an understanding of transitioning to plantation-based system, and the decline on wild stocks?
- What have been the motivations for smallholders to plant sandalwood?
  - How has VDoF overcome the time and financial costs associated with establishing a sandalwood system?
- Who has been involved in producing sandalwood knowledge outputs?
  - What has been the role of local Ni-Vanuatu in informing the type of knowledge produced?
- How frequently is the training manual disseminated? How is it received among communities?
- What is the nature of the relationship between smallholders and VDoF?
- Have there been students, postdocs, or similar involved in producing the knowledge?
  - Prompt: ask for records of student flows.
- How has the demand for sandalwood seedlings and training knowledge changed?
- Have smallholder's experiences/needs changed since the start of ACIAR projects?
- How do issues of distance and access influence smallholder's ability to plant sandalwood?
- Have there been any groups/forums that link research, government, and industry?
  - Prompt: ask who has led this, their purpose, their relevance to the current market behaviour.
- Are other forums emerging? If so, what would their purpose be/who is leading them?
- Historically, what has been the support for sandalwood?

- Who has been responsible for exporting wild sandalwood?
- What were some of the drivers that led to the early 2000s interest in sandalwood?
  - Prompt: ask about environmental concerns, demand for sandalwood products?
  - Prompt: what led to the interest? why were you interested?
- Was the interest on sandalwood a policy-driven interest or a community/farmer-driven interest?
- What is the nature of the relationship between VDoF, researchers, industry, and farmers?
- Where do farmers/industry get the latest knowledge/information/skills about sandalwood production and market behaviour?
  - Prompt: focus on extension officers—where do extension officers get the knowledge? Do they use past knowledge?
  - Prompt: discuss the role of non-government organisations and the private sector in the market, notably tourism operators?
- Has the focus on sandalwood jeopardised interest/support for other commodities?
- Can you please tell us how the sandalwood value chain works? List the main actors and processes to export sandalwood from Vanuatu?
- Have there been any policies geared towards halting wild harvesting (assume not)? Why have there been no policies of this kind?
- The 80-tonne export quota seems to be there to control wild harvest exports. Are there discussions on this quota changing as plantation-based systems come into the market?
- Are there any subsidy or related policies that support the sandalwood plantation sector?

Cyclones

- How is environmental change factored into sandalwood plantations?
- Do smallholders receive any training on managing their crops in light of increasing cyclones?
- If so, what type of training to they receive?
- What were some of the impacts of the 2016 cyclone on sandalwood crops?
- Did farmers face financial losses from this cyclone (that is, loss of sandalwood crops)

Appendix 2: Calculating producer gains from a productivity shift

The distribution of benefits to producers and consumers from a productivity shift depends on the nature of the shift and the supply and demand elasticities.

A common approximation to estimating the gains from research is *k*PQ, where k is the productivity shift and P and Q are price and quantity.

In the Vanuatu sandalwood case, as illustrated in Figure A1:

- P = A$12,500/t
- Q = 80/t/year
- annual revenue equals A$1 million.

With *k* = 2, production and exports increase to 160 t and annual revenue equals A$2 million.

Producer surplus is revenue minus costs, the area between the supply curve and the price. Assuming nothing is supplied below A$6,000/t, the initial producer surplus is 0.5*(12,500–6,000)*80=A$260,000.

After the productivity enhancement, the producer surplus is A$520,000. The change in producer surplus is the shaded area. The gains depend on the nature of the shift, which reflects the additional costs. Figure A1 shows a pivotal shift. A parallel shift would produce around twice the gains.

These calculations assume the increased supply does not suppress prices received by producers. This reflects that Vanuatu, as a small supplier on the global market, cannot affect prices.

More generally, the slope of the demand curve matters. Here, it is flat. If the demand curve is very steep, implying that consumers do not respond much to prices, most of the productivity gains are passed on to consumers.

What matters is the relationship between the elasticity of supply and elasticity of demand. If the elasticity of supply is less than the elasticity of demand, a pivotal shift with the origin constant will increase producer surplus.

As the supply curve gets more elastic (flatter), producer surplus will fall once it exceeds the elasticity of demand, as shown by Miller et al. (1988). The fall in prices offsets the increased production. Productivity gains benefit society as a whole, but might not benefit producers.

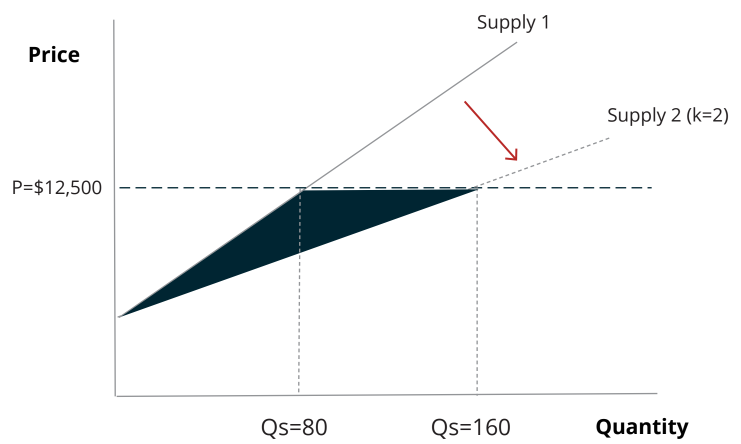

Figure A1 Effects of a productivity improvement with fixed price

Appendix 3: Long-term price and price variability

We developed a multi-region, single commodity, dynamic, stochastic, non-linear partial equilibrium model of world sandalwood trade.

Sandalwood is assumed to be homogenous, which implies that imports from different countries are close substitutes. This allows us to treat trade as if regions import or export into a global pool, without specifying bilateral flows, for example from Vanuatu to China.

The aim is to show how changes in demand and supply will affect world prices, and hence the prices received by producers in Vanuatu at harvest time.

The world market is characterised by:

- excess demand in India, China and the European Union
- excess supply in Australia and Vanuatu.

Australia has 15,000 ha almost ready to harvest on the Ord River. Vanuatu supplies about 2% of the world market, and so has little influence on world prices, at least at present production levels. The additional supply from Vanuatu will have a negative, although marginal, impact on prices received.

Demand and supply equations in each region are specified as follows:

$$D_i = \alpha_i P_i^{\varepsilon_d} (1 + f_i)^t \qquad (3)$$

$$S_i = \Upsilon_i P_i^{\varepsilon_s} (1 + g_i)^t (1 + \mu_i) \qquad (4)$$

Time subscripts are dispensed with, except where it is necessary to avoid confusion.

- D_i is annual consumption in region *i*
- S_i is annual production
- P_i is the domestic price
- α_I and γ_I are constant parameters
- ε_d and ε_s are demand and supply elasticities
- f and g are exogenous growth rates in demand and supply in each region
- μ_i is a stochastic parameter reflecting uncertainty in annual production.

Equation 3 specifies a non-linear, non-stochastic domestic demand function. The supply function specification of equation 4 provides for additive stochastic shocks μ_i, which are assumed to be independent and randomly distributed.

For Vanuatu, we assume a logistic supply function for the additional supply of sandalwood from 100,000 seedlings as follows:

$$S_i = \frac{K}{1 + e{-}(b_1{+}b_2 t)} + cP_i^{\varepsilon_s} \qquad (5)$$

Where:

- K is the maximum likely harvest from 100,000 seedlings (about 220 t)
- b_2 is the growth rate (0.3)
- b_1 and b_2 shift the function left or right
- c is a constant that calibrates the function to the base value.

The function has an initial value of 80, a growth rate of 0.3%, and a maximum of 300 t. Production (harvest) also responds to prices.

In each region, net exports are the difference between domestic supply and demand, as per equation 6

$$X_i = S_i - D_i \qquad (6)$$

The price linkage equation is equation 7:

$$P_i^d = \phi_i + \theta_i P_w \qquad (7)$$

Domestic prices are linked to world prices, P_w, through two components. ϕ_i represents a shift component unrelated to the world price, such as a specific tariff, transport costs and so on. The term θ_i represents the direct relationship between domestic and world prices, and can be interpreted as a transmission elasticity. For $\theta_i < 1$, domestic prices are insulated from and fluctuate less than world prices. Under free trade, ϕ_i equals 0 (excluding transport costs and other margins) and θ_i equals 1.

Although sandalwood is a storable commodity, we assume no change in stocks from year to year. Thus, the market clearing (equation 8 below) requires that each period global supply equates with global demand, and that global imports equal global exports.

$$\Sigma D_i - \Sigma S_i = 0 \qquad (8)$$

The model is solved by finding the global prices that equates global imports and exports. This is done using Solver in Excel.

We divide the world into six regions with production, consumption, trade and growth in production and consumption as shown in Table A1.

Table A1 Sandalwood trade model-base data

Regions	Production (t)	Consumption (t)	Net exports (t)	Growth in production (%)	Growth in consumption (%)
Vanuatu	80	10	70	30	0
India	3,000	4,000	–1,000	0	2
China	1,000	2,000	–1,000	0	5
Australia	3,000	50	2,950	5	0
European Union	0	1,000	–1,000	0	2
Rest of the world	900	920	–20	1	1
Total	**7,800**	**7,800**	**0**	—	—

Source: Authors' calculations.

The major features are that Vanuatu supplies a little over 1% of the world market, but production is expected triple to 240 t in 18 years. This is consistent with the planting of 100,000 seeds and 5% of the stock being harvested and replaced each year. We also assume maximum production is 300 t. Sandalwood supply on Vanuatu is modelled as a logistic function.

The only other major supplier which shows any growth is Australia. This is also modelled as a logistic function, reflecting the expansion on the Ord River in Western Australia. Some 32,000 trees were harvested in 2016—about 300 t of heartwood—according to press reports (ABC Rural 2016).

On the demand side, the most obvious growth comes from China, reflecting increasing incomes rather than population growth. There is moderate growth in demand in India and the European Union as well.

We assume the elasticity of demand is –0.8. This is based on the notion that sandalwood is a discretionary purchase, as opposed to a necessity. A survey of the literature shows a great range of elasticities, but we found no estimates for sandalwood or essential oils specifically.

Figure A2 shows the projected supply for Vanuatu. Supply responds to prices, but the logistic curve reflects the gradual adoption of 100,000 seedlings distributed in recent years. This amounts to a threefold increase in 18 years.

Assuming the initial trade flows and growth rates are correct, we estimate an increase in prices of 10% or so over 10 years, and then a fall over the next 10 years, as Australian supplies offset the increase in demand from China and India (Figure A3).

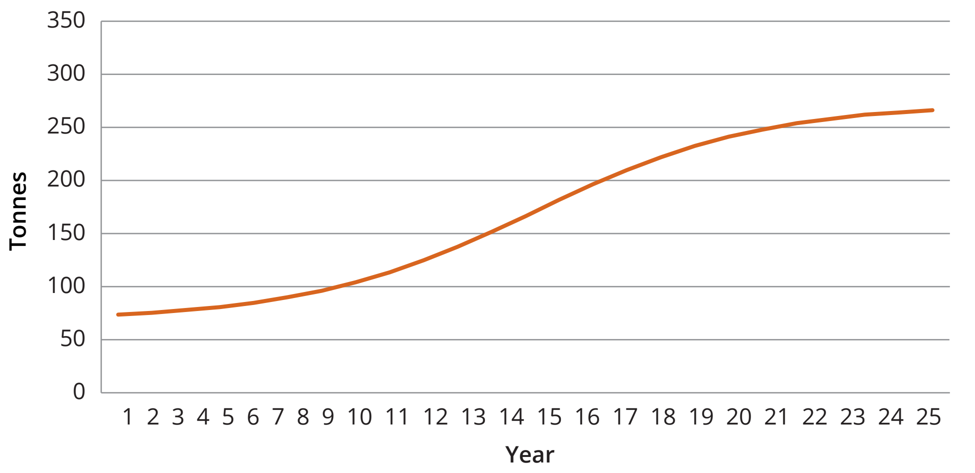

Figure A2 Projected Vanuatu supply of sandalwood
Source: Authors' calculation.

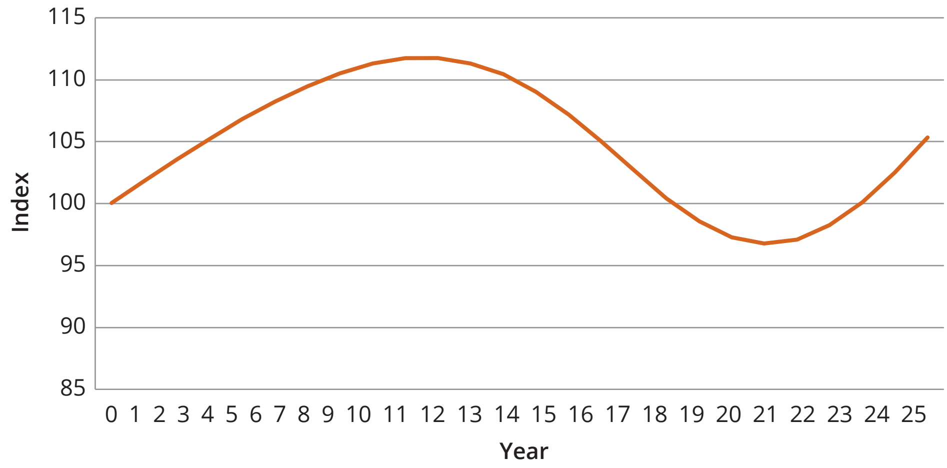

Figure A3 World sandalwood price index
Source: Authors' calculations

Vanuatu's rapid growth rate does have a modest effect on world prices. In the absence of any exogenous growth, world prices would rise 15% before levelling off. Vanuatu's additional supply suppresses world prices by about 3%.

For the moment, our projections exclude stochastic shocks. Assuming supply in each region could vary from the trend by 5% a year, this has relatively little effect on world prices (5%–10%). But this is because we assume the random shocks are independent and uncorrelated, so tend to cancel each other out.

Limitations of the analysis centre on poor data. There is great uncertainty about future price movements. Most price data quoted are sourced from just one study. Data on production and trade tended to be anecdotal, from media reports and the like.

There are no official trade statistics. Our elasticities, reflecting how producers and consumers respond to prices, are taken from estimates of other timber products. Given sandalwood is a discretionary good, our estimates of demand may be too low. This means additional supply would have a greater dampening effect on prices. But the impact of the NPV and IRR calculations would be minimal. Exogenous price shocks, unrelated to Vanuatu's production, might have a much greater effect. We have ignored the ability of consumers and producers to substitute into other products.

From the partial equilibrium modelling, we conclude that prices are likely to fall when Vanuatu's expanded sandalwood forest becomes ready for harvesting. Prices now are very high, but are likely to revert back to the long-term trend as other suppliers expand their production to take advantage of the high prices. For this reason, we have chosen a rather conservative (low) farm gate price of A$12.50/kg (VT1,000).

Another conclusion is that sandalwood production has only a limited impact on world prices. But this conclusion may be overstated, because it assumes all sandalwood supplies are homogenous or at least close substitutes, whereas Vanuatu sandalwood is considered superior to Australian and Indian sandalwood. This means that the increase in supply from Vanuatu might have a greater dampening effect on prices than we calculate.

No.	Author(s) and year of publication	Title	ACIAR project numbers
1	Centre for International Economics 1998	Control of Newcastle disease in village chickens	AS1/1983/034, AS1/1987/017, AS1/1993/222
2	George P.S. 1998	Increased efficiency of straw utilisation by cattle and buffalo	AS1/1982/003, AS2/1986/001, AS2/1988/017
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, CS2/1989/019
6	Ryan J.G. 1998	Pigeonpea improvement	CS1/1982/001, 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, FST/1988/048
9	ACIL Consulting 1998	Sulfur test KCL–40 and growth of the Australian canola industry	PN/1983/028, 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, 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, CS1/1988/039
14	McLeod R., Isvilanonda S. and Wattanutchariya S. 1999	Improved drying of high moisture grains	PHT/1983/008, PHT/1986/008, PHT/1990/008
15	Chudleigh P. 1999	Use and management of grain protectants in China and Australia	PHT/1990/035
16	McLeod R. 2001	Control of footrot in small ruminants of Nepal	AS2/1991/017, AS2/1996/021
17	Tisdell C. and Wilson C. 2001	Breeding and feeding pigs in Australia and Vietnam	AS2/1994/023
18	Vincent D. and Quirke D. 2002	Controlling *Phalaris minor* in the Indian rice-wheat belt	CS1/1996/013
19	Pearce D. 2002	Measuring the poverty impact of ACIAR projects—a broad framework	
20	Warner R. and Bauer M. 2002	*Mama Lus Frut* scheme: an assessment of poverty reduction	ASEM/1999/084
21	McLeod R. 2003	Improved methods in diagnosis, epidemiology, and information management of foot-and-mouth disease in South-East Asia	AS1/1983/067, AS1/1988/035, AS1/1992/004, AS1/1994/038

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22	Bauer M., Pearce D. and Vincent D. 2003	Saving a staple crop: impact of biological control of the banana skipper on poverty reduction in Papua New Guinea	CS2/1988/002-C
23	McLeod R. 2003	Improved methods for the diagnosis and control of bluetongue in small ruminants in Asia and the epidemiology and control of bovine ephemeral fever in China	AS1/1984/055, AS2/1990/011, AS2/1993/001
24	Palis F.G., Sumalde Z.M. and Hossain M. 2004	Assessment of the rodent control projects in Vietnam funded by ACIAR and AusAID: adoption and impact	AS1/1998/036
25	Brennan J.P. and Quade K.J. 2004	Genetics of and breeding for rust resistance in wheat in India and Pakistan	CS1/1983/037, CS1/1988/014
26	Mullen J.D. 2004	Impact assessment of ACIAR-funded projects on grain-market reform in China	ADP/1997/021, ANRE1/1992/028
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/1984/057, FST/1987/036, FST/1988/048, FST/1990/044, FST/1994/025, FST/1996/125, FST/1997/077
31	Pearce D. 2005	Review of ACIAR's research on agricultural policy	
32	Tingsong Jiang and Pearce D. 2005	Shelf-life extension of leafy vegetables—evaluating the impacts	PHT/1994/016
33	Vere D. 2005	Research into conservation tillage for dryland cropping in Australia and China	LWR2/1992/009, LWR2/1996/143
34	Pearce D. 2005	Identifying the sex pheromone of the sugarcane borer moth	CS2/1991/680
35	Raitzer D.A. and Lindner R. 2005	Review of the returns to ACIAR's bilateral R&D investments	
36	Lindner R. 2005	Impacts of mud crab hatchery technology in Vietnam	FIS/1992/017, FIS/1999/076
37	McLeod R. 2005	Management of fruit flies in the Pacific	CS2/1989/020, CS2/1994/003, CS2/1994/115, CS2/1996/225
38	ACIAR 2006	Future directions for ACIAR's animal health research	

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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, PHT/1990/051
40	Corbishley J. and Pearce D. 2006.	Zero tillage for weed control in India: the contribution to poverty alleviation	CS1/1996/013
41	ACIAR 2006	ACIAR and public funding of R&D. Submission to Productivity Commission study on public support for science and innovation	
42	Pearce D. and Monck M. 2006	Benefits to Australia of selected CABI products	
43	Harris D.N. 2006	Water management in public irrigation schemes in Vietnam	LWR1/1998/034, LWR2/1994/004
44	Gordon J. and Chadwick K. 2007	Impact assessment of capacity building and training: assessment framework and two case studies	CS1/1982/001, CS1/1985/067, LWR2/1994/004, LWR2/1998/034
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, AS2/1999/060
47	Fisher H. and Gordon J. 2007	Improved Australian tree species for Vietnam	FST/1993/118 and FST/1998/096
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, 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 in India	CS2/1994/050

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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, FIS/2006/144
56	Lindner B. and McLeod P. 2008	A review and impact assessment of ACIAR's fruitfly research partnerships—1984–2007	CP/1997/079, CP/2001/027, CP/2002/086, CP/2007/002, CP/2007/187, 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, PHT/1990/051, PHT/1993/87, PHT/1994/133
57	Montes N.D., Zapata Jr N.R., Alo A.M.P. and Mullen J.D. 2008	Management of internal parasites in goats in the Philippines	AS1/1997/133
58	Davis J., Gordon J., Pearce D. and Templeton D. 2008	Guidelines for assessing the impacts of ACIAR's research activities	
59	Chupungco A., Dumayas E. and Mullen J. 2008	Two-stage grain drying in the Philippines	PHT/1983/008, PHT/1986/008, 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, PHT/1990/009
63	Harding M., Tingsong Jiang and Pearce D. 2009	Analysis of ACIAR's returns on investment: appropriateness, efficiency and effectiveness	
64	Mullen J.D. 2010	Reform of domestic grain markets in China: a reassessment of the contribution of ACIAR-funded economic policy research	ADP/1997/021 and ANRE1/1992/028
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, 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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68	McClintock A. and Griffith G. 2010	Benefit–cost meta-analysis of investment in the International Agricultural Research Centres	
69	Pearce D. 2010	Lessons learned from past ACIAR impact assessments, adoption studies and experience	
70	Harris D.N. 2011	Extending low-chill fruit in northern Thailand: an ACIAR–World Vision collaborative project	PLIA/2000/165
71	Lindner R. 2011	The economic impact in Indonesia and Australia from ACIAR's investment in plantation forestry research, 1987–2009	FST/1986/013, FST/1990/043, FST/1993/118, FST/1995/110, FST/1995/124, FST/1996/182, FST/1997/035, FST/1998/096, FST/2000/122, FST/2000/123, FST/2003/048, FST/2004/058
72	Lindner R. 2011	Frameworks for assessing policy research and ACIAR's investment in policy-oriented projects in Indonesia	ADP/1994/049, ADP/2000/100, ADP/2000/126, AGB/2000/072, AGB/2004/028, ANRE1/1990/038, ANRE1/1993/023, ANRE1/1993/705, EFS/1983/062, EFS/1988/022
73	Fisher H. 2011	Forestry in Papua New Guinea: a review of ACIAR's program	FST/1994/033, FST/1995/123, FST/1998/118, FST/2002/010, FST/2004/050, FST/2004/055, FST/2004/061, FST/2006/048, FST/2006/088, FST/2006/120, FST/2007/078, FST/2009/012
74	Brennan J.P. and Malabayabas A. 2011	International Rice Research Institute's contribution to rice varietal yield improvement in South-East Asia	
75	Harris D.N. 2011	Extending rice crop yield improvements in Lao PDR: an ACIAR–World Vision collaborative project	CIM/1999/048, CS1/1995/100, PLIA/2000/165
76	Grewal B., Grunfeld H. and Sheehan P. 2011	The contribution of agricultural growth to poverty reduction	
77	Saunders C., Davis L. and Pearce D. 2012	Rice–wheat cropping systems in India and Australia, and development of the 'Happy Seeder'	LWR/2000/089, LWR/2006/132, CSE/2006/124
78	Carpenter D. and McGillivray M. 2012	A methodology for assessing the poverty-reducing impacts of Australia's international agricultural research	
79	Dugdale A., Sadleir C., Tennant-Wood R. and Turner M. 2012	Developing and testing a tool for measuring capacity building	
80	Fisher H., Sar L. and Winzenried C. 2012	Oil palm pathways: an analysis of ACIAR's oil palm projects in Papua New Guinea	ASEM/1999/084, ASEM/2002/014, ASEM/2006/127, CP/1996/091, CP/2007/098, PC/2004/064, PC/2006/063

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81	Pearce D. and White L. 2012	Including natural resource management and environmental impacts within impact assessment studies: methodological issues	
82	Fisher H. and Hohnen L. 2012	ACIAR's activities in Africa: a review	AS1/1983/003, AS1/1995/040, AS1/1995/111, AS1/1996/096, AS1/1998/010, AS2/1990/047, AS2/1991/018, AS2/1993/724, AS2/1996/014, AS2/1999/063, AS2/1996/090, AS2/1996/149, AS2/1996/203, AS2/1997/098, CP/1994/126, CS2/1990/007, EFS/1983/026, FST/1983/020, FST/1983/031, FST/1983/057, FST/1988/008, FST/1988/009, FST/1991/026, FST/1995/107, FST/1996/124, FST/1996/206, FST/2003/002, IAP/1996/181, LPS/1999/036, LPS/2002/081, LPS/2004/022, LPS/2008/013, LWR/2011/015, LWR1/1994/046, LWR2/1987/035, LWR2/1996/049, LWR2/1996/163, LWRS/1996/215, LWR2/1997/038, SMCN/1999/003, SMCN/1999/004, SMCN/2000/173, SMCN/2001/028
83	Palis F.G., Sumalde Z.M., Torres C.S., Contreras A.P. and Datar F.A. 2013	Impact pathway analysis of ACIAR's investment in rodent control in Vietnam, Lao PDR and Cambodia	ADP/2000/007, ADP/2003/060, ADP/2004/016, AS1/1994/020, AS1/1996/079, AS1/1998/036, CARD 2000/024, PLIA/2000/165
84	Mayne J. and Stern E. 2013	Impact evaluation of natural resource management research programs: a broader view	
85	Jilani A., Pearce D. and Bailo F. 2013	ACIAR wheat and maize projects in Afghanistan	SMCN/2002/028, CIM/2004/002, CIM/2007/065
86	Lindner B., McLeod P. and Mullen J. 2013	Returns to ACIAR's investment in bilateral agricultural research	
87	Fisher H. 2014	Newcastle disease control in Africa	AS1/1995/040, AS1/1996/096
88	Clarke M. 2015	ACIAR-funded crop–livestock projects, Tibet Autonomous Region, People's Republic of China	LPS/2002/104, CIM/2002/093, LPS/2005/018, LPS/2005/129, LPS/2006/119, LPS/2008/048, LPS/2010/028, C2012/228, C2013/017
89	Pearce D. 2016	Sustaining cocoa production: impact evaluation of cocoa projects in Indonesia and Papua New Guinea	SMAR/2005/074, HORT/2010/011, ASEM/2003/015, ASEM/2006/127, PC/2006/114
90	Pearce D. 2016	Impact of private sector involvement in ACIAR projects: a framework and cocoa case studies	PC/2006/114, ASEM/2006/127, SMAR/2005/074, HORT/2010/011

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91	Brown P. R., Nidumolu U. B., Kuehne G., Llewellyn R., Mungai O., Brown B. and Ouzman J. 2016	Development of the public release version of Smallholder ADOPT for developing countries	
92	Davila F., Sloan T. and van Kerkhoff L. 2016	Knowledge systems and RAPID framework for impact assessments	CP/1997/017
93	Mullen, J.D., de Meyer, J., Gray, D. and Morris, G. 2016	Recognising the contribution of capacity building in ACIAR bilateral projects: Case studies from three IAS reports.	FST/1986/030, FST/1993/118, FST/1998/096, FIS/2005/114
94	Davila F., Sloan T., Milne M., and van Kerkhoff L., 2017	Impact assessment of giant clam research in the Indo-Pacific region	FIS/1982/032, FIS/1987/033, EFS/1988/023, FIS/1995/042
95	Ackerman J.L. and Sayaka B. 2018	Impact assessment of ACIAR's Aceh aquaculture rehabilitation projects	FIS/2005/009, FIS/2006/002
96	Clarke, M. and Mikhailovich, K. 2018	Impact assessment of investment in aquaculture-based livelihoods in the Pacific islands region and tropical Australia	FIS/2001/075, FIS/2006/138
97	Mullen J.D., Malcolm B. and Farquharson R.J. 2019	Impact assessment of ACIAR-supported research in lowland rice systems in Lao PDR	CSI/1995/100, CIM/1999/048, CSE/2006/041
98	Clarke M. 2019	Impact assessment of ACIAR investment in citrus rootstock, scion and production improvement in China, Vietnam, Bhutan and Australia	CSI/1987/002, CS1/1996/076, HORT/2005/142, HORT/2010/089
99	Abell J., Chudleigh P. and Hardaker T, 2012	An impact assessment of conservation tillage research in China and Australia	LWR2/1992/009, LWR2/1996/143
100	Yet to be published		
101	Davila, F, Vanzetti, D and Sloan, T, 2021	Mixed-methods impact assessment of sandalwood research in Vanuatu	FST/2002/097, FST/2008/010

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