Australian Government
Australian Centre for International Agricultural Research

Final report

project	**Development of advanced veneer and other products from coconut wood to enhance livelihoods in South Pacific communities**
project number	FST/2009/062
date published	24/08/2016
prepared by	Associate Professor Gregory Nolan, Director, Centre for Sustainable Architecture with Wood (CSAW), School of Architecture and Design, University of Tasmania (UTAS)
co-authors/ contributors/ collaborators	Dr Rob McGavin, Research Facility and Project Manager, Agri-Science Queensland, Department of Agriculture and Fisheries (QDAF) Dr David Blackburn, Research Fellow, CSAW School of Architecture and Design, University of Tasmania Sairusi Bulai, Coordinator, Forests and Trees Group Land Resources Division, Pacific Community (SPC)
approved by	Tony Bartlett, Forestry Research Program Manager
final report number	FR2016-26
ISBN	978-1-925436-73-0
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

This publication is published by ACIAR ABN 34 864 955 427. Care is taken to ensure the accuracy of the information contained in this publication. However, ACIAR cannot accept responsibility for the accuracy or completeness of the information or opinions contained in the publication. You should make your own enquiries before making decisions concerning your interests.

Contents

1 Acknowledgments

This project's development and achievements were made possible through the enthusiasm, co-operation, and hard work of many individuals, companies and institutions in Australia, and partner countries.

The project was initially developed by Dr Henri Bailleres and member of his QDAF team, with support from SPC's Mr Sairusi Bulai, the Fijian Ministry of Fisheries and Forestry's Mr Sevanaia Tawake and Mr Semi Dranibaka, ACAIR's Mr Tony Bartlett and others. UTAS continued project development with additional insights from ACIAR's Mr Richard Markham.

Research collaborators in each participating country and industry in Australia and the South Pacific supported the project's progress.

Research collaborators in the partner countries included:

- Mr Sairusi Bulai and other members of the Pacific Community team in SPC's Nasinu office and Mr Gideon Bouro in their Honiara office.
    - Special acknowledgement goes to the project-appointed research officer at SPC, Ms Moana Bergmaier-Masau for her role in effectively coordinating activity between the project teams in the Australia and the partner countries.
- The Fijian Ministry of Fisheries & Forests' Timber Utilisation Division (TUD) team lead initially by Mr Sevanaia Tawake, ably replaced by Mr Semi V. Dranibaka and then Mr Rafaele Raboiliku.
- The Samoan Forestry Department of the Ministry of Natural Resources and the Environment, led by Moafanua Tolusina Pouli, and supported by Ms Elizabeth Kerstin.
- Solomon Islands' Ministry of Forestry and Research (MFR), led by Mr Reeves Moveni, and supported by Ms Stephanie Rikoi.

Industry and community stakeholders in the partner countries who contribute their time and expertise included:

- Mr Peter Kjear of the TeiTei Taveuni Farmer Association, Fiji.
- Graham Haynes of Savusavu, Fiji.
- The staff and management of Valebasoga Tropikboards Ltd, Fiji.
- Mr Joe Strickland and the staff from Strickland Bros in Apia, Samoa.
- Ms Nanette Tutua of Timol Timber.
- The staff of Solomon Islands' Value-Added Timber Association (VATA).

Industry and community stakeholders in Australia who contribute their time and expertise included:

- The wood production and building design professionals who contributed to the project's Market Assessment process.
- Mr Simon Dorries for the Engineered Wood Products Association of Australasia.
- Mr Soren Holm, of Global Ventures – EcoCore.
- Ms Juel Briggs and Mr Paul McGovern of Briggs Veneers.

Finally, the project manager wold like to acknowledge the contribution and dedication of:

- Dr Henri Bailleres, Dr Rob McGavin and the rest of the QDAF team at their Salisbury Research Facility, particularly Mr Eric Littee.
- Other UTAS participants, particularly Mr Geoff Dean, Dr Anna Wrobel-Tobiszewska and Mr Matt Prince.

2 Executive summary

Coconut plantations are a valuable economic and social resource for many communities in South Pacific Islands. However, many palms are senile, have lost much of their vitality and productivity, and act as a major constraint on improved agricultural production. Yet, they present a significant opportunity for a sustainable increase in wood production. Over 65,000 hectares of senile coconuts, or 6.3 million senile stems, are thought to exist in the three South Pacific countries participating in this project.

The project aimed to develop the technologies, processes and expertise to produce high quality veneer and complementary soil conditioning products from senile coconut stems on an economically, socially and environmentally sustainable basis and thereby enhance livelihoods in South Pacific communities. Achieving this could support community acceptance and action for an orderly and profitable senile coconut plantation renewal program in South Pacific communities.

To achieve its aim, the project developed new knowledge and processes critical to establishing the technology that underpins for a sustainable coconut veneering industry. In doing so, it determined that:

- High-density senile coconut logs can be reliably peeled into quality veneer using available spindle-less lathe techniques. 68% of the veneer recovered during trials had a density of 500 kg/m^3 or more. However, appropriate machine settings and log preconditioning are required. Once peeled, the veneer can be dried and handled using standard industry equipment.
- The veneer produced differs from traditional wood veneers in that its minimum production thickness is 2 mm and its surface has a natural roughness that requires careful gluing and moderate sanding.
- The veneer produced can be used for a range of architectural and structural products. Optimum utility and value is likely to be achieved by exploiting coconut veneer's colour, visual characteristics and hardness in architectural application. This requires quality production, batching the recovered veneer by colour and density, and grading it to a market-aligned standard.
- Coconut veneer can be reliably glued into structural plywood and LVL products but relatively low MoE and shear values mean that lighter competitor wood products provide superior performance. Viable structural products may result from blending coconut veneer with material from other forest resources
- A robust by-products suite is needed to use the significant quantities of residue generated on the harvest sites and at processing facilities. Coconut residues as fuel and as a base resource in community-scale composting appear to be cost effective and practical options. The use of coconut wood chips as a base for mushroom or plant growing mediums was largely unsuccessful. Trials with coconut wood biochar were inconclusive.
- Economic modelling of the coconut veneer value chain indicates that it is likely to be financially attractive for existing veneer producers and potentially additional small-scale processors to develop a viable coconut veneer industry.
- Fragmented community ownership of many coconut estates presents a risk to regular log supply and may be a significant impediment to establishing a coconut veneer value chain. Extension tools in estate planning and harvesting were developed to help address this risk.

A series of high quality technical reports detailing the methodologies and outcomes of each research area were produced along with important supporting outputs, including: a coconut estate renewal planning model and process; guidelines for the harvesting of coconut palms; and a financial business model for five options for coconut veneer production facilities based on Pacific Island conditions and data. These outputs should assist with the adoption of the outcomes by senile coconut resource owners and wood processors. All of these reports and resources are available at www.cocowood.net.

The project sought to establish independent research capacity in veneer-based product manufacture. A rotary veneer processing equipment suite was established at the TUD facility in Suva, Fiji, and key staff were trained in its operation. This facility can be the base for future work on coconut and other small diameter wood resources in the region. The Crawford Fund also supported training in Brisbane, Australia, and education online.

Additional work to improve outcomes for any developing coconut veneer industry and the coconut production sector include: extension support to assist industry tune their equipment and processes to reliably peel senile coconut stems into high-quality veneer and assemble it into products; research into solid wood applications for the upper log in the coconut stem; larger-scale controlled trials of composting coconut residues, and a comprehensive value-chain study. Lastly, more effective project development and management practices are probably needed for projects working across supply sectors and support networks.

3 Background

Large areas of mature coconut palms in estates across the Pacific region are considered senile and unproductive when compared to younger palms and newer varieties. To generate an economic driver for estate owners to replace their senile stems, ACIAR has funded two recent research projects.

The ACIAR funded Cocowood Project, *FST/2004/054,* analysed the properties of coconut wood and processing technologies to investigate whether the harvest of this product could provide one solution to waning global timber resources. This project was successful providing knowledge on the coconut stems properties, identifying appropriate solid wood processing protocols and developing a range of products. However, there were limitations in the production process of coconut wood with an average recovery of 30-35% of log volume in viable wood product. Due to the low return, a new use for the coconut stems was proposed – coconut veneer and veneer-based products. These products would be produced through the rotary peeling of the coconut stems rather than saw milling, with a significant increase in recovery to 60-65% of log volume.

The CocoVeneer project FST/2009/062 aimed to develop the technologies, processes and expertise to produce veneer and veneer-based products from senile coconut stems in three partner countries: Fiji, Samoa and Solomon Islands. The use of residues for by-products such as soil conditioning products was also investigated.

The Pacific coconut estate & effects of palm senility

Coconut plantations are a valuable economic and social resource for many communities and private estates in South Pacific Islands. However, many palms in South Pacific coconut plantations are old and have lost much of their vitality and productivity. Known as senile coconuts, these palms provide only low nut yields (Forstreuter, SPC 2013). Given this, plantations of senile palms act a major constraint on improved agricultural production yet present a significant opportunity for a sustainable increase in wood production. This is an ongoing problem as levels of senility will increase without established renewal processes.

Senile coconut palms form a significant part of the plantation estates in the three partner countries: Fiji, Samoa and Solomon Islands, as well as other Pacific Island nations. Table 1 summarises the UN Food and Agriculture Organization's (FAO 2014) most recent estimates for the partner countries. The accuracy of these figures is difficult to verify due to the lack of regular survey.

Table 1: Estimated total areas of all and senile coconut palms in in three Pacific countries

	Fiji	Solomon Islands	Samoa
Total area of coconut plantations (ha)	65,000	59,000	93,000
Percentage area of senile palms (%)	60	20	16
Total area of senile palms (ha)	39,000	11,800	14,880

The economic activity forgone due to palm senility is significant. As part of Objective 2.1 of this project and discussed further in Section 7, estimates were prepared for the potential increase in nut production and senile palm log volumes available for harvest under a range of coconut estate renewal scenarios. The estimated outcomes for Fiji's nut and log production under a 50 year replacement period for its senile estate is shown in Figure 1. In short, nut production is projected to increase by approximately 230% from current production level by year 45 as renewed palms increase average nut productivity. At the same time, approximately 550,000 senile palms are estimated to be available for harvest each 5 years. This equates to around 64,000 m^3 of coconut logs being available for processing every year, assuming only a single 6m butt log is recovered from each palm.

Significant palm residues will also be generated during this process at the coconut estate and at the process mill. Without renewal, coconut production will continue to decline.

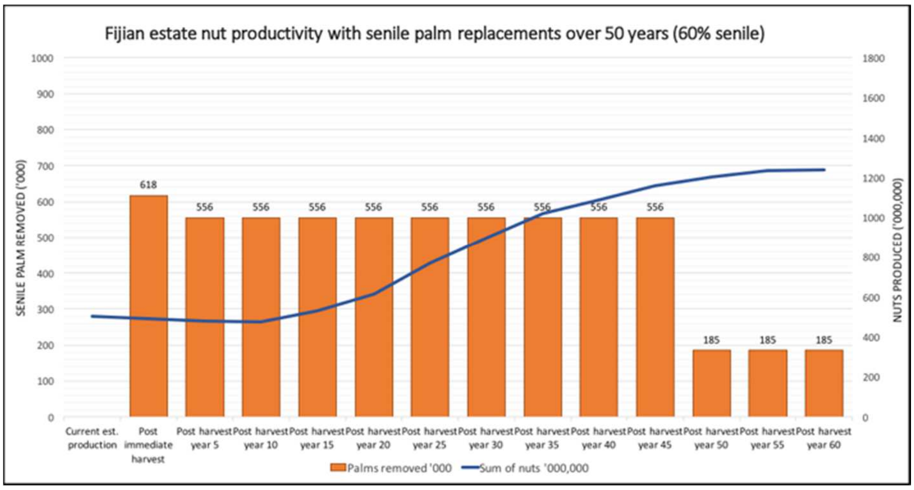

Figure 1: Estimated change in nut productivity and log production from coconut estate renewal in Fiji, based on a constant estate area with renewal over 50 years, and a harvest event at 5 yearly intervals.

Given the potential national economic and community welfare benefits demonstrated by this modelling, generating a demand for coconut logs can establish an incentive on a local scale for plantation owners to remove low-productivity senile stems and realise the potential of more productive land uses.

The character of coconut wood and its impact on wood products

Senile coconut palms are potentially a valuable resource for the manufacture of wood products in Fiji, Samoa and Solomon Islands. However, the use of coconut stems as a 'wood' product is unconventional due to the palm's properties. The stem fibre of the coconut palm (*Cocos nucifera*) is not a true wood. As a monocot (grass), the properties of its 'wood' and the arrangement of its cells are significantly different to the properties and cell arrangement found in the wood of softwood and hardwood tree species. The stem has a high density zone towards the periphery while the inner zone is lower in density. This is due to the variation in the occurrence of high-density vascular bundles across and up the stem. As shown in Figure 2, vascular bundles are concentrated in the periphery of the stem and become much less frequent in the stem's middle. Parenchyma, a spongy, low-density tissue that is foam-like in texture, fills the spaces between the vascular bundles and provides a low level of radial and tangential connection between the bundles. See Figure 3. Logs are generally small with a diameter of 350 mm or less.

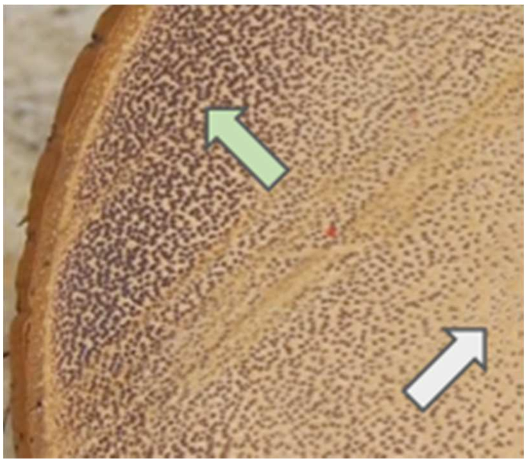

Figure 2: Vascular bundles clustered in the periphery of a senile coconut log

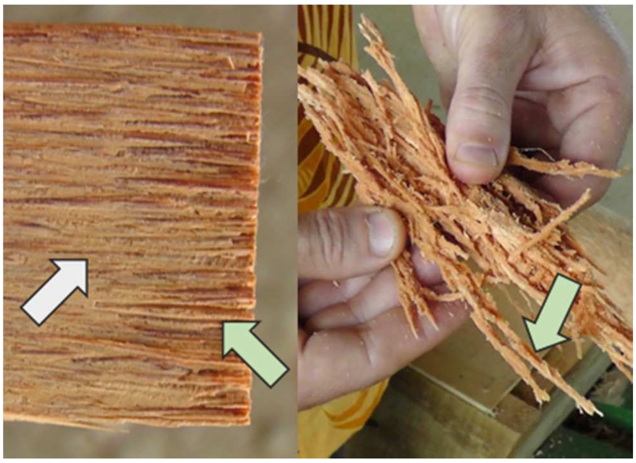

Figure 3: Vascular bundles apparent in the low-density, foam-like parenchyma tissue

The stem's vascular structure and small log diameters complicate conversion into wood products for buildings and furniture. Historically, coconut stems have been used in the round as poles or columns or sawn into board. Traditional methods of sawing a log can provide a low return of viable product, especially from small logs with variable physical properties. Milling harvested coconut stems give an average recovery of 30-35% of log volume. However, during sawing, the log is 'squared up' to produce traditional sawn boards. This leads to significant losses, especially of the denser 'hard' wood-like outer material that is most attractive for high-value timber products. Also, a significant proportion of recovered boards can include a mixture of hard and soft material in the piece, decreasing the board quality and value. Despite considerable research effort, milling of substantial quantities of coconut stems for high value boards is challenging in any of the partner countries.

Potential of spindle-less lathe production

Prior to this project, techniques to successfully peel coconut logs into veneer were not available. Traditionally, forest logs were peeled into veneer using a spindle lathe. These suspend and spin the log on two spindles, then pushes it against a knife to peel a continuous ribbon of thin veneer from the log periphery. However, traditional spindles are unable to grip the soft inner core of the coconut stem sufficiently to enable peeling of the hard outer material. Also, spindle lathes are relatively inefficient in processing small logs as they leave a residual core of at least the diameter of the spindle. A spindle-less lathe is an alternative to a spindle lathe. These lathes use periphery drive rollers to grip, spin and push the log against the blade for peeling. Because of this, they can peel small logs efficiently down to a residual core of 60 mm or less. Spindle-less lathe technology has been available for many years but their use and availability was limited until about a decade ago.

Peeling harvested coconut logs with a spindle-less lathe offers greater efficiency, recovery and utilisation of the stem when compared to sawing. The log is converted into a long ribbon of veneer down to a small core quickly and 60-65% of log volume can be recovered into product. The resulting veneer can then be dried and glued together to make valuable products such as plywood or LVL. The processing residue from this process, the innermost core and the outlying bark of the coconut stem may then be used for by-products such as wood chips, fuel wood or a resources for composting.

Figure 4: A senile coconut log in a spindle-less lathe

4 Objectives

As access to traditional resources for veneer and veneer-based products are constrained, particularly from native forests, an opportunity exists for the significant volume of wood held in the estimated 65,000 hectares of senile coconut plantations in the partner countries to become an attractive alternative resource. With the development of suitable technologies, processes and expertise, a sustainable coconut wood veneering industry sector may be established to use this resource. Such an industry could underpin the renewal of the coconut estate, with a consequent increase in nut and other agricultural production. The industry could include the harvest and re-establishment of coconut plantations, conversion of recovered stems into veneer, assembly of composite products for local use or export, and production of useful agricultural products and fuel from stem and crown residues.

This project aimed to develop these technologies, processes and expertise to produce high quality veneer and complementary soil conditioning products from senile coconut stems on an economically, socially and environmentally sustainable basis and thereby enhance livelihoods in South Pacific communities. The project sought to answer the key research and development questions critical to establishing a sustainable coconut veneer industry, namely:

a. Can coconut wood logs be peeled into marketable veneer using spindle-less lathes and can it be peeled, dried and handled efficiently and effectively?

b. Can products made from this veneer satisfy the performance requirements established in likely local and export markets?

c. Can viable uses be found for the considerable amounts of residual material and by-products generated from this process?

d. Can the whole process cycle of harvesting and reestablishment, log supply, milling, and marketing be sufficiently refined to ensure that it is economically robust, and sustainable given the necessary cultural, social and environmental dimensions that exist in the Pacific?

The project objectives cover the whole of the value chain for a coconut veneer based supply and production industry. They are to:

1. Identify the most promising product options for the veneer from coconut stem. This includes:
    1. Market assessment and product development.
    2. Value-chain analysis.
    3. Stakeholder engagement.
2. Develop protocols and capacity for sustainable low-impact coconut wood harvesting, plantation rehabilitation, and log grading, handling and transport. This includes:
    1. Log acquisition.
    2. Technical support for coconut log supply.
3. Establish experimental veneer-peeling capacity in the South Pacific. This includes:
    1. Commission a spindle-less lathe equipment suite.
    2. Assess the potential of a regional demonstration program.
4. Determine the optimum processing parameters and protocols for peeling coconut stems and the properties of the recovered veneer through repetitive trials.
5. Assemble the product suite and establish its characteristics and in-service performance. Characterisation would be to local and export performance standards.

6. Determine the costs and benefits of using the residual cortex and soft, central cores for bio-char and other agricultural products.

A detailed description of the methodology employed to achieve these objectives is included in Part 5.

5 Methodology

Project organisation

This project was a collaborative effort between the two Australian research agencies: the University of Tasmania's Centre for Sustainable Architecture with Wood (CSAW) and the Queensland Department of Agriculture and Fisheries (QDAF) Innovative Forest Products Team; and participating country teams coordinated through the Forests and Trees Group of Pacific Community (SPC). Associate Professor Gregory Nolan led the CSAW team, Dr Rob McGavin, the QDAF team, and Mr Sairusi Bulai, the SPC team. The participating country teams included the:

- Fiji Ministry of Fisheries & Forests, with Mr Semi V. Dranibaka and Mr Rafaele Raboiliku and his Timber Utilisation Division (TUD) group in Suva.
- Forestry Department, Ministry of Natural Resources and the Environment (MNRE), Samoa, led by Moafanua Tolusina Pouli.
- Ministry of Forestry and Research (MFR), Solomon Islands led by Mr Reeves Moveni.

CSAW coordinated the project and conducted the work focused on market assessment, community engagement, forestry and residue applications. This was CSAW's first ACIAR project and work in Pacific. However, CSAW has considerable experience with industry-focused collaborative research, broad wood product manufacture and multi-disciplinary research in Australia. The QDAF team has internationally recognised expertise in forest product research and development including veneer processing, and veneer product design, manufacture and testing, coupled with extensive experience in Pacific and other countries in other ACIAR projects. The QDAF team lead the veneer processing, product manufacturing and evaluation sections of the project.

Three project officers from the participating country teams were particularly active: Ms Moana Bergmaier-Masau, a project-appointed officer working for SPC, Ms Elizabeth Kerstin from MNRE Samoa, and Ms Stephanie Rikoi from MFR in Solomon Islands.

As the coconut stem processing value chain straddles both agriculture and wood processing, the participating country teams' alignment with the forestry sector impacted progress in parts of the project. Coconut stem management and harvest residue applications such as composting are predominantly agricultural activities. While the relevant Agricultural department were generally supportive, active interaction on the ground was not always possible.

Report format

During the project, stand-alone reports were produced for discrete objectives and distributed to stakeholders. Generally, the methodology and findings of these objective reports are summarised in this final report while the full document is included in the appendices.

Objective 1: Identify the most promising product options for the veneer from coconut stem

This objective has three components: Market assessment and product development; value-chain analysis; and stakeholder engagement.

1.1 Market assessment and product development

Activity in market assessment and product development used a two stage process.

1. Initial market surveys were conducted with designers and industry producers.
2. After initial test products were produced and assessed, interviews were held with Australian timber suppliers and artisans.

CSAW and QDAF conducted separate market surveys using questionnaires developed to target either designers or engineered wood product manufacturers. CSAW staff carried out market assessment through questionnaire and telephone interview of architects and designers, focusing on the visual appeal of provided samples for appearance applications such as joinery and linings. Twenty-one people/companies were sent the information. Seven responses were collected. QDAF staff used a standard questionnaire to interview 10 members of the timber production industry from six enterprises in person.

As discussed below, these initial assessments provided valuable insights into likely market acceptance and constraints for effective coconut veneer supply. However, they were constrained because the likely properties of recovered coconut veneer were poorly understood and limited volumes of veneer was available initially as samples to demonstrate the product to architects and designers. Once material properties were more clearly defined by work in Objective 5 and significant material samples became available, productive interviews with decorative veneer and plywood suppliers were held.

1.2 Value-chain analysis

The coconut veneer value chain study examined if and when a value proposition exists for the establishment of a resilient coconut veneer value chain. A value-chain for the coconut rotary peeled veneer can be defined as the identified range of activities required to produce, market, trade and deliver this product to the final consumer. These activities include: the harvesting of the wood resource to be used in production of the product; the transportation of the resource to downstream processors, the physical transformation of the wood resource by one or more processors; and the trades and services required to get the product to the final customer.

As a commercial value chain for coconut veneer does not exist, this study produced a value-chain proposal for coconut veneer which focused on the chain's commercial impacts and examined the value proposition by identifying the economic values at each stage in the chain. More specifically, the study:

- Traced the product flows.
- Determined resource availability.
- Identified products and process flows.
- Identified the cost of production facilities and services that will contribute to product manufacture.
- Established the required level of community and institutional support.
- Defined strategies to improve earning opportunities for all players in the chain.

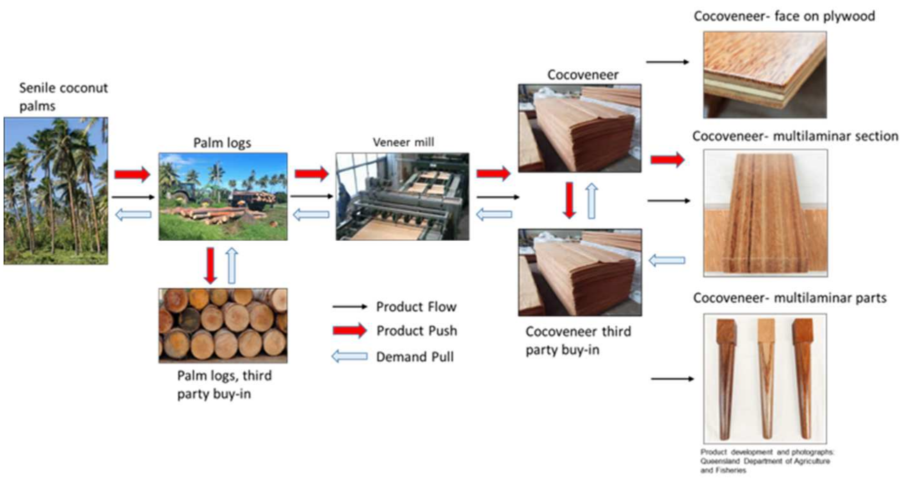

Figure 5: Coconut veneer product value-chain flows

Coconut stem are a by-product of the primary coconut value-chain, which focuses on the production of nuts for a range of food and oil products. The product value-chain flow for coconut veneer products is shown in Figure 5.

The five enterprise options modelled in the study were.

- Option 1. A single low cost 8-foot (2.4 m) spindle-less rotary peeled veneer (SRPV) processing line installed at an existing sawmill operating, processing 15,000 m^3 of peeler logs to produce 8,250 m^3 of green coconut veneer product per annum.
- Option 2. One 8-foot (2.4 m) and one 4-foot (1.2 m) high-grade SRPV processing line installed at an existing sawmill, processing 50,000 m^3 of peeler logs to produce 27,500 m^3 of green coconut veneer product per annum.
- Option 3. Independent veneer drying and grading facility at an existing peeler mill, processing 35,000 m^3 of delivered green veneer to produce 28,000 m^3 of dried coconut veneer product per annum.
- Option 4. An extra shift at an existing peeler mill with some capital upgrading, processing 35,000 m^3 of delivered green veneer to produce 28,000 m^3 of dried coconut veneer product per annum.
- Option 5. A new integrated mill installed at a greenfield site with an 8-foot (2.4 m) and a 4-foot (1.2 m) high-grade SRPV line, a new heat plant and one new quality build continuous dryer processing 50,000 m^3 of peeler logs to produce 27,500 m^3 of dried coconut veneer per annum.

The options have different equipment configurations selected for different scales of operations and are presented as balanced options. The equipment has been selected to produce quality veneer in line with the results of this project's processing research, meet the capacity of the production output being modelled, and complement other equipment included in the processing line. Cash-flows were modelled over a 20 year period.

As final green and dry veneer product prices are unknown, price estimates per cubic metre of product were adjusted in the cash flow models until the IRR for establishing and operating the enterprise modelled in the option achieved a 12% target at five-years. Using the IRR to calculate a product price that is feasible for processing allows potential investors to examine if this is a realistic price for that product and assess the potential for downstream processing, or for making direct sales.

A sensitivity analysis was also performed. A set of both favourable and unfavourable percentage changes to base cost variables (set to achieve the 12% - at 5 years IRR benchmark) were performed for the enterprise models to gauge the changes in the IRR at 5 and 10 years of operation.

The results of the cash flow analysis and the required product prices for each option are described in Section 7.

1.3 Stakeholder engagement

In addition to day-to-day project interaction, stakeholder engagement included formal stakeholder meetings, rounds of regional briefings, an active internet presence, and key stakeholder training described in Section 8.2.

Stakeholder meetings

Formal stakeholder meetings were held in Suva. They included the inception meeting in July 2012 and annual meetings in August of 2013, 2014 and 2015. A diverse group of industry, government, collaborator and community stakeholders attended the Inception meeting. Only direct collaborators attended the annual meetings proper. However, industry and government representatives attended demonstration sessions and briefing held in conjunction with the 2014 and 2015 meetings.

Regional briefings

Regional stakeholder meetings and briefings were held to inform government, industry and community stakeholders in partner countries of the work progressing in Australia and Fiji. As discussed in Section 8.4, effective regional interaction in an equipment-intensive project such as this is difficult. Face-to-face explanations and communication tools such as videos were used to help overcome this. Regional meeting and briefing rounds are held in:

- June 2012 in regional Fiji, Samoa and Solomon Islands.
- April 2015 in regional Fiji, Samoa and Solomon Islands.
- February 2016 in regional Fiji, Samoa, Solomon Islands and Vanuatu.

Internet presence

An active internet presence was maintained through the rebuilding and upkeep of the Cocowood web site at www.cocowood.net. The site includes information about both the ACIAR CocoWood project and CocoVeneer project and contains project overviews with:

- Research notes. These are compact 2 page notes on aspects of the research.
- Research report. These are copies of the current project research reports.
- Meeting and presentation information. This includes the PDF of presentations from annual meetings.
- Videos of project activities. These show the potential of processing coconut stems into veneer and explain aspect of coconut's material characteristics.

Since August 2015, an active email notification campaign has supported the site and the release of the project notes. This activity is discussed in Section 8.4.

Objective 2: Develop protocols and capacity for sustainable low-impact coconut wood harvesting, plantation rehabilitation, and log grading, handling and transport.

This objective has two components: log acquisition for trials and technical support for coconut log supply through estate coconut renewal planning; and the development of harvesting guidelines.

2.1 Log acquisition for trials

Logs or disks had to be acquired for processing trial in France, Australia and Fiji. Disks were required for the micro-lathe processing Trial 1 at the École Nationale Supérieure d'Arts et Métiers facility (ENSAM) in Cluny, France. A total of 43 senile coconut palms 70 or more years old were sampled from several Fijian plantations by Fijian Forestry staff. Four discs, 25 mm thick, were taken from each palm trunk. These were cut from the trees at breast height and then 25, 50, and 75% of the stem height and labeled accordingly. Green sample discs were stored in air-tight film and dispatched to France.

Processing Trial 2 included peeling coconut stems at QDAF's Salisbury Research Facility to calibrate the project lathe and produce an initial batch of experimental veneer. Due to quarantine requirements that effectively prohibit the import of coconut logs from Fiji, attempts were made to acquire suitably dense coconut logs from northern Australia. CSAW staff acquired logs from northern Queensland but these proved unsuitable. In a further attempt to calibrate the lathe in Australia, CSAW and SPC staff acquired dense hollowed out logs from a Fijian coconut processer Pacific Green Industries Ltd. These were treated to comply with quarantine requirements and imported into Australia.

Logs for processing in Trial 3 at TUD once the lathe had been installed were again acquired from Pacific Green. This was due to the relatively small number of logs required, difficulties involved in locating a community close to Suva willing to sell senile palms, and the costs involved in planning and harvesting a small number of stems.

A major log harvesting trial was conducted at the Graham Haynes Estate, near the Naidi Village in the Savusavu area of Vanua Levu, Fiji in May, 2015. This harvesting was to support the major industry peeling Trial 4 in Labasa the following month, to trial the harvesting procedures planned for the harvesting guidelines and to access the potential and difficulties of using harvesting residue on an estate. CSAW staff planned and conducted the harvesting trial in association with Fijian Forestry officers. QDAF provided the required logs volume and specification for the trial, CSAW planned and supervised harvesting, while Fijian Forestry officers organised fallers and log transport and managed arrangements with the estate owner, The Savusavu area was chosen for log supply as it is the copra processing hub for surrounding large and mainly senile coconut stands and was directly accessible to Labasa by road. A total of 96 x 6 m peeler quality butt logs were recovered from approximately 65 year old coconut palms on the estate. The log specification called a lower diameter range of 29 – 35 cm, log sweep less than 3 cm in any 2.5 m length, and no presence or evidence of termites or other pests and disease. The logs arrived in Labasa and were stored. To prevent degrade, they were wet daily and covered. A portion of the logs were scheduled to be delivered for the second stage of Trial 3 at TUD in Suva but they failed to arrive on time.

2.2 Technical support for coconut log supply

During application preparation, it was assumed that coconut supply and harvesting approaches would mirror traditional log supply processes, and outputs were framed accordingly. However, as field work in the project developed, it became apparent that this is not the case. As discussed more fully in Section 7, coconut stems are part of an agricultural value chain and this operates differently to highly regulated forestry processes. Communities and estates own most coconut stands and control stem harvesting. They view their right to operate differently to forest owners and are used to acting independently. Also, log harvesting is democratic. Anyone in a community can harvest logs regarded as theirs at any time without reference to an authority, except in Samoa, where a licence is required to harvest coconut stem but only if they are used for wood products. However, no restrictions apply to who harvests the logs.

These realisations and collaborator feedback resulted in the team abandoning the concept of an enforceable Code of Practice and structured training around this. Focus changed to the development of technical outputs supporting voluntary log supply from communities and safe coconut stem harvesting. These are:

- A Guide to Community Development of Estate Coconut Renewal Plans.
- Guidelines for Harvesting Coconut Palms.

Developing Estate Coconut Renewal Plans.

CSAW prepared the Guide to Community Development of Estate Coconut Renewal Plans after discussion with collaborators about the need to provide guidance to estate owners on the benefits likely to accrue over time if coconut estates were renewed. To provide realistic guidance on the extent of benefits, estate productivity modelling was conducted to determine on the likely change in log and nut production for a range of senility rate and replacement scenarios, including:

- 60% senile estate, replaced in either a 50 or 25-year renewal period. This matches Fiji's reported coconut senility rate.
- 40% senile estate, replaced in either a 40 or 20-year renewal period.
- 20% senile estate, replaced in either a 30 or 15-year renewal period, matching Solomon Islands' rate
- 16% senile estate, replaced in either a 30 or 15-year renewal period, matching Samoa's reported situation.

These results were worked into a method for communities to estimate the impact of coconut renewal. National coconut and log supply estimates were also prepared using the the participating country senility and replacement rates. These are reported in Section 7.

Guidelines for Harvesting Coconut Palms

CSAW prepared the Guidelines for Harvesting Coconut Palms drawing on experience in the Savusavu harvesting trial, recommendations for site rehabilitation from local agricultural departments, harvesting and storage recommendations from other coconut processing publication (Killman et al. 1996, Bailleres et al. 2010) and the requirements of the harvesting codes of practice in operation in the three countries; namely

- The Fiji Forest Harvesting Code of Practice 2nd Ed. (2013). Republic of Fiji Ministry of Fisheries & Forests. Suva, Viti Levu. Fiji.
- The Revised Solomon Islands Code of Logging Practice (2002). Ministry of Forests, Environment & Conservation, Honiara, Solomon Islands.
- The Samoan Code of Practice for Harvesting of Native Forest and Plantations (2001) URS FORTECH with stakeholders from Industry, Government and Landowner bodies.

The guide contains sections on: legal compliance; pre-harvest arrangements; the Harvesting Plan; harvesting personnel; coconut palm harvesting; environmental protection; and restoration and rehabilitation. The guide was circulated to relevant officers in the partner countries for comment and subject to field trial during harvesting at Savusavu before being finalized. It is attached in Appendix 2.

Objective 3: Establish experimental veneer-peeling capacity in the South Pacific.

This objective has two components: establishment of experimental veneer processing capacity in the South Pacific; and assessing the potential of a regional demonstration program.

3.1 Establishing experimental veneer-peeling capacity in the Pacific

The purchase and installation of rotary veneer processing equipment suite was a late addition to a project initially planned around processing trials in Australia and with Fijian industry. This addition significantly altered the core of the project, creating initially unrecognised challenges and unexpected benefits. These are detailed more fully in Section 7.

QDAF was responsible for the specification, selection and modification of the lathe while CSAW was responsible for the selection and fabrication of support equipment, and the purchase, installation and general commissioning of the equipment suite at TUD. After attempts to obtain meaningful understandings of machine quality and operation in Australia from overseas suppliers proved unsuccessful, QDAF and CSAW staff visited potential suppliers and viewed machines in China and south-east Asia in February and March 2013. QDAF subsequently recommended a lathe, clipper and support material from Tajamas Sales and Service in Malaysia. This equipment suite was ordered and delivered to QDAF's Salisbury Research Facility in September 2013 where the lathe was modified to improve safety and control, and was subject to initial trials. Concurrently, CSAW staff designed and ordered conveyor, log infeed and steam generation equipment. This was assembled with the lathe in Salisbury and shipped to Fiji, arriving in June 2014.

Figure 6: Lathe equipment suite established at TUD in Suva.

As the lathe and support equipment were being prepared in Australia, modifications were made to TUD's Nasinu facility to accept the equipment. These included preparation of concrete support pads and a significant upgrading of the electrical supply to the building. The equipment suite was installed in July 2014, and demonstrated in operation to collaborator organisations at the 2014 annual meeting. CSAW staff supervised the installation process while SPC and Fijian Forestry staff provided invaluable assistance and support.

While the lathe and support equipment operated satisfactory, the log conditioning chamber proved unable to reliably heat the coconut logs to the necessary temperature range of around 80 degrees. Subsequently, a replacement water-bath conditioner was fabricated in Fiji and installed at Nasinu where it satisfactorily heated logs for the staff training sessions conducted in parallel with the annual meeting in August 2015. Additional safety and operational upgrades to parts of the support equipment suite were also completed at this time.

3.2 Assess the potential of a regional demonstration program.

This objective was included after project funding for a veneer processing equipment suite was confirmed. Initially, it was felt that centralising the lathe at a research facility in Suva would not maximise its potential to demonstrate the benefits of coconut peeling to areas of economic need in remoter parts of Fiji and other partner countries. Given the inability of stake-holders to easily travel to Suva to tour a research facility, moving the equipment suite between locations for a regional trial and demonstration program was discussed. However, the costs for this exercise could not be meaningfully estimated before project approval and a feasibility study was added to the program to determine these. CSAW staff conducted the study. Questionnaires were provided to collaborator staff in Fiji, Samoa and Solomon Islands and these were used to collect cost and support information from industry. Direct industry interview and discussion confirmed and extended this information set. Four sites in three regional trial locations were investigated in detail for the study. These were:

- One TeiTei Taveuni (TTT) Farmer Association selected location at Taveuni, Fiji.
- Strickland Brothers Ltd facility at Apia, Samoa.
- Two locations at Honiara, Solomon Islands: The Timol Timber facility and the Value-Added Timber Association (VATA) Timber yard.

Three equipment options were modelled: adapting the existing lathe suite and moving it to the trial locations; acquiring and adapting an additional lathe suite and moving that to the trial locations; and acquiring three additional lathe suites and positioning one in each of the countries. Equipment option 2 and 3 have been included because:

- Option 1 will remove TUD's peeling research capability for over a year. Options 2 and 3 leave the TUD facility operational.
- Several government and industry collaborators expressed an interest in having a peeling facility in their country. The information included for Options 2 and 3 helped define potential costs for this.

Building from the experience gained in acquiring and installing the TUD equipment set, a ten-stage regional trial and demonstration program was proposed, including regional and local training and local infrastructure assessment and upgrade. The staff, capital and operating costs were estimated and the cost of conducting the three program options was calculated. After a draft report was presented to the 2014 Annual meeting, figures were confirmed on site in Samoa and Solomon Islands during the regional briefing program in April 2015. A final report was circulated in August, 2015.

Objective 4: Determine the optimum processing parameters and protocols for peeling coconut stems and the properties of the recovered veneer

This objective initially included five processing trials:

- Trial 1: Assessing veneer processing parameters from cocowood disks.
- Trial 2: Calibrating processing parameters at DAF in Qld.
- Trial 3: Initial compact experimental peeling trial in Fiji.
- Trial 4: Compact commercial peeling trial in Fiji.
- Trial 5: Broad industrial peeling trial in Fiji.

Due to delays in conducting Trial 4 and unexpected log and mill costs associated with holding it, Trial 5 was not held as a materials processing trial. Research peeling at TUD occurred after Trial 4 but primarily focused on training the TUD lathe operating team, and confirming operational procedures and processing parameters.

4.1 Trial 1: Assessing veneer processing parameters from cocowood disks

As discussed previously, representative 25 mm thick sample disks were supplied to ENSAM in France for experimental veneer processing. QDAF's Dr Henri Bailleres led this work. The trial used a specialized micro-lathe system equipped with sufficient control and instrumentation equipment to investigate key rotary peeling processing parameters in a controlled manner. The 25 mm thick discs were first debarked and rounded to remove the natural trunk edge. Peeling followed at a linear cutting speed of 45 m/min. Instead of using traditional chuck systems, the drive system used large-diameter (110 mm) clamping plates to hold the discs in place. This prevented problems with gripping the low-density centre of the coconut disc. The peeling parameters studied included: cutting forces; veneer quality assessment, compression rate, heating temperature, veneer thickness and basic density. Further detail on the methodology for the trial are available in Bailleres *et al*. (2015) 'Experimental investigation on rotary peeling parameters of high density coconut wood' in Appendix 4.

4.2 Trial 2: Calibrating processing parameters at QDAF in Qld

Quarantine requirements restrict the importation of coconut logs into Australia. As a result, attempts were made to access and peel a suitable batch of Australian grown coconut logs to confirm ENSAM's processing recommendations and produce an initial batch of experimental veneer at QDAF's Salisbury Research Facility.

22 mature coconut stems docked into nominal 1.4 m lengths were acquired in three batches from a Cairns-based supplier and shipped to QDAF Salisbury. Unfortunately, the density of the material in these logs was too low to meaningfully replicate the densities expected from senile Pacific stems and further work on this material was discontinued.

In a further attempt to confirm parameters and produce veneer in Australia, arrangements were made for Fiji producer Pacific Green to supply 27 high-density hollow core stems that would meet quarantine requirements when treated. SPC staff coordinated delivery and the logs were prepared and packaged at TUD in Suva and then imported into Brisbane in October 2013. QDAF staff attempted various means to fill the centre of the logs but in each case, the core could not sustain the required peeling pressures and the dense outside cases split apart. The trial was discontinued without producing an initial batch of experimental veneer.

4.3 Trial 3: Initial compact experimental peeling trial in Fiji

QDAF staff led this processing trial conducted in August 2014 at the TUD facility in Nasinu, Fiji. The trial specific objectives were to:

- Commission and test the veneer equipment suite.
- Demonstrate rotary veneer peeling of coconut stems to project stakeholders.
- Deliver introductory training to key project staff.
- Produce sufficient quantity of coconut veneer for recovery and quality assessments.
- Supply coconut veneer feedstock and specifically high-density veneer for preliminary product development activities.

Logs supplied by Pacific Green were docked to 1300 mm lengths, ‘rounded’ to provide a near cylindrical billet, and measured, prior to pre-conditioning. As identified by Bailleres *et al.* (2015) in Trial 1, temperatures above 80 degrees Celsius were necessary to gain the most benefit from reducing lathe cutting forces and improving veneer quality. As a result, log temperatures of 85 degrees Celsius was targeted for the trial. Logs were pre-conditioned in saturated stem for approximately 14-18 hours prior to peeling. Complications with the pre-conditioning chamber and its commissioning limited the temperature that the logs could achieve prior to peeling. Most peeling was conducted with log temperatures between 40 and 55 degrees, negatively impacting veneer quality, especially veneer from the high-density periphery of the logs.

Figure 7: TUD crew working during Trial 3.1.

The logs were peeled on the installed spindle-less veneer lathe. As the lathe manufacturer’s knowledge and experience was restricted to low to medium density coconut (i.e. <600 kg/m^3) and spindle-less lathe performance and optimal settings for higher density coconut (i.e. >600 kg/m^3) were largely unknown, the trial intended to include a range of lathe settings to progressively fine tune the peeling performance as the trial proceeded. Information from the lathe manufacturer, QDAF experience in spindle-less lathe operation combined with the results of Trial 1 reported by Bailleres *et al.* (2015) provided the base line initial settings and guided subsequent changes.

23 logs (1.5 m^3) were processed to a minimum residual core of 60 mm and 249 veneer sheets were produced. Peeled veneer was clipped targeting a sheet width of approximately 1,300 mm. Each sheet was labelled with a unique identifier before being prepared for drying. The clipped veneer was stripped in double layers of veneer sheets between rack sticks at approximately 350 mm intervals. Veneer stacks were loaded into a gas-assisted solar kiln and dried to a target moisture content (MC) of approximately 10%. Dried veneers were re- stacked, packaged and forwarded to QDAF's Salisbury Research Facility. QDAF staff provided Introductory training throughout the trial to key operational and technical staff from SPC and TUD. Further details on the methodology for the trial are available in the technical report in Appendix 4.

A repeat of this trial using the replacement water-bath pre-conditioner and logs harvested from Savusavu was planned for June 2015. However, it could not proceed as the logs failed to arrive at TUD while the QDAF project team were at the site.

Figure 8: Accessing veneer thickness during Trial 3.

Figure 9: TUD staff replacing the veneer blade between peeling runs.

4.4 Trial 4: Commercial peeling trial in Fiji

QDAF staff led this processing trial conducted in June 2015 at the Valebasoga Tropikboards Ltd (VTB) commercial plywood mill located in Labasa, Fiji. The trial objectives were to:

- Demonstrate coconut palm stems being processed into rotary veneer within an industrial environment using machinery settings and processing protocols developed during earlier project trials.
- Engage with a major rotary veneer and plywood producer in the South Pacific and further evaluate the commercial possibilities for coconut veneer.
- Test and advance the processing protocols that were developed during smaller-scale processing trials using research and semi-industrial equipment.
- Produce sufficient quantity of coconut veneer to determine indicative recovery rates and veneer qualities from an industrial processing plant and to identify possible processing challenges.
- Supply a quantity of coconut veneer feedstock for product development activities.

- Deliver introductory training and exposure to key project staff on veneer processing equipment setup, operation and maintenance along with veneer processing trial R&D protocols and veneer drying.

Prior to pre-conditioning, 6 m long logs harvested from the Graham Haynes Estate near Savusavu were each docked to provide two peeling billets, measuring approximately 2700 mm long. These were pre-conditioned in an underground water-steam chamber with a target core log temperature of around 80-90 degrees Celsius. Billets were debarked and rounded in a dedicated rounding lathe to produce an almost cylindrical billet for peeling. Log diameters were measured and recorded prior to and after rounding.

The billets were peeled on a Chinese-built spindle-less veneer lathe. While the VTB staff had substantial knowledge and experience with lathe settings for commercial timber species, they had no experience with settings suited to coconut palm peeling. QDAF experience in spindle-less lathe operation combined with the learnings from previous processing trials provided the base line initial settings and guided subsequent changes.

153 coconut palm billets (25.1 m^3) were peeled into rotary veneer. The minimum residual core size was approximately 48 mm. The veneer was clipped into a sheet width of approximately 1,350 mm. Each veneer sheet was labelled with a unique identifier before drying. Veneer was dried using a commercial jet box drier using a modified drying schedule to a MC of 6%. Dried veneers were packaged and forwarded to QDAF Salisbury for further assessment.

Figure 10: Peeler line at VTB, Fiji

Figure 11: Peeling coconut logs at VTB, Fiji.

The Industry collaborator VTB reported that they attempted to rotary peel several coconut billets in the days immediately prior to the trial commencing. This attempt was unsuccessful, confirming the difficulties and non-traditional protocols required to peel coconut palms. Applying some modified lathe settings (including knife position, nose bar compression etc.) and processing protocols made immediate improvements which were further improved throughout the process. Further detail on the methodology for the trial are available in the technical report in Appendix 4.

4.6 Properties and recovery assessment

Veneer from Trial 3 was graded at QDAF's Salisbury Research Facility for a range of natural and process induced qualities. As a veneer grading standard relevant to coconut does not exist, QDAF developed a grading method to characterise specific features. This is discussed further in Section 7. In addition to volume recovery, the attributes assessed and rated were: density, colour, veneer roughness, splits, brittleness, collapse; decay; holes and tear-out; compression; handling splits; wane; and insect tracks.

A subset of better quality veneers from across the density range was selected for Modulus of Elasticity (MoE) measurement. From the edge of each selected veneer sheet, a sampling strip, approximately 1,200 mm long and 150 mm wide, was collected and conditioned to 12% MC. MoE was measured using an acoustic natural-vibration method as described by Brancheriau and Bailleres (2002). Sample dimensions and weight were measured to calculate density for each sample.

A randomly selected subset of veneers from Trial 4 was graded at QDAF's Salisbury Research Facility for a range of natural and process induced qualities. The grading method developed during processing Trial 3 was adopted with minor improvement to the grading thresholds to improve the assessment of two attributes: brittleness and handling splits. In addition to volume recovery, the attributes assessed and rated were: density, colour, veneer roughness, splits, brittleness, collapse; decay; holes and tear-out; compression; handling splits; wane; and insect tracks. A sampling strip was removed from the graded veneer sheets and tested as described above to measure veneer MoE and density.

In addition to the QDAF's measurement of colour using a colorimeter, a CSAW colour design specialist visually sorted a randomly selected pack of veneer from Trial 4. He identified a suite of 5 potential colour groups from this material useful for interior and other designers in the market.

As published information of the susceptibility of coconut wood to lyctid beetle and bamboo borer infestation is limited, QDAF established five exposure trials to assess the susceptibility of coconut wood of varying densities to attack by lyctid beetles (*Lyctus sp. and Lyctus brunneus*) and bamboo borer (*Dinoderus minutus*). Both insect groups are significant pests for timber and wood products and the sale of lyctus susceptible material is prohibited in several Australian states. Three exposure trials were established at QDAF's Salisbury Research Facility to assess the impact of wild colonies of lyctid beetles or cultured colonies of Lyctus brunneus. 120 coconut blocks from five nominal density groups and 125 control blocks (spotted gum and blackbean sapwood) were exposed to lyctid beetle for periods ranging from 6-18 months. Two trials were established to expose coconut blocks to bamboo borers. The trials included exposure to either wild colonies of bamboo borers within QDAF Salisbury or contained exposures within purpose-built cages. 150 coconut wood blocks from five nominal density groups and approximately 200 bamboo rings (either actively infested or freshly cut) were exposed to bamboo borer infestation for periods ranging from 3-8 months. Further detail on the methodology for properties and recovery assessment are available in the technical reports in Appendix 4.

Objective 5: Assemble the product suite and establish its characteristics and in-service performance.

As processing Trial 2 was unsuccessful in producing an initial batch of veneer for product trials, the veneer recovered in Trial 3 was the first material available for initial product assembly while the veneer recovered in Trial 4 provided the bulk of material used for detailed product assessment.

QDAF led the initial product assembly. The available veneer was sorted into four broad density groups: Low density (<400kg/m^3), Medium density (400-600kg/m^3) Medium-high density (600-800kg/m^3) and High density (>800kg/m^3). Veneer from within these groups was then selected to assemble products in line with specific construction strategies. Veneer sheet quality also influenced selection.

As detailed in McGavin, Vella and Littee (2015), initial product assembly included making up: plywood, laminated veneer lumber, overlay panel, engineered flooring, and multilaminar wood. Multilaminar wood is a thick LVL style product that can be resawn into boards or turning blanks. Blanks were made, turned and finished. Surface modification with stains was also attempted.

QDAF also sorted Trial 4 material into four broad density groups and within these groups, the veneers were graded into batches of face and core veneers, in line with the criteria detailed by McGavin and Bergmaier-Masau (2016) for grades 2 and 3 respectively. Product assembly included making up plywood and laminated veneer lumber.

Nominally 15 mm thick, 5-ply plywood panels were manufactured using four different plywood construction strategies. Using only coconut veneer, these strategies were

- Panel A: Low density veneers.
- Panel B: Medium density veneers.
- Panel C: Medium-high density veneers.
- Panel D: High density face veneers with medium density core veneers.

Four different LVL construction strategies were selected to manufacture either 13-ply or 12-ply LVL panels. The panels were further processed to provide LVL beams. The construction strategies mirrored those of ply, with Panel A: Low density veneers; Panel B: Medium density veneers; Panel C: Medium-high density veneers, and Panel D: High density face veneers with medium density core veneers (8 medium density core and 2 high density outer veneers per face).

Before product assembly, the veneers were conditioned in a controlled environment to a MC of approximately 9%. A phenol formaldehyde resin system was applied to both faces of each core veneer. The face and back veneers were fed through the spreader 'best face to best face' ensuring that adhesive was applied to the inner surfaces but not to the final face of the board. The laid-up veneers had an open assembly time limited to five minutes prior to pre-pressing for 15 minutes at 1 MPa. A 25 minute closed assembly time preceded a final hot-press at 135℃ and 1.2 MPa. The final hot-press time was 12 minutes and 30 minutes respectively for the plywood and LVL.

QDAF tested the assembled material's mechanical properties in their NATA registered engineering laboratory. The plywood was tested for: four-point bending parallel and perpendicular to the face grain; panel shear strength parallel and perpendicular to the face grain; Janka hardness; and bond quality (chisel test). The manufactured coconut veneer LVL beams were tested for: four-point bending on edge, and shear strength both on edge (perpendicular to the glue line) and on flat (parallel to the glue line).

Static bending stiffness (MOE) and strength (Modulus of Rupture (MOR)), and shear strength are the mechanical properties that will most likely limit a product's final structural grade. Janka hardness indicates the influence varying construction strategies had on product hardness as this is required for end-uses such as flooring and table tops. Further detail on the methodology for product suite assembly and assessment are available in the technical reports in Appendix 5.

In addition, QDAF supplied a selection of colour-graded veneer sheets and veneered board to the University of Tasmania's Inveresk-based Furniture School to explore joinery and assembly. The veneer sheet was converted into plywood and LVL blocks, while the veneer on board was sanded in a commercial joinery and converted to furniture samples.

Cocowood Veneer User's Manual

During application development, a *Cocowood Veneer User's Manual* was planned as an output from Objective 5. At the time, this appeared a logical complement to Bailleres et al. (2010) *Cocowood processing manual* produced in ACIAR project, *FST 2004/054 Improving value and marketability of coconut wood*. However, as the CocoVeneer project progressed, the difficulty in producing a relevant veneer user's manual became apparent. FST 2004/054 focused on improving the accuracy of a long-standing and well-documented coconut wood processing technique, sawing, to manufacture a refined product for a specific application, engineered flooring. In contrast, the CocoVeneer project explored the technical underpinnings necessary to produce coconut veneer reliably and then assemble and define the performance characteristics for a full range of experimental coconut veneer-based products. Further, while potential markets for coconut veneer products have been identified, they remain broad application areas, not specific applications.

As specific user advice cannot be reasonably provided to such a general product suite and application range, a separate manual was not progressed but an extended Research Note on Coconut Veneer Processing was prepared and made available. This combines the results from the project's processing work while referencing the detailed resources included in Bailleres et al. (2010) for machining and finishing coconut wood. These are directly transferrable to fabricating coconut veneer components.

Objective 6: Determine the costs and benefits of using the residual cortex and soft, central cores for bio-char and other agricultural products.

Applications for generated residues are an important part of the coconut wood and veneer value chain. Large volumes of residues will be produced at harvest sites and at wood or veneer production facilities. During application development, agricultural trials were planned for Taveuni, Fiji and Samoa. While the biochar field trial was held with TeiTei Taveuni (TTT) Farmer Association, the planned mulching trials became unviable when funds for a large shared chipper planned for the island was directed to the purchase of several smaller units, incapable of chipping coconut stems. The invitation to Samoa to participate in residue trials was also unsuccessful. Given the importance of this area, CSAW conducted additional trial, largely at UTas facilities in Hobart. In addition to estimating the potential volume of coconut wood residues, four application areas were investigated. These were residues as fuel and as a resource for growing mediums, biochar, and compost.

6.1 Estimation of residue volume

As part of the estate productivity modelling work conducted for Objective 2.2, CSAW generated estimates of the productivity structure of coconut palm estates in the three partner countries and the volume of residues generated from an indicative smallholding, a 20 ha plantation area (block). The plantation block estimates indicated the number of palms available for harvest and the volume of residues available in a five-year period. The assumptions made in preparing the estimates were:

- The reported levels of palm senility are correct and are addressed over 50 years for plantations in Fiji and 30 year periods for plantations in Solomon Islands and Samoa.
- The plantation rotation period is 60 years. As a result, on average 1/12th of palms on the 20 ha block will become senile every 5 years.
- Senile palms will be harvested on the plantation every 5 years.
- Average height of a 60 year-old palm is 35 m.
- Average diameter of the palm is 30 cm (over height).
- A six metre butt (bottom) log is removed from 80% of the senile stems and will be extracted for solid coconut wood products (boards or veneer).

6.2 Residues as fuel.

Forestry and wood residues are an important fuel source in the South Pacific Islands and particular in rural locations. This section investigated the potential use of coconut palm harvest and log processing residues as a potential fuel source for residential and both small, and large-scale industrial use. The energy content of coconut wood and nut was compared to other fuel sources. The figures suggest that coconut palm wood has a comparable energy content to forest wood wastes and for copra drying is not much lower than the traditionally burnt shell and husk. The material's potential for copra drying. electricity production, and timber drying are discussed in detail.

6.3 Residues as growing medium

Previous QDAF studies (Poulter and Hopewell, 2010) indicated that coconut wood has suitable physical properties for a growing medium and recommended that future plant growth trials investigate the nutrient base stored in the wood and its chemical properties. To explore this, CSAW conducted two lines of investigation at research facilities in Hobart producing mushrooms and plant growing mediums and assessing their usefulness in trials.

Mushroom growing medium

Previous research (Gibe, ZC. 1985) found reasonably high levels of available carbohydrates in coconut wood. This and mushroom production observed in Samoa encouraged examination of coconut woodchip as a substrate for mushroom production.

One mushroom growing medium was prepared and its performance assessed. Twenty-four bagged samples were trialled using equipment and inoculated grain purchased from reputable industry suppliers. Based on a formulation derived from Stamets, P. (2000), the mushroom growing medium comprised 12 parts coconut wood chips and sawdust, 1 part rye bran and 1/8th part gypsum. Thoroughly mixed by volume with water, the medium was placed into 24 pasteurised growing bags, sealed, and sterilised.

After cooling, grain inoculated with the strain *Pleurotus ostreatus* (White Oyster) was added to each bag before they were placed in an environmental chamber in conditions representative of a South Pacific island climate. After mycelium (fungi) had spread throughout the majority of the growing bags, the bags were split and the environment chambers left open to circulate fresh air and expose the mycelium grown to a temperature of 12 ^{0}C for 24 hours. After 24 hours the chambers were closed and the lights were left on for 24 hours. Primordial fruiting of small mushroom buttons began to show within a week. In the following two weeks, when the first flush of mushrooms was expected, the mushrooms were assessed. To further initiate fruiting, the chamber's temperature was decreased to 8 C for a 12-hour period. An additional flush of mushrooms occurred and this was also assessed.

Plant growing medium

Three plant growing medium treatments were prepared and their performance assessed. Two samples of coconut woodchips screened to a particle size of < 3.0 mm and a commercially available potting mix manufactured to AS 3743:2003 were used as a plant growing medium. Ten replicate radish and ten sweetcorn seeds per treatment were sown in the pot mediums and their germination rates monitored. During plant growth, one sample of the coconut woodchip was treated with Hoagland's nutrient solution.

After two weeks' growth, plant heights were recorded. The radish was removed and the biomass grown in each treatment weighed. At four weeks the sweet corn plants were removed and leaf samples from each treatment were taken for laboratory dry-ash analysis. To determine nutrient availability in the growing mediums, the woodchip growing medium was chemically analysed and compared to the AS3743:2003 potting mix. Results are reported in Section 7.

6.4 Residues for biochar

This study investigated the potential for using coconut residues for biochar production. Residue cores of harvested logs were collected from a Fijian coconut wood milling facility and chipped, dried and fumigated in Fiji before being shipped to Brisbane, Australia in mid-2014. Chaotech Pty Ltd then processed the residue woodchip into biochar. The material was heated with limited oxygen (pyrolysis) in a stationary kiln under three different temperature regimes (350°C, 500°C, and 750°C) to test the effect of temperature on the product's chemical and physical properties. The resulting biochar was then sealed in steel drums and shipped to Tasmania for chemical analysis by AgVita Analytical, and scanning electron microscopy at the University of Tasmania's Central Science Laboratory.

A repeat analysis of the biochar was planned but held to be unnecessary as the material has remained in sealed containers during storage.

Biochar field trial

To assess the impact of biochar on agricultural production, the University of Tasmania's Geoffrey Dean conducted a biochar field trial on the Fijian island of Taveuni. The trial examined the potential of coconut biochar to alleviate soil health problems.

As well as testing the three coconut wood biochar products described above, these trials included comparison treatments of locally produced biochar. This was from two feedstock sources: low density coconut wood and guava wood and the pyrolysis conducted in controlled kiln conditions at a temperature of 500 ^{0}C. Priming of the biochar with nutrients and beneficial organisms is generally regarded as improving the timeliness of the biochar effects, and reducing the potential for the soil fixing the nutrients. Primed treatments were mixed with fishmeal; soft rock phosphate fortified with additional potassium; and small amounts of molasses; compost and water. The different biochars, incorporation methods, and rates of application resulted in sixteen treatments, which were all primed except for the controls. The different treatments were either incorporated in the seedling hole or spread and mixed with a tractor mounted rotivator. Due to extreme drought conditions during the trial period, irrigation water was applied to prevent losing the trial. Results were evaluated by assessing changes in the yield of taro produced after the addition of coconut biochar to the soil. Results are discussed in Section 7.


.

Figure 12: BiocharTaro-corm field crop trial Taveuni, Fiji

Biochar pot trial

Attempts were made to organise biochar pot trials with Pacific Island collaborators but proved unsuccessful. Subsequently, biochar was included in one of the treatments in the sweet corn growing trial reported below.

6.5 Residues as a resource for composting

The study aimed to establish if coconut woodchip residue material is a potential suitable feedstock material for composting. Composting is an increasingly common and relatively simple means of converting potentially large amounts of residual biomass into useful soil conditioning or landscaping products. The key machinery requirements for composting are a chipper capable of handling coconut log segments and a tractor with a shovel or backhoe attachments.

At CSAW's Hobart facilities, garden-scale composting techniques were adapted to produce 100 litres of compost from Fijian coconut woodchip. 80 litres of coconut woodchip, 20 litres of green garden waste and grass clippings, 10 litres of organic nitrogen fertiliser (fish-meal) and approximately 20 litres of water were mixed in a 135 litre garden compost tumbler. The compost tumbler was placed in a hot-house environment with a constant temperature of 25 ^{0}C. To maintain aerobic bacterial activity, the tumbler was rotated daily for 12 weeks. After the compost was produced a sample was sent for laboratory analysis and a plant growth toxicity test performed.

Following this, a plant growth trial with a randomised block of 7 treatments x 5 replicates per treatment was conducted. The growth mediums used in the treatments included the coconut wood compost produced, a southeast Tasmania sandy loam soil, coconut biochar previously produced for the project, and a commercially available compost. The treatment mixture rate with soil were equivalent to 22 L /5 m^2 (top-dressed) for compost, 12% by volume for the biochar and urea applied at 90 kg /ha top-dressed. To assist in priming the biochar, the pots were left to stand under glasshouse overhead sprinkler irrigation for 4 minutes per day for 4 weeks, then the mediums were remixed just prior to planting.

A germination test was performed to test the viability of sweet corn (*Zea mays*) seed. Five seeds were sown into each pot at a depth of 10 mm. The pots were placed on a glasshouse bench in a randomised order, one pot per treatment in each of 5 replicates and irrigated. After 10 days the germination rates in each pot were recorded. After 63 days, the plants were removed and dried at 40^{0}C for 48 hours, and the leaf and stem biomass of each plant was recorded.

To test the growth response seen in the sweet corn, a smaller-scale three=treatment trial was performed using pea plants. The three treatments were soil; soil and coconut wood compost, and coconut wood compost and vermiculite. Pea seeds were soaked overnight and sown with two seeds per pot. Following germination, seedlings were thinned to one plant per pot. The trial was conducted in the glasshouse on benches, receiving overhead sprinkler irrigation. After 42 days, the plants were removed and dried at 40^{0}C for 48 hours, and the leaf and stem biomass of each plant was recorded. Further detail on the methodology for the residue trials are available in the technical report in Appendix 6.

CSAW attempted to coordinate commercial and semi-commercial scale coconut residue composting trials in Fiji and Samoa during the second half of the project. While some industry support existed for these, chippers are not readily available in most Pacific countries. The lack of a suitable machine, local collaborator support or both constrained each attempt.

6 Achievements against activities and outputs/milestones

Objective 1: Identify the most promising product options for the veneer from coconut stem

no.	activity	outputs/ milestones	completion date	comments
1.1	Market assessment and product development	Initial market demand and performance requirement assessment completed (A)	01/14 – 10/14 A	CSAW and QDAF reports received, combined with assessment and distributed.
		Initial product suite defined (A)	04/15 A	Market reports combined with initial material properties results into a draft product plan.
		Final product suite and application range defined (A)	08/15 – 03/16 A	Market and material assessment combined with further industry interview into a final report included in Appendix 1, as Nolan and McGavin (2016).
1.2	Value-chain analysis	Critical value points identified (A)	01/13 – 10/14 PC and A	Key operational parameters for value chain operation identified.
		Interim value-chain analysis complete (A)		Interim value chain held over due to delays in trials and associated recovery information.
		Final value-chain analysis and conclusions complete (A)	05/16 A	Trial results compiled into economic assessment of the value-chain, included in Appendix 1 as Blackburn and Nolan (2016a).
1.3	Stakeholder engagement	Inception meeting (PC)	07/12 PC and A	Inception meeting completed.
		CocoWood internet site upgraded (A)	11/12 and 09/15 A	Initial upgrade complete in November, 2012. Further site upgrade and restructure completed in September 2015
		Stakeholder meeting / and field day series completed (A, PC)	Annual meeting 07/13, 07/14 07/15 Demonstration 07/14 07/15 Regional briefings 07/12, 04/15, 02/16 PC and A	Annual meeting and subsequent demonstration at TUD, Fiji. Regional briefing in Samoa, Solomon Islands and occasionally, rural Fiji.
		Final report series completed (A, PC)	05/16 PC and A	Delivery date impacted by Cyclone Winston.

PC = partner country, A = Australia

Objective 2: Develop protocols and capacity for sustainable low-impact coconut wood harvesting, plantation rehabilitation, and log grading, handling and transport.

no.	activity	outputs/ milestones	completion date	comments

2.1	Local resource assessment and harvesting	Local resources assessed and supplied for Trial 1 (PC)	10/12 and 03/13 PC and A	Disks secured and dispatched in two batches.
		Local resources assessed and supplied for Trial 3 (PC)	06/14 PC and A	Logs for Stage 1 secured from Pacific Green. Savusavu logs for Stage 2 failed to arrive on time.
		Local resources assessed and supplied for Trial 4 (A, PC)	05/15 PC and A	Logs harvested from Graham Haynes Estate, in the Savusavu area and delivered to mill.
		Local resources assessed and supplied for Trial 5 (A, PC)	07/15	Trial 5 downgraded to lathe calibration and training sessions. Logs secured from Pacific Green.
2.2	Development and training in harvesting and handling protocols	Draft harvesting and associated protocols completed (A, PC)	07/15 PC and A	Draft guidelines circulated prior to Annual meeting, discussed and revised.
		Final harvesting and associated protocols manual completed (A, PC)	02/16, 06/16 PC and A	Final draft presented at Regional Briefings. Final report included in Appendix 2 as Blackburn and Nolan (2016b). Also, given the importance of community participation in log supply and an estate planning guide was prepared. Final draft presented at Regional Briefings. Final report included in Appendix 2 as Nolan and Blackburn (2016).
		Train the trainer sessions delivered in partner countries (A, PC)	02/16, 06/16 PC and A	While structured training was not a viable option given the unregulated nature of the log harvesting supply structure, presentations on the harvesting guidelines and community estate planning were given the Ministry staff in the partner countries. This is explained in more detail under Objective 2 in Section 5, The extension components of Blackburn and Nolan (2016b) and Nolan and Blackburn (2016) were incorporated into the 2016 Regional Briefings and the EOP program.
		Local training in harvesting and handling (A, PC)		See note above.

PC = partner country, A = Australia

Objective 3: Establish experimental veneer-peeling capacity in the South Pacific.

no.	activity	outputs/ milestones	completion date	comments
3.1	Commission a spindle-less lathe equipment suite	Purchasing recommendation, advantages and disadvantages outlined. Orders placed.	05/13 A	International assessment trip completes, recommendations made and orders placed

		Spindle-less lathe purchased and installed at DAF Salisbury research facility for testing and optimisation (A)	10/13 A	Lathe delivered to QDAF Salisbury for commissioning and testing.
		Lathe tested and modified DAF Salisbury research facility.(A)	05/14 A	Modifications complete and lathe and secondary equipment packed, ready for shipment.
		Support components relocated to Fiji and installed. (A, PC)	07/14 PC and A	Local infrastructure upgraded to receive the equipment. Equipment delivered from Australia and installed.
		Lathe relocated to Fiji and commissioned with the support components for use (A, PC)	07/14, 07/15 PC and A	Lathe suite demonstrated at the 2014 Annual meeting. Equipment refinement and upgrade continued to the 2015 Annual meeting. Videos of the lathe in operation are available at www.cocowood.net.
3.2	Assess the potential of a regional program	Assessment of the potential of a regional testing and demonstration program reported.	07/14, 07/15 PC and A	Detail draft presented at the 2014 Annual meeting. Reviewed during regional briefing in early 2015 with final version presented at the 2015 Annual meeting. The report is included in Appendix 3 as Nolan (2015).

PC = partner country, A = Australia

Objective 4: Determine the optimum processing parameters and protocols for peeling coconut stems and the properties of the recovered veneer

no.	activity	outputs/ milestones	completion date	comments
4.1	Trial 1: Assessing processing parameters from disks in France	Trial complete and results reported (A)	07/15 A	Results reported in the journal ‘Bioresources’. See Bailleres et al. (2015) in Appendix 4
4.2	Trial 2: Calibrating processing parameters at DAF in Qld	Methodology confirmed and trial complete (A)	04/15 PC and A	Scope of Trial 2 was significantly reduced due to lack of representative coconut stems, despite significant effort to supply them from Australia and Fiji. No useful veneer was produced.
		Results analysed, reported and subjected to industry review (A)	04/15 PC and A	See note above
4.3	Trial 3: Initial compact experimental peeling trial in Fiji	Methodology confirmed and trial complete (A, PC)	07/14 PC and A	Trial conducted concurrently with 2014 annual meeting. Stage 2 in May 2015 disrupted as logs failed to arrive on time.
		Results analysed, reported and subjected to industry review A, PC)	07/15 PC and A	Report presented at 2015 annual meeting with material samples. Report included in Appendix 4 as McGavin (2015).

4.4	Trial 4: Compact commercial peeling trial in Fiji	Equipment assessment and calibration complete and methodology confirmed (A, PC)	06/15 PC and A	Equipment inspected and filmed in 04/15 and methodology determined in association with industry prior to the trial date.
		Trial complete (A, PC)	06/15 PC and A	Trial conducted at VTB over 3 days.
		Results analysed, reported and subjected to industry review (A, PC)	03/16 PC and A	QDAF report circulated. Report included in Appendix 4 as McGavin and Bergmaier-Masau (2016).
4.5	Trial 5: Broad industrial peeling trial in Fiji	Methodology confirmed and trial complete (A, PC)	07/15 PC and A	Trial downgraded to training and equipment calibration.
		Results analysed and reported (A, PC)	07/15 PC and A	See above.
4.6	Properties and recovery assessment	Trial material assessed and results reported (A, PC)	07/15 and 03/16 PC and A	QDAF reports circulate at 2015 annual meeting and subsequently. Reports included in Appendix 4, incorporated in McGavin (2015) and Bergmaier-Masau (2016).

PC = partner country, A = Australia

Objective 5: Assemble the product suite and establish its characteristics and in-service performance.

no.	activity	outputs/ milestones	completion date	comments
5.1	Experimental product assembly	Methodology confirmed and assembly complete (A, PC)	06/15	Completed using veneer recovered from Trial 3.
		Results reported (A, PC)	07/15	QDAF Report circulated at the 2015 annual meeting. Report included in Appendix 5 as McGavin, Vella, and Littee (2015).
5.2	Product characterisation and testing	Methodology confirmed and testing complete (A, PC)	02/16	Assembly and testing at QDAF.
		Results reported (A, PC)	04/16	QDAF report circulated. Report included in Appendix 5 as McGavin at al. (2016).
5.3	Product assessment in-service	In-service performance assessed and reported (A, PC)	06/16	Trial appearance products assembled into display furniture for EOP meeting.
		Production of a Cocowood Veneer User's Manual	06/16	Aspects of the originally planned manual are covered in McGavin et al. (2015) in Appendix 3 while machining and finishing processes in Bailleres et al. (2010) are directly transferrable to coconut veneer components. To avoid repetition but present useful advice, an extended Research Note on Coconut veneer processing was prepared and made available.

PC = partner country, A = Australia

Objective 6: Determine the costs and benefits of using the residual cortex and soft, central cores for bio-char and other agricultural products.

no.	activity	outputs/ milestones	completion date	comments
6.1	Collaboration with agricultural projects	Mulching trials complete (A, PC)	03/16	Mulching trials became unviable in Taveuni due to change in local equipment purchases. The work was conducted as a UTas-based composting and pot trial program. Report is included in Appendix 6 as Blackburn, Andrews and Nolan (2016)
		Soft core material incorporated in Samoan agricultural trials (PC)	03/16	Invitation to participating country to participate was unsuccessful. The work was conducted as a UTas-based mushroom composting and pot trial program. Reports included in Appendix 6 as Dean (2015) and Blackburn, Andrews and Nolan (2016).
		Residue and biochar trial results and costs and benefits (A, PC)	06/16	Segments released progressively as Research Note from 07/15. Report is included in Appendix 6 as Blackburn, Andrews and Nolan (2016)
6.2	Biochar trials	Technical assessment of cocowood biochar complete and reported. (A)	07/15	Biochar research note presented at 2015 annual meeting. Report included in Appendix 6 as Blackburn, Andrews and Nolan (2016) and in Appendix 7 as Research Note 6.2 Coconut Biochar.
		Bio-char produced and incorporated in ag. trials (A, PC)	03/16	Attempts to incorporate biochar in pot and secondary field trials in partner countries proved unsuccessful. Biochar was incorporated in an additional round of UTas pot trials with results incorporated in the report in Appendix 6 as Blackburn, Andrews and Nolan (2016).
		Fijian local trial of cocowood biochar production complete and reported.	07/15 and 06/06.	Trial was conducted in 2014 and a report was presented at 2015 annual meeting. It then summarised and incorporated in the report in Appendix 6 as Blackburn, Andrews and Nolan (2016).

PC = partner country, A = Australia

7 Key results and discussion

This project sought to answer key research and development questions critical to establishing a sustainable coconut veneering industry, namely:

1. Can coconut wood logs be peeled into marketable veneer using spindle-less lathes, what is the veneer quality, and can it be peeled, dried and handled efficiently and effectively? This question was the focus of Objective 4.
2. Can products made from this veneer satisfy the performance requirements established in likely markets? This was the focus of Objective 5 and part of Objective 1.
3. Can viable uses be found for the residual material and by-products generated from this process? This was the focus of Objective 6.
4. Can the whole process cycle of harvesting and reestablishment, log supply, milling, and marketing be sufficiently refined to ensure that it is economically robust, and sustainable given the necessary cultural, social and environmental dimensions that exist in the Pacific? This question was the focus of part of Objective 1 and Objectives 2 and 3.

To address these questions, the project was structured around an iterative materials research program and used a collaborative, multi-disciplinary research and development approach. Both technical and extension outputs were produced, described below and are attached in the appendices.

Before discussing the objective in order, there is value in establishing the differences and similarities between a processing value chain for coconut veneer and one for traditional timber species. In brief, supply of coconut stems and residues processing are primarily part of an agricultural value chain, coconut wood and veneer is not ‘true’ wood, and, despite these differences, coconut veneer needs to be produced in wood production facilities and be marketed to conventional wood product users.

The supply of coconut stems and residues processing are primarily part of an agricultural value chain. Coconut stems management focuses on the production of nuts. In this, senile coconut stems are a by-product. The owner may provide the stem for sale only if there is a positive return and they are convinced replacement will eventually lead to greater nut production. Agricultural value chains differ from forestry value chains. They are characterised by many small providers operating in a low regulation, free market environment. In Pacific countries, these providers may regularly be communities or private estate owners operating diversified businesses. In contrast, many forestry value chains involve fewer and more organised providers operating in a more highly controlled and regulated environment.

It is highly unlikely that coconut log supply will ever be as regulated or as predictable as forestry log supply. Communities and estates view their right to operate differently to forest owners and are used to acting independently. This attitude carries over to coconut harvesting. Regulations similar to those covering log harvesting do not (and are unlikely to ever) apply to coconut harvesting. Only Samoa has any legal requirement for coconut stem harvesting. They require plantation owners to have a licence to harvest coconut stems but only if they are being felled for solid wood products. No other restrictions apply.

Also, communities and estates do not operate as regular log suppliers. For their part, processors in a coconut veneer value chain needs a regular coconut log supply for processing and this can develop if communities decide to renew their coconut plantations to increase nut production, and sell logs to generate immediate incomes. In discussion, industry felt that logs sales would occur through direct negotiation with community land-owners or by industry offering to buy logs at an agreed price at set collection points. This is similar to copra supply processes.

Coconut wood and veneer is not ‘true’ wood. As a monocot, its material characteristics are fundamentally different to true wood and make the stem a very uneven resource with uneven physical properties for processing. Its density varies from core to cortex to a degree largely unknown in true wood while the difference in material characteristics between the coconut matrix’s primary component: the vascular bundles and the surrounding parenchyma, are significantly greater than those found between the different cell types in true wood. A furniture designer’s usefully described coconut wood’ texture as being like steel cables in builder’s bog.

Coconut veneer needs to be produced in wood production facilities and be marketed to conventional timber and wood product users. Processing coconut into veneer or sawn wood requires types of equipment and levels of capitalisation, staff training, and operational skill common to basic wood production. However, processing coconut wood successfully requires adaption of the production processes to accommodate coconut’s unique characteristics. In the market, coconut wood and veneer has to compete and be measured against ‘true’ wood products.

Objective 1: Identify the most promising product options for the veneer from coconut stem

This objective has three components: Market assessment and product development; value-chain analysis; and stakeholder engagement. Methodologies for these components are included under Objective 1 of Section 5 while technical reports are attached in Appendix 1 as Nolan and McGavin (2016) and Blackburn and Nolan (2016a). Discussion on stakeholder engagement is included in Section 8.

Market assessment

It is highly likely that markets exist for coconut veneer in appearance markets as colour-matched veneered board, plywood and LVL products. Markets are likely to also exist in structural markets in composite coconut and wood products.

Any material derives usefulness, value and marketability through the functions it can perform economically and its availability through a reliable value chain. In this, its physical properties strongly influence the functions that can be performed (Marra 1972). As discussed above and detailed below, coconut’s material properties significantly influence the potential functionality and marketability of recovered coconut veneer and the products made from it. These properties differ significantly to those of similar wood products. However, in practice, the market tends to regard sawn coconut wood and peeled veneer broadly as wood products and a direct competitor with other wood products. Impressions and assumptions about wood products will broadly apply to coconut wood products and their performance. Like most wood products, the major markets for coconut veneer products are likely to be in building construction. The major segments of these markets are appearance and structural applications.

Given these realities and the responses supplied by design professionals and wood products manufacturers to market assessment interviews, coconut veneer’s ‘competitive’ advantages in the market appear to include:

- The hardness / density of the outside of the stem. With density greater than 600 kg/m^3, this material is generally acceptable for commercial floor traffic.
- The visual consistency of individual sheets. They have a mottled, lively texture to the surface. Traditional timber ‘features’ are absent, providing an even surface appearance.
- A relatively narrow colour range, being mainly straw to mid and dark browns.
- A graduation in colour from dark to light. The dark material is particularly attractive.
- The potential for reassembling veneer into sizes larger than sawn boards.
- An available log supply, given the volume of standing senile stems.
- Supply with a clear environmental message.

Coconut veneer's 'competitive' disadvantages in the market appear to include:

- A relatively narrow colour range that limits design diversity.
- The visual liveliness of the material. The smooth grain, texture, and colour patterns of high quality wood species are missing.
- A tendency to split during processing and handling, particularly in thin sheets.
- A standard production thickness for coconut veneer of 2 mm or thicker, greater than conventional appearance woods veneers. Because of this, coconut veneer will not be a 'like-for-like' replacement for other veneers in design selections.
- A relatively low average MOE compared to many commercial wood species.
- Low shear strength, given the longitudinal nature of the vascular bundles and the poor structural properties of the inter-bundle matrix.
- Relatively low average structural characteristics. This implies that lower strength material will not be particularly useful for structural applications.

These competitive realities suggest a range of possible product utilities, shown in Table 2. Utility is an estimate of likely profitable production and supply to the target market. In the table, density is used as a surrogate for properties necessary for applications.

Table 2: Likely utility of coconut veneer in applications and products
(HD= density > 600 kg/m^3, MD= density 400 - 600 kg/m^3, LD= density < 400 kg/m^3)

Application	Likely high utility	Likely medium utility	Likely low utility
Flooring	▯□HD, MD for sheet ply flooring or overlay on a substrate.		
Lining	▯□HD, MD, LD for veneered board, ply or LVL		
Joinery surfaces (sides)		▯□HD, MD, LD for veneered board or ply	
Joinery surfaces (tops and solids)	▯□HD, MD for veneered board, ply or LVL		
Bench tops	▯HD, MD for ply or LVL		
Architectural structures		▯□HD, MD for LVL	
Form ply			▯□HD, MD for face veneer
Structural ply (Face material)			▯□ HD, MD for face veneer
Structural ply (core material)		▯HD, MD, LD	
LVL (structural)			▯HD, MD
Specialist light joinery plywood	▯□LD with HD face veneer.		

Environmental credentials

Environmental credentials and recognition in the marketplace are important aspects of building demand for coconut wood and veneer products. Environmental credentials for wood products internationally fall into three main types: market assurance of environmentally responsibility, legality of supply, and forest certification. Market assurance is an informal credential that is based upon the public image and is a valuable market tool. As value recovery products from an agricultural plantation produced in developing countries, coconut wood and veneer products have ready-made marketing narrative for environmental and social responsibility. The existence of harvesting and site rehabilitation guidelines supports this narrative.

Legality of supply is a required credential for the import of wood products into Australia. However, with few legal requirements for the harvest of coconut trees, this criterion can be met.

Forest certification is the only form of environmental credential recognised internationally. It involves both forestry certification and CoC certification by a third party environmental certification scheme. As a demonstrable plantation product, the certification of coconut wood and veneer products is conceptually straightforward. However, the procedures needed to establish formal certification in a company or value chain are expensive and difficult to achieve, operate and maintain. It is unlikely that coconut producers will seek forest certification for their products or that the market will require it. For more information, see RN1.1 CocoVeneer Enviro Credentials in Appendix 7.

1.2 Value-chain analysis

Table 3 presents the results of the cash-flow analysis for the five modelled options. It shows the average product price required in Australian dollar per cubic meter for each option to achieve the benchmark IRR at a 12% target at five-years. The staff estimated employed under each option is listed in Table 4.

Table 3: Five enterprise options with different production configurations.

Enterprise Options	Production Capacity	Product price required to achieve benchmark IRR at a 12% target at five-years. (AUD/m^3)
Option 1. A single low cost 8-foot (2.4 m) spindle-less rotary peeled veneer (RPV) processing line installed at an existing sawmill operating on a single day-shift.	Processing 15,000 m^3 of peeler logs to produce 8,250 m^3 of green coconut veneer product per annum.	$174.5 (green veneer)
Option 2. One 8-foot (2.4 m) and one 4-foot (1.2 m) high-grade spindle-less RPV processing line installed at an existing sawmill and operating on two day-shifts.	Processing 50,000 m^3 of peeler logs to produce 27,500 m^3 of green coconut veneer product per annum.	$176.5 (green veneer)
Option 3. Independent veneer drying and grading facility. At an existing peeler mill, with a quality built continuous veneer dryer and upgraded heat plant operating one day shifts.	Processing 35,000 m^3 of delivered green veneer to produce 28,000 m^3 of dried coconut veneer product per annum.	$355 (dry veneer)
Option 4. An extra shift at an existing peeler mill. Costs have been included for staff night shift loadings and upgrading of the heat plant and buildings for the additional production output.	Processing 35,000 m^3 of delivered green veneer to produce 28,000 m^3 of dried coconut veneer product per annum.	$291 (dry veneer)
Option 5. A new integrated mill installed at a greenfield site with an 8-foot (2.4 m) and a 4-foot (1.2 m) high-grade spindle-less RPV line, a new heat plant and one new quality build continuous dryer operating two shifts for peeling and one for drying. This is included mainly for the Solomon Island and Samoa.	Processing 50,000 m^3 of peeler logs to produce 27,500 m^3 of dried coconut veneer per annum.	$396 (dry veneer) with a new boiler and heat plant. $328 (dry veneer) with a refurbished boiler and heat plant.

Option 1

This scale of operation was modelled for existing small sawmill operators or timber manufacturers to consider investing in additional processing equipment to complement their operations. Because of the smaller processing scale, initial capital investment costs are much lower, but the lower volume of logs processed means the operation is highly sensitive to any fluctuations in both operation costs and to final product prices. Small changes could dramatically alter all measures used to assess financial returns. Another limitation for this option is the high-cost of LPG required for billet preconditioning, although this is essential as a high recovery of quality veneer is necessary for operation revenues.

This scale of operation may be suited to the low demand for coconut veneer, likely until products are established and the markets well defined.

Table 4: The staffing levels required for the option shown in Table 3.

STAFFING	Option 1	Option 2	Option 3	Option 4	Option 5
Log docking	0.5	2	0	0	2
Loader operator	0.5	1.5	0	0	1.5
Line operators / Fork-lift driver	6	10	13	13	23
Supervisor / leading hand	1	2	1	1	2
Maintenance /Control room	0.5	1	1	1	2
Sales, Admin & Accounting	0.5	1.5	2	2	2
General Manager	0.5	1	1	1	1
TOTAL	9.5	19	18	18	33.5

Option 2

This larger-scale of operation is configured to annually process most of the coconut palm logs available in a regional South Pacific Island location. Presently green veneer production is not considered as an option for Solomon Islands and Samoa, as they have no established veneer drying operations. The model assumes coconut veneer based products have been established and a defined market exists, and that there is a continual demand for the logs. Similar to *Option 1* above, the main limitation is the high cost of liquid petroleum gas (LPG) used for pre-conditioning. Although this larger-scale option has not the same degree of sensitivity to operating costs as Option 1, it remains fairly sensitive to fluctuations in the returns for green coconut veneer. Ideally this operation would be installed at or near an existing rotary peeling mill with a continuous veneer dryer.

Option 3

The high quality jet-box continuous drying line chosen for this option is expensive when compared to veneer drying lines available from Chinese manufacturers. However, industry advice is that the quality of European built dryers and their reliable technical support has proved more cost effective to their operations in the longer term. For an independent drying/grading enterprise without onsite peeling, a relatively high dry veneer product price is required to achieve the target IRR 12% benchmark. The main shortcoming of the stand-alone drying-grading facility under study is that all the fuel required would need to be supplied from external sources. The costs associated with direct gas heated dryers and water-tube boilers heated with wood residues and/or diesel were examined. Establishing the drying and grading facility at either a sawmill or an existing veneer mill with a heat plant with additional capacity to run a jet-box dryer was considered the only possible option that would make this enterprise financially viable at the chosen IRR benchmark. It is highly unlikely a new heat plant of $AUD 8-12 million could be amortised into cash flows if the dry veneer price was market competitive, while at the same time attractive returns ensued for investors.

Option 4

Purchasing green coconut veneer at a price viable for green veneer producers and drying the veneer within an existing rotary peeling operation proved to be the most financially attractive option with an IRR 12% benchmark achieved at a relatively low price. However, because of low capital investment and the higher staffing costs accrued by operating a proposed night shift, the operation was moderately sensitive to operating costs and to both green veneer and final dried coconut veneer product prices. This option appears to be suited for initial establishment of a coconut veneer based product industry where small-scale green coconut veneer peeling operations, also working on low capital investment, could supply their dried veneer to a centralised drying operation, which in-turn could scale-up its operations to match any increasing demand from downstream processors. If demand was constant and sufficient, additional capital investment could be sought to increase the mills capacity and to complement existing operations, Options 2 and 3 above could be considered. This option could be attractive for an existing rotary peeling mill with a continuous veneer dryer, such as the mills that operate on Vanua Levu in Fiji.

Option 5

Both Solomon Islands and Samoa have no existing veneer peeling operations or large sawmills with heat plants installed for producing kiln dried timber. Therefore, the main impediment to a competitive final dried veneer product price is the required investment capital to install a new fully integrated veneer processing plant. However, both Island countries have access to low cost coconut palm logs and lower labour costs than Fiji, which means substantially lower operating costs and to some degree this can offset the cost of capital investment over a 10-year depreciation. The overall product price estimate of $396 per m^3 for dried coconut veneer could be reduced to a more competitive $328 per m^3 if a refurbished boiler and heat plant were installed at approximately half the new cost estimated. A large capital investment is needed to finance such a facility and a more detailed study would be required to verify the business case for potential investors.

Objective 2: Develop protocols and capacity for sustainable low-impact coconut wood harvesting, plantation rehabilitation, and log grading, handling and transport.

This objective has two components: log acquisition for trials and technical support for coconut log supply through estate coconut renewal planning; and the development of harvesting guidelines. The methodologies for these components are included under Objective 2 of Section 5 while technical reports are attached in Appendix 2 as Nolan and Blackburn (2016) and Blackburn and Nolan (2016b).

2.1 Log acquisition for trials

In addition to testing the Harvesting Guidelines discussed under Objective 2.2, the log harvesting trial conducted at the Graham Haynes Estate provided insight into the likely recovery of usable logs for an established estate. Of the material available for harvest, approximately:

- 65% of standing palms produced a peeler log (diameter 29 – 35 cm).
- 30% produced a larger butt log, (diameter > 35 cm) probably suitable for sawing.
- 5% had excessive sweep in the logs (less than 3 cm in any 2.5 m length).

The palms stems were normally 35-40 m high.

2.2 Technical support for coconut log supply

As described above, communities and estates own most coconut stands, control coconut plantation renewal and stem harvesting and operate in an open, low-regulation agricultural value chain. As the implications of this were realised, the team abandoned the concept of an enforceable Code of Practice and instead focused on developing technical and extension outputs supporting broad coconut renewal, voluntary log supply and safe coconut stem harvesting. In addition to national coconut and log supply estimates, two guides were produced: a guide to community development of estate coconut renewal plans; and guidelines for Harvesting Coconut Palms.

National coconut and log supply estimates

For industry to invest in establishing a coconut veneer value chain, a regular log supply has to be available to producers over time. Economic drivers that can assist or hinder this supply also need to be defined. The potential log supply pool is the senile portion of the existing plantation estate. Log supply is likely to be driven by a desire to replace senile palms and increase nut production, and the income generated directly from log sales.

To assess potential log supply and nut production increase from senile stem replacement, CSAW researchers modelled these aspects using: the United Nations' Food and

Agriculture Organization's (FAO 2014) most recent estimates of the total areas of all and senile coconut palms in the three Pacific countries participating in this project; the estimated trend of coconut nut productivity published by Forstreuter (SPC, 2013), recovery from the Savusavu trial; the assumptions detailed under *6.1 Estimation of residue volume* in Section 5, and an orderly replacement process over time. National coconut estate estimates are summarised in Table 5 and shown graphically in Figure 13.

Table 5: Estimated total areas of all and senile coconut palms in three Pacific countries

	Fiji	Solomon Islands	Samoa
Total area of coconut plantations (ha)	65,000	59,000	93,000
Percentage area of senile palms (%)	60	20	16
Total area of senile palms (ha)	39,000	11,800	14,880
Estimated number of existing senile palms	3,705,000	1,121,000	1,413.600
Present total number of productive palms	2,470,000	4,482,000	7,421,400
Total number of palms in the estate @95% survival	6,177,000	5,605,000	8,835,000

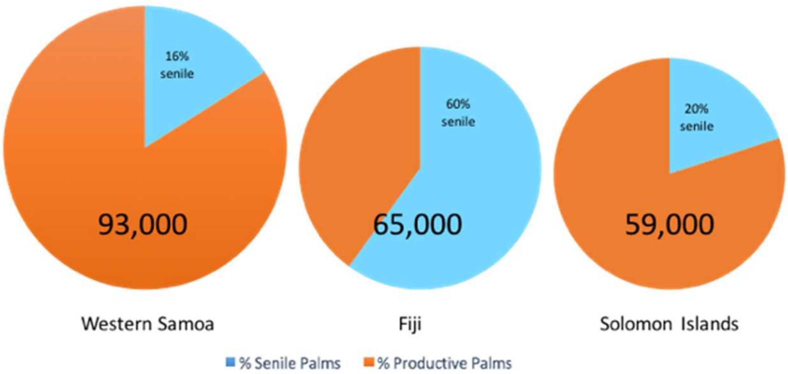

Figure 13: Estate size and senility in three Pacific countries

The estimated potential change in nut productivity and log production from coconut estate renewal in Fiji over a 50 year period are shown in Figure 14, in Solomon Islands over a 30 year period are shown in Figure 15, and in Samoa over a similar period are shown in Figure 16. The estimated potential annual log volumes available at Year 25 and the maximum percentage increase of nut production over current levels over the 60 years modelled is included in Table 6.

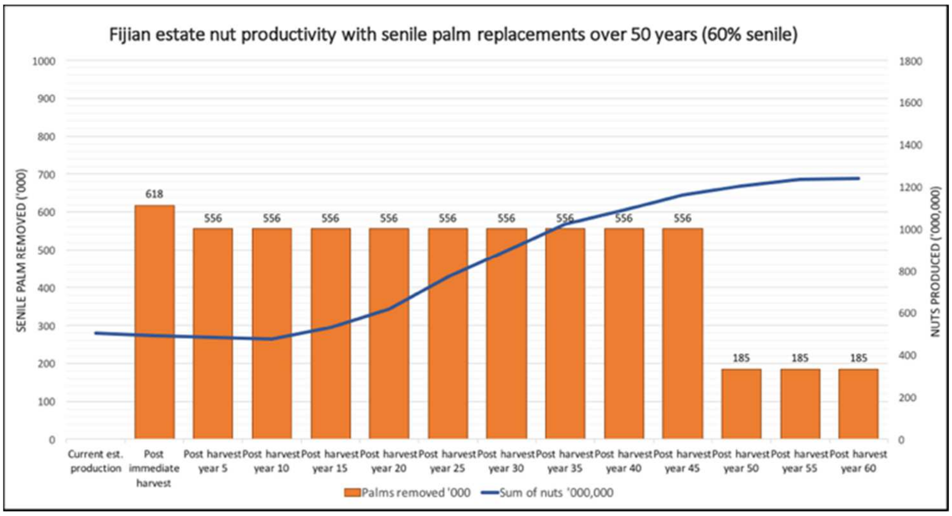

Figure 14: Estimated change in nut productivity and log production from coconut estate renewal in Fiji, based on a constant estate area with renewal over 50 years, and a harvest event at 5 yearly intervals.

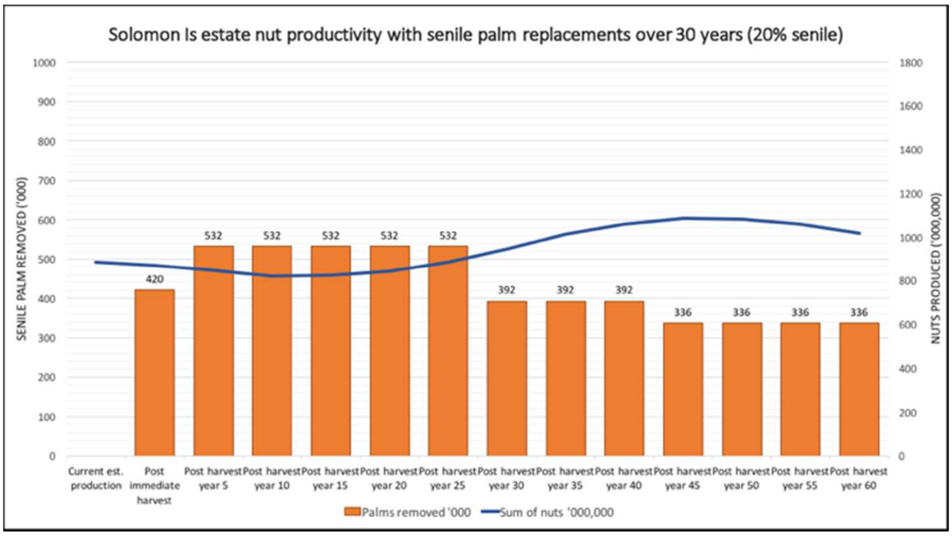

Figure 15: Estimated change in nut productivity and log production from coconut estate renewal in Solomon Islands, based on a constant estate area with renewal over 30 years, and a harvest event at 5 yearly intervals.

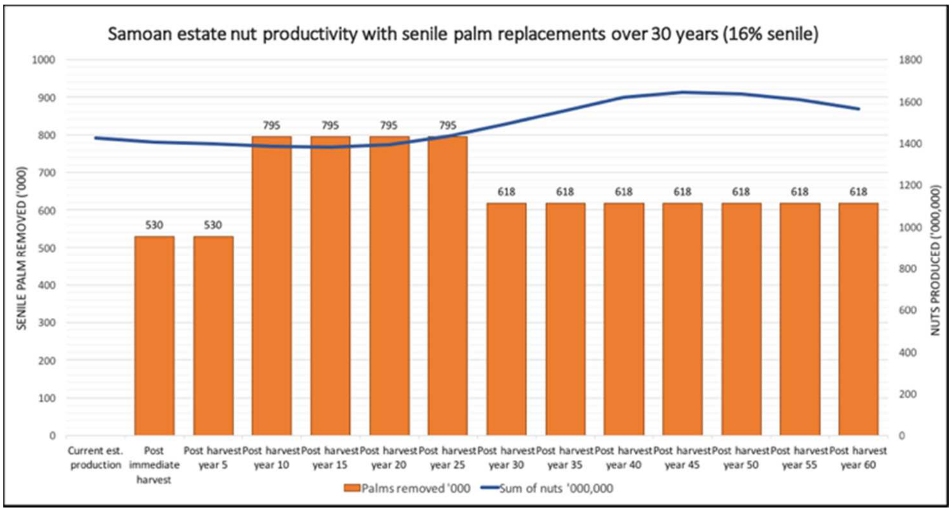

Figure 16: Estimated change in nut productivity and log production from coconut estate renewal in Samoa, based on a constant estate area with renewal over 30 years, and a harvest event at 5 yearly intervals.

Table 6: Estimated potential annual log volumes available at Year 25 and the maximum percentage increase on current nut production levels.

	Fiji	**Solomon Islands**	**Samoa**
Potential log availability at Year 25 (m^3/annum) assuming a 6m butt log.	64,200	61,500	92,000
Maximum initial decline in current nut production from senile stem replacement (%).	94	93	97
Maximum increase in nut production (%) above current production across 60 years.	146	23	15

Developing Estate Coconut Renewal Plans

An impediment to regular log supply is a natural reticence in communities to remove a resource that they know provides nuts, if only a few, for new stems that may not supply nuts for some years. After discussion with SPC and other stakeholders, CSAW researchers developed a guide to help overcome this reticence and support orderly estate renewal and log supply from communities. The guide proposes a structured but achievable, 6-step process to assist communities make strategic decisions about the future use and development of their coconut plantations, based on the plantation's current performance. Decisions are then recorded. The guide includes:

- A framework for developing an estate coconut renewal plan. This includes:
  - Establishing the structure of the existing coconut plantation estate and assessing the performance of the coconut stems in it.
  - Modelling the impact of changes in nut production and log supply under different performance and replacement scenarios
  - Encouraging a structured process for establishing community priorities for their coconuts.
- Resource information to assist plantation managers decide whether to retain, renew or replace their senile coconut palms.
- Example worksheets and checklists.

This guide complements the *Guidelines for Harvesting Coconut Palms in South Pacific Island Countries* and recommends regular interaction with the local Departments of Agriculture.

Figure 17: Preparing to access a coconut stand

Guidelines for Harvesting Coconut Palms

While there was a view though the project that stem harvesting would be similar to forest harvesting - subject to licence and regulated by a mandatory code of practice - the reality is that coconut stems are part of an agricultural value chain and the chance of increased regulation being accepted for coconut stem harvesting is very small.

The objectives of the Guidelines for Harvesting Coconut Palms include:

- Recommending practices that are complementary to the established native forestry and logging 'Codes of Practice' in these countries.
- Establishing sustainable harvesting practices that address the harvesting and replacement of the existing areas of senile coconut palms.
- Prescribing safe working practices aimed at protecting the natural environment, its assets and users.
- Allowing the execution of economically viable operations within acceptable safety standards.

Guideline sections include: scope, legal compliance, pre-harvest arrangements, the harvesting plan; harvesting personnel, coconut palm harvesting operations; environmental protection; and restoration and rehabilitation of the harvest area.

Objective 3: Establish experimental veneer-peeling capacity in the South Pacific.

This objective has two components: the establishment of experimental processing capacity in the South Pacific; and assessing the potential of a regional demonstration program. The methodologies for these components are included under Objective 3 of

Section 5 while reports and support material are attached in Appendix 3 as McGavin et al. (2015), Bergmaier-Masau (2016) and Nolan (2015).

3.1 Establishing experimental veneer-peeling capacity in the Pacific

The purchase and installation of a spindles-less lathe equipment suite was a late addition to a project initially planned around processing trials in Australia and with Fijian industry. In retrospect, this addition significantly altered the core of the project, creating initially unrecognised challenges and unexpected benefits.

Most of the challenges centred around defining and then establishing an experimental equipment suite on a site that didn't necessarily have the infrastructure, staff or support mechanisms for that equipment. These shortcomings had to be recognised and overcome. The unexpected benefits included providing:

- The information necessary to realistically advise potential industry adopters of the cost, infrastructure, and training demands of establishing a similar processing line commercially in regional areas of the Pacific.
- An alternative to trials in Australia. As discussed above, acquiring representative logs in Australia or importing them from overseas was unviable.
- An alternative to industry-based trials. Only one spindle-less lathe was operational in Fiji at the beginning of the project and while that number has increased in the last year of the project, the potential to conduct controlled trials in an industrial setting is limited. Also, unlike Australian industry collaborators who often contribute in-kind support to projects, Fijian industry requires payment for the cost of staff and machine time incurred during trials. These costs were largely under-budgeted.

Realisation of the significance of the connection between log conditioning and successful peeling increased through the project, and were reinforced by the results of peeling trials 1 and 3. The need to adequately condition the logs impacted:

- The design of the TUD lathe equipment suite, as described in Section 5.
- The projected cost of the regional demonstration program, described below.
- The potential for small scale regional producers to operate viably. These producers are unlikely to have the capital, staff or skill to operate a boiler and so will need to rely on either gas or biomass as a heat source for their logs. Gas heating costs can be significant.

3.2 Assess the potential of a regional demonstration program.

The study conducted under this objective aimed to determine the technical potential and costs of relocating the lathe and its associated equipment suite to other locations in Fiji, Samoa or Solomon Islands for a regional trial and demonstration program.

As described in Section 5, three equipment options were modelled for three locations: Taveuni in Fiji, Apia in Samoa and Honiara in Solomon Islands. The estimated total cost of the running program for each equipment option in each location is shown in Table 7.

Table 7: Estimated trial cost

Project cost summary ($)	Option 1	Option 2	Option 3
Personnel	$100,997	$102,636	$105,534
Supplies and services	$34,093	$29,193	$23,217
Travel	$48,293	$47,337	$47,337
Capital items	$59,898	$167,398	$420,148
Contingency (22.5%)	$54,738	$77,977	$134,153
Total	$298,019	$424,541	$730,389

The length of the demonstration trial program would vary with the selected equipment option. Assuming the demonstration ran consecutively, under Equipment Option 1, the program would run for an estimated 12 months. For Option 2, the program would be 16 months and for Option 3, 18 months. In practice, parallel research activity and local factors could influence the length of each demonstration trial and the efficiency of running them one after the other.

The technical potential of the program is associated with the risk to its successful completion. Activity under Objective 3.1 clarified many of the risks of equipment purchase and modification, the required capacity of site infrastructure, and the difficulty of equipment installation while colleagues from TUD clarified staff training risk. However, other risks remain. None of the sites regularly dry timber in significant volumes and so may lack the processes and equipment necessary to handle and dry veneer sheet without significant avoidable degrade. None have the capacity to run a boiler or a veneer industry standard jet drier. Given inspection of each site, the likely technical and operational risk profiles for a demonstration program are set out in Table 8.

The exposure to risk of running a regional trial and demonstration program is low to medium in Samoa and is low to high in the Solomon Island. The exposure to risk of conducting the trial in Taveuni is very high.

This is mainly due to the services available in each centre and the industry collaborator's experience. Both the Samoan and Solomon Islands sites operate in regional service centres, regularly mill and handle timber, have experience in operating and maintaining equipment internally, have established equipment maintenance and support networks externally, often dispatch and receive containers, and have an adequate and regular power supply. In contrast, a largely agricultural region like Taveuni lacks a port or container handling facilities; regular 'town' electricity and established light-medium industry support mechanisms. Also, while the local collaborators were experienced and skilled business people, they are unexperienced with the more focused requirements of log supply, mill equipment maintenance, and staff supervision.

Table 8: Activity risk profiles

Activity	Taveuni	Samoa	Solomon Islands
Stage 1: Initial training.	Low		
Stage 2: Infrastructure upgrades.	Very high	Medium	Medium
Stage 3: Equipment preparation.	Low - medium		
Stage 3: Equipment preparation - Dispatch	Medium	Low	Low
Stage 4: Regional equipment installation.	Very high	Medium	High
Stage 5: Regional training.	Medium		
Stage 6: Regional research.	Medium		
Stage 7: Regional demonstration.	Medium		
Stage 8: Repack and despatch.	Very high	Medium	High
Stage 9: TUD Reinstall.	Medium		
Stage 10: Central coordination	Low - medium		

The risks associated with the regional demonstration program reflect the technical difficulty of establishing viable coconut peeling operations in similar locations.

With sufficient planning, staff training and capital, it would likely be possible to establish technically viable peeling operations in Fiji, Samoa and Solomon Islands if the facilities were established in active regional service centres such as Savusavu and Apia. The chances of success increase if the operation is set up as part of an existing milling operation. However, the risks in establishing viable coconut peeling operations in mainly agricultural areas away from regional service or processing centres can be very high.

Objective 4: Determine the optimum processing parameters and protocols for peeling coconut stems and the properties of the recovered veneer

At the beginning of the project, limited information was available on cocowood veneer processing and the optimum parameters for economically peeling coconut material were unknown. Opportunistic industry trials that attempted to peel coconuts stems into veneer were largely unsuccessful due to the hardness of the outside layers, the softness of the core, and the resource's small average log diameter. The methodologies for the component below are included under Objective 4 of Section 5 while technical reports are attached in Appendix 4 as Bailleres et al. (2015), McGavin (2015), McGavin and Bergmaier-Masau (2016) and Fitzgerald, Bailleres and McGavin (2016).

Trial 1 test results.

The study of coconut veneer peeling at ENSAM focusing on the high-density outer part of the trunk successfully established the cutting characteristics of rotary-peeled coconut wood. The trial's major findings were that:

- Heating the logs above 70 °C was necessary to significantly reduce the cutting forces observed, improve surface quality, and limit premature knife damage.
- Even with this heating, the cutting forces were still high compared to usual wood cutting forces.
- The use of a roller nose bar and a relatively low compression rate (around 10%) provided a favorable effect on most of the critical processing parameters, including cutting forces, checks, and surface quality.
- The minimum peelable veneer thickness is around 2 mm. This limit is imposed by the size of the fibrovascular bundles.
- The high density of coconut wood requires a positive clearance angle to limit the forces on the clearance face of the knife.
- Due to the abrasive nature of the coconut wood and its extremely hard fibrovascular bundles, the use of a micro-bevel knife is expected to improve the knife service life and potentially reduce cutting forces.

Importantly, the veneer quality was found to be poor when targeting veneer thicknesses below 2 mm. This was due to unacceptable checks, fragmentation, and surface roughness. A microscopic examination showed that very dense and large-diameter bundles (0.5 to 2 mm) surrounded by soft ground tissue influence deep check formation. On such thin veneers, the checks continued through the soft tissue until they were either stopped by a bundle or passed through the entire veneer.

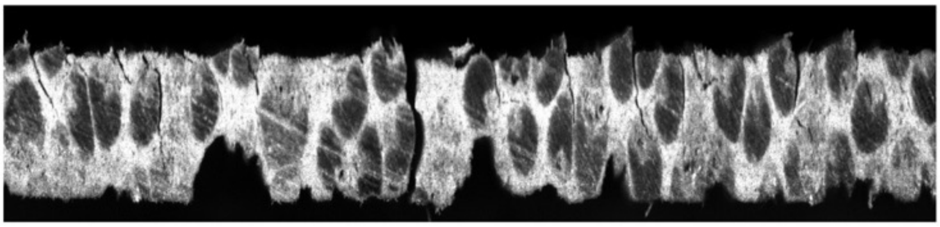

Figure 18: Deep checks and severe roughness on a 2-mm-thick veneer. The cutting conditions were a roller pressure bar, 2.5-mm veneer thickness, 45 m/min speed, and 80 °C.

These results informed the specification and purchase of the project lathe and the design of subsequent trials.

Trial 3 processing and veneer results

In Trial 3, the TUD installed veneer lathe performed satisfactorily and successfully peeled coconut stems with densities up to around 800 kg/m^3. Gross veneer recovery of approximately 61% was achieved. The distribution of veneer air-dry density is presented in Figure 19. Due to the profile of the processed logs, veneers with densities between 400 to 700 kg/m^3 dominated and accounted for 70% of the veneer produced. Only 4% of veneers (8 sheets) contained densities above 800 kg/m^3. An example of the radial density variation found in a sheet of veneer from one log is shown in Figure 20

The veneer MoE was measured on 47 samples from across the range of veneer densities As shown in Figure 21, average MoE was 5,290 MPa, the highest was 11,936 MPa and the lowest was 940. The standard deviation was 2,674 MPa. Figure 22 shows a moderately positive correlation between density and MoE.

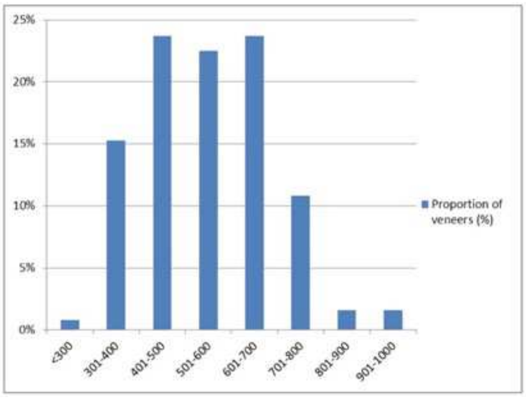

Figure 19: Trial 3 - Distribution of recovered veneer dry density

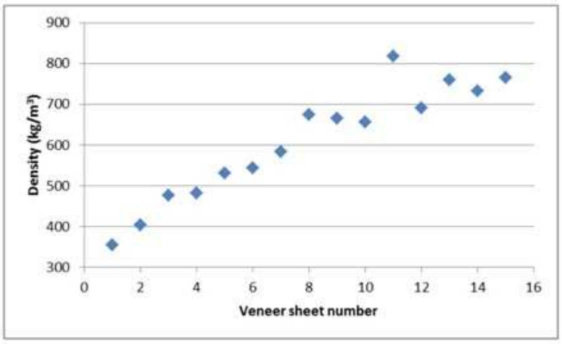

Figure 20: Trial 3 - Example of density radial variation from the centre to the outside of a coconut log.

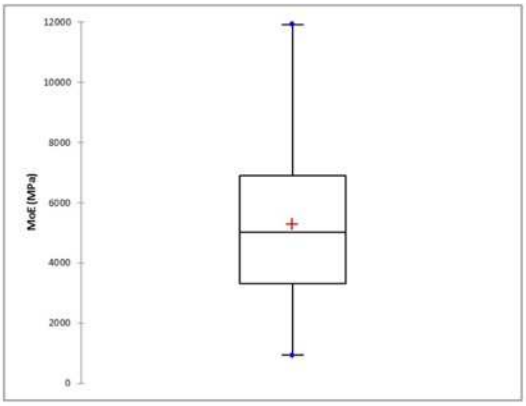

Figure 21: Trial 3 - Veneer MoE range

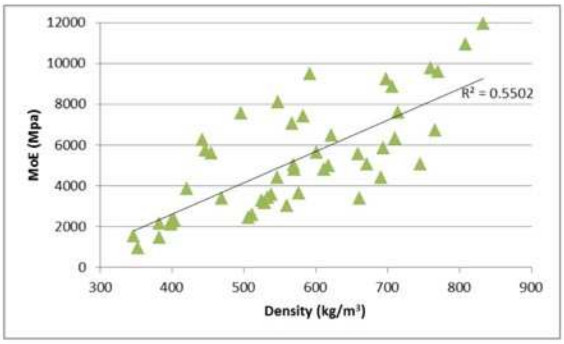

Figure 22: Trial 3 - Correlation between veneer MoE and density

The impact on veneer quality from inadequate log heating reinforced the importance of effective conditioning in any future production scenario, and led to a variation of the TUD equipment suite. Also, the small volume of veneer produced was insufficient to facilitate significant follow-on activities in product prototyping and manufacture. In particular, only a very small amount of high density veneer was produced.

Trial 4 processing and veneer results

The trial successfully demonstrated that with appropriate processing protocols, coconut stems can be processed efficiently into rotary veneer within industrial facilities. However, the trial also showed that deviating outside the relatively narrow processing protocol target ranges negatively impacts veneer quality and increases machinery loading. The commercial scale veneer processing equipment performed satisfactorily. However, some mechanical failures demonstrated the need for robust rounding and peeling equipment if coconut palms are to be peeled in large volumes. Equipment designed for relatively low density true wood is unlikely to perform adequately. Commercial veneer drying approaches dried the recovered veneer to a satisfactory standard.

Veneer recoveries were within the expected range for the processing approach, log dimensions and equipment limitations. A total of 153 coconut palm billets (25 m^3) were processed into rotary veneer. Resulting veneer was dried through a commercial jet box drier using a modified drying schedule to a target dry veneer MC of 6%. After drying, 12.5 m^3 of veneer was recovered reflecting a recovery rate of 50% (or 65% of rounded billet volume). This is similar to the recovery result achieved during Trial 3 despite the increase in lathe size and capacity: 1300 mm wide lathe for Trial 3 and 2600 mm wide for Trial 4. When a trimming factor was applied, 11.4 m^3 of veneer was recovered reflecting a recovery rate of 45%.

The recovered veneer contained a range of features and other characteristics. However, with modified processing protocols in place, significant quality gains were made between Trials 3 and 4 for veneer splits, handling splits, brittleness, collapse and compression.

Overall density distributions in Trials 3 and 4 were similar. Densities between 400 to 700 kg/m^3 dominating and accounted for around 70% of the veneer produced and only 4% of veneers contained densities above 800 kg/m^3. Density distribution is shown in Figure 23. Figure 24 shows the distribution when the veneer was grouped in density bands. The variation in density that exists within a coconut log and along a ribbon of veneer is potentially two to three times that found in traditional wood resources. Since density is a key indicator of other properties useful in products, managing this variation in production is one of the challenges of converting a coconut resource into veneer and requires responses in billet processing, veneer quality segregation systems and target product manufacture.

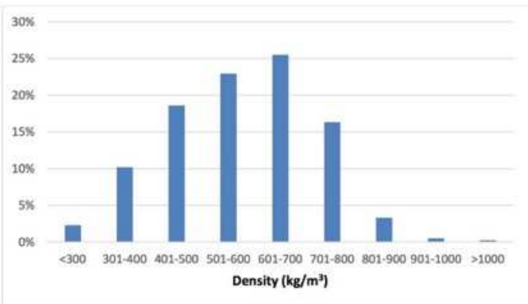

Figure 23: Trial 4 - Distribution of recovered veneer dry density

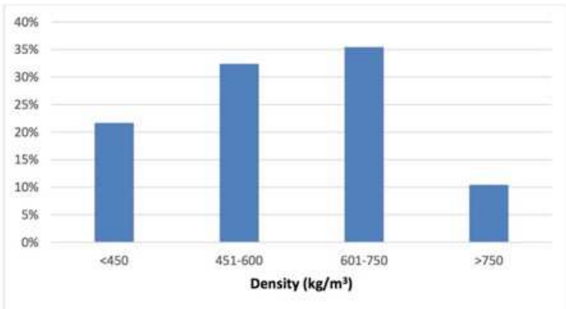

Figure 24: Trial 4 - Distribution of recovered veneer dry density when grouped into density bands.

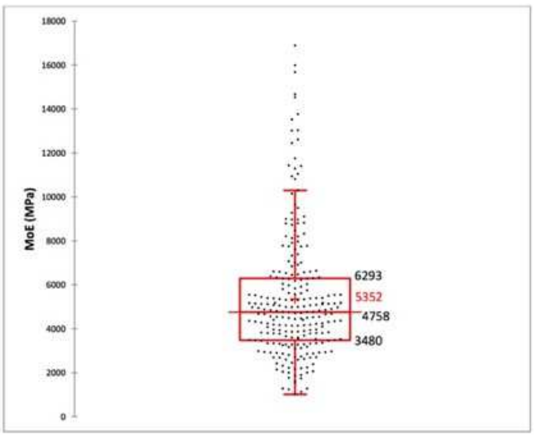

Figure 25: Trial 4 - Veneer MoE range

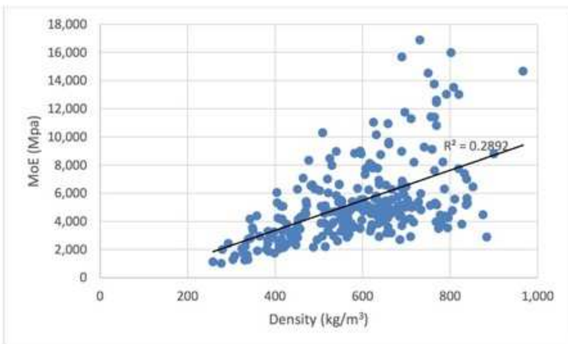

Figure 26: Trial 4 - Correlation between veneer MoE and density

The veneer MoE was measured on 247 samples from across the range of veneer densities As shown in Figure 25, average MoE was 5,352, the highest was 16,883 MPa and the lowest was 1,013. The standard deviation was 2,896 MPa. Figure 26 shows a positive but weak correlation between density and MoE.

The MoE results from the recovered veneer are both low compared to most commercial wood species and have a far greater range from low to high. Both aspects have product and processing implications. While not the only important mechanical properties, MOE provides a very useful indicator of the veneer suitability for a range of structural products. As a broad guide, market demand for wood-based structural products with MoE values below 10,000 MPa are limited and they often have low value. To overcome this, coconut veneer will either have to be blended with other forest resources in viable structural products or appearance product will have to be developed that exploit coconut veneers' other properties, such as its colour, visual characteristics and hardness.

With reduced options in structural markets, the importance of processing quality and material sorting and grading for appearance applications will also increase.

Veneer roughness was also a noticeable characteristic in the trial. The trial veneer produced a wide range of veneer roughness qualities with score distributions very similar to that reported for Trial 3. As per Trial 3, no veneer was considered 'smooth' (score 1) and a roughness score of 3 dominated. This indicates that the veneers would need moderate sanding to be made smooth.

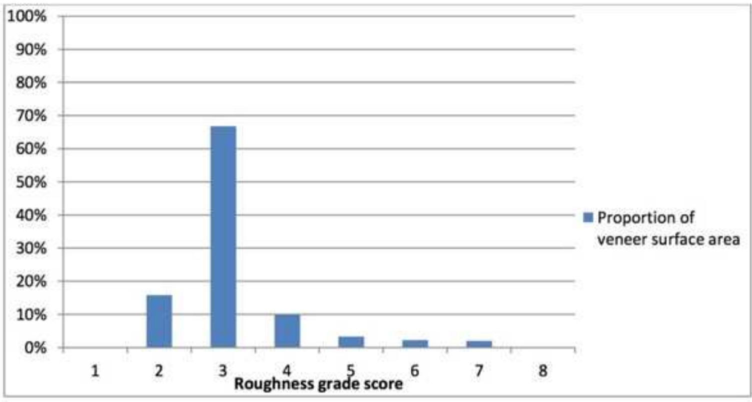

Figure 27: Trial 4 – Veneer sheet roughness (1=smooth finish, 8=very rough finish).

Unfortunately, sanding is only a practical solution for the surface of a final product. Roughness must be managed through the product manufacturing process as excessive roughness presents real challenges in achieving reliable and efficient glue bonds. While the coconut stem's structure presents considerable natural challenges to the production of smooth veneer, increased control of log pre-conditioning and further optimisation of the veneering process are likely to improve this quality.

Veneer grade definitions and grade recovery

Like most wood products, veneers are normally batched during production by grades. The grading process usually involve separate assessment of the properties of the wood in the piece against grade criteria (such as visual, structural or other characteristics); and the quality of the piece's form as a board or sheet against specific tolerances for aspects such as roughness, splits, etc.

For most commercial forest product feedstocks, grades have been established over time into either industry-wide standards or specific product standards agreed between producer and the customer. These standard-defined grades provide an enforceable definition of product performance, denote suitability for particular purposes, and encourage market confidence that the supply of graded feedstock from a producer can meets accepted manufacturing and quality requirements. Grades are also used in the market to assign value to batches of material with desirable characteristics. High grade product can often attract a price premium.

While many veneer grading systems exist for ‘true’ wood, they may only be of marginal use with coconut because of the veneer’s unique character. To be marketed effectively, coconut veneer needs a new or modified veneer grading system.

Grade definitions usually evolve in the market over time to reflect product suitability, market acceptability and product performance expectations. However, as markets do not currently exist for coconut veneer, grade criteria are proposed in Table 9 for three nominal coconut veneer grades, namely superior quality (Grade 1), high quality (Grade 2) and standard grade (Grade 3). These nominal grades provide an indicative spread of qualities when all veneer characteristics are evaluated together and may provide a useful benchmark for the future development of a grading standard for coconut veneer.

Table 10 shows the recovery for Trial 4 when the material was graded against these criteria. 50% of the veneer recovered made superior or high quality veneer, another 34% qualified as standard grade. 16% fell outside of the grade criteria. This range indicates that several end-products may be needed to ensure full product utilisation.

Table 9: Minimal grade scores for three proposed coconut veneer grades

Veneer Characteristic	Grade 1	Grade 2	Grade 3
Density	≥600 kgm3	≥450 kgm3	No restriction
Roughness	≤score 3	≤score 5	≤score 7
Splits	≤score 3	≤score 6	≤score 6
Brittleness	≤score 2	≤score 3	≤score 7
Collapse	≤score 3	≤score 4	≤score 6
Decay	score 1	≤score 5	≤score 7
Holes and tear-out	≤score 2	≤score 4	≤score 7
Compression	score 1	≤score 2	≤score 4
Handling splits	≤score 4	≤score 7	≤score 9
Wane	score 1	≤score 2	≤score 2
Insect tracks	≤score 2	≤score 2	≤score 3

Table 10: Trial 4 veneer grade recovery for three nominal grade

	Grade 1	Grade 2 or better	Grade 3 or better
Grade recovery (% of total recovered veneer)	15	50	84

Given the likely importance of veneer colour in appearance applications, this criteria may be overlaid on the grading criteria proposed in Table 9. However, unlike aspects of such a roughness, the demand for particular colour groups will vary with design trends and colour grade boundaries are likely to be dynamic.

Insect resistance

At the completion of the trials undertaken to assess the susceptibility of coconut wood of varying densities to attack by lyctid beetles (Lyctus sp. and Lyctus brunneus), no coconut wood block contained evidence of infestation by lyctid beetles. At the completion of the trials assessing coconut’s susceptibility to bamboo borer (Dinoderus minutus), no coconut wood block contained any evidence of infestation by bamboo borers. Given these results, coconut wood and veneer can be marketed and used without additional treatment against these pests.

Summary

The work conducted in this objective demonstrates that high density billets from senile coconut palms can be successfully and reliably rotary peeled into marketable veneer using currently available spindle-less lathe technologies and existing veneer drying and handling techniques.

The approaches developed and employed in the trials overcome the recovery and drying constraints of sawing coconut stems into board and previously identified barriers to peeling using traditional veneering approaches. Adoption of these approaches will enable producers to process the available senile coconut resource and use logs whose qualities are below that normally demanded for sawmilling.

Processing

To regularly peel senile coconut billets and produce quality veneer in a commercial operation, specific lathe settings and processing protocols are required. Initial research-generated settings have to be refined for the model of the machine in the production line as the configuration and performance of spindle-less lathes varies considerably between models. The initial settings and protocols, reported in detail in Appendix 4, include:

- The use of a roller nose bar and a relatively low compression rate (around 10%).
- Maintenance of a positive clearance angle to limit the forces on the clearance face of the knife.
- The use of a micro-bevel knife to improve the knife service life and potentially reduce cutting forces.
- Use of a lathe sufficiently rugged to handle the forces necessary to peel high-density logs in a production setting.
- Conditioning the logs in a moisture-rich environment to at least 70 °C before peeling and maintenance of that temperature up to peeling. In a hot water bath, this takes at least 8 hours.

Even following these protocols:

- The size of the fibrovascular bundles and the nature of their arrangement limits the minimum peelable veneer thickness to around 2 mm. A thicker veneer may be required to reduce degrade during normal operational handling.
- The veneer's surface roughness will be higher than that expected from normal wood veneer produced in equivalent facilities.

Failure to follow the protocols results in production-induced characteristics in the veneer that lower quality and reduce grade recovery.

Material recovery

Peeling high-density coconut logs increases product recovery over sawing the material. Recovery of trimmed veneer in Trial 4 was 45.4% of initial log volume while gross green sawn recovery of coconut stems of board is lower (Hass & Wilson 1985). Drying the veneer is faster than drying timber and the veneer has less degrade than sawn boards in equivalent facilities.

Rotary veneering captures a higher recovery of the higher density material from the log periphery. This dense material is likely to be the most attractive characteristics in the marketplace. Hass & Wilson (1985) reported recovery of approximately 14% of dense grade boards (over 500 kg/m^3) from milling senile log while 68% of the veneer recovered in Trial 4 had a density of 500 kg/m^3 or more.

Material properties and grading

A wide range of veneer qualities (mechanical, physical and visual) are recovered from the veneering process. This variation of properties along the veneer ribbon reflects the variation in the stem from its periphery to its core. However, veneering enables more efficient management of coconut's variable material properties than sawing.

The careful management of these qualities through grading and segregation is necessary to gain the most value and greatest utilisation of the veneer. Current industry grading rules for wood veneers are not directly transferable to coconut. Some desirable features of coconut, such as density and colour, are not prominent or included in current grading processes. A grading system for coconut veneer is proposed but industry will need to adopt an effective veneer grading systems along the value chain as markets develop. This will allow the efficient trade of veneer and veneer-based products with agreed qualities.

Objective 5: Assemble the product suite and establish its characteristics and in-service performance.

The key question for this objective was ‘can products made from the recovered veneer satisfy the performance requirements established for likely markets’? To determine this question, a first round of experimental materials was assembled, followed by a much larger second round of manufacture and testing of plywood and LVL assemblies. The methodologies for these stages are included under Objective 5 of Section 5 while technical reports are attached in Appendix 5 as McGavin, Vella, and Littee (2015) and McGavin at al. (2016).

The results for coconut veneer-based plywood in the four tested construction strategies are included in the figures below. Type A panels were made from low density veneers, type B panels from medium density veneers, type C from medium-high density veneers and type D from high density face veneers with medium density core veneers. MoE parallel to the grain is shown in Figure 28, MOR parallel to grain in Figure 29, shear parallel to the grain in Figure 30 while Figure 31 shows Janka hardness.

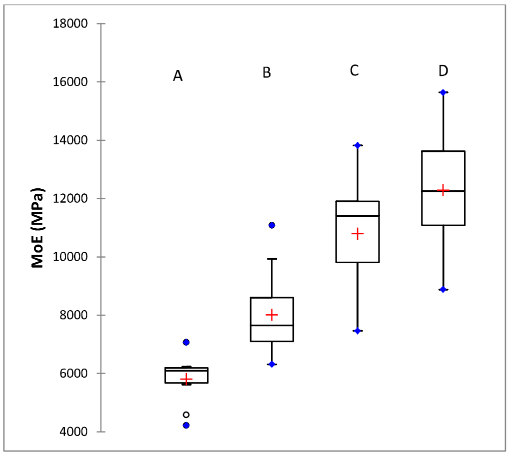

Figure 28: Plywood MoE in flexure parallel to the face grain for each construction strategy. N=65 total (A=10, B=15, C=20, D=20)

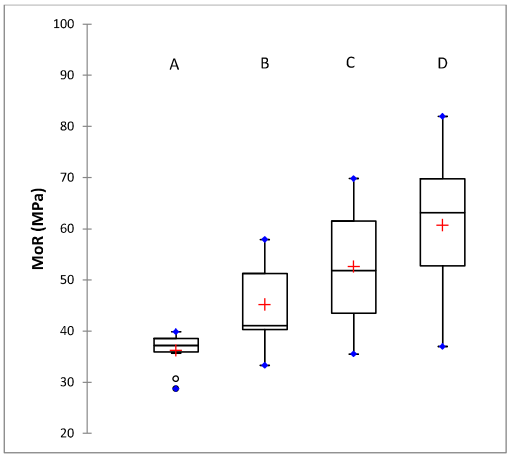

Figure 29: Plywood MoR in flexure parallel to the face grain for each construction strategy. N=65 total (A=10, B=15, C=20, D=20)

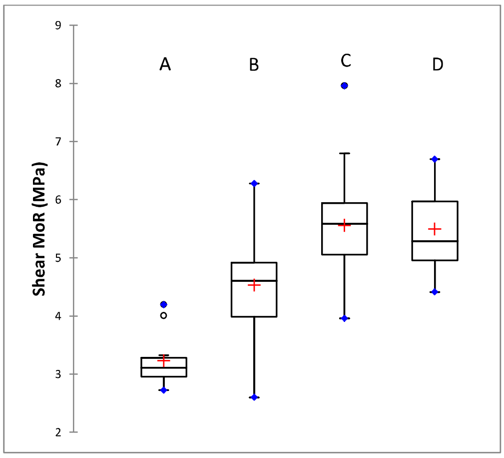

Figure 30: Plywood MoR in shear parallel to the face grain for each construction strategy N=64 total (A=10, B=15, C=19, D=20)

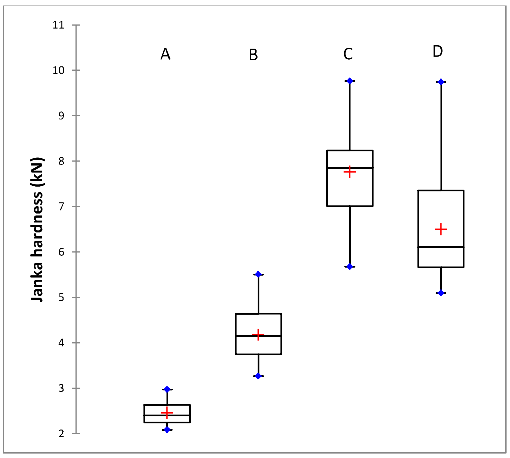

Figure 31: Plywood Janka hardness for each construction strategy. N=65 total (A=10, B=15, C=20, D=20)

There was a positive regular trend of increasing MoE from panel type A to panel D when tested parallel to the face grain. Large MoE variation exists within each construction type due to the expected density disparity within each batch and a significant thickness variation between veneers and their positioning within manufactured panels. The average MoE values for panel types A to D were 5804, 8007, 10787 and 12286 MPa respectively. Similar trends were observed in panel MOR. Average MoR values for panel types A to D were 36.2, 45.2, 52.6 and 60.7 MPa respectively.

Figure 32: Applying glue to coconut veneer sheets

Figure 33: Testing LVL sections

Stress grade equivalents were assigned to each of the measured characteristic were assigned and are presented in Table 11. Generally, the F-grade assigned to the panel would be equivalent to the lowest F-grade across all characteristics. Panel shear strength, and in particular shear strength parallel to the face grain is a major limiting property across all four construction strategies. This is due to the heterogeneous tissue of coconut wood and the veneer brittleness induced by rotary peeling. Better shear values are likely to result from construction strategies that combine coconut veneers with high shear strength timber veneers, such as material from tropical pines.

Table 11: Assigned F-grades on coconut veneer plywood for each construction strategy and test method.

Construction strategy	Bending MOE (E)		Bending MOR (f'b)		Panel shear (f's)	
	Para	Perp	Para	Perp	Para	Perp
A	F4	F4	F8	F11	F4	F4
B	F5	F8	F11	F17	F4	F4
C	F11	F11	F11	F22	F5	F11
D	F11	F7	F14	F17	F8	F14

The average Janka hardness values for panel types A to D were 2.5, 4.2, 7.8 and 6.5 kN respectively. In traditional wood applications, material with a Janka hardness of 6 kN or higher are generally regarded as being suitable for high traffic decorative flooring. Timbers with a Janka hardness below that may be used in light traffic areas.

The results for coconut veneer-based LVL in the four tested construction strategies are included in the figures below. LVL MoE on edge per panel type is shown in Figure 34. Measured MOR on edge on is Figure 35. Panel shear on edge is in Figure 36 while Figure 37 shows Janka hardness for each panel type.

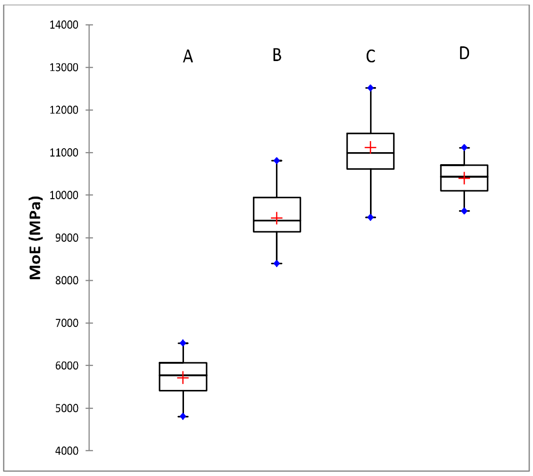

Figure 34: VL MoE flexure on edge for each construction strategy. N=77 total (A=21, B=21, C=21, D=14)

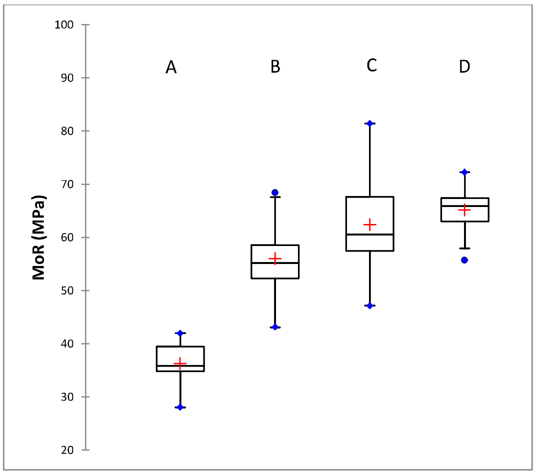

Figure 35: LVL MoR flexure on edge for each construction strategy. N=77 total (A=21, B=21, C=21, D=14)

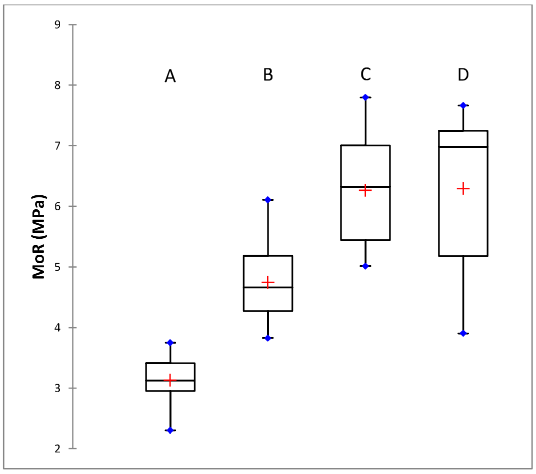

Figure 36: LVL shear MoR on edge for each construction strategy. N=55 total (A=15, B=15, C=15, D=10)

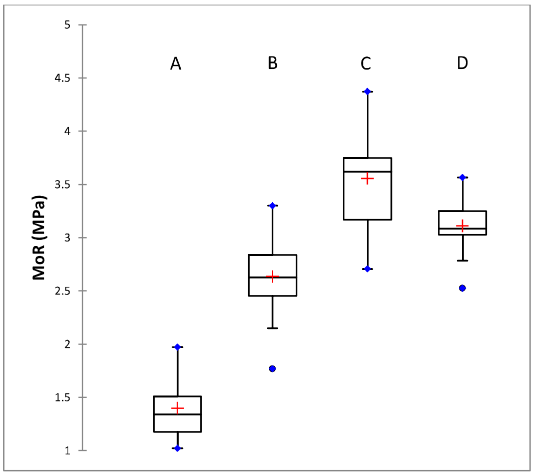

Figure 37: LVL shear MoR on flat for each construction strategy. N=58 total (A=15, B=15, C=14, D=14)

There are no generic stress grades for LVL. Each manufacturer determines the design properties of their products through testing to AS/NZS 4063.2:2010. These results are made available to engineering designers along with span tables for common applications.

Summary

Coconut veneer can be assembled using available adhesives into a range of products that satisfy performance market requirements. Manufactured using only coconut veneer or a combination of coconut veneer and traditional wood feed stocks, the range includes:

- Structural products, such as plywood and laminated veneer lumber (LVL).
- Architectural products, such as appearance veneer on board, engineered flooring, and multilaminar products.

With a sensible target product mix, and intelligent product construction strategies, all the high quality veneer produced during processing could be used. Low quality veneer may be used for core material.

Structural assessment focused predominantly on existing and common veneer-based wood products while appearance grade material was assembled and used in design trials.

These assessments confirmed that coconut veneer's unique material properties present advantages and constraints across the product range.

Testing showed that there was a wide variation in the mechanical properties across the assembled plywood and LVL, mainly due to the construction strategy employed. Panels assembled from lower density veneers achieved low mechanical properties in general while panels assembled from higher density veneer returned mechanical properties in line with market expectations for structural product. However, the veneer and product MOE results were generally low compared to commercial wood species of similar density.

Improved performance levels may be achieved by blending coconut and timber veneers in a target product or by making thicker coconut veneer products that deliver the same performance as thinner timber products. While not a disadvantage in some markets, increased weight is undesirable in many structural applications due lower site productivity and increased concerns about workplace health and safety (WHS).

While coconut veneer's material properties constrain its performance in many structural products, its hardness, colour and visual appeal are advantages for many appearance products.

Hardness is a useful indicator of timbers ability to resist wear and indentation and the higher density coconut veneers fall within the hardness range considered suitable for applications where this resistance is critical. Hard coconut veneer can be used as surface on engineered flooring, and provide an alternative to thin sawn laminate. This has several advantages including higher recovery of surface area from the coconut log, reduced variation in quality, and reduced feedstock preparations. Engineered flooring is a large and growing market. With the anatomical structure of coconut, an opportunity exists to further explore the link between hardness and wear resistance. It is possible that coconut veneer's wearing properties are better than indicated by the Janka hardness test.

Resawing appearance and colour graded coconut plywood, LVL or multilaminar blocks provides an opportunity to use a wide range of coconut veneer's qualities for joinery, lining, and furniture. Opportunities also exist to manipulate veneer arrangement by colour or orientation to broaden the range of options offered to the market. A light weight, joinery plywood with a dense, dark outside face over a light, pale core is an example.

Objective 6: Determine the costs and benefits of using the residual cortex and soft, central cores for bio-char and other agricultural products.

Large volumes of various types of residues will be produced at harvest sites (boles, logs and fronds) and significant and concentrated volumes will be generated at wood or veneer production facilities. Residues managed appropriately can be a valuable resource and augment company return or community benefits. Residues managed poorly can be a source of infestation. Given the variety of post-harvest and production coconut residues generated, a robust by-products suite is needed. In addition to estimating potential residues generated, four application areas were investigated under this objective: residues as fuel and residues as a resource for growing mediums, biochar, and compost. The methodologies for each are included under Objective 6 of Section 5. The technical report covering these areas is attached in Appendix 6 as Blackburn, Andrews and Nolan (2016) and Dean (2015).

6.1 Estimate of residue volume

A coconut wood and veneer value chain will produce significant volumes of coconut product and residue. The majority will be produced on harvest site as only the bottom 6 - 8 m of log is likely to be recovered for wood products from harvested stem 25 - 35m high when 60 years old. Table 12 provides estimates of the volume of residues generated at each harvest on a typical 20 ha plantation with national average level of stem senility.

Table 12: Estimated number of senile coconut palms and volume of harvest residue generated from a typical 20 ha plantation in a 60 year rotation period with a harvest event every 5 years. Initial level of senility varies with the country average.

Years	Fiji 20 ha No. of palms	Fiji 20 ha Vol.m^3 of residue	Solomon Is. 20 ha No. of palms	Solomon Is. 20 ha Vol.m^3 of residue	Samoa 20 ha No. of palms	Samoa 20 ha Vol.m^3 of residue
Post immediate harvest	190	390	142	291	115	235
Post harvest year 5	171	351	180	369	115	235
Post harvest year 10	171	351	180	369	172	352
Post harvest year 15	171	351	180	369	172	352
Post harvest year 20	171	351	180	369	172	352
Post harvest year 25	171	351	180	369	172	352
Post harvest year 30	171	351	133	272	134	274
Post harvest year 35	171	351	133	272	134	274
Post harvest year 40	171	351	133	272	134	274
Post harvest year 45	171	351	114	233	134	274
Post harvest year 50	57	117	114	233	134	274
Post harvest year 55	57	117	114	233	134	274
Post harvest year 60	57	117	114	233	134	274

Fiji has the highest level of stem senility and the highest rate of harvesting in any orderly coconut renewal program until the senility level is address. Given the residue volumes estimated, larger scale and low cost solutions are a priority as small scale residue solutions are likely to be irrelevant.

Also, given the ratio of saw or peeler log recovered to residues remaining, options to peel or otherwise convert logs from higher up the stem warrant further study.

6.2 Residues as fuel.

High volumes of coconut can be used as fuelwood at the harvest site or the processing centre. In comparison to imported liquid fuels, the energy content of coconut palm wood is low. However as shown in Table 13, it compares well with other biomass sources. If available after harvesting, coconut palm residue may be attractive for residential and industrial use in remote rural locations where the landscape is not heavily timbered.

Table 13: A comparison of the energy content of various fuel types used across the South Pacific Islands (derived from Mario, R. 2000)

Fuel	Gigajoules per Tonne
Automotive Gasoline or Diesel	46
Liquid Petroleum Gas	49.4
Coconut Oil	38.4
Charcoal	30.0
Wood waste @ 40 % MC	10.8
Wood waste @ 12 % MC	17.1
Coconut palm wood	11.5
Coconut shell and husk	14.0
Sugar bagasse	9.7

6.3 Residues as growing medium

Mushroom growing medium

Previous research (Gibe, ZC. 1985) found reasonably high levels of available carbohydrates in coconut wood. This and mushroom production observed in Samoa encouraged examination of coconut woodchip as a substrate for mushroom production. Chipped coconut can be used as a basic growing medium from mushrooms but results are disappointing and alternatives have superior performance.

After following the procedure outlined in Section 5, the growing bags only produced a small total yield of 230 grams of mushrooms in the first flush and185 grams in the second flush. This compares to the 4 - 5 kilograms of mushrooms that could be expected from each bag when using this method (Stamets P, 2000). Causes for the lack of mushroom productivity include minor contamination of the bags or high level of sodium in the coconut. Although coconut woodchip has high levels of available sugars, other elements are present that would substantially reduce mushroom yields. Elevated levels of sodium had been reported in a previous ACIAR project (Hopewell, G. 2012) and subsequent chemical analysis in this current project may be toxic to and inhibit the primordial fruiting of mushrooms. Washing of the chip may leach some sodium, but with extensive native forest and timber operations on the Islands, other more suitable material for a mushroom growing medium may be readily available.

Plant growing medium

Chipped coconut can be used as a basic growing medium for plants but alternatives have superior performance. After following the procedure outlined in Section 5, seed germination rates were very consistent with 8 and 9 out of 10 plants in each treatment. At two weeks, the average sweet-corn plant heights varied between 5.2 cm for those grown in a ground coconut woodchip medium without nutrient solution, and 9.5 cm for plants grown in a commercial potting mix. Plants grown in woodchip without additional nutrients grew successfully, but at a slower rate than those given additional fertiliser or grown in the potting mix, indicating negligible toxicity was present in the raw woodchip. See Table 14.

Table 14: Plant germination and growth results

Plant	Growing medium	Germination rate	Av. biomass g	Av. height cm
Radish	Coconut woodchip	9 out of 10	9	2.1
Radish	Coconut woodchip + nutrients	9 out of 10	18	2.9
Radish	Potting mix - AS3743-2003	9 out of 10	21	3.1
Sweet corn	Coconut woodchip	8 out of 10	-	5.2
Sweet corn	Coconut woodchip + nutrients	9 out of 10	-	6.3
Sweet corn	Potting mix - AS3743-2003	9 out of 10	-	9.5

Table 15: Chemical structure comparison of coconut woodchip with a commercial potting mix manufactured to AS3743:2003

Property / Nutrient		Units	Ground coconut woodchip	Potting Mix	Status
Air-filled Porosity		%	25	*≥13*	*Pass*
Total Water Holding Capacity		%	42	*≥50*	*Fail*
Wettability		min	1m 20s	*≤2*	*Pass*
pH			6.1	*5.3 - 6.5*	*Pass*
Electrical Conductivity		dS/m	5.4	*≤2.2*	*Fail*
Chloride	Cl	mg/L	162	*≤200*	*Pass*
Ammonium	N	mg/L	2.75	*≤100*	*Pass*
NH4 + NO3	N	mg/L	2.96	*≥50*	*Fail*
Phosphorus	P	mg/L	14	*8 to 40*	*Pass*
Potassium	K	mg/L	55	*≥30*	*Pass*
Sulfur	S	mg/L	8	*≥40*	*Fail*
Calcium	Ca	mg/L	28	*≥80*	*Fail*
Magnesium	Mg	mg/L	25	*≥15*	*Pass*
Ca:Mg Ratio		Ratio	1.1	*1.5 to 10*	*Pass*
K:Mg Ratio		Ratio	2.2	*1 to 7*	*Pass*
Sodium	Na	mg/L	511	*≤130*	*Fail*
Iron	Fe	mg/L	1.0	*≥25*	*Fail*
Copper	Cu	mg/L	0.1	*0.4 to 15*	*Fail*
Zinc	Zn	mg/L	1.0	*0.3 to 10*	*Pass*
Manganese	Mn	mg/L	1.0	*1 to 15*	*Pass*
Boron	B	mg/L	0.07	*0.02 to 0.65*	*Pass*

The leaf analyses showed the nutrients present in coconut woodchip are available to plants and encouragingly, the levels of uptake were similar in the coconut woodchip without additional nutrients and in the potting mix. Plant growth rates and results from the leaf analyses appeared favourable. The coconut woodchip was ground and subject to chemical analysis where it was found to have very high level of sodium.

Plant growth rates indicated negligible toxicity in the raw woodchip. The leaf analyses showed that although some ionic salts had been incorporated at levels higher than in leaves of plants grown in the potting mix, the level present was not sufficient enough to inhibit plant growth significantly.

This study was the first to examine the nutrient status of coconut woodchip and consider its potential as a plant growing medium. The chemical analyses comparison between a commercially available potting mix and the coconut woodchip in Table 15 indicates some salts are present at unfavourable levels for the woodchip to be used as an independent plant growing medium. However, these results and ones from previous studies suggest there could be some potential, with or without further processing, to use the woodchip material as a soil amendment in broader scale agricultural cropping.

6.4 Residues for biochar

The biochar trial was conducted but results were inconclusive. Chemical analysis of the biochar showed elevated levels of available phosphorous and potassium (Colwell P and K in Table 16). The samples exhibited high pH levels indicating strong liming capabilities. Sodium chloride level was also high. Cation-exchange-capacity (CECe) was favourably high. The different biochar processing temperatures generated some differences regarding the availability of macronutrients and liming values. A high product porosity was consistent at all three temperatures.

Table 16: Chemical analysis of coconut biochar produced at three different pyrolysis temperatures. Analysis by AgVita Analytical, Tasmania, Australia.

		350 C		500 C		750 C	
Analyte	**Units**	**Result**	**Status**	**Result**	**Status**	**Result**	**Status**
pH ($CaCl_2$)	-	8.49	very high	9.02	very high	10.61	very high
EC	dS/m	2.01	moderate	2.24	moderate	3.96	high
Organic Carbon	%	9.38	high	8.48	high	6.5	high
Sodium (NH_4Cl)	meq/100g	47.83	very high	68.24	very high	130.8	very high
Aluminium (KCl)	meq/100g	0.01	very low	0.01	very low	0	very low
Colwell P	ppm	181	very high	277	very high	242	very high
Colwell K	ppm	1296.86	very high	1388.19	very high	2095.81	very high
Boron (hot water)	ppm	0.43	low	0.42	low	0.45	low
Copper (DTPA)	ppm	0.07	low	0.05	low	0.09	low
Iron (DTPA)	ppm	0.78	low	0.5	low	1.55	low
Zinc (DTPA)	ppm	0.18	low	0.31	low	2.01	very high
CECe	meq/100g	51.6	very high	76.08	very high	142.01	very high
Calcium (% CEC)	%	3.55	very low	6.62	very low	3.94	very low
Magnesium (% CEC)	%	1.4	very low	0.95	very low	0.88	very low
Potassium (% CEC)	%	2.35	low	2.74	low	3.07	low
Sodium (% CEC)	%	92.7		89.7		92.1	
Total Carbon	%	69.24		80.06		85.92	
Total Nitrogen	%	0.53		0.49		0.66	

Elevated levels of the biochar's phosphorous and potassium could result in release of these elements to the growing medium, consequently increasing their availability for plants. High cation exchange capacity indicated a strong ability of the biochar to retain essential nutrients and improve overall soil quality. The elevated sodium chloride level can be considered unfavourable and could possibly antagonise the release of other elements.

The produced biochar was used in a field trial on Taveuni in Fiji and in standard pot trials, described below. Table 17 shows the biochar treatments and growth results on the Taveuni estate. A mean corm weight of 1247 g was measured across all treatments. There were no statistically significant differences in mean corm weight between biochar treatments and no consistent effects of initial feedstock, pyrolysis temperature, rate of biochar and priming. The spread and incorporated primed biochar treatments (Treatments 14 and 15) tended to outperform the controls unprimed and treatments applied in the hole. There was very little noticeable corm rot (0.5%) and no incidence of mealybugs, a commonly found plant pest of economic significance on taro grown in the South Pacific Islands. Both of these are indicators of poor soil health.

Table 17: Results of biochar treatments applied to a taro corm crop in Taveuni, Fiji

Trt	Feedstock	Temp (^{0}C)	Incorporation method	Rate	Units	Primed	Corm wt (g)	% of cntl
1	None (nil)	-	applied to hole	0	g/hole	-	1291	100
2	none	-	applied to hole	0	g/hole	=y	1205	93
3	cnut-Aus	350	applied to hole	100	g/hole	y	1257	97
4	cnut-Aus	500	applied to hole	100	g/hole	y	1280	99
5	cnut-Aus	750	applied to hole	100	g/hole	y	1208	94
6	cnut-Tav	500	applied to hole	50	g/hole	y	1189	92
7	cnut-Tav	500	applied to hole	100	g/hole	y	1154	89
8	cnut-Tav	500	applied to hole	200	g/hole	y	1256	97
9	cnut-Tav	500	applied to hole	100	g/hole	no	1209	94
10	guava-Tav	500	applied to hole	100	g/hole	y	1202	93
11	guava-Tav	500	applied to hole	200	g/hole	y	1275	99
12	guava-Tav	500	applied to hole	100	g/hole	no	1220	95
13	none	-	spread, incorp	0	t/ha	=y	1293	100
14	cnut-Tav	500	spread, incorp	10	t/ha	y	1349	105
15	guava-Tav	500	spread, incorp	10	t/ha	y	1308	101
16	guava-Tav	500	spread, incorp	10	t/ha	no	1253	97

Factoring in the low rainfall during the trial's growing season and the average corm size recorded elsewhere on the island, the mean corm weight of 1247 g measured across all treatments was considered as exceptionally good. However, the irrigation water applied could have potentially masked any beneficial water holding properties of the biochar.

In the biochar properties study, the elevated sodium level could be considered unfavourable. However, the effect of biochar on soil nutrient status depends on both the biochar's properties and soil type. The soil sodium levels at the trial site were relatively low at 31 mg/kg. Yield response tended to be improved when biochar was primed and spread broad scale before sowing. This may be a quantity effect as the amount of biochar applied to these plots was 10 fold higher than the standard 100g applied in each taro hole. Finally, it is also generally recognized that the benefits of biochar are long term and thus there may have been insufficient time for the benefits to show.

6.5 Residues as a resource for composting.

Composted coconut appears to perform very well against alternatives. The compost produced on a small scale indicates that a usable cocowood compost could potentially be produced at a larger commercial windrow scale.

The pot trial results indicate a favourable growth response could be expected if crop plants were sown into a soil amended with the addition of cocowood compost. The observed seed germination rates in both sweet corn and pea trials were 100%. By day ten, all plants had germinated, indicating reliable seed stock and non-toxic growing treatments. Table 19 shows that favourable growth results were observed for sweet corn grown in treatments 3 and 5 containing the coconut wood compost. The mean growth response for plants grown in coconut wood compost exceeded that of the plants grown in the same soil and a commercially available organic compost. Table 20 shows a similar results for peas. See Figure 38 and Figure 39. Compared to earlier trials using unprocessed coconut chip as a growing medium, the composting process substantially improved nutrient availability and has reduced potentially toxic salt levels, most likely due to the leaching effect of water added during compost production. See Table 18

Table 18: Chemical analysis of the garden-scale tumbler produced coconut wood compost to Australian Standard AS3743:2003. Analysis by the AgVita Analytical, Tasmania. Australia.

Aust. Std. AS3743:2003	Nutrient	Units	Value	Acceptable Range
Moisture Content		%	74	*>40*
Air-filled Porosity		%	..	*≥13*
Total Water Holding Capacity		%	..	*≥40*
Wettability		min	..	*≤5*
pH (1:1.5)		pH units	7.3	*5.3 to 6.5*
Electrical Conductivity (1:1.5)		ds/m	1.62	*≤2.2*
Chloride	Cl	mg/L	98	*≤200*
Ammonium	N	mg/L	28.12	*≤100*
NH4 + NO3	N	mg/L	3.8	..
Nitrogen Drawdown Index		NDI	..	*≥0.2*
Toxicity		mm	..	*≥70*
Phosphorus	P	mg/L	424	..
Potassium	K	mg/L	824	*≥30*
Sulphur	S	mg/L	86	..
Calcium	Ca	mg/L	568	*≥50*
Magnesium	Mg	mg/L	214	*≥15*
CA: Mg Ratio		Ratio	2.7	*1.5 to 10*
K:Mg Ratio		Ratio	3.9	*1 to 7*
Sodium	Na	mg/L	195	*≤130*
Iron	Fe	mg/L	10.3	*≥25*
Copper	Cu	mg/L	1.96	*0.4 to 15*
Zinc	Zn	mg/L	22.8	*0.3 to 10*
Manganese	Mn	mg/L	14	*1 to 15*
Boron	B	mg/L	1.14	*0.02 to 0.65*

Table 19: Pot trial results of sweet corn leaf and stem biomass by weight at 63 days.

Trt.	**Rep.**	**Wt. g**	**Trt.**	**Rep.**	**Wt. g**	**Trt.**	**Rep.**	**Wt. g**	**Trt.**	**Rep.**	**Wt. g**	**Trt.**	**Rep.**	**Wt. g**	**Trt.**	**Rep.**	**Wt. g**
1	1	13.86	**2**	1	13.31	**3**	1	14.31	**4**	1	10.2	**5**	1	51.33	**6**	1	24.94
1	2	9.91	**2**	2	10.26	**3**	2	12.06	**4**	2	11.36	**5**	2	15.94	**6**	2	13.37
1	3	10.44	**2**	3	6.69	**3**	3	25.66	**4**	3	12.81	**5**	3	8.09	**6**	3	12.05
1	4	18.24	**2**	4	16.89	**3**	4	17.76	**4**	4	10.74	**5**	4	21.58	**6**	4	19.66
1	5	10.21	**2**	5	15.47	**3**	5	14.05	**4**	5	10.61	**5**	5	13.71	**6**	5	15.1
	Mean	12.532		Mean	12.524		Mean	16.768		Mean	11.144		Mean	22.13		Mean	17.024

Trt. = Treatment, Rep = Replicate, Wt.= Weight, Trt 1: Soil; Trt 2: Soil 3.6 L + coconut wood biochar; Trt 3: Soil + coconut wood compost; Trt 4. Soil + commercial compost; Trt 5: Soil + coconut wood compost and coconut wood biochar; Trt 6: Soil + coconut wood compost and coconut wood biochar + urea.

Table 20: Coconut wood compost pot trials peas leaf and stem biomass leaf by weight at 42 days.

Trt.	Rep.	Wt. g	Trt.	Rep.	Wt. g	Trt.	Rep.	Wt. g
1	1	1.47	**2**	1	5.72	**3**	1	0.82
1	2	1.44	**2**	2	6	**3**	2	0.96
1	3	2.2	**2**	3	5.2	**3**	3	0.82
1	4	2.46	**2**	4	3.85	**3**	4	0.55
1	5	1.77	**2**	5	3.88	**3**	5	0.61
	Mean	1.868		Mean	4.93		Mean	0.752

Trt.= Treatment, Rep = Replicate, Wt.= Weight,
Trt 1: Soil Trt 2. Soil + coconut wood compost Trt 3. coconut wood compost and vermiculite 50:50 ratio.

Figure 38: Coconut compost incorporated with soil, compared to a commercially available compost in sweet corn growth trials.

Figure 39: Coconut compost incorporated with soil, compared to soil and compost with vermiculite in pea growth trials.

Summary for Objective 6

Given the variety and volume of post-harvest and production residue material generated, more than one viable by-products type is needed to address the need to use coconut stem residues. The use of coconut wood chips to provide a direct growing medium for either mushrooms or as plant growing mediums was largely unsuccessful. Better commercial alternatives exist. The use of coconut wood biochar to improve crop yields proved inconclusive, which is common to other research investigating the use of biochar's in horticulture. The favourable growth response shown from biochar priming and broad-scale spreading would suggest more nutrients were made available to the plant when the biochar was primed and spread, rather than incorporated in a concentrated form at the plant seedling hole. Clearly more research is required to investigate optimal biochar application methods.

The use of coconut palm residues for fuel, particularly for industrial use and electricity generation bodes well, provided demand exits and transportation costs are acceptable, and that capital investment is available for the necessary infrastructure. The model that demonstrates this is feasible presently exists in Labasa, in Fiji.

The composting of harvest residues for soil amendments appeared to be the most cost effective means of utilising coconut palm harvesting residues. As suitable, economic chippers can be imported into the partner countries, little additional investment is required to generate a product that would be directly beneficial to local communities and the productivity of their gardens. The elevated salt levels observed in raw coconut woodchip samples during these studies were substantially reduced in the small-scale composting trial, most likely due to leaching from wetting and other biochemical reactions occurring during the composting procedure. This would also occur at the larger windrow paddock scale.

Evidence from previous studies, assessment of residues and discussion with Australian commercial composters suggest that coconut woodchip is suitable for composting into a nutrient rich medium that can be readily used for improving future crop yields. Composting is a largely forgiving process that can occur over a wide range of conditions. It is an environmentally sound method of converting material generally regarded as waste into a product that can be used in agriculture, horticulture, landscaping and remediation of contaminated sites. Additionally, the Pacific Island region has an appropriate climate for cost-effective composting. An increased tendency for intercropping and/or mixed farming operations in the Pacific Islands means more products are removed from the land and therefore the export of nutrients is high. The composting of coconut wood residues would provide an opportunity to address that nutrient loss and potentially increase crop productivity. Further opportunities for product sales could exist.

Larger-scale trials are now recommended to examine the feasibility of this activity using coconut palm harvest residue material as a feedstock.

8 Impacts

8.1 Scientific impacts – now and in 5 years

The project's primary scientific impacts were produced through the work on peeling high density senile coconuts stem in Objective 4, the assessment of coconut veneer-based products in Objective 5 and the exploration of coconut residues as growth mediums or soli-conditioning agricultural supplements in Objective 6.

Prior to the work in Objective 4, high density senile coconut stems could not be peeled into usable veneer, the properties of that veneer and their variability were unknown, and no thought had been given to how the veneer might be sorted into usable groups. The trial program identified and then developed the techniques and protocols necessary to peel this material satisfactorily. The work then extended to identify major features of coconut production likely to be difficult to overcome through improved production techniques, such as minimum veneer thickness and likely high level of surface roughness, and those that may respond to improved production techniques, such as reduced collapse and splitting. These impacts provide the technical underpinning of new industry practice now and in the next 5 – 10 years as industry moves from a development stage to one where it is refining production to exploit more quality sensitive markets. Work in the current project indicates where efforts to improve production is likely to yield the highest returns. The properties and profile of the material were established for the first time. These results will provide the basis of comparison between this Savusavu resource and repeat trials of other material in the future. The proposed grade structure is a major operational impact, as it allows industry to establish an initial quality benchmark as it commences coconut veneer production, and then develop that benchmark after customer interaction.

The work in Objective 5 identified the mechanical performance of coconut veneer-based plywood and LVL products. This is foundational work in the development and appreciation of a new wood-based product. It establishes the performance for material of known origin and established its variability when batched by density. In the short term, the work indicates that coconut veneer can be used in structural plywood and LVL products but that lighter competitor wood products will provide superior performance. This limits coconut competitiveness in commodity structural market but it highlights the importance of coconut's appeal in appearance markets. The work in Objective 5 also supports the eventual development of composite wood / coconut products that may be competitive in structural markets. This will be important as wood resources are further constrained in the Pacific and in other markets over coming years.

The work in Objective 6 established valuable but negative results for the use of ground coconut as a growing medium for either mushrooms or plants and identified a potential cause for this: high sodium level in the material. Coconut can be made into biochar and the material's response to pyrolysis at different temperature are provided with inconclusive results from a Taveuni field trial employing project and locally produced biochar in taro production. Positive results were received from composting coconut residue and using the output as a soil conditioning agent or an additive in potting mixes and similar products. Supported by chemical analysis of the compost and the leaf material of the plants grown in the pot trial, these results show how the nutrient potential identified by previous work can be mobilised, and the impediments to its use, notably excess sodium, can be overcome. This is an important result that should be validated by larger scale field trials in the partner countries. The work demonstrates that composting of coconut and other local bio-resources has real potential in supporting increased agricultural productivity. It also provides wood and coconut veneer producers with a means to profitably manage processing residues.

8.2 Capacity impacts – now and in 5 years

This project included an iterative materials research program with a significant equipment establishment component. It developed significant equipment capacity, primarily at TUD in Suva and notable staff capacity extending beyond Fiji to other partner countries.

Significant technical infrastructure and capacity in rotary peeling research was established at the TUD facility in Nasinu. The equipment suite purchased and installed included a 1300 mm wide spindle-less lathe, a veneer conveyor belt, a veneer clipper, log pre-conditioners, a log deck, and associated handling and racking equipment. This was supported by major upgraded to building electrics and surrounding work areas.

Early-career researcher (ECR) and local production team capacity was also developed. and in doing so contributed to empowering women working in the forestry sector in the Pacific. Three female early career researchers were enrolled under scholarships in the University of Tasmania's Graduate Certificate of Timber (Processing and building). All capable young women, the ECRs involved are:

- Ms Moana Bergmaier-Masau, who works with Pacific Communities,
- Ms Stephanie Rikoi, of the Ministry of Forestry and Research of Solomon Islands and
- Ms Elizabeth Kerstin, of the Forestry Division, Ministry of Natural Resources and Environment in Samoa.

Ms Bergmaier-Masau completed her GradCert Timber in 2015 and recommended others be provided with the same opportunity. Ms Rikoi and Ms Kerstin began study in 2016. The project met Ms Bergmaier-Masau's scholarship and is contributing to the other two. The Crawford fund has agreed to meet the bulk of these scholarships beyond the life of the project. Strategically, these are important scholarships. The three recipients are in the position to introduce new research expertise to the region in quickly developing processing technologies. With an expansion of wood processing technologies in Fiji and interest in processing plantation resources in Samoa and Solomon Islands, this is an important contribution to the regional skill base. In the longer term, their study will provide valuable support and training to local communities, with the potential to encourage more young women to undertake a career in a largely male dominated industry.

Figure 40: QDAF's Eric Littee discussing veneer quality with TUD and Samoan project officers

Further, Ms Bergmaier-Masau and Mr Ilikimi Carati-Bokadi underwent extensive training at DAF's Salisbury Research Facility to develop their skills in independent research and development with veneer-based products. They worked closely with QDAF researchers for six week across September and October 2015, jointly funded by the project, Pacific Communities and the Crawford Foundation. A report on their experience is included in Appendix 7.

Equipment is only of use if staff are proficient in operating it. QDAF staff, in particular Dr Rob McGavin and Mr Eric Littee, worked with the TUD lathe production team to train them in the equipment's operations. See Figure 40. After a 4-day training session held in conjunction with the 2015 annual meeting, the team were able to successfully operate the equipment and conduct basic research tasks with only minor supervision. Training sessions also occurred during other peeling sessions at TUD. Support documents were prepared and provided. QDAF prepared and held training sessions based on its manual *Producing rotary-peeled coconut veneer*, while SPC's Ms Bergmaier-Masau prepared, *Peeling coconut veneer - Activity Manual*. This includes detailed procedures for the lathe's operation. Both are included in Appendix 3.

In summary, the project has established the basic capacity in the South Pacific for researchers to investigate the potential of peeling small diameter log resources into graded veneer. Capacity was also encouraged in industry collaborators. Interaction during Trial 4 at the private sector collaborator (VTB in Labasa), introduced innovation to their production approaches.

As this was an equipment and material trial based project operating within a forestry and wood products stream, constraints existed on generating capacity impacts outside direct project participants. Wood products industry members in partner countries outside Fiji expressed disappointment that project equipment could not be brought or provided to them for local trials and that the results were not available when they were first engaged. The project timeline was longer than they were necessarily prepared to wait. As they were concerned with the day-to-day requirements of operating businesses, they had a direct interest in application, but less interest in discussing possible and eventual application.

Operating across the forestry - wood products and agricultural value chains generated constraints in capacity building as these value chains represent different disciplines and are supported by different government department. As discussed above, they also have different approaches to regulation and control.

8.3 Community impacts – now and in 5 years

The project's community impacts are largely potentials. The project has established techniques to manufacture, assemble and market coconut veneer-based products and to process coconut residues into soil amendment products useful in agriculture. The community impact from these technical developments can be considerable if they are adopted by industry and, by doing so, achieve the strategic goal of this and similar coconut wood projects: establishing community acceptance and action in an orderly senile coconut renewal program. This renewal program can be instrumental in establishing (or partially be driven by) a coconut processing sector. The operation of both can increase economic activity and social wellbeing significantly. The scale of benefit increases with the level of senility in the national estate. Also, in addition to addressing current coconut senility, renewal processes can address stem senility in coming years. 1.6% of any estate become senile on average each year. In Samoa, this is about 1,500 hectares or 125,000 stems annually, a considerable resource for processing.

8.3.1 Economic impacts

Economic impacts can be generated by an eventual increase in coconut production, the value added to the wood products industry from coconut veneer sales, and increased agricultural production from residue usage.

Nut production will decline under all scenarios modelled under Objective 3 after any senile coconut renewal program starts. This continues the decline that will necessarily occur without senile stem replacement. However, as shown in Section 7, nut production increases broadly after Year 20. Where senility rates are low, eventual production increases are 15-20% above current production. Eventual production increase where senility rates are high, such as in Fiji, are significant with nut production increasing over 140% above current production.

The economic impacts of veneer production are more immediate. Assuming only the bottom 6 metres of stem is usable, approximately 210,000 m^3 of coconuts stem will be available across the three partner countries each year for nominally 25 years as senile stems are replaced. This then declines as sustainable senile stem replacement continues. Assuming the rates of trimmed veneer recovery achieved in Trial 4 of 45% are realised by industry, this log supply represents about 94,000 m^3 of peeled veneer per annum, with a notional export value over $50 m per annum. This volume of log and veneer recovered increases proportionally if material from higher up the stem can be successfully converted into marketable products. After their participation in Trial 4, at least one Fijian producer can now produce coconut veneer, develop their production skill and supply material into the market.

Figure 41: Composting can support additional inter-cropping. Senile coconut stand in Samoa.

The majority of material volume generated from senile coconut renewal is notionally residue, left on community estates after harvesting or concentrated on veneer production sites. For example, mills may generate more than 100,000 m^3 of coconut residue per annum. Fuel and composting appear to offer the most attractive large-scale application options for coconut residue, either on estates or production centres. Coconut and other wood residues are already established industrial, agricultural and domestic fuels and new processing techniques can be applied to this material to increase its efficiency. Industrial scale composting is less well understood in the Pacific but now an established part of industry residue and community waste management in Australia. A representative 20 ha. Fijian estate may generate 350 m^3 of coconut residues which will reduce to approximately 120 m^3 of compost every 5 years. The economic impacts of processing residue for agricultural products may be generated by the increase in agricultural production and the reduction in the importation of fertiliser and similar soil-conditioning and landscaping materials.

8.3.2 Social impacts

The project's direct social impacts include the effects of capacity building and the interaction detailed in Section 8.4 below. Indirect social impacts will accrue with the economic impacts and employment generated from the establishment of a coconut renewal program. These will increase nut production and employment in agricultural and processing facilities, and enhanced career paths for community members. As shown in Table 4, direct employment

The project also sought to address a major impediment to log supply: reticence by communities to renew their coconut estates and replace their senile stems. As noted in other projects, this is a fundamental constraint on establishing coconut wood or veneer value chains in Pacific countries. The work in Objective 2 identified the importance of this and sought to develop extension tools that could be used to address it. The estate planning tool was based on team member interaction with communities and observations on general skill level in partner countries, while the harvesting guidelines were based on local forest harvesting guidelines tempered by experience in harvesting material during trials.

Given coconut's place in a largely unregulated agricultural value chain, these outputs seek to enhance community capacity to make informed decisions about their own future by providing them with the tools to assess the current position of their estates and project improvements to their nut and log supply into the future. The processes outlined in the plan and guidelines can be achieved through the skills one would expect to find in a community in a developing country with an active education system such as Fiji: occasional access to the internet and simple office tools such as a photocopier, rudimentary computer skills, and a developed understanding of the productivity and condition of their own community lands and the resources on it.

8.3.3 Environmental impacts

As discussed above, coconut wood and veneer products are value recovery products from an agricultural plantation produced in developing countries. In addition to providing a ready-made "first-world" marketing narrative for environmental and social responsibility, these characteristics are environmentally significant in the partner countries. Senile coconuts currently represent a significant forgone resource agriculturally and in building material production. Using coconut stems for building products such as plywood and veneer can reduce demand for other resources in the partner countries, reduce dependency on imports, or help meet increasing demand from the population growth obvious in these countries.

The potential to use coconut stems to produce potential large amounts of useful soil conditioning or landscaping products throughout the partner countries also has significant environmental impact. There is considerable nutrient export in many local soil, and dependence on expensive imported fertilizers encourages poor agricultural practice, and reduces community incomes and resilience. Recycling the nutrients in coconut and other available biomass through composting techniques refined for local conditions can reduce fertiliser dependence, build community resilience, and food security. Increased (or at least more secure) agricultural production can then reduce pressure and potential degradation on marginal landscapes.

8.4 Communication and dissemination activities

The project has sought to communicate information about its activities through regional briefing and demonstration, community and industry discussion, and an active online presence. Information tools used during these activities include:

- **Research notes.** These are compact stand-alone 2 page notes that describe key aspects of the project and research. Designed for a general audience, the research notes summarise and explain key aspects of the projects. Seven notes have been produced, and have been used during regional briefings, are available on the cocowood.net site, and included in Appendix 7.
- **Research reports.** These are the technical research reports generated from each stage of the project. Copies of the reports are made available on the cocowood.net site and, where relevant made available at regional briefings.
- **Meeting and presentation information**. PowerPoint presentations were prepared for each objective for each of the annual meetings and each round of regional briefing. In addition to being used at the relevant meetings, PDFs of these presentations were prepared and made available online and distributed by local participating collaborators. For example, after the regional briefings in Honiara in 2016, local SPC and Forestry Research staff received copies of the presentation

PDF's to distribute to local stakeholders. Copies of the presentations are also available on the cocowood.net site.

- **Videos of project activities.** 14 short videos, varying in length between 30 seconds and 10 minutes have been prepared during the project to show the potential of processing with a spindle-less lathe, explain key aspect of coconut veneer production, and to discuss marketing. Used widely in the annual meetings and regional briefings, the videos are hosted on CSAW's YouTube site. They are also linked to the Cocowood site and can be found by opportunistic search. The video content outlines and addresses are detailed in Appendix 3. View numbers are available on YouTube.

Regional briefings and demonstrations

Engagement with direct project collaborators occurred regularly through email, phone, skype and other discussions while participating country representatives were present at the project annual meetings. To increase interaction with industry and other stakeholders, additional regional briefing and demonstration rounds were held in regional Fiji, mainly in Labasa, in Apia in Samoa, in Honiara in Solomon Islands, and once by request in Port Vila in Vanuatu in 2016.

Figure 42: Stakeholder briefing in Solomon Islands, April 2015.

Figure 43: Further stakeholder briefing in Solomon Islands, February, 2016.

These rounds were held in:

- June 2012 to introduce the project and meet local collaborators.
- April 2015 to demonstrate project progress, particularly the operation of the spindles lathe established in TUD in Fiji. This trip included additional interaction with local collaborators and confirmed technical information for activities under Objective 2 and 3.

- February 2016 to present the major conclusions of the project to industry and participants unlikely to be able to attend the end-of-project meeting. Between 15 and 25 participants attended workshops in each country, while 35 attended the workshop in Port Vila.

Veneer peeling and projects demonstration were also held at TUD in Suva in conjunction with the 2014 and 2015 annual meetings.

Community and industry discussions

During each round of regional briefings, additional meetings were held with industry and stakeholder groups to explain the project, coordinate some aspect of project interactions such as log supply, or to determine factors that could influence local involvement or adoption. In these meetings, the most potent information tool was the videos of peeling coconut stems, shot overseas or in Fiji. Though in a developing country, local industry and community members are highly visually literate and could quickly understand the potential of the processing being shown.

Figure 44: Community member at Nagigi, near Savusavu, watching a video of coconut stems being peeled at TUD, in Fiji prior to discussions about log supply.

Online presence

CSAW took over control of the existing Cocowood web site (www.cocowood.net) at the beginning of the project, upgrading it in late 2012 and again in 2015. The site includes information about both the ACIAR CocoWood project and CocoVeneer project and acts as the central information distribution point for the project. Google Analytics is used to monitor activity, and shows that the site had 360 visitors in the September quarter of 2015, 1,005 in the December quarter 2015 and 490 in the first three months of 2016.

Since August 2015, an active email notification campaign has supported the site and the release of the project notes. Approximately 125 emails were circulated every 6 weeks mainly to Pacific Island stakeholders in each distribution. Email addresses were collected from regional meeting, stakeholder interaction and other means and retained in a contact database.

9 Conclusions and recommendations

9.1 Conclusions

This project's strategic goal is to support community acceptance and action in an orderly senile coconut plantation renewal program through developing advanced veneer and other products from coconut stem to enhance livelihoods in South Pacific communities.

Coconut plantations are a valuable economic and social resource for many communities and private estates in South Pacific Islands. However, many are senile, have lost much of their vitality and productivity, and act as a major constraint on improved agricultural production. Yet, they present a significant opportunity for a sustainable increase in wood production. In the three South Pacific countries participating in this project, over 65,000 hectares of coconuts are believed to be senile. This is over 6.3 million senile stems. With orderly harvest and renewal, this represents a resource of over 64,000 m^3 of saw or peeler log per year for 50 years in Fiji alone, plus large amounts of coconut wood residues. Plantation renewal over time can more than double current nut production.

To achieve its strategic goal, the project developed new knowledge and processes critical to establishing the technology that underpins for a sustainable coconut veneering industry. In doing so, it determined that:

- High-density senile coconut logs with suitable preconditioning can be reliably peeled on spindle-less lathes operating with appropriate machine settings. The veneer produced differs from the material recovered from traditional wood species. Its minimum production thickness is 2 mm and its surface has a natural roughness that requires careful gluing and moderate sanding of the final product. With further commercial development, high quality veneer could be reliably produced in production facilities and dried and handled using standard industry equipment.
- The veneer produced can be used for a range of architectural and structural products. Optimum veneer utility and value is likely to be achieved by batching the veneer by colour and density, and grading it in line with a standard adapted to suit coconut veneer's particular properties and market characteristics. To assist industry with this, a draft grading standing has been proposed. The material produced can be reliably glued onto a substrate, or into plywood, LVL or similar veneer-based products. The most profitable markets for these products are likely to be in architectural surfaces, linings and joinery. However, uses may be found for all recovered material by combining coconut veneer with traditional wood veneers in composite structural products.
- While producing saw and peeler logs, coconut stem harvesting will produce significant quantities of residue on the harvest sites and concentrated volumes at processing facilities. Given this, a robust by-products suite is needed. Tests with coconut biochar were inconclusive. However, the use of coconut palm residues for fuel, particularly for industrial use and electricity generation bodes well, provided demand can be developed and transportation costs are acceptable. Further, the composting of harvest residues for soil amendments appears to be a cost effective means of utilising coconut palm harvesting residues. Little additional investment is required to generate a product that could be directly beneficial to local communities through increasing local agricultural productivity.
- Economic modelling of the coconut veneer value chain indicates that it is likely to be financially attractive for existing veneer industry producers and potentially additional small-scale processing facilities to develop a viable coconut veneer industry. The modelling also indicates that larger scale processing options may be viable as the industry develops and grows.
- Fragmented community ownership of many coconut estates presents a risk to regular and adequate log supply and this may prove to be a significant impediment

to establishing a coconut veneer value chain. Support processes need to be developed that encourage communities to critically assess and then renew their coconut estates in an orderly manner, and, by doing so, provide a reliable log supply to a growing coconut veneer-based industry. Extension tools providing guidance on community planning, and sustainable log harvest were developed to help address this risk.

Technical reports detailing the methodologies and outcomes of each research area were produced and are available with other support outputs at www.cocowood.net.

In addition to these technical and extension outcomes, the project sought to establish independent research capacity in veneer-based wood production. A rotary veneer processing equipment suite was established at the TUD facility in Suva, Fiji, and key staff were trained in its operation. This facility can be the base for future work on coconut and other small diameter wood resources in the region. The potential to relocate or replicate this facility in other South Pacific centres was investigated. The costs of this were determined and key success factors identified. These reinforced the impracticality of attempting to establish facilities of this type away from existing industry support infrastructure. The Crawford Fund also supported training in Brisbane, Australia, and education online.

Complications occurred in the project due to CSAW's inexperience in operating in Pacific countries, the difficulties inherent in a project straddling agricultural and wood products value chains and support networks, and other factors. Most were successfully overcome.

9.2 Recommendations

While the project identified clear technical solutions or opportunities for most objectives, additional work could improve outcomes for any developing coconut veneer industry and the coconut production sector. These include:

- Extension support to assist industry tune their production veneer equipment, (where possible), and their processes to reliably peel senile coconut logs into high-quality veneer. As detailed in the report, lathe settings need to be refined for each model of spindle-less lathe and skills have to be developed in handling the differences between coconut and traditional wood veneers and products.
- Research into solid wood applications for the upper log of the coconut stem. Previous wood processing research targeted only the bottom six meters of a stem that may be 30 metres tall. Given the results achieved in this project peeling the harder senile material in the butt log, additional useful products may be recovered from the higher log, significantly expanding available log volumes.
- Larger-scale controlled trials of composting coconut residues, and of establishing and comparing the costs and benefits of incorporating coconut compost and unprocessed coconut wood chips into a range of agricultural settings.
- A comprehensive value-chain study to more closely identify the range of coconut wood veneer based products that would be valued by customers, and to better understand how these products, services and information can be delivered to benefit all coconut veneer industry value-chain partners.

In addition to these technical activities, more effective project planning and management processes are probably needed to overcome the difficulties facing cross-sectoral projects, such as those that work across wood production and agricultural activity or between private industry and community estate owners. Anecdotally, efficient economic exploitation of many long-term tree plantations in the Pacific is constrained as much by a lack of community capacity to recognise and manage their potential as log suppliers over time as it is by a lack of technical understanding of harvesting and converting the material into useful products, or of the desirability of the products themselves.

10 References

10.1 References cited in report

Bailleres, H, Denaud, D, Butaud, J and McGavin, RL 2015, 'Experimental investigation on rotary peeling parameters of high density coconut wood', *BioResources* 10(3), 4978-4996, DOI: 10.15376/biores.10.3.4978-4996

Bailleres, H, Hopewell, G, House, S, Redman, A, Francis, L and Ferhrmann, J 2010, *Cocowood processing manual, From coconut wood to quality flooring,* Department of Employment, Economic Development and Innovation, Brisbane, Queensland, Australia.

Bergmaier-Masau, M 2016, 'Peeling Coconut Veneer - Activity Manual', Pacific Community, Suva, Fiji.

Blackburn, D and Nolan, GB 2016a, 'Objective 1.2: Coconut Veneer Value-Chain Proposal', Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Blackburn, D and Nolan, GB 2016b, 'Objective 2: Guidelines for Harvesting Coconut Palms in South Pacific Island Countries', Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Blackburn, D, Andrews, P and Nolan GB 2016, 'Objective 6: Assessment on the use of Coconut wood harvesting and processing residues for by-products', Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Brancheriau, L and Bailleres, H 2002, 'Natural vibration analysis of clear wooden beams: a theoretical review', *Wood Science-and-Technology* 36(4): 347–365. DOI: 10.1007/s00226-002-0143-7

Fitzgerald, C, Bailleres, H, McGavin, RL 2016, 'DAF Report – Susceptibility of cocowood to lyctid beetle and bamboo borer infestation', Queensland Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

Food and Agriculture Organisation of the United Nations FAO Office for Asia and Asia Pacific Coconut Community- APCC 2014, Report of the FAO High Level Expert Consultation on Coconut Sector Development in Asia and the Pacific Region.

Forstreuter, W 2013, *Needs for and Status of Capacity for Pacific Coconut Resource Inventory*, Presentation by Wolf Forstreuter, Secretariat of the Pacific Community October 8th 2013, Suva, Republic of Fiji.

Gibe, ZC 1985, 'The Philippines' recommendations for coconut timber utilisation', Philippine Coconut Authority, PCARRD, Philippines.

Haas A, Wilson L 1985, 'Coconut wood: Processing and use', Food And Agriculture Organization Of The United Nations, ISBN 92-5-102253-4, 68pp.

Hoagland, D 1938, 'The water-culture method for growing plants without soil', California Agricultural Experiment Station, California, USA.

Hopewell G and Bailleres H 2010, Improving value and marketability of coconut wood, Final report, project ACIAR FST/2004/054. http://aciar.gov.au/publication/fr2012-08

Killmann W and Fink D, 1996, 'Coconut Palm Stem Processing Technical Handbook', Protrade, Deutsche Gesellschaftfur Technische Zusammenarbeit (GTZ) GmbH.

Marra GG 1972, 'Wood Products in the Future – A Technological Extrapolation' in Anderson EA & and Earle GF (ed.), *Design and aesthetics in wood*, State University of New York Press, Albany.

McGavin, RL 2015, ‘DAF Report – Coconut palm stem veneer processing – Trial 3’, Queensland Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

McGavin, RL and Bergmaier-Masau, M 2016, ‘DAF Report – Coconut stem veneer processing, Trial 4.’ Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

McGavin, RL, Bailleres, H, Vella, R, and Fehrmann, J 2016, ‘*DAF Report – Cocoveneer product development Report 2 – Structural products’*, Department of Agriculture and Fisheries, Brisbane, unpublished report.

McGavin, RL, Leggate, W, Hopewell, G, Fehrmann, Bailleres, H, Fitzgerald, C, House, S 2015, ‘Producing rotary-peeled coconut veneer**’,** Queensland Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

McGavin, RL, Vella, R, and Littee, E 2015, ‘DAF Report – Cocoveneer product development -Report 1’, Queensland, Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

Nolan, GB 2015, ‘Objective 3.2: Assessing the potential of a regional trial and demonstration program’, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Nolan, GB and Blackburn, D 2016, ‘Objective 2: Guide to Community Development of Estate Coconut Renewal Plans in South Pacific Island Countries’, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Nolan, GB and McGavin, RL 2016, ‘Objective 1.1 Market assessment and product development’, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Poulter, R. and Hopewell, G 2010, ‘Secondary coconut products- potting mix fine-ground cocowood for growing media’, Queensland Department of Employment, Economic Development and Innovation, Brisbane, Queensland. Australia.

Stamets, P 2000, Growing Gourmet and Medicinal Mushrooms, Berkley, CA,USA: Ten Speed Press, California, USA.

10.2 List of publications produced by project

Technical publications

Objective 1 reports included in Appendix 1

Nolan, GB and McGavin, RL 2016, ‘Objective 1.1 Market assessment and product development’, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Blackburn, D and Nolan, GB 2016a, ‘Objective 1.2: Coconut Veneer Value-Chain Proposal’, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Objective 2 reports included in Appendix 2

Nolan, GB and Blackburn, D 2016, ‘Objective 2: Guide to Community Development of Estate Coconut Renewal Plans in South Pacific Island Countries’, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Blackburn, D and Nolan, GB 2016b, ‘Objective 2: Guidelines for Harvesting Coconut Palms in South Pacific Island Countries’, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Objective 3 reports included in Appendix 3

McGavin, RL, Leggate, W, Hopewell, G, Fehrmann, Bailleres, H, Fitzgerald, C, House, S 2015, 'Producing rotary-peeled coconut veneer**',** Queensland Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

Bergmaier-Masau, M 2016, 'Peeling Coconut Veneer - Activity Manual', Pacific Community, Suva, Fiji.

Nolan, GB 2015, 'Objective 3.2: Assessing the potential of a regional trial and demonstration program', Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

Objective 4 reports included in Appendix 4

Bailleres, H, Denaud, D, Butaud, J and McGavin, RL 2015, 'Experimental investigation on rotary peeling parameters of high density coconut wood', *BioResources* 10(3), 4978-4996, DOI: 10.15376/biores.10.3.4978-4996

McGavin, RL 2015, 'DAF Report – Coconut palm stem veneer processing – Trial 3', Queensland Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

McGavin, RL and Bergmaier-Masau, M 2016, 'DAF Report – Coconut stem veneer processing, Trial 4.' Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

Fitzgerald, C, Bailleres, H, McGavin, RL 2016, 'DAF Report – Susceptibility of cocowood to lyctid beetle and bamboo borer infestation', Queensland Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

Objective 5 reports included in Appendix 5

McGavin, RL, Vella, R, and Littee, E 2015, 'DAF Report – Cocoveneer product development -Report 1', Queensland, Department of Agriculture and Fisheries, Brisbane, Queensland, Australia.

McGavin, RL, Bailleres, H, Vella, R, and Fehrmann, J 2016, '*DAF Report – Cocoveneer product development Report 2 – Structural products'*, Department of Agriculture and Fisheries, Brisbane, unpublished report.

Objective 6 reports included in Appendix 6

Blackburn, D, Andrews, P and Nolan GB 2016, 'Objective 6: Assessment on the use of Coconut wood harvesting and processing residues for by-products',

Dean, G 2015, 'Coconut biochar: Taveuni field trail', Extended research note, Centre for Sustainable Architecture with Wood, University of Tasmania, Tasmanian, Australia.

ACIAR annual reports

Shanks, J and Nolan G, 2013, ACIAR CocoVeneer 2013 *Annual Report*

Shanks, J and Nolan G, 2014, ACIAR CocoVeneer 201 *Annual Report*

Nolan, G 2015, ACIAR CocoVeneer 2015 *Annual Report*, research report

Research notes and training reports in Appendix 7

Bergmaier-Masau, M 2015, Crawford Training report, unpublished report.

CocoVeneer research note: RN1 Project Overview.

CocoVeneer research note: RN1.1 Environmental credentials for coconut products.

CocoVeneer research note: RN4 Cocowood Properties.

CocoVeneer research note: RN4 Why try and peel coconut stems?

CocoVeneer research note: RN6.1 Plant growing mediums from coconut palm harvest residues.

CocoVeneer research note: RN6.2 Coconut biochar: Taveuni field trial.

CocoVeneer research note: RN6.2 Coconut biochar.

Appendixes