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Abbreviations and Acronyms

AROB	Autonomous Region of Bougainville	OISCA	Org. for Industrial, Spiritual and Cultural Advancement
AUD	Australian Dollar (currency)	p20	Code candidate plus tree clones for teak
Bmde	Branch Mode (tree form category)	Paxis	Persistence of Axis (tree form category)
BSz	Branch size (tree form category)	PGK	Papua New Guinea Kina (currency)
CDEP	Community Development Employment Projects	PGPD	National Tree Planting Initiative (PNGFA) *'Painim Giraun na Planim Diwai'* (Secure land for Tree Planting)
CYP	Cape York Peninsula	PNG	Papua New Guinea
DBH	Diameter at breast height (1.3m) over bark	Qld	Queensland
DAF	Dept. of Agriculture and Fisheries Queensland	SED	Small end diameter
ENB	East New Britain Province	s39	Code selected clones for teak
FA	Papua New Guinea Forest Authority	StS	Stem straightness of primary axis (tree form category)
FPCD	Foundation for People for Community Development	UNRE	Papua New Guinea University of Natural Resources and Environment
FRI	Papua New Guinea Forest Research Institute	UWSyd	University of Western Sydney
ICT	Information Communication Technology	USC	University of the Sunshine Coast
IOM	International Organization for Migration	WNB	West New Britain Province
IRR	Internal Rate of Return	WP	Western Province
KPA	Kariuku Project Area	WUE	Water Use Efficiency
MAI	Mean Annual Increment	WYA	Women and Youth in Agriculture
MTA	Material Transfer Agreement	OISCA	Org. for Industrial, Spiritual and Cultural Advancement

NARI	PNG National Agricultural Research Institute	p20	Code candidate plus tree clones for teak
NPA	Northern Peninsula Area of Cape York	Paxis	Persistence of Axis (tree form category)
		PGK	Papua New Guinea Kina (currency)

2 Executive summary

Many lowland forests in PNG have been commercially logged and further exploited for local use and/or cleared for agriculture. This has led to localised shortages of forest products for local use, and reduced income opportunities through sale into domestic and export markets. Smallholder-led commercial forestry offers the potential to address these shortages and diversify income. This ACIAR project was designed to respond to this opportunity for three key commercial species (a) teak (*Tectona grandis*), (b) PNG sandalwood (*Santalum macgregorii*) and (c) CYP sandalwood (*S. lanceolatum*). The project aimed to address the following research objectives: (1) advance the teak genetic improvement program in PNG, (2) develop robust and smallholder-appropriate silviculture, (3) develop capacity for an ongoing genetic improvement program for sandalwood in PNG (4) advance the sandalwood genetic improvement program in Cape York Peninsula for use by local landowners, and (5) communicate and disseminate research outputs to improve uptake and impact.

PNG Teak

Smallholder teak production in PNG has been constrained by the availability of high quality seed supply. To address this limitation the project (a) identified and captured teak plus-tree clones (UNRE & FRI) (b) established teak clonal archives (UNRE & FRI), (c) established genetically diverse provenance-based (OISCA) and clonal stands (UNRE & FRI) and (d) deployed germplasm to growers (OISCA). The genetic resources provide a foundation for the species' ongoing domestication in PNG and deployment of seed to growers. Selection and thinning of underperforming trees was conducted at OISCA & UNRE, but further thinning will be required for them to function as seed production areas. The wider deployment of this germplasm to smallholder growers will require additional capacity, in order for project partners to fully utilize future seed production.

The project developed and documented robust nursery techniques for teak, which were extended through grower networks in East New Britain Province (ENB). Smallholder teak nurseries were established at low cost, comprising simplified bare-root stump production in ground beds, a methodology which avoided the need for significant capital inputs. Landowners considered this technology accessible, and it was adopted widely, with 38 community nurseries distributing seedlings to smallholders within their communities. By this procedure over 22,500 teak trees were established for 500 growers (36 ha). The nurseries and woodlots were established using seed and technical advice provided by the project, with growers providing land and labour. While the rate of adoption could be considered modest, the independence of the growers in establishing these woodlots without cash support offered a sustainable model for scaling out as local seed supply increases. The project also established 4 teak demonstration spacing plots in ENB to provide practical options for smallholder adoption. These trials were located strategically along major roadways to maximise exposure, and PNG-project-partner OISCA have reported that the trials have stimulated a rising demand for teak seed.

An evaluation of potential markets and values for plantation grown teak was conducted. PNG plantation teak (Brown River/Kuriva plantation) is currently being exported to India from PNG for an average under sap price of K800/m^3 (USD250). The study demonstrated a strong domestic market for sawn timber, with prices across a range of species (c.PGK1,000 to K2,000/m^3) equivalent or higher than for export markets (c.PGK1,000/m^3). The PNGs housing sector represents a strong potential market for plantation grown teak. In ENB Province modelling of the demand for domestic housing demonstrated that 1104 new permanent houses by 2045 would consume c. 11 040 m^3 of sawn timber, requiring at least 184 $ha.yr^{-1}$ of teak woodlots. Nationally 10,500 new permanent households are constructed annually, requiring 107,000 to 161,000 m^3/y of sawn timbers in 2020, projected to increase to 210,000 to 315,000 m^3/y in 2050. The smallholder teak woodlots in ENB are closer to the housing market and ports for export than current sources of native timbers, potentially making them accessible to small- to medium-enterprises.

The products from thinning (poles and posts) can also meet growing demand in the traditional housing market. In ENB there is a distinct lack of suitable materials for constructing traditional dwellings, and teak products can fill this demand. Significant demand in local and informal markets was recorded for thinned-from-below (e.g. smaller) trees at age nine years. The round posts sold had a mean over-bark small-end-diameter (SED) of 15 cm. The posts were sold on a linear metre basis for PGK5.00/ Linear m (AUD2.00) which equated to PGK433 to PGK1,731/m^3. This demand for thinning products is considered an important stimulus for the establishment of smallholder woodlots, and an incentive for appropriate woodlot maintenance.

PNG Sandalwood

The harvest and trade of PNG sandalwood began over a century ago, but little has been documented regarding the regulation of its harvesting and trade. To address this the project examined recent export permit data, interviewed resource owners and traders and evaluated forestry legislation and regulations. Export declarations have been the only means by which authorities can monitor grades and volumes of wood traded. There is evidence that exporters have been under-declaring both grades and prices at point of export. Export records since 1997 have revealed volumes of up to 126 tonnes annually were traded in the early 2000s, but rapidly declined with very little traded in the past ten years. The natural resource has yet to recover from previous over-exploitation, but trade is still permitted.

To demonstrate the potential of sandalwood production in PNG the project engaged landowners to establish sandalwood plantings in three locations: two in Central Province and one in Gulf Province. The project used an extension approach to build landowner capacity for seed collection, nursery and woodlot establishment. While direct material support for nurseries was provided, landowners established their woodlots without external payments. Plantings were established at the family- (Kairuku), subclan- (Girabu) and clan-level (Iokea) These plantings were productive at both the family- and the subclan-level. The low performance of the clan-based planting at Iokea was influenced by complex social interactions among clan members, resulting in issues with maintenance and interference. Sandalwood production was most applicable at the family level, where land ownership, woodlot management and benefit sharing issues were simplified. This was demonstrated in Kairuku, where the adoption rate (35 growers) and number of trees successfully established (1,580) was greater than Girabu (1 grower 225 trees) and Iokea (1 grower and 179 trees).

To support the domestication of *S. macgregorii* in PNG the project undertook a systematic evaluation of the morphological, heartwood and essential oil characters in 126 *S. macgregorii* trees across five populations within the Central, Gulf and Western provinces in PNG. The study found its heartwood oil was characterised by extreme tree-to-tree variation in key fragrant compounds and heartwood content. It also revealed broad provenance-based variations in fragrant properties between trees from the Western Province and those from Central and Gulf Provinces. The significant variation found for oil composition offered the opportunity for selection of individuals with elevated levels of Z-α- and Z-β-santalol and heartwood percentage to be used as the basis for improved germplasm. Utilising improved germplasm can improve the commercial value of new plantings. This would make a greater contribution to future income generation among farmers. The study also highlighted the importance of conserving the few remaining wild stands of this threatened species.

CYP Sandalwood

In Cape York Peninsula (CYP) the local sandalwood variety (*S. lanceolatum*) offers potential to be integrated into existing Indigenous land management plans and established as commercial plantings. The project has furthered the commercial potential of the species by: (i) screening genetic diversity and developing genetically improved germplasm for future seed supply; (ii) training community members in establishing and managing the sandalwood trials and (iii) developing a business case and linking the community with corporate sandalwood producers.

The participatory research approach in the Northern Peninsula Area (NPA) resulted in the establishment of two 0.5 ha progeny trials, comprising 18 families derived from selected clones. Grafts of an additional 12 trees (clones) from more recently discovered CYP sandalwood trees have been captured. This brings the number of trees captured as grafted clones in the NPA to 30.

Genetic analysis of 156 wild individuals sampled from five populations in the NPA was undertaken using microsatellite markers. This revealed low levels of genetic diversity, with moderate differentiation in one geographically isolated population. The study found little evidence of inbreeding, but a highly clonal genetic structure, with over 50 % of trees in the region likely to be clones.

The participatory approach to the research involved discussions and meetings with Traditional Owners (TOs). These meetings included knowledge sharing and options for developing a sandalwood business in the NPA. This culminated in the development of a sandalwood business case for traditional owners in NPA. Dialogue with sandalwood production company Quintis has been ongoing with a growth trial of *S. lanceolatum* being established under Quintis commercial systems in the Burdekin. To build capacity to manage the plantings training workshops were conducted in conjunction with the planting of the progeny trials, and also when the progeny trials were measured.

Communication and dissemination for improved uptake and impact.

The project demonstrated that smallholders have a strong motivation to plant trees for future cash returns and house building materials. Interest in planting forestry trees was found to be ubiquitous among questionnaire, workshop and training participants, suggesting forestry development interventions have high potential for adoption. Smallholder knowledge of woodlot management was identified as a primary constraint to adoption so the project conducted a training needs and preference assessment. While respondents suggested they lacked knowledge on timber tree planting and management, many had skills with managing other tree crops (cocoa, coconut, fruits etc). This permits training and extension for nursery production and tree growing to leverage existing knowledge among landowners to rapidly improve capacity and confidence.

Face-to-face and peer-based training was preferred, but the duration of training preferences differed among participant, which appears related to their existing commitments. The use of a lead farmer extension approach within the target areas was used to extend information to smallholder farmers. This method of extension was found to be effective in transferring knowledge of woodlot planting and maintenance. However, additional project extension was required to support the lead farmers by conducting in-field woodlot owner training for pruning. Forestry training can potentially be accommodated within existing programs including (1) women's program within the church fellowship and (2) ward (village) meetings. Both of these meetings occur weekly and the latter for an entire day, and training can be conducted as a component within. Participants also considered scope for including forestry training within the 'community life skills training' that is delivered within the Local Level Government (LLG).

With matrilineal land tenure prominent in East New Britain the project sought to understand women's perception of tree planting and constraints that may restrict their adoption. To achieve this the project conducted four workshops with women smallholder farmers in ENB. Women clearly articulated a strong interest for tree planting on their own matrilineal land. This interest was driven primarily by their own needs for timber (particularly house construction) as well as commercial sale to meet the perceived high demand in their local area. The women considered their adoption of tree planting was constrained primarily by (i) a lack of knowledge and access to information, (ii) competing responsibilities and associated lack of time, (iii) limitations to mobilise traditional sources of family or community labour and (iv) a lack of access to suitable land. Further research and support is required to address these constraints.

Training resources developed under the project included technical notes and manuals as well as videos. The target audience for these resources was primarily farmers, but also education and extension practitioners. To ensure these resources were available to the target audience they were distributed among the project extension partners as well as through a village-based resource centre established by the project. All resources have been made available to project partners and other stakeholders though the Tree Growers Toolkit on the Pacific Islands Projects website and google drive.

3 Background

The mining and energy sectors of Papua New Guinea (PNG) have grown rapidly in recent decades and now represent around 80 percent of total export revenues (MoTC&A 2016; PNG CoM&P 2017). While these industries have delivered significant benefits to the national economy, they have produced limited benefits for much of PNG's rural population (MoTC&A 2016). The Vision 2050 document advocated broadening the economy beyond the mining and energy sectors, to enable sectors such as manufacturing, services, agriculture, forestry, fisheries and eco-tourism to generate around 70% of national GDP by 2050 (Kavanamur 2010). The document (p.24) identified plantations and forestry, including village-based forestry, as being potentially very important areas for the future development of PNG's rural economies.

The current planted forest estate is estimated to be around 60-70,000ha, comprising both government and corporate plantings. Existing commercial plantings in PNG are based on three lowland (e.g. Eucalyptus, Balsa, Teak) and two upland species (Hoop and Klinki pine) (UNDP 2018). Non-wood forest products such as eaglewood and sandalwood have also been promoted for planting in PNG (MoTC&A 2016). Expanding the planted forest estate is the key objective of the national program Operation *Painim Graun na Planim Diwai* (PGPD '*locate land and plant trees*'). This program has proposed three types of plantations (industrial, environmental and woodlots) at three scales (landscape-, compartment- and small-scale) (PNGFA 2018). Expansion of industrial plantations has been hampered by lack of government funding, landowner disputes and legal challenges and competition with other land uses (PNGFA 2014; PNGFA 2018). According to PNGFA, the revenues generated through the reforestation levy collected from logging companies are not sufficient to fund large scale reforestation (PNGFA 2014). Expansion of the national planted estate through smallholder woodlots is an area requiring further research to determine its feasibility.

Operation PGPD aims to 'plant 800,000 hectares of trees for commercial, community and conservation purposes by the year 2050' (Sabuin 2018). This equates to 1,1000 hectares of trees planted every year for each of PNGs 21 provinces. It is an ambitious national target and achieving it will depend on the participation of both institutions and smallholders in the establishment of plantations. Traditional PNG agroforestry systems provide a foundation for smallholder commercial tree production (Kanowski et al. 2014). Smallholder participation can be facilitated by the existence of simple and robust plantation forestry systems, the availability of superior genetics and access to markets (UNDP 2018). The Forest Authority (PNGFA) and Forest Research Institute (FRI) have identified both teak and sandalwood as important development priorities (Gunn 2013). This ACIAR project sought to promote rural economic development by enabling the establishment of smallholder commercial woodlots for these two high-value tree crops.

Teak is an important and high-value timber species that has the potential to address the localised shortage of durable construction timber in PNG (PNGFA 2014). The increased quantity of timber could be sold through existing export markets (SGS 2020). Landowner response to teak has been highly positive, largely related to its high growth rate, good form, robust nature and adaptability. Teak timber can be sold as individual trees aggregated into container loads as a unit of export. On the Gazelle Peninsula (ENB), historical logging activities and increasing population pressures have left a landscape almost devoid of timber resources. Establishment of planted teak could offer a source of timber for local construction and an increased potential for export. While native hardwoods have been planted to supply local markets, teak has a clear advantage in international markets due to its reputation and value. With increasing interest in this species, FRI has been tasked to establish germplasm sources that can supply high quality seeds. Further development and deployment of teak germplasm and development of smallholder teak silviculture was a priority of the current project.

Sandalwood (*S. macgregorii*) has been identified as a development priority for PNG (MoTC&A 2016). This project considered PNG sandalwood to be an appropriate species, due to its suitability for production in village agroforestry systems (Rome and Oa 2019) and its strong export markets (Turia and Saliau 2019). Sandalwood has been a commercially important product harvested from wild sources in PNG (Paul 1990; Saulei and Aruga 1994; Bosimbi and Bewang 2007). These resources have been over-exploited, and most rural communities can no longer earn income from sandalwood harvesting. *S. macgregorii* is currently listed as 'threatened' by IUCN (Eddowes 1998) and it is 'therefore considered to be facing a very high risk of extinction in the wild' (IUCN 2012). The lack of a natural resource has stimulated landowner interest and motivation for restoration and conservation of the species. A cash crop such as sandalwood is well suited to these areas, particularly in light of the limited options for high-value agricultural cash crops, given the poor transport infrastructure and market access for perishable goods.

The primary constraints to the development of planted sandalwood in PNG have been (i) access to sufficient quantities of quality seed; and (ii) knowledge and skills regarding the establishment and maintenance of sandalwood plantings (Bosimbi and Bewang 2007; Kiapranis 2012). Seed supply constraints have been due to a lack of productive wild trees and likely inbreeding. This project considered partnerships with landowners as important in identifying a diverse range of mother trees for seed collections. We also worked with landowners to adapt existing knowledge of sandalwood production to suit a range of planting types.

In the Cape York Peninsula area of Australia there are often limited options for commercial development, but sandalwood is a promising opportunity (Lee *et al.* 2018). The potential to incorporate sandalwood within existing indigenous land management and further extend this into commercial plantings has created an opportunity to utilise an endemic tree species for economic development. While returns for these forestry trees are expected in the medium term, management requirements would be relatively minimal after the establishment years. Even during establishment, activities would peak at certain periods, which would allow other cultural, community and commercial activities to successfully coexist with the enterprise. The substantial returns offered for sandalwood would make it potentially attractive for both community and investment forestry. Further development of the selections would provide an asset for developing new plantations as well as attracting potential commercial investors. This project sought to evaluate the potential for commercial partnerships with Traditional Owners in Cape York Peninsula to enable production of this unique form of sandalwood.

In areas with shortages of accessible fuelwood and timber (PNGFA 2014; Dalsgaard and Pedersen 2015), smallholders are interested to establish woodlots to meet their own needs as well as providing an income. Teak and sandalwood would produce high value products with existing export demand, and information already exists regarding their silviculture. While smallholder farmers have a strong desire to plant these species they are constrained by access to seed/seedlings and knowledge on appropriate production regimes (Kanowski *et al.* 2014). This project sought to address these constraints by (i) establishing germplasm resources to supply improved seed; (ii) refining and documenting silvicultural knowledge through field trials and smallholder woodlots; (iii) defining potential markets for their products and (iv) developing training materials and extension capacity of project partners and their stakeholders.

4 Objectives

The **aim** of the project was to develop germplasm sources and smallholder-friendly silviculture systems for teak and sandalwood. This would provide new opportunities for enhancing smallholder livelihoods and assist in achieving PNG's plantation development target.

The following five objectives and activities were established to meet the project aim:

1. To advance the teak genetic improvement program in PNG through first generation selection to produce high quality germplasm.

1 Activities:Further develop existing provenance-progeny trials as first generation seedling seed orchards;

1.2 Identify outstanding plus tree candidates and establish clonal seed orchards; and

1.3 Develop nursery protocols for commercial production and dissemination of improved teak germplasm

2. To ensure maximum realisation of genetic gains made by the project through the development of robust and smallholder-appropriate silviculture.

2 Activities:Identify appropriate establishment silviculture prescriptions;

2.2 Define silvicultural systems that optimise economic returns; and

2.3 Model estate and marketing plan.

3. To develop capacity for an ongoing genetic improvement program for sandalwood in PNG.

3 Activities:Establish species/provenance sandalwood trials;

3.2 Characterise intra- and inter-population variation for *S. macgregorii* in PNG;

3.3 Develop nursery capacity for production of wild-collected and improved sandalwood germplasm; and

3.4 Assist communities to market their sandalwood by preparing appropriate marketing plans.

4. To advance the sandalwood genetic improvement program in Cape York Peninsula for use by local landowners.

4 Activities:Establish sandalwood progeny trial with improved germplasm;

4.2 Explore opportunities for the commercialisation of existing selected clones; and

4.3 Capture additional genetic resources of the material to facilitate a small but viable on-going tree improvement program of the CYP source of sandalwood.

5. To communicate and disseminate research outputs to improve uptake and impact.

5 Activities:Capacity Building and Communication; and

5.2 Project monitoring and evaluation.

5 Methodology

This project was implemented in Papua New Guinea and Australia in four main regions including East New Britain (ENB), Central & Gulf Provinces, Morobe Province and Cape York Peninsula. Both research and research for development activities for teak were carried out in ENB, a location where this species has been demonstrated to perform well under plantation. In ENB, research was conducted primarily by UNRE, and community engagement and development were carried out by OISCA. In Central and Gulf Provinces, research for development activities for sandalwood, which was implemented by FA, were conducted with communities. Sandalwood occurs naturally in these areas, and therefore it was considered a logical place to commence domestication and resource restoration research. FRI, based in Lae, is the lead forestry research agency in PNG, and therefore research related to the domestication of both teak and sandalwood was conducted by FRI staff within Morobe Province and other project areas. The Northern Peninsula Area (NPA) in Cape York was the focal region for the sandalwood domestication research. This area was chosen based on the unique and high-quality sandalwood oils found within the natural populations of *Santalum lanceolatum*. It was considered that there would be strong market demand for a high-quality niche sandalwood product produced with indigenous communities.

The project was a collaboration among:

- Three government departments - PNG Forest Authority, PNG Forest Research Institute and Queensland Department of Agriculture & Fisheries;
- Two local NGOs (Organisation for Industrial, Spiritual and Cultural Advancement (OISCA), and Pacific Island Projects (PIP); and
- Three universities – The University of the Sunshine Coast (USC), the PNG University of Natural Resources and Environment (UNRE) and Western Sydney University.

Objective 1: To advance the teak genetic improvement program in PNG through first generation selection to produce high quality germplasm.

1.1 Further develop existing provenance-progeny trials as first generation seedling seed orchards.

<u>*UNRE*</u>

Two teak clonal provenance trials established at UNRE under FST/2007/078 in East New Britain Province in PNG provided the foundation for quantifying genotype and provenance variation under this project. The trials comprised clonally-propagated progeny population from bulk seed collections of 8 (trial 1a) & 11 (trial 1b) imported and 2 local PNG (both trials) teak sources. Measures of height, diameter and form were conducted in trial 1a at 0.9 (height and diameter), 1.7 (diameter and form), 2.8 (height and diameter) and 3.5 years (diameter and form) after establishment. Measurements of diameter and form were conducted in trial 1b at 3.5 years after establishment. At 3.5 years trees were selected in the clonal provenance trial 1a and 1b based on their phenotypic performance, with some of these clonally propagated for establishing a clonal test trial for conversion to a clonal seed orchard (see activity 1.2). Variation in measured variables within clone source, clones and clone type (i.e. candidate plus vs selected trees) were evaluated using a general linear model (GLM) with Tukey's test for pairwise comparison of means at 0.05 level. Associations between variables and repeated measurements were determined using Pearson's and Spearman's-rank correlation coefficients.

FRI

A teak provenance trial was established in Situm (Morobe Province) on customary land during May 2015. The trial comprised seven seed sources, including Laos (TG7), Thailand (TG8), China (TG9), Honduras (TG10), Santa Alicia (TG11), Jicaro (TG12) and Nambi (TG13) (Nambi). The design was an incomplete block design (IBD) comprising 5 replicates, 7 plots per replicate and 9-tree plots, with a tree spacing of 4 m x 4 m. Teak stumps from TG12 (Jicaro) were planted as single-buffer row enclosing the trial planting. Tree height and stem diameter (DBH) were measured yearly to four years (June 2019), to examine variation within and between provenances.

A second teak progeny-provenance trial was established, which was planted adjacent to the teak international provenance trial. Incomplete block design (IBD) was applied, with 8 replicates, 8 plots per replicate and 9-tree plot in an area of 1.03 ha. Initial spacing was 4 m x 4 m. They included 24 progenies including 20 (plus one bulk collection) from Mt Lawes, 3 from Kuriva and one from Oomsis. The trial also included 7 provenances and TG14-Mansion, TG15-Nambi, TG16-Penas Blancas, TG17-Santa Cruz, TG18-Nellicutha, TG25-Taliwas and TG29-Honjancha).

1.2 Identify outstanding plus tree candidates and establish clonal seed orchards.

CSO in Vudal and Warrangoi (ENB)

Within the two clonal provenance trials at UNRE (see activity 1.1) teak trees were selected based attaining a minimum score for each of the following:

(1) A stem diameter mean annual increment (MAI) of >4cm yr^{-1};
(2) Primary axis branches out in 3rd to 4th quarter or complete persistence (Paxis);
(3) Primary axis straight to slightly crooked (StS≥4); and
(4) Branch diameter between ½ and less than ¼ of trunk diameter (BSz≥3).

A clonal test trial (2a) using 21 phenotypic selections was established in Aug 2017 at UNRE, as complete randomised block design with 20 replications. The aim was to include each of the 20 candidate plus (p20) clones in each of 20 replicates, but numbers of available cuttings meant that 11 x p20- & 10 x s39- clones were utilised, with replication ranging from 4 to 30. Each replication contained 4 rows and 5 columns, with trees spaced at 4 x 4 m. The site was blocked in both north-south (4 blocks) and east-west (5 blocks) directions. The trial was measured for stem diameter and form scores in Aug 2019 at 2 years after planting. Variation between clone source, clones and clone type (i.e. candidate plus vs selected trees) was evaluated using a general linear model (GLM), with Tukey's test for pairwise comparison of means at 0.05 level.

Plus-tree candidates and slower-growing provenances from the teak clonal trials at UNRE (1b & 2a) were screened for growth and water-use efficiency (WUE), inferred from leaf δ13C. The collections were done in January 2019 and August 2019, with a total of 125 leaf samples collected from 28 clones across trials 1b and 2a at age 24 months and 79 months respectively. The aim of this research activity was to understand growth and performance among teak clones.

CSO at Kuriva (Central Province)

A teak clonal seed orchard (CSO) was established at Kuriva (Central Province) in June 2017. Clones were derived from three sources (1) Mt Lawes CSO in Central Province (13 clones); (2) Kuriva plantation in Central Province (4 clones); and (3) Vunapalading-Kerevat plantation in East New Britain Province (4 clones). The seed orchard design comprised a Randomized Complete Block Design (RCB) with 8 replicates of 21 clones. A total of 168 measurable clones with an additional 40 clones as buffers were planted. A wide spacing (6 x 8m) was used to ensure adequate space for each clone, to encourage flowering and seed production.

Clonal Archive FRI, Lae (Morobe Province)

The teak clonal archive was expanded through bulking of existing clones and capturing of additional selected trees from additional sources.

In August 2018, 86 truncheons were harvested from 9 plus-trees, selected in the first generation of teak woodlot established at Erima, Madang in June 2012. These plus-trees include Jicaro (T1), Jicaro (T2 & T3), Santa Alicia (T4 to T8) and Honduras (T9 & T10). Successful truncheons from Honduras (T10) and Santa Alicia (T4, T5 & T6) were planted in the teak clonal bank in April 2019. Teak seeds were supplied to FPCD, facilitated by a previously concluded ACIAR FST/2007/078 project to distribute to teak growers in Madang.

In September 2018, 173 truncheons were harvested from 10 selected plus-trees in East Sepik Province and air-freighted to FRI to propagate in the mist house. These plus-tree were sourced from Ambuti, Mandii-Turubu, Naramko-Maprik, Passam (T1), Passam (T2), Passam (T3), Tawaiya-Turubu, Wara Bung-West Yangoru, Wingei No.1 (T1), and Wingei No.1 (T2). Six rooted truncheons sourced from woodlots in East Sepik were planted in the clonal archive in August 2019.

1.3 Develop nursery protocols for commercial production and dissemination of improved teak germplasm.

Seedling production

The development of methods suitable for smallholder teak seedling production was an iterative process, and was achieved by working collaboratively with all project partners. Nursery production protocols were developed through the adaptation of published information for teak combined with local availability of tools, resources and preferences. The goal of this collaborative approach was to develop robust and cost-effective method of seedling production that can be implemented without the use of external capital. This was considered important because smallholder production of seedlings can offer a sustainable model for seedling deployment. OISCA was the primary partner who tested the methods with lead farmers. OISCA worked with farmers to establish satellite nurseries for distribution of seedlings to interested growers within their village. When the seedlings were ready for planting the satellite nursery became the hub for practical extension delivery on nursery and woodlot establishment. These protocols were disseminated by means of a number of extension tools including technical notes, videos, and a silviculture manual.

Clonal production

Clonal propagation offers a rapid method for capturing and deploying genetically improved teak germplasm. Work on developing clonal propagation was carried out at both FRI (Anton Lata & Sonia Inu) and UNRE (Sylvester Kulang). Three primary methods of capturing mature mother trees were tested, including leafy stem cuttings, truncheons of various sizes and cuttings from stimulated coppice shoots. Successfully cloned individuals were then established within a clonal archive and managed as hedged stock plants. The capturing of mother trees was undertaken through several collections, in order to build up the clonal archive with trees from different sources. The hedged stock plants were then used as a source of leafy stem cuttings that were propagated in either mist (FRI) or non-mist propagators (UNRE). Clones were sourced from identified candidate plus trees Mt Lawes and UNRE trial 1a & 1b and single tree selections from Kuriva, Oomsis, Vunapalading and UNRE trial 1a & 1b. Replicated cuttings were potted into polybags and grown in the nursery until sufficient numbers of seedlings could be generated for establishing clonal trials and seed orchards. The resulting replicated clones were established as a GSO in Kuriva (PNGFA) and a clonal test at Vudal (UNRE) and Warrangoi OISCA. A technical report (Lata 2019) describing capturing and propagating teak cuttings was written, and a video on propagating stem cuttings from hedged stock plants was recorded (Kulang).

Objective 2. To ensure maximum realisation of genetic gains made by the project through the development of robust and smallholder appropriate silviculture.

2.1 Identify appropriate establishment silviculture prescriptions.

Tree spacing within teak plantings was historically 1498 stems.ha^{-1} (2.7 X 2.4 m). More recently woodlots have been planted at 625 stems/ha (4 X 4 m). To identify an appropriate spacing and management regime for teak, four spacing trials were established in East New Britain. These trials were designed to test close spacing for poles (2 X 2 m resulting in 2,500 stems/ha), routine spacing (4 X 4 m resulting in 625 stems/ha) and wide spacing for agroforestry (6 X 6 m resulting in 277 stems/ha).

A total of two teak silviculture trials (Oisca blocks 3 & 4 and Gunanur) (Figure 1) were established using seed from Penas Blanca (Costa Rica). Five months after sowing, seedlings with a collar diameter of c. 2cm were prepared as bare root stumps with a length of c. 30 cm. Three spacing treatments were applied 2x2m, 4x4 and 6x6m within each of the four trial sites (Table 1).

Three additional spacing demonstration plots were established including: (1) Napapar, Gazelle District (212 trees – Feb 2018); (2) Irena Ward, West Pomio LLG, Pomio District (226 trees - Sep 2017) and (3) Lavakaka Ward (Rabaul Dist Admin) Balanataman LLG, Rabaul District (466 trees – Feb 2018). Very good survival was recorded at both Napapar and Irena, but complete loss of the trial at Lavakaka was caused by cattle entry and grazing.

Table 1: Details of the trial site attributes and yield plot size.

Site	OISCA block 4			OISCA block 3			Napapar			Gunanur		
District	Pomio			Pomio			Gazelle			Kokopo		
Previous land-use	Ex-cocoa block			Ex-cocoa block			Ex-garden block			Ex-coconuts & cocoa		
Planted date	19/07/2017 to 21/07/2017			04/08/2017 to 04/08/2017			2018 02			10/07/2018		
Provenance	Penas Blanca			Penas Blanca			Penas Blanca			Penas Blanca		
Spacing (m)	2 X 2	4 X 4	6 X 6	2 X 2	4 X 4	6 X 6	2 X 2	4 X 4	6 X 6	2 X 2	4 X 4	6 X 6
Area (ha)	0.18	0.29	0.29	0.17	0.11	0.22	0.05	0.08	0.10	0.29	0.31	0.34
Planted (n)	459	184	83	432	69	63	128	54	30	735	198	96
Totals	726			564			212			1029		
Trees in Yield Plot	49	49	49	36	36	36		Demo only		81	81	81

Figure 1: Alex Kuariri and OISCA staff with teak stumps for the spacing trial at OISCA (left) and Jaupo Minimulu (UNRE) laying out stockpiles of teak stumps ready to plant (Images Sylva Systems).

2.2 Define silvicultural systems that optimise economic returns.

A financial model was developed to test teak woodlot returns and management. By its nature the model was not a 'black box', and there were nil fixed values hardwired. This is a cause for caution, in that any assumption can be included, and a model run must be based on defendable assumptions. The financial model was provided to the PNGFA (Forest Development Directorate; Policy and Planning) and FRI (Planted Forest Section) to assist with planning of teak within Operation *Painim Graun na Planim Diwai*.

Therefore, the model included a range of individual woodlot management options as capabilities:

- Participants: The model can include up to four parties involved with a teak woodlot to allow for a range of business structures.
- Silviculture: All elements of a silvicultural regime are variables in the model. For example, initial spacing can be varied to adjust stocking rates and tree piece size at harvest.
- Nursery: While part of silviculture, the model has specific ability to adjust all elements of nursery management e.g. number of teak fruits per kilogram of seed. This provide maximum flexibility to test all aspects of teak management.
- Harvest: A harvesting regime can be developed defined by the number of stems and basal area removed. If the same percentage is used, thinning is uniform across all tree size classes. If a lower basal area is removed compared to number of stems, this thinning removes the smallest trees and is a thinning from below. The model has capacity for up to five thinnings and a final clear fall. The mean attributes of the trees thinned are presented.
- Products: The model has capacity for up to five products with each product defined by name and unit price (k/m^3). Given that some investors may seek physical products (a crop share) and a return, the model allows allocation of products to participants for each operation. This is a fundamental option given that supply of stumps to a farmer may be in return for supply of poles at first thinning (a logical and plausible business arrangement).
- Financial assumptions: The model generates a cost profile for each operation based on units of physical inputs and the cost of a unit on input. In effect individual line budgets are created for each operation. Each value can be varied based on specific local information.
- Budget: The model generates a cashflow budget for the full rotation as set by the thinning and harvesting regime, combined with all other decisions (assumptions) made. In line with multiple participants, each participant can be allocated a set input to the woodlot budgets.

2.3 Model estate and marketing plan

The financial model addressed teak development on a Provincial basis.

- An estate: The model aggregates a defined number of woodlots (hectares) on a normal forest basis (equal area planted each year) into an estate and generates estate level wood flows and cash flows.
- Seed orchards: The model develops a required area of seed orchards to satisfy the required teak seed to develop the modelled estate.

- Housing: Given the importance of housing markets, the estate model links to a house potential module. That is, how many permanent households could be constructed based on the expected wood flows? A key assumption is the quantity of sawn timber consumed during house building. This can be varied.
- Carbon: The model converts standing stocks and wood flows into a tCO_2-e equivalent based on standards protocols. This include capacity to run multiple rotations using the same physical systems assumptions. The model has the capacity to select a carbon price and generate a summary of carbon values for the modelled estate.

Objective 3. To develop capacity for an ongoing genetic improvement program for sandalwood in PNG.

3.1 Establish species/provenance sandalwood trials.

A sandalwood species/provenance trial comprising three species and six seed sources (*S. album* - Ethereal, Mackay, Wiles; *S. austrocaledonicum* – Vanuatu and *S. macgregorii* - Kuriva, and Gomore) was planted in at Kuriva in Feb 2018. The trial was 0.8 ha and established on a 4 m x 4 m grid, with double rows of host species *Acacia crassicarpa* (Ac) and *Acacia auriculiformis* (Aa) planted at 4 x 12 m. Two rows of sandalwood were planted between the host rows (Figure 2)(Lata 2018). This design created 3 host treatments 1. Aa, 2. Ac and 3. Aa+Ac. A total of 356 sandalwood and 180 host seedlings were established. The design included 10 tree plots for five sources (excepting Vanuatu) replicated five times, in between the host rows. This randomised complete block design permitted statistical evaluation of the performance of provenances from the two species *S. album* and *S. macgregorii.*

An 'extension' to the trial allowed inclusion of *S. austrocaledonicum*. In rows 17/18 and 20/21 plots were reduced to 8 and 6 trees respectively with the Kuriva provenance substituted with Vanuatu. Beyond row 22, a 12-tree Vanuatu plot was planted.. *S. austrocaledonicum* was established at the Rocky Creek end to determine its broad suitability to the site, rather than systematic comparison with the other species.

Survival and growth of sandalwood seedings was assessed at 12 months. Given significant (~90%) mortality, refilling of the site occurred at 18 months . The refilling removed the Eterael source and introduced an additional source of *S. album* from around Lae (PNG), which was originally sourced from Kununurra seed orchards under ACIAR project FST/2004/009 (Gunn 2013).

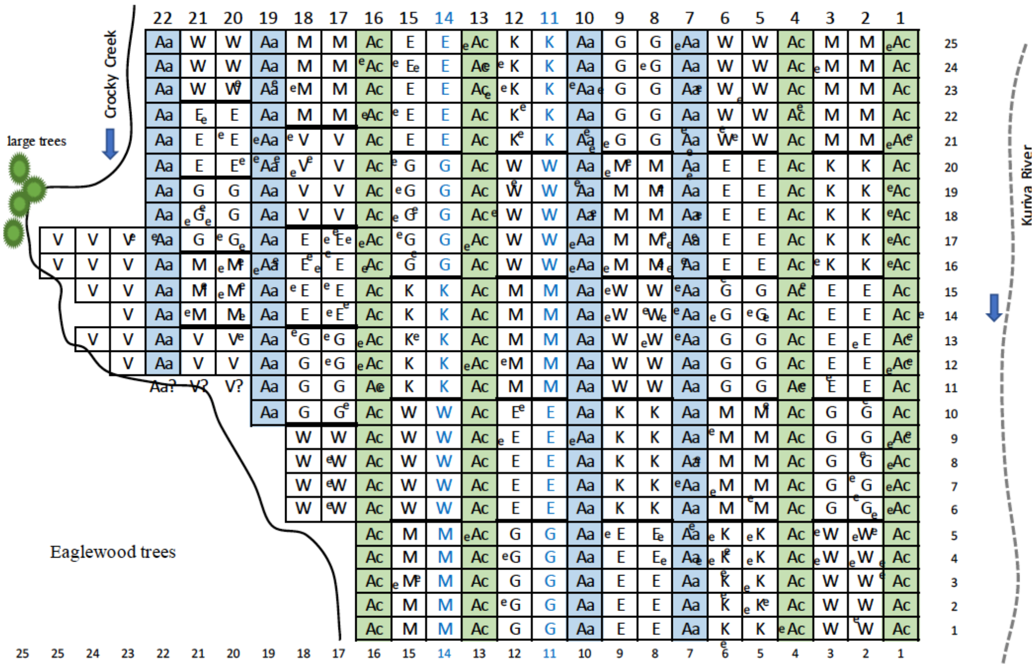

Figure 2: Layout of the sandalwood species/provenance trial established in Kuriva. Hosts *Acacia crassicarpa* (Ac) and *A. auriculiformis* (Aa) in blue and green highlighted columns. Sandalwood species are *S. album* (M = Mackay, E = Eterael, W = Wiles), *S. macgregor*ii (K = Kuriva, G = Gomore) and *S. austrocaledonicum* (V = Vanuatu).

3.2 Characterise intra and inter population variation for S. macgregorii in PNG.

Study Area

S. macgregorii was sampled in Rigo (9°46'S 147°34'E 30-150 masl) and Kairuku (8°44'S 146°35'E 10-130 masl) districts within Central Province, Iokea (8°24'S 146°17'E 05-85 masl) district in the Gulf Province, and a small area of the South Fly to east of the Mai Kussa River around the villages of Buzi, Berr and Sibidiri (9°07'S 142°15'E 10-30 masl) in Western province, Papua New Guinea. (Figure 3). The trees sampled were either located within cultivated areas close to or within village areas, in a protected situation within savannah woodlands, or within or adjacent to vine thickets along water courses/drainage lines that run through savannah woodlands. In Western Province trees were found in savannah woodlands (Figure 4).

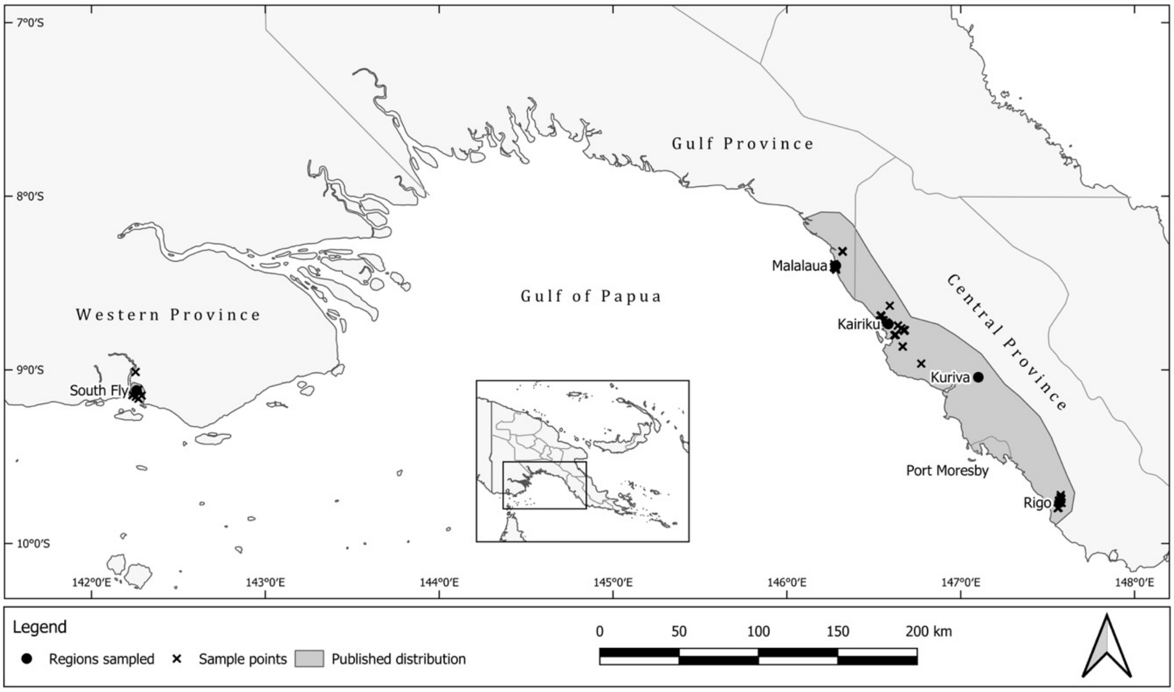

Figure 3. Location of trees sampled showing districts.

Tree Selection & Site Descriptors

Selection of sampled trees was restricted to trees greater than 10 cm basal diameter, however, on occasion, smaller trees were included in areas where trees were present but larger specimens were not present. For planted specimens some trees >10 cm were excluded when they appeared to be derived from root suckers of a sampled tree. Location, land form and land surface were described using the basic principles outlined in (Terrain 2009).

Figure 4: Typical savannah woodland in Rigo (Central Province) (left) and Southern Fly (Western Province) (right) where sampled sandalwood trees were located.

Tree Description & Samples

The collection team comprised members of PNG FA, FRI and USC (Figure 5). The trees were described in detail, including total height, bole height, habit, diameter over bark at 0.2, 0.7 and 1.3m, age estimate, canopy spread from north to south and east to west, and count and measurement of fire scars. Reproductive status was calculated by estimating the density of buds, flowers, maturing fruits and mature fruits on a scale of 0 (nil) to 5 (high). Recruitment of suckers and seedlings within 10 m were counted and either basal or breast height diameter were measured when > 100 cm height. Any physical or biotic damage was recorded on a scale of 0 (nil) to 5 (high). Physical damage was further classified as deliberate or indiscriminate for bark slashing, and heart-check was noted for severity, frequency and cardinal direction.

One bark-to-bark wood core was extracted from each tree sampled at a nominal height of 0.2 m (Figure 5). Additional cores at 0.7 m and sometimes at 1.3 m were extracted, depending upon the amount of heartwood in the first core, the physical condition of the tree and permission given by the owner to take additional cores. The presence and quantity of heartwood was determined across the length of the core. Leaf samples were also collected for mensuration and storage for potential future molecular genetic study. A photograph was taken and the core placed in an air-tight container containing indicator silica gel for quick drying, in order to preserve the oil constituents for later extraction.

Figure 5: Sandalwood survey team (left) and extraction of sandalwood heartwood samples (right).

3.3.Develop nursery capacity for production of wild-collected and improved sandalwood germplasm.

The building of nursery capacity occurred at both the institutional level (Forest Authority) and smallholder level, with in-service and formal training activities. At the commencement of the project there was little sandalwood seed available, and initial training using imported seed sources occurred with FA staff at the central Port Moresby Nursery. The training included seed pre-treatment methods, media components and formulations, pot host and fertiliser requirements and shading and sun hardening. This training resulted in the production of over 3,000 sandalwood seedlings that were used in the establishment of the clonal provenance trial (*S. album*, *S. austrocaledonicum* and *S. macgregorii*) and distribution to growers (*S. macgregorii*).

Given that the lack of local seed supply was an impediment to establishing community-based woodlots, there was a need for capacity building in the collection of high quality seeds. Printed technical training materials were developed and distributed in combination with field visits to landowners with seed producing mother trees. Annual landowner meetings and two formal training workshops were also conducted in order to build local capacity across all important aspects of sandalwood nursery woodlot management.

3.4 Assist communities to market their sandalwood by preparing appropriate marketing plans.

Given the genuine concern for the sustainability of sandalwood trade in PNG, the development of a marketing plan for communities was not considered appropriate. Instead the project undertook a study to characterise the existing industry by examining export records, interviewing resource owners and traders and reviewing forestry legislation and regulation (Rome *et al.* 2020) . The study confirmed that the overharvesting of natural stocks, regular outbreaks of fire and the growing dependency on a cash economy in local communities has placed a burden on species protection and regeneration. It is clear that, since its IUCN endangered classification, *S. macgregorii* remains under threat (Eddowes 1998). The PNG Forest Authority has therefore suggested that consideration be given to placing a temporary ban (e.g. 10 years) on natural sandalwood harvesting (Turia and Saliau 2019).

The review of PNG's regulation of the sandalwood trade found that little provision has been made for the trade in minor forest products such as sandalwood within the Forestry Act (1991) or associated policies. Sandalwood is not a prescribed commodity tracked under the National Log Export Monitoring system (SGS 2020). There is evidence that both grades and prices have been under-declared at point of export. Over the past eight years export permits contained no record of any high grade products, and export prices were lower than the domestic prices paid to resource owners. Consequently there is a need for policies that support a more regulated and sustainable trade in PNG sandalwood. Given the low volumes of sandalwood relative to the trade in large round logs, an alternative system for independent tracking of sales is required. It is recommended that PNGFA establish a sales registry system that records the buyer, seller, grades, volumes, prices and geographical source of PNG sandalwood. This can provide an effective means of monitoring volumes traded from different areas, and will facilitate cross-checking of the grades and volumes exported. Resourcing this system is problematic because, while the taxes for other minor forest products are allocated to the PNGFA, the taxes from sandalwood sales are allocated to PNG Customs. If tax revenues from sandalwood were available to PNGFA, this would provide a revenue stream to fund the regulation of the trade.

A financial model for sandalwood production was developed based on inputs and outputs recorded for the 1ha woodlot in Girabu. The model was designed with a user friendly interface so that key variables could be modified to determine their effect on the profitability of the venture. This interface was chosen to make it more accessible for practitioners and farmers seeking such information. A technical document outlining the key financial information was also produced.

Objective 4. To advance the sandalwood genetic improvement program in Cape York Peninsula for use by local landowners.

4.1 Establish sandalwood progeny trial with improved germplasm.

Seed was collected from 18 *S. lanceolatum* clones (previously established in clonal seed orchards). This seed was sown at the Gympie nursery to allow establishment of a progeny trial on CYP in the 2016-2017 wet season. Two 0.5 ha trials were successfully planted in the NPA during February 2017. One of these trials was established with the assistance of high school students at the Northern Peninsula Area College, and the other with assistance of Community Development Program workers at the Bamaga Farm. These trials had good initial survival. They suffered some defoliation due to generalist insect herbivores. As a result the trials were sprayed with Confidor™ in June 2017 to protect the plants. In addition a trial on Quintis land in the Burdekin was established, with appropriate IP protection of the germplasm, to safeguard its ownership by the TOs. Pollination studies undertaken in a grafted clone bank at Gympie indicated that the Cape York Sandalwood has the potential to self-pollinate. An Honours student project investigated this self-pollination possibility, and also investigated the population structure of the remnant stands in the CYP using microsatellites, in order to improve our knowledge of the breeding system of the species and help with the genetic improvement of the species.

4.2 Explore opportunities for the commercialisation of existing selected clones.

Discussions and meetings have been held with Traditional Owners (TOs), which included discussing their knowledge of sandalwood and the potential of the species to be the basis of a successful business in the NPA. These discussions involved field visits, workshops at the trials and attendance at formal, Indigenous-led meetings. Project staff met with a range of potential partners with whom TOs had engaged (both face to face in the NPA and via teleconferences), to discuss the potential, business opportunities and commercialisation of CYP sandalwood. In addition, the trial established on Quintis land in the Burdekin (the largest commercial sandalwood grower in Australia) built important links with this company. This could lead to commercialisation opportunities for the Indigenous people of the NPA (e.g. via seed sales / royalty payments / seedling supply). Quintis is interested in testing the species on their sandalwood plantation estate but is not currently interested in progressing this further without more knowledge of the species.

4.3 Capture additional genetic resources of the material to facilitate a small but viable on-going tree improvement program of the CYP source of sandalwood.

Grafts of an additional 12 trees (clones) from more recently discovered CYP sandalwood trees have been captured. This brings the number of trees captured as grafted clones in the NPA to 30. The trees targeted for grafting were from populations or areas that had not been previously sampled (e.g. trees near Somerset). These trees have unknown oil profiles, but were considered worthy of capture as they broadened the genetic profile on the basis of isolation by distance. The 30 trees in the breeding program protect and conserve the species from losses due to fire and other risks, and form the nucleus of a tree improvement program. Eleven trees had wood frass collected with TO (Traditional Owner) approval, so their oil profile could be evaluated using GCMS.

Objective 5. To communicate and disseminate research outputs to improve uptake and impact.

5.1 Capacity Building and Communication.

Explore constraints to participation by women in tree planting

Four workshops were conducted with women's groups representing 8 LLGs (Local Level Government) and 34 wards (villages) in East New Britain Province of Papua New Guinea, with 11, 23, 40 & 30 female participants respectively. The workshops were held at Tinganagalip Rural Resource Centre (T1- 8th Dec 2016 & T2-28th Mar 2017), OISCA eco-tech training centre (O3 – 24th Aug 2018) and Valaur Community Hall (V4 – 20th Aug 2019).

Female facilitators included women from local organisations such as ENB WYiA (East New Britain Women Youth in Agriculture), OISCA (Organisation for Industrial, Spiritual and Cultural Advancement), IOM (International Organisation for Migration) and UNRE (University of Natural Resources and Environment). The workshop was delivered in both English and Tok Pisin languages, and facilitators were available to interpret and explain anything unclear.

Quantitative information, such as the frequency of group responses and group nominated proportions of respondents, was recorded. Quantitative information was also collected during two prioritisation activities to address (i) individual perceptions of the main constraints to involvement in tree planting and (ii) individual preferences for communication and delivery of information. The prioritisation activities were conducted by giving individuals adhesive labels coded for 1st, 2nd and 3rd priority in order of importance, with first being the most important. Participants were then able to allocate their priorities by placing the labels next to the constraint or communication mode listed on a board. The constraints and communication modes had been identified by the groups during earlier sessions.

Constraint response categories were classified based on the broad area or 'capital' to which it related including Financial, Human, Intellectual, Market, Natural, Social and Physical. Training preference response categories were classified as Formal, Informal, Extension or Media. Training delivered by external agencies was defined as being either formal training (longer-term (>1 week) with formal qualification issued), or extension training (short term training (<1 week) with no formal qualification issued). Informal was generally defined as peer-based learning from friends, colleagues, teachers or lead farmers that do not necessarily hold any formal qualifications in forestry or closely allied fields. Media was any form of information, and communication methods including radio, television, newspaper, printed technical information, social media and internet.

A simple standardised preference index (SPI) for each response category was calculated based on sum of the weighting of first (x3), second (x2) and third (x1) preferences and dividing by the sum of the weighted preferences by all workshop responses. The index is expressed as a proportion relative to total participants. This approach permitted comparisons between workshops on the strength of preferencing.

Qualitative information was collected during the group discussions by female facilitators who were assigned to assist 2-3 groups to (i) clarify the meaning of workshop questions; (ii) provide background information where required; (iii) ensure equitable contribution of group members; and (iv) record pertinent qualitative information not captured in the group responses.

Training Needs Assessment

Training needs assessment and preferencing was conducted via three interconnected research activities: (1) a stakeholder (farmer) situation analysis conducted to understand farmer needs, motivations and competencies; (2) a landowner questionnaire using 3 male and 2 female local enumerators (OISCA, PIP and PNG Missions); and (3) the four women's workshops conducted in activity 5.1.2 (above) and three farmer training events.

Stakeholder situation analysis was conducted through semi-structured interviews held in the field with OISCA extension agents and lead farmers, who shared their experiences and understanding of agricultural and forestry management. Further insights into skill-based competencies were captured by observation of the OISCA team both in undertaking field works and during their interaction with the farmers of ENB. The landowner questionnaire collected information about interest, experience and constraints to tree planting. In order to validate the findings of the analysis and questionnaire, the results were incorporated into broader group discussions during the four women's workshops and three farmer training events.

Develop training resources to meet vocational training needs for teak & sandalwood

Training resources were developed following compilation of the results of the training needs analysis, with written technical and video instructional materials developed. These included short, practical, visually descriptive materials about discrete tasks for farmers and practitioners, as well as more comprehensive silviculture documents with more detailed information. These resources were developed in collaboration with project partners such as OISCA, FRI and FA that have links with communities in ENB, Central, Gulf, Morobe and Madang Provinces. These materials were developed by USC, Sylva Systems and FRI, with PIP conducting the typesetting and publishing. The short form training resources have been made available through the PIP website and their communication hub network. The training resources are being used by OISCA for building capacity among technical and implementing staff and lead farmers. Similarly, for sandalwood, FA extension staff have increased capacity and confidence in the aspects of woodlot management. The knowledge has been adapted for practical delivery during workshops among interested farmers.

5.2 Project monitoring and evaluation.

Develop project specific monitoring and evaluation plan

A project monitoring and evaluation (M&E) plan was developed by Jo Roberts for the Planning for Monitoring and Evaluation Workshop. This workshop involved all project partners and was held on 12 August 2015. The Monitoring and Evaluation Plan was designed to be a project management tool to help qualify the outputs, outcomes and impacts of the project. The project (1) measured the level of adoption of smallholder teak and sandalwood woodlots during project partner extension and engagement of lead farmers; (2) evaluated the transfer and adoption of knowledge related to management of nurseries and woodlots; and (3) recorded the dissemination of extension materials. The outputs for monitoring and evaluation are located in Section 7 Activity 5.2 "Project monitoring and evaluation".

6 Achievements against activities and outputs/milestones

Objective 1: To advance the teak genetic improvement program in PNG through first generation selection to produce high quality germplasm.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
1.1	**Further develop existing provenance-progeny trials as first generation seedling seed orchards**			
1.1.1	Quantify growth parameters across the provenance/progeny trials	Data that quantifies relative performance of provenances and families	Y1/M6 12.2015	See below The results of activity 1.1.1 are used as the basis for activity 1.1.2.
	UNRE: Growth and form measures for the UNRE clonal plots were conducted at 0.9, 1.7, 2.8, 3.5 and 5.5 years and used to determine the relative performance of the provenances as clones. The measurement procedure was developed into a technical note (Page *et al.* 2018c) for staff capacity building and standardisation of assessment across the project. In August 2019 leaf samples were systematically collected from the clonal teak trials at UNRE for evaluation of carbon isotope discrimination. Overall, 125 leaves from 28 clones across two different trials were sampled and analysed (Ellsworth 2019). **FRI:** The first teak provenance trial was established during May 2015 in Situm, Morobe Province, and assessed each year for the first four years. The trial was established in May 2015 with 315 seedlings from 5 provenances. Tree growth over four years was exceptional across all the provenances tested, with no significant difference between them during any year. The following site data at 4 years mean DBHOB (18.1cm) MAI (4.5cm.yr^{-1}), height (16.0m) and basal area (12.9 m^2). A second teak trial was established at Situm in April 2016. It was a teak progeny-provenance trial which was planted adjacent to the teak international provenance trial. Incomplete block design (IBD) was applied, with 8 replicates, 8 plots per replicate and 9-tree plot in an area of 1.03 ha. Initial spacing is 4 m x 4 m. A total of 584 seedling stumps were planted in the trial, with 100 seedling stumps from Kuriva Tree number 15 (KU15) used as single-buffer planting (Lata *et al.* 2019). This trial has had excellent growth and although it is yet to be measured, seems set to provide important genetic contribution to teak breeding in PNG.			
1.1.2	Undertake comparative statistical analyses of growth parameters between provenances and make appropriate selections	Identification of superior family lines for inclusion in the domestication strategy.	Y1/M9 03.2016	This work is reported in more detail in the results section of this report as well as in Page *et al.* (2018b). The results of activity 1.1.2 are used as the basis for activity 1.1.3.
	UNRE: A total of 91 individual trees representing 59 genotypes were selected at 41 months. The clones were categorised as being putative plus clones (denoted as 'p20' with 2 to 4 individuals of the same clone selected) or selected clone (denoted as 's39' with only 1 individual of the clone selected). **OISCA:** Yield plots across all provenances plots at OISCA were established and used as the basis for comparison among them. The first phase of individual tree selection was conducted across all OISCA plantings that were established from 2011-2016. These trees were classified and marked in Sep 2019 in a collaborative exercise between OISCA and UNRE. **FRI:** Survival varied from 16 % to 34 %, and mortality was influenced by site variation. Honduras and Nambi sources displayed rapid growth, although the straightness and branching size were better for Honduras compared to Nambi. Thailand provenance displayed a better score of 1.5 and 6 for stem form and branching size compared to other provenances. Individual tree selections from Situm provenance trials are yet to be made.			

<table>
<tr><th>No.</th><th>Activity</th><th>Outputs/ milestones</th><th>Due date of output/ milestone</th><th>Progress</th></tr>
<tr><td>1.1.3</td><td>Implement thinning of the provenance trials and removal of underperforming trees.</td><td>First stage of conversion to seedling seed orchards</td><td>Y2/M12
06.2017</td><td>An Excel-based model was developed to assist in planning of the thinning of woodlots and trials. The model permits the testing of different thinning strategies and their effect on the stand attributes and tree spacing.
The developed models have been applied to UNRE, OISCA and farmer woodlots.</td></tr>
<tr><td></td><td colspan="4">OISCA: Thinning was undertaken in OISCA Block 4 (TG5- Mt Lawes) in February 2016. The results of the thinning were used for sale at and construction of small roadside market houses along the road from Warrangoi to Kokopo (Figure 42).
UNRE: Underperforming individual trees and clones were thinned in January 2019. The stand was reduced from 590 stems/ha to 442 stems/ha, with the ultimate goal of a rate of 200 stems/ha as a seed orchard. Consistent with a thinning from below, 25% of standing stems and 14% of basal area was removed by this operation. This was the first stage of conversion to an improved seedling seed orchard. The details for the thinning operations are found in Jenkin and Minimulu (2019b)</td></tr>
<tr><td>1.1.4</td><td>Evaluate options for promoting sexual maturity in teak.</td><td>Method for stimulating early onset of seed production</td><td>Y1/M12
06.2016</td><td>Project partner teak stands began to produce seeds during the project and therefore research into promoting sexual maturity was not considered necessary.
Seed collections made by project partners during the course of the project was limited to two. The production from existing stands are likely to increase over time. Through progressive thinning of underperforming trees, the project partners can become self-sufficient in teak seed to supply smallholder growers.</td></tr>
<tr><td></td><td colspan="4">OISCA: The teak trees established at OISCA between 2011 & 2014 (4-7 years) produced seed annually from 2017/18 onwards. In August 2019 OISCA expressed that these provenance blocks represent a sustainable source of teak seeds for community woodlots. A simplified seed collection protocol was developed for collecting teak seed from the provenance plots (Page et al. 2020d) and the first seed collection (up to 1kg) was made by OISCA and UNRE staff in 2020.
UNRE: Seed collections were made from 12 individuals in clonal plot 1a in Sep 2017. Eight of these seedlots failed to germinate, while the germination rate in the other four seedlots ranged from 1.8% to 24.7%. This low germination rate is consistent with the known seed viability issues with the species, and the young age of the trees. Seed collections were also made (Feb 2018) from two locally growing sources at Kerevat and Kereba, with 1320 and 1393 seeds sown immediately from the respective sources and resulting in 25.3 and 13.1% germination respectively.</td></tr>
<tr><td>1.2</td><td colspan="4">Establish a network of seed orchards (CSO) and clonal hedges of plus trees.</td></tr>
<tr><td>1.2.1</td><td>Undertake truncheon cuttings of selected individuals (plus trees).</td><td>Clonal plus trees in the nursery</td><td>Y1/M12
06.2016</td><td>Selected trees were captured as clones through a range of propagation methods conducted by UNRE & FRI. A technical protocol of the successful truncheon cutting method was documented in Lata (2019).</td></tr>
<tr><td></td><td colspan="4">UNRE: Clonal capture studies including (a) clonal hedge gardens; (b) truncheons; and (c) cincture were conducted. Truncheon technique resulted in 40% rooting success. An overlapping girdle/cincture was applied to nine of the outstanding clones of the selected teak trees during 2018, in an attempt to promote epicormic growth. All but one tree produced basal shoots and cuttings were collected, resulting in the capture of 3 of the 9 (see activity 1.2.2). More detailed results are contained in (Kulang 2018b; Kulang 2018a).
FRI: Truncheons cuttings formed the basis for capturing selected clones from 6 sites in the country including Kerevat-Vunapalading, Oomsis Forestry Station, Mt Lawes CSO, Kuriva, Erima (Madang) and East Sepik. These truncheons were propagated at FRI nursery using leafless teak stems of varying sizes.</td></tr>
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<table>
<tr><th>No.</th><th>Activity</th><th>Outputs/ milestones</th><th>Due date of output/ milestone</th><th>Progress</th></tr>
<tr><td>1.2.2</td><td>Establish clonal hedge garden of selected clones</td><td>Plus tree clonal hedges</td><td>Y2/M8
02.2017</td><td>Hedge gardens comprised of superior clones were established at UNRE, OISCA & FRI. See Below</td></tr>
<tr><td></td><td colspan="4">UNRE: Clones were selected from high performing trees established in the UNRE Clonal Plot 1a at age 3½ years (Page et al. 2018b). Two types of clones were identified candidate plus trees (p20) (with 2 or more ramets selected) and selected (s39) trees (with only one ramet selected). Two hedge gardens were established using these clones, one each at UNRE and OISCA. The number of p20 available as seedlings/hedge plants in the UNRE nursery was 13 clones, and at OISCA was 19 clones.
FRI: A total of 61 hedge plants representing 47 clonal genotypes were established in the clonal bank by end of August 2019 (Inu 2019; Lata et al. 2019). The hedge garden comprises clones originating from the following locations: Vunapalading-Kerevat (7 June 2012 & 21 December 2013), Oomsis (December 2013), Mt Lawes CSO (planted May-Aug 2014, Feb-Mar 2015), Kuriva (planted Feb-Mar 2015), teak woodlot-Madang of Honduras & Santa Alicia origin (planted April 2019), and East Sepik (planted Aug 2019). The work rescued 28 clones (out of 29 clones) represented at the Mt Lawes CSO before it was harvested in 2019. A significant impact by the project to rescuing the remaining teak genetic materials before it was clear-felled.</td></tr>
<tr><td>1.2.3</td><td>Bulk up cuttings of selected plus trees</td><td>Plus tree clones ready for distribution.</td><td>Y2/M12-Y4M12
06.2017-06.2019</td><td>See Below

The results of activity 1.2.3 are used as the basis for activity 1.2.4.</td></tr>
<tr><td></td><td colspan="4">UNRE: Clonal propagation of teak was achieved throughout the project using hedged stock plants and non-mist propagators. Experiments were conducted to capture additional clones within trial 1a using truncheon cuttings and leafy stem cuttings collected from the canopy as well as coppice material resulting from overlapping cinctures.
FRI: A series of cutting experiments was undertaken to improve propagation protocols and supplement the available cuttings. The resulting cuttings were used for the establishment of Rocky Creek Teak CSO at Kuriva Plantation. The experimental results were documented in Lata et al. (2016).</td></tr>
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<table>
<tr><th>No.</th><th>Activity</th><th>Outputs/ milestones</th><th>Due date of output/ milestone</th><th>Progress</th></tr>
<tr><td>1.2.4</td><td>Establish either clonal seed orchards or hedges with participating institutions and/or external nurseries</td><td>Network of teak germplasm for improved seed and clones</td><td>Y3/M12-Y4/M12
06.2018-06.2019</td><td>Two clonal tests (UNRE & OISCA) and one clonal seed orchard (Kuriva) was established using selected teak clones.
Full details of the UNRE Clonal Trial Series is provided in Page et al. (2018a). Information on the clonal seed orchard at Kuriva is located in Lata (2017a) and Lata (2017b)</td></tr>
<tr><td></td><td colspan="4">UNRE: A clonal test (2a) was established at UNRE on a site adjacent to the existing clonal planting in August 2017. The clonal test was established to determine the validity of early selection in teak by evaluating the growth and performance of the ‘p20’ and ‘s39’ selections as replicated ramets. The trial was established as a complete randomised block design with 20 replications. The aim was to include all ‘p20’ clones across the 20 replicates, but numbers of available cuttings meant that 11 x p20- & 10 x s39- clones were utilised. Based on mean stem diameter (DBH) growth in the clonal test 2a, the candidate plus clones (12.2 cm and 6.1 cm.yr^{-1} respectively) significantly outperformed selected clones(10.9 cm and 5.5 cm.yr^{-1} respectively). Therefore phenotypic selection based on two or more individuals (ramets) is therefore a better indicator of clonal (genetic) performance compared with single tree selections.
FRI:
A clonal seed orchard comprising 208 clonal ramets was established at the Rocky Creek site at Kuriva 21st June 2017 (Lata 2017b; Lata 2017a). Mean stem diameter at 12 months ranged from ~2.5 (Clone 26 from Mt Lawes) to 5.85 cm (Clone 12 from Mt Lawes). Mean tree height at 12 months ranged from ~3.5 (Clone 26 from Mt Lawes) to 6.17 m (Clone 12 from Mt Lawes). Good performance in stem diameter growth (<4cm) was found across 6 clones, with 2 each from Mt Lawes (C12 & C41), Kuriva (K24 & K26) and Vunapalading (T1 & T4).
OISCA
A clonal test was established on OISCA grounds in Aug 2019 comprised of 20 clones: 16 classified as putative plus tree (P20) and 4 classified as selected (S39). The trial was established as an incomplete block design with 9 replicates of 20 clones. These include the candidate plus tree (p20) clones C25 (11 ramets), CST5-08 (11), CST5-11 (7), H07 (9), I06 (11), I08 (6), J10 (8), K02 (4), L08 (6), L09 (8), T05 (7) and the selected clones(s39) clones C33 (11), CST5-01 (11), CST5-03 (11), CST5-06 (6), I02 (6), I05 (11), K07 (11), K09 (11), K11 (11).
Nursery Network
The project has been successful in establishing 38 smallholder nurseries that can produce bare-root teak seedlings for distribution among other smallholders. During this project the seed and extension inputs were provided by the project and the seedlings were distributed gratis to interested growers.</td></tr>
</table>

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
1.3	Develop nursery protocols for commercial production and dissemination of improved teak germplasm			
1.3.1	Conduct workshop with candidate nurseries	Identify commercially focused nurseries with an interest and capacity to incorporate teak.	Y1/M2 08.2015	Output recorded in nursery workshop report (Page 2015).
	A workshop with nursery owners was held in Kokopo on 15th October 2015 to seek input from the nursery sector and government in ENB about a suitable approach to teak development, and also to identify constraints to the development of commercial teak production in ENB. A total of 20 participants attended the workshop representing government (NARI, PNGFA, Provincial Administration), Institutional (NGIP Agmark, ENB Workers Union) NGO (WYA), Education (UNRE) and 3 smallholder-owned private nurseries. The workshop comprised presentations (PNGFA, USC, JCU, OISCA, Sylva systems & UNRE). The primary feedback was that clonal teak propagation should be the domain of specialist nurseries such as UNRE, OISCA & NARI. Private nursery owners were reluctant take on the technical demands of producing clonal teak. The five smallholder nurseries (Michael Keras, Ereman Bethuel, Kaepas Tika, Patrick Varagai & Jeffrey Willie) were very interested in producing bare rooted seedlings owing to the simplicity and cost effectiveness of production (Page 2015). UNRE is the only nursery with the capacity to produce clonal teak in ENB. Extensive In-field nursery extension with lead foresters, nursery owners, school groups and individual farmers has been conducted by OISCA throughout the project. Lead Foresters have been actively engaging other interested farmers to become involved with the project (see task 1.3.3).			
1.3.2	Review of existing literature for teak nursery production and development of specific training materials	Teak specific nursery content added to Tree Planting Tool-Kit.	Y1/M6 12.2015	A literature review has informed the development of nursery techniques to build on current PNG practices and previous works undertaken by the PNG FRI. An important step has been to document the current nursery practices of seedling establishment, management and growth. The process of “stump” preparation from the resulting seedlings has been documented (Jenkin and Page 2017a). The literature review informed the development of the teak silvicultural manual in activity 2.1.1 (Jenkin 2019b). The results of activity 1.3.2 are used as the basis for activity 1.3.3, 2.1.7 & 5.1.3

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
1.3.3	Provide training to participating nurseries for the clonal and seed propagation of teak	Nursery network with a capacity to produce teak for market.	Y1/M8 02.2016	See below
	OISCA has completed in-field demonstrations of site preparation, demarcation and teak stump (bare root) planting have been conducted across all 38 nurseries. This has led to the distribution of over 22,500 teak stumps across 500 recipients. Extension activities conducted by OISCA have greatly enhanced farmer capacity and interest in developing nurseries and cultivating teak Recipients include • 2 Community Trial Sites (Irena – West Pomio, Napapar #5 Central Gazelle). • 8 Demonstration Sites (1 Church, 1 Pastor College, 6 Schools (1 Elementary and 5 Primary). • 8 Lead Farmer Woodlots • 500 farmer woodlots • 8 Project Workers planting on own customary land The average size of each planting is 70 seedlings, but typically either 50 or 100 each. Survival has been recorded across 195 of 500 recipients with an average of 87% planted seedlings surviving.			
1.3.4	Prepare development proposal for potential donors (microenterprise development)	Development Proposal	Y1/M6 12.2016	See below

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
	Based on contacts with other agencies in PNG, awareness has been raised on the ACIAR project's teak elements. This has resulted in the UNDP exploring ENB as a pilot candidate for funding from the Green Climate Fund during mid 2018 with OISCA Director Norbert Perry being invited to a planning meeting in Port Moresby. Inputs have been made into the PNGFA's plantation development program of 'Operation Painin Graun na Planim Diwai' on development of commercial plantations and woodlots in PNG through Pacific Island Projects throughout the ACIAR project. The ACIAR project (OISCA, PIP and USC) hosted ITTO (International Tropical Timber Organisation) in East New Britain during August 2019 to explore the potential for developing an agroforestry-based development project that builds on the genetic, information and community resources of this ACIAR project. Through these interactions OISCA are now a partner in a new ITTO project "Enabling Customary Landowners to Participate Effectively in Community Forest Management - PD 764/14 Rev.2 (F)". OISCA presented the ACIAR project activities at the UNPD "Subnational Design Workshop of the GEF-7 Impact Programme" in Kokopo in Nov 2019. Since then the UNDP-GEF concept note covers activities in East and West New Britain. The title is *Establishing systems for sustainable integrated land-use planning across New-Britain Island in Papua New Guinea.* The following activities relate to the work being done by ACIAR project partners in ENB: Output 3.7: Development of small-scale woodlot support system through small scale service providers at district level with inclusion of support to forest rehabilitation and Output 4.3: A knowledge exchange platform created with conferences, knowledge products and national and international learning exchanges through participation in the FOLUR community of practice of the global Platform.			

PC = partner country, A = Australia

Objective 2: To ensure maximum realisation of genetic gains made by the project through the development of robust and smallholder appropriate silviculture.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
2.1	**Identify appropriate establishment silviculture prescriptions.**			
2.1.1	Review existing silviculture practices for teak and sandalwood around the world	A documented review of current teak and sandalwood silviculture focusing on general species requirements	Y1/M4 10.2015	The literature review for teak was incorporated into the silvicultural manual (Jenkin 2019b). The literature review for sandalwood contributed to the publication of a scientific manuscript (da Silva *et al.* 2016) The results of activity 2.1.1 are used as the basis for activity 1.3.3, 2.1.7 & 5.1.3. and 2.2
	The teak silvicultural manual document represents a consolidated statement of the silviculture of Teak with particular reference to farmer woodlots, resulting from a collation of a wide range of historic and contemporary information (Jenkin 2019b). A sandalwood literature review on propagation, production, and hosts was completed, which contributed to the publication of a research manuscript for international sandalwood. Relevant content from this review and an evaluation of similar training resources was used to inform the development of training and extension materials, including brochures and video content (see activity 2.1.7), as well as a regional growers' manual encompassing PNG sandalwood (Page *et al.* 2020a).			
2.1.2	Select communities and/or individual smallholders to host silvicultural trials, based on interest and capacity	Candidate communities and /or individual smallholders selected and engaged	Y1/M3 09.2015	For teak five sites were selected in consultation with OISCA. These include OISCA, Gunanur (CPL), Irena Ward, Napapar #5 Ward, and Lavakaka. For sandalwood three communities were selected in consultation with PNGFA: Iokea, Girabu and Kairuku.
	Teak:Two teak spacing trials were established at: • OISCA ecotech training Centre (1290 trees 1.26 ha Jul/Aug 2017) good to moderate survival • Gunanur (CPL) Kokopo/Vunamami LLG, Kokopo District (1029 0.94 ha trees - Jul 2018), good survival Three teak spacing demonstration plots established at: • Irena Ward, West Pomio LLG, Pomio District (226 trees 0.3ha - Sep 2017), good survival • Napapar #5 Ward, Central Gazelle LLG, Gazelle District (212 trees 0.23ha trees - Feb 2018) good survival • Lavakaka Ward (Rabaul Dist Admin) Balanataman LLG, Rabaul District (466 trees 0.45ha – Feb 2018), complete loss of the trial due to cattle entry and grazing **Sandalwood**: Awareness activities were undertaken to identify candidate growers with the potential to host the trials (Oa and Rome 2015). Water tanks, hand tools (secateurs, pruning saw and loppers gum boots etc), shade cloth, nursery fertiliser (thrive) were provided to each of the three communities (Guduru Rome, Linden Oa & Mark Hasu) for establishment of central nurseries and maintenance of the trial plots (Rome 2018). ILG consultations were conducted in both Girabu and Iokea clan/community groups during 2016, 2017 and 2018 (Rome 2016; Rome 2017; Rome 2018). The ILG project sites were mapped and clan members identified in both Iokea and Girabu. No ILGs were successfully established during the project. The main issue was the change in ILG format requiring all members to have the National Identification (NID), which required a birth certificate. All the work done up until the restructure of the ILG process was voided and so the process needed to be repeated. Also associated with the ILG was the MOU required between PNGFA and the Lands Department so that PNGFA officers could conduct the registration. The MOU was drafted but it took three years for it to be ratified. The lack of an ILG did not have an effect on the progress of works undertaken at Iokea or Girabu. In Kairuku sandalwood woodlots were established with individual smallholders, and ILGs were not required.			

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
2.1.3	Undertake land management and needs assessment with each community	Current land management systems and landowner needs documented for the engaged communities	Y1/M6 12.2015	Land management needs have been evaluated during the workshops to identify landowner constraints to participation in the planted forestry/agroforestry. This information was summarised in (Jenkin 2019c).
2.1.4	Source and germinate seed and establish teak stump beds and sandalwood seedlings.	Teak stumps and sandalwood seedlings ready for planting	Y1/M4 10.2015	See Below The results of activity 2.1.2 are used as the basis for activity 2.1.5.
	Three teak seed introductions were made during the project: (1) 50kg teak seed from Tanzania in October 2015; (2) 215.4 kg of teak seed from Costa Rica in September 2016; and (3) 1.5kg seed from Laos. The seed from Tanzania and Costa Rica was divided among all project partners, while the seed from Laos was distributed to UNRE. The Costa Rican consignment comprised 7 seed lots, 4 of which have been imported before (Honduras, Jicaro, Penas Blanca, Hojancha) and 3 were new introductions (LaCruz, Guanacaste and Natora). Seed from six of the seven Costa Rican seedlots (excluding Jicaro) were distributed to non-partners NARI (0.5kg of each six) in WAYiA (0.66kg of each six) and Paul Hittamore in Central Province (0.5kg of each 6 Costa Rican seedlots). A 1.5 kg teak seedlot from Laos was imported into PNG in August 2017 and provided to UNRE. OISCA has facilitated further distribution of the imported teak seeds to 38 community nurseries in four districts of ENB: i) 24 in Gazelle; ii) 6 in Kokopo; iii) 5 in Pomio; iv) 2 in Rabaul; and v) 2 outside of ENB. PNG Forest Authority (PNGFA) facilitated the establishment of a sandalwood nursery in collaboration with the Kairuku, Iokea, Girabu and communities. For more information on the sandalwood seedlots arranged for this project see activities 3.1.1 and 3.1.2.			
2.1.5	Establish silviculture trials with 3-4 communities for each of teak and sandalwood	Adaptive plantation silviculture	Y2/M1 07.2016	Reporting on this project activity for teak (Jenkin and Minimulu 2019a) and sandalwood (Rome and Oa 2019). Project partners (OISCA & PNGFA) have reported that the trials and demonstration plots have stimulated smallholder and institutional interest in planting these trees.
	Teak: Five teak silviculture plots have been established in East New Britain since Jul 2017, with three spacing treatments (2 x 2, 4 x 4 & 6 x 6m), using the Costa Rican teak source Penas Blanca. The aim of the silvicultural trials was to explore the outcomes of teak silvicultural strategies from the perspective of smallholders in ENB. A secondary aim was to explore the most cost effective and efficient methods of establishing and managing planted teak at all scales of development. Site selection covered four districts and trial sites were located along main roads. This has been shown to be effective for demonstration purposes to foster public interest in teak and tree planting and in commercial teak development. Sandalwood: Girabu: The silviculture trial in Girabu has performed well with <97% survival across the site. The pot host proved to be very effective weed control, protecting the sandalwood roots from the hot sun and providing a host. There was no difference in growth of sandalwood between the two long-term host treatments (Cassia and Leucaena). Garden crops were maintained during the wet season in the first four years. Pineapple persisted on the site for at least 5 years and vanilla was planted under each of the Cassia trees at age 3-4. Iokea: The Iokea trial site performed well for the first 18 months. With the abandonment of the garden crops after this time the kunai grass recolonised the site. Host plants and sandalwood were overgrown with kunai grass. A deliberately lit fire entered the site in Aug-Sept 2017 and caused significant mortality. The trees were measured in November 2019 with 92 surviving seedlings (18.4%). Kairuku**:** The approach taken in Kairuku differed from Girabu and Iokea. Kairuku is an area with high population and families generally reside in their own blocks of up to 1ha. Given the distribution of the population across small blocks the project engaged with multiple nuclear families. The project assisted them to establish small garden woodlots, boundary or specimen plantings within their homestead. At least 35 small family woodlots (mean 45 trees each) across 8 villages were established in Kairuku during the project.			

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
2.1.6	Quantify growth and performance parameters of silvicultural trials	Adaptive plantation silviculture report	Y3 & 4/M1 07.2017 07.2018	Reporting on this project activity for teak (Jenkin and Minimulu 2019a) and sandalwood (Rome and Oa 2019).
	Measurement of the trial sites was conducted in collaboration with UNRE scientists and OISCA field staff. Tree DBHOB was measured at OISCA block 3 (17 months), Napapar (19 months) and Gunanur (19months). OISCA block 3 site was not measured as the trees were too small. The early growth measures determined that competition between trees commenced at between 1.5 and 2 years (basal area of 5 to 7 m^2/ha) for 2x2m. While this seems to be a low trigger for thinning, it demonstrates he rapid growth of teak in ENB. For replicates planted at 4X4 m spacing and based on current stocking rates, a basal area of 6m^2/ha (a mid-point of indicative competition thresholds) would be achieved at a mean DBHOB of 11.3 to 12.0 cm. For replicates planted at 6X6 m spacing and based on current stocking rates, this would be achieved at a mean DBHOB of 17.2 to 22.2 cm. Results from the teak clonal and provenance trials suggest that competition among teak at 4x4 m spacing occurs at between year 2 & 3 (see activity section Key Results & Discussion Objective 1.1 Situm and 1.2 UNRE Clonal Test). Sandalwood productivity was found to be highly variable between sites. A mean annual increment for diameter (DBH) of 0.74cm.$year^{-1}$ when planted into grassland areas without soil cultivation. In contrast sandalwood productivity was found to reach up to 2cm.$year^{-1}$ in sites where soil has been cultivated and gardening implemented for a period of 3 years. At year four no significance difference in sandalwood growth was found between the two host treatments *Cassia fistula* and *Leucaena leucocephala*. While Leucaena offers scope for being used as green livestock fodder, in PNG it is rarely used for this purpose. Fire caused significant losses (84%) in the Iokea plot. Fire remains the most significant threat to sandalwood production in PNG particularly in areas where the fire-adapted grass *Imperata cylindrica* dominates.			
2.1.7	Produce extension materials for smallholder systems for teak and sandalwood.	At least 3 interim tech notes prepared The outcomes of the designed systems documented	Y2/M11 05.2017 Y4/M6 12.2018	Two teak fact sheets, four technical notes, and three manuals were produced for teak. Five fact sheets and four technical notes were produced. A total of 18 instructional videos were produced. Distribution of printed resources are outlined below. All these resources are provided on the PIP website: http://www.pip.com.pg/projects/completed-projects/185-improvement-and-management-of-teak-and-sandalwood-in-png-and-australia The adoption of the silviculture system for teak was evaluated during the woodlot inspections, lead farmer interviews and tree grower focus group discussions (Page and Vinarut 2017). The outcomes of the sandalwood systems were documented during inspection and measurement of the woodlots (Rome and Oa 2019).
	Both OISCA and Mission Base Resource centre have been provided with 500 printed brochures for distribution among their grower networks. Up to 50 printed extension documents were distributed to the farmers and field workers at the following locations: • Togoro Community (Bitapaka LLG, Kokopo District) with OISCA • Toma Valley Community (Toma Vunadidir LLG, Kokopo District) with OISCA and PNG Missions • Ramalmal Community (Reimber-Livuan LLG, Gazelle District) with OISCA • Division of Conservation & Environment (ENB Provincial Administration) • Division of Primary Industry (ENB Provincial Administration) • Puktas Community (Lassul Baining LLG, Gazelle District) with PNG Forest Authority			

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
2.2	Define silvicultural systems that optimise economic returns			
2.2.1	Develop teak and sandalwood smallholder “financial” models.	A financial model developed and road tested	Y1/M8 02.2016	Financial models were developed for teak and sandalwood. The models demonstrate that smallholder production of these trees is financially viable. Both models are available for download on the PIP Website.
	Teak: A financial model calculated revenue generated from the sale of thinning material and sawn timber at full rotation of 20 years. The following assumptions were made: Planting density of 625 stems/ha Thinning of 30% of standing trees at ages 2 (fuelwood & poles), 6 (fuelwood and posts), 10 (fuelwood, posts and 2nd grade saw log), and 15 (fuelwood, posts and 2nd grade saw log) years with clear fell harvest of 150 mature trees at year 25 for 1st and 2nd grade sawlog production. Maintenance costs including establishment (PGK2494/ha, 44.5 person days labour input), pruning (PGK587/ha - 23.5 days), thinning (PGK3805/ha - 152.2 days) and final harvest (K378/ha - 15.1 person days/ha). The prices allocated per m3 for fuelwood PGK100, poles PGK300, posts PGK500, 2nd grade sawlog K150 and 1st grade sawlog K300. At a discount rate of 7% the NPV was PGK18,212/ha at year 25 with a return to labour of PGK342/day and an Internal Rate of Return 23.5%. **Sandalwood:** A financial model for sandalwood was developed in Excel and based on a stocking rate 232 sandalwood and 168 long-term host plants per hectare. Three price scenarios are provided within the model for minimum, expected and maximum values for heartwood products. The model also included provision for the presence or absence of agricultural crops produced in the first four years. The figures presented here are for the expected heartwood value and no agricultural crops produced. Silvicultural practices in the model includes: fertilization at planting and annually until year three of 50g/tree, pruning up to year four, weeding up to year seven. Planting costs including establishment (PGK7,604/ha), pruning (PGK444/ha), weeding (K1015), opportunity costs (PGK2,000) tree protection (K507) and harvesting and transport (PGK7,293). Heartwood yield based on production model of (Page *et al.* 2012) split at 25% carving wood (PGK30/kg) and 75% heartwood (PGK10/kg) harvested at 15 (half fell) and 20 year (clear fell) rotation. At a discount rate of 7% and using the most likely product prices the Net Present Value (NPV) was PGK17,033 and PGK24,427 for the woodlot planting and agroforestry planting models respectively. The respective Internal Rates of Return (IRR) was 15% and 24%. The most likely return to labour is PGK56 and PGK69 per day for the woodlot and agroforestry plantings respectively. This return to labour exceeds the PNG minimum wage of PGK24 per day.			
2.2.2	Document outcomes of the application of the two models		Y1/M12 06.2016	Key financial information derived from the sandalwood model was included within a technical document to inform smallholder investment in planted sandalwood (Page *et al.* 2020a.
2.2.3	Define smallholder adaptive silvicultural systems for teak and sandalwood	Review completed and report prepared	Y2/M06 12.2016	Adaptive silviculture documents for teak (Jenkin and Minimulu 2019a) and sandalwood (Page *et al.* 2020a)
2.3	Model estate and marketing plans			
2.3.1	Develop a working arrangement and modelling protocol together with species (teak and sandalwood) business plan template	Arrangements and modelling developed and documented.	Y2/M12 06.2017	Discussions with the PNGFA, in line with the national objectives to develop up to 800,000 ha of planted trees by 2050. An estate modelling excel template was developed for teak that was incorporated into the financial analysis.
2.3.2	Prepare specific regional business plans and mapping.	Business plans and mapping developed, workshop held	Y3/M12 06.2018	A model estate and marketing plan was developed for teak (Jenkin 2019a). While a workshop was not held for this activity sandalwood stakeholder engagement included interviews of 12 previous and current sandalwood resource owners, 6 traders and 2 exporters. From this a review of sandalwood policy and marketing of sandalwood including and recommendations for reforming trade was developed (Rome *et al.* 2020).

Objective 3: To develop capacity for an ongoing genetic improvement program for sandalwood in PNG.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
3.1	**Establish species/provenance sandalwood trials.**			
3.1.1	Engage with local landowners to work collaboratively on seed collections from across the natural range of *S. macgregorii*	Seed collected from a range of *S. macgregorii* populations	Y2/M06 12.2016	See Below The results of activity 3.1.1 are used as the basis for activity 3.1.3 and 3.1.4.
	Sourcing seed from S. macgregorii With repeated visits to landowners in Gomore that have a small sandal woodlot, they are now collecting significant volumes of reasonable quality seed for sale. During the project 7kg of *S. macgregorii* seeds were secured from Gomore (Lava & Helalo). This seed was distributed to eight different recipients including Girabu (Rome - 2kg), PNGFA (2.3kg), Hitamoore (500g), FRI (1050g), Kairuku (Popo - 500g; Fauma - 200g, Oa - 250g) and Iokea (Hasu - 250g). In 2019 seed (1.0 kg) from the project woodlot in Girabu was distributed locally (500g) and to Kairuku (500g).			

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
3.1.2	Identify and introduce seed from exotic commercial sandalwood species	Seed sourced from a range of commercial sandalwood species.	Y1/M12 06.2016	See below Seedlings resulting from this activity were used in activity 3.1.3.
	Four sources of *Santalum album* (Australian sources Mackay, Ethereal, Wiles & Pronk) and two sources of *S. austrocaledonicum* (Vanuatu) were introduced during the project. A total of 15,000 seeds were sown with ~1,500 seedlings produced representing an germination of 10%. The variable seed germination represents an issue of seed quality rather than germination or nursery techniques since there was variable quality with germination ranging from 0 to 87% (Table 4). This represents a significant issue for the commercially available seed supplies for sandalwood. This also demonstrates the need for PNG to develop its own reliable sources of sandalwood seed. The 1,500 seedlings have been used to establish the provenance trial as outlined in activity 3.1.3.			
3.1.3	Establish ~4ha central species/provenance sandalwood trial from all species	Species provenance trial established	Y2/M12 06.2017	See Below Seed procured under 3.1.1 and 3.1.2 were used in this activity
	Kuriva A sandalwood species/provenance trial (0.8 ha) was established at Kuriva in early Feb 2018. At 18 months the site was refilled with substitution of Ethereal seed source with *S. album* from Lae originating from a Kununurra seed orchard imported as part of FST/2004/009. Survival was recorded in Jul 2019, and of 328 (92%) surviving sandalwood seedlings, 49.3% were measured as 'normal seedlings', while 50.7% were classified as coppices. These coppices were developed mostly at the root collar from seedlings debarked or chewed by rats. In August 2019 'normal' seedlings were measured and had a mean height of 1.8m and 2.5cm basal diameter (200mm AGL). **Situm** The 1ha sandalwood trial at Situm was established in mid-2017 and comprised 3 species (*S. album, S. macgregorii and S. austrocaledonicum*) with two different sources *S. album* (Mackay & FRI). Each source was replicated twice in an incomplete randomized block design. Each replicate has number of seedlings ranging from 17-22 with the host plants (rosewood cuttings) allocated among the sandalwood trees. This trial had significant mortality which was attributed to the high and consistent annual rainfall without a dry season. The high mortality led to the abandonment of the trial in late 2018.			
3.1.4	Establish *in situ* 1-3ha seed stands/host trials of *S. macgregorii* within three participating communities	Report on achievements towards in situ conservation and seed stands	Y2/M12 06.2017	Stands were planted at Girabu (1ha) Iokea (0.5ha) and Kairuku (~3ha). The Iokea stand was destroyed by fire These community sandalwood initiatives function as *in situ* seed stands and results were presented as a paper at the Sandalwood Regional forum in Vanuatu in Nov 2019 (Rome and Oa 2019)

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
	This study has demonstrated that expansion of the resource through planting offers one option for resource restoration. The project provided support in the form of capacity building (training) and materials (nursery supplies, germplasm, water tanks, small tools and safety gear), but no cash payments were made. The target of 1-3 ha woodlots established in three communities was achieved in Kairuku with an overall planting rate of ~3ha at 400 stems ha^{-1}. In Girabu 1.0 and 0.5ha woodlot was successfully established. In Iokea 0.5ha woodlot was planted but ultimately succumbed to fire. Sandalwood production is most applicable at the family level, where land ownership, and benefit sharing issues are simplified and can be sustainably managed at this scale. Sandalwood production is also applicable when established in home gardens where hosts are readily available, thus simplifying the production process. This was demonstrated in Kairuku where adoption rate and number of trees planted was greater than the two clan-based plantings.			

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
3.2	Characterise intra and inter population variation S. macgregorii in PNG.			
3.2.1	Undertake morphological, oil chemistry and botanical assessments and genetic collections in *S. macgregorii*.	Morphological relationships characterised	Y2/M06 12.2016	The resource survey was conducted during Aug and Sep 2019 and surveyed 126 trees across five geographic locations in Gulf, Central and Western Provinces.
	The descriptions of sampled trees included: total height, bole length, habit, diameter over bark at 0.2, 0.7 and 1.3 m, age estimate, canopy spread from north to south and east to west, count and measurement of fire scars. Tree form was assessed as to four categories (1) single stem, (2) trunk forking, (3) 2-3 primary stems from the base or (4) multi-stemmed shrub. Stem taper calculations were based on stem diameter reduction between measurement points per linear meter of stem (*i.e.* ($Dia_{0.2}$–$Dia_{0.7}$)/(0.7-0.2m)). The reproductive status was estimated by observing the density of buds, flowers, maturing fruits and mature fruits using a scale of 0 (nil) to 5 (high). Recruitment via suckers and seedlings within 10 m of sampled trees were counted and either basal or breast height diameter were measured when recruits were > 100 cm in height. Any physical or biotic damage was recorded on a scale of 0 (nil) to 5 (high). Physical damage was further classified as deliberate or indiscriminate for bark slashing and heartwood check was noted for severity, frequency and cardinal direction. Heartwood check is a practice where people make wedge shaped cuts of various depths into the tree stem to check for the presence of heartwood			
3.2.2	Examine and describe botanical relationships within *S. macgregorii* and between *S. lanceolatum* in CYP.	Research paper into the botany of S. macgregorii and S. lanceolatum	Y4/M6 12.2018	Output published in Sandalwood Regional Forum (Jeffrey *et al.* 2019) and manuscript under review (Page *et al.* 2020b)
	The South Fly population of *S. macgregorii* in Western Province has morphological and biochemical similarities with *S. lanceolatum* occurring in Cape York Peninsula. This includes leaf morphometrics, bark morphology, flower colour and heartwood oil biochemistry. South Fly sandalwood is found to be divergent from the contiguous PNG populations of *S. macgregorii* of Gulf and Central Province sites for all of these traits. These results suggest that CYP and South Fly sandalwood may be a cryptic species or subspecies. Further work to demonstrate the existence of a new form of sandalwood will require molecular genetic evidence. The collection of dried leaf samples during this project will permit further exploration of the genetic relationships among *S. macgregorii* and *S. lanceolatum*. Samples of eastern PNG *S, macgregorii* were included as outgroups in the phylogenetic analysis of the CYP sandalwood and its congeners, as the South Fly populations had not been sampled at the time of the molecular study.			
3.3	Develop nursery capacity for production of wild-collected and improved sandalwood germplasm.			
3.3.1	Candidate nurseries identified and engaged	Participating nurseries confirmed.	Y1/M6 12.2015	Nurseries in all three communities were established in Iokea (central nursery and satellite), Girabu (central nursery) and Kairuku (central and satellite nurseries) More information is provided in 3.3.2 and 3.3.3
3.3.2	Review of existing literature for sandalwood nursery production and development of specific training materials	PNG specific training materials developed	Y1/M12 06.2016	The results of activity 3.3.2 are used as the basis for activity 2.1.7 and 5.1.3. A range of training materials were developed and can be found in notes on activity 2.1.7
	Sandalwood nurseries have functioned to supply seedlings for the two project sites (Iokea and Girabu) and for self-supply of seedlings in Kairuku. In Girabu a single central nursery was established by the project that supplied an estimated 500+ sandalwood seedlings for the project site and other growers. In Iokea 12 micro nurseries operated during the course of the project that supplied seedlings to the Hasu sandalwood project site. In 2019 a central sandalwood nursery was established in Biotu adjacent to the highway in Kairuku project area. A proforma document to guide FA staff to record the key information of each project nursery was drafted (Rome and Page 2018), but not completed for any of the 3 central nurseries.			

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
3.3.3	Provide training to participating nurseries for seed propagation of wild-collected sandalwood	Nurseries with a capacity for producing sandalwood seedlings Report on sandalwood production by local nurseries	Y2/M06 12.2016 Y2/M12 06.2017	Two sandalwood growers workshops were held in Dec 2017 in Iokea and Kairuku. These workshops covered sandalwood-specific content over two days with a classroom-based session on Day 1 and a field-based session on Day 2. The workshops were attended by 136 people across 10 villagers in 2 districts (Iokea and Kairuku) (Page and Oa 2017a). Further extension work by PNGFA staff have been conducted across these three sites (Rome and Oa 2019).
	A mix of central and family nurseries were developed during the course of the project. There were three central nurseries established at each of the communities, which were funded by the project. The Girabu nursery operated intermittently from 2015 to 2019 and produced over 1000 seedlings. These seedlings were used to establish the Girabu woodlot and for distribution to other families in the community. The Iokea central nursery operated for two growing seasons during the project and produced around 500 seedlings that were used to refill the trial. The Iokea nursery was upgraded with a larger water tank in the final year of the project. The Kairuku central nursery was established only towards the end of the project and produced close to 50 seedlings. In addition to these central nurseries, temporary family nurseries were established in Iokea (10) and Kairuku (15) by individual families. These nurseries supplied seedlings commercially for the project planting in Iokea (~500) and for own use and commercial sale for the family woodlots in Kairuku (over 1530 seedlings). All nurseries produced sandalwood using primarily (60%) seed sourced from local mother trees on customary land. The remaining seed was sourced by the project from the Minima (Gomore) woodlot and distributed to growers in each of the three locations. None of the nurseries were recorded to produce other types of tree seedlings.			

Objective 4: To advance the sandalwood genetic improvement program in Cape York Peninsula for use by local landowners.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
	Establish sandalwood progeny trial with improved germplasm			
4.1.1	Undertake seed collections from the sandalwood clonal seed orchards in CYP	Seed collected from a range of CYP genotypes.	Y1/M12 06.2016	See below
	Seed was collected from the 18 trees representing the genotypes captured into the clonal seed orchards/ clone bank of the species. Early seed collections were used to establish two progeny trials back 'on country'. More recent seed collections have increased the supply of this previously scarce resource with enough seed on- hand to establish over 20 hectares of trials and/or commercial plantings of the species if additional funds become available. The Traditional Owners have land available to establish plantations, but do not access to the funds needed to establish and manage the plantations. Seed has also been collected from six more recently captured (grafted) wild trees. Seed viability tests on a clonal basis range from 42 to 100%. Selection of CYP genotypes was based on earlier studies indicating higher oil genotypes along with a requirement to ensure genetic diversity was captured by limiting the number of trees sampled at any location. Publications relating to this and showing successful delivery of this aspect of the project include: (Lee *et al.* 2019) (Australian Forestry) and, (Lee *et al.* 2020b) (Regional Sandalwood Forum).			
4.1.2	Investigate reproductive biology of CYP sandalwood.	Report on reproductive biology of CYP sandalwood.	Y2/M06 12.2016	Publications relating to this and showing successful delivery of this aspect of the project include: Brunton 2019 (Honours Thesis) Lee et al 2019b (Sandalwood Regional Forum) and Brunton et al manuscript (submitted to American Journal of Botany).
	Genetic diversity and inbreeding study: A USC-funded Honours student undertook a molecular genetics study of CYP sandalwood. He focused on the population structure of the isolated stands of sandalwood and the level of inbreeding in these stands. A key finding was that: 55% of the trees in the NPA were clones (range 26-87% depending on the population). Despite this there were low levels of inbreeding in the wild populations. This study highlighted that the species is locally threatened, probably due to previous over-harvesting (1860-1937) and recent fires in the region. **Pollination study:** In a pollination study there were significant differences between fruit set of the four clones used but position (within a potted clonal seed orchard or remote from the seed orchard) did not impact seed set, either indicating the pollinators visited the flowers equally or that the species readily 'selfs'. Publications relating to this and showing successful delivery of this aspect of the project include: Oostenbrink and Lee 2017 report.			
4.1.3	Establish replicated progeny trials using seed produced in the clonal seed orchards and additional wild seed.	Progeny trial established with participating communities	Y2/M12 06.2017	Publications relating to this and recording the successful delivery of this aspect of the project include: (Lee *et al.* 2019) (Australian Forestry) and (Lee *et al.* 2020b) (Regional Sandalwood Forum) and (Burridge and Lee 2020) (Regional Sandalwood Forum)
	Seed collected from 18 *S. lanceolatum* clones were sown at the Gympie nursery to allow establishment of two 0.5 ha progeny trials in the NPA during the 2016-2017 wet season in February 2017. Both progeny trials were successfully established: one at the Northern Peninsula Area College (NPA) (irrigated trial, 6 replicates) with the assistance of students. The other non-irrigated trial at the Bamaga Farm, which has 4 replicates was established with assistance of Community Development Program (CDP) staff. Trials were established with a 5 m spacing between rows and a 2 m spacing between trees along the row, resulting in a stocking of 1000 stem per hectare. The trials in the NPA only contained sandalwood from that region, in order to avoid gene flow into the wild populations. Host species in the trial include: *Acacia simsii*, *Pongamia pinata*, *Melaleuca leucadendra*, *M. viridiflora*. Tree guards were put around the base of the trees to avoid ringbarking during mowing/ whipper snipper work undertaken by school / CDP staff. Training of students (n=20) and CDP staff (n=6) was a component of the establishment of these trials. This training included discussion of biology, history, potential and how to plant and manage the sandalwood trees. The students have continued to be involved in the trial at the campus, as it is used in the Agricultural class lessons. This includes monitoring the trial, watering it and being trained in the measurement of the trial. A third progeny trial (0.4 ha) was established on Quintis land (the largest commercial sandalwood grower in Australia) in the Burdekin, with appropriate IP protection for the TO's. Planting date was April 2017. This trial had CYP sandalwood and *S. album* (Indian sandalwood) established in the trial, so a direct comparison between the two species was possible. This also created the possibility of collaboration between a commercial sandalwood grower and the Indigenous owners of the germplasm. The commercial grower has said it would be many years (10+) before they would be interested in growing this unknown sandalwood taxa commercially. Host species in this trial include: *Acacia trachycarpa* and *Sesbania formosa*.			
4.1.4	Assess growth and development parameters of all families based on early growth	Genetic variation in growth and development documented in a report	Yrs 3 & 4 12.2017 & 12.2018	Publications relating to this and showing successful delivery of this aspect of the project include: (Lee *et al.* 2019) (Australian Forestry) and (Lee *et al.* 2020b) (Sandalwood Regional Forum).

<table>
<tr><th>No.</th><th>Activity</th><th>Outputs/ milestones</th><th>Due date of output/ milestone</th><th>Progress</th></tr>
<tr><td></td><td colspan="4"> Trials in the NPA: Early growth and survival (at 4 months) of the trials planted in the NPA was good. However, the sandalwood seedlings were chewed by generalist insect herbivores. As a result, the trials were sprayed with Confidor™ to protect the plants. The trial was fertilised at this time with 200 g Nitrophoska special. Generalist insects have continued to be a problem for some families and this needs to be monitored. The other main problem has been vine weeds that can climb over the sandalwood and the hosts. These have to be pulled off by hand. The trial design, layout, management and data has been captured on a secure Structured Query Language (SQL) database managed by DAF Forestry Science Qld.
Two-year survival in the irrigated progeny trial was excellent (96 %) and moderate in the non-irrigated trial (78 %). Growth in the irrigated trial was also better with sandalwood trees averaging 2.01 m height and 2.4 cm DBHOB. The fastest growing family in this trial averaged 2.61 m height and 3.3 cm DBHOB at this measure. In contrast S. lanceolatum trees in the non-irrigated trial averaged 1.75 m height and 0.9 cm DBHOB, with the fastest growing family in this trial averaging 2.25 m height and 1.3 cm DBHOB. The trial at the school was damaged by wild cattle breaking through the fence. This resulted in approximately 10% of the sandalwood trees being damaged. The fences have been repaired. Cattle will continue to be an issue unless adequate fencing in maintained.
Trial in the Burdekin: At 14 months the growth of the collaborative trial in the Burdekin was measured and the CYP sandalwood had averaged 1.63 to 1.78 m across two soil types whereas the commercial S. album averaged 1.88 to 2.13 m (0.25 to 0.35 m taller). Given the S. album is improved commercial material, this difference in height between the two sandalwood sources is small and indicated promise for the CYP sandalwood. This trial has survived one cyclone/flood that went through the region </td></tr>
<tr><td>4.2.1</td><td>Explore options for business development on traditional owner/ community lands with the seed / seedlings from the CSOs.</td><td>Range of business opportunities summarised for communities.</td><td>Y1/M12
06.2016</td><td>See Below</td></tr>
<tr><td></td><td colspan="4"> A business case has been prepared by the project for Ipima Ikaya Aboriginal Corporation RNTBC (Registered Native Title Body Corporate: the group that owns the land) and the Gudang/Yadhaykenu Group (Traditional Owners (TOs) of the northern part of the CYP). The TOs have presented the business case to potential backers in order to evaluate the backers' interest in supporting the initiation of a plantation industry in the NPA. Two meetings were undertaken with potential investors on-site in the NPA, with companies the TOs had contacted. This included Boston Global and the Platinum Finance Group, who were interested in finding investments in the NPA. In addition, David Lee and Tony Burridge were involved in teleconferences with potential Indian and Chinese investors the TOs had come in contact with. The general response to all of these explorations of business opportunities was that it was too early to consider investing in this unknown species at the time and larger trials and more research was needed.
During the project three arranged meetings with the Indigenous people in the NPA have been conducted, with: the Aputhuma Land Trust, members of the Ipima Ikaya Aboriginal Corporation RNTBC and the Gudang/Yadhaykena Group. At these meetings we discussed business opportunities and provided information and guidance on what was needed to develop a sandalwood business in the NPA (Lee and Burridge, 2017). Another option to explore business opportunities was to Links have also been developed, with approval from the Traditional Owners, with commercial growers. A trial was established on Quintis land in the Burdekin. Quintis also consider it to be too soon to commercialise CYP sandalwood, as too little is known about the species.
Business opportunities explored with the Indigenous people of the NPA include:

Seed production for sale;
Nursery production of seed;
Plantation development on the NPA farm and elsewhere;
Effluent usage to irrigate sandalwood plantations;
Inclusion of ecotourism in a sandalwood enterprise (e.g. history, bush tucker and conservation of the species); and
An integrated project that has all of the above.

To date none of these opportunities has been realised as the species has only been grown in plantations for the last couple of years and has not been harvested from the wild for the last 80 years, so it has no market profile. Hence, there has been no commercial investment.
In addition the project team has met with State Members and Qld Government staff in the NPA including: Glenn Butcher MP (Ministerial Champion for the NPA) chief advisors and regional Directors of the Qld Department of Agriculture and Fisheries. They reacted positively to the potential development of a sandalwood business in the NPA following appropriate research.
Publications and project report relating to this activity, showing successful delivery of this aspect of the project include: Lee et al. 2019a (Australian Forestry) and Lee et al 2019b (Sandalwood Regional Forum) and Lee and Burridge 2017 (report provided to the leaders of the Gudang/Yadhaykennu Group and investors). </td></tr>
<tr><td>4.2.2</td><td>Conduct workshop on business acumen and present options for sandalwood business development.</td><td>Community statement of intent to further develop sandalwood.</td><td>Y2/M6
12.2016</td><td>See below</td></tr>
</table>

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
	Workshops were run in conjunction with the planting of the progeny trials, during inspections of the progeny trials in the NPA and specifically with the Aputhuma Land Trust, members of the Ipima Ikaya Aboriginal Corporation RNTBC and the Gudang/Yadhaykena Group. Reporting on these workshops is described in 4.4.1. The Indigenous leaders were impressed with what we have achieved and wanted to see the work progress. Hence, they have initiated discussions with potential collaborators and investors to see if funds can be found to develop further plantations. Land security has been an issue to date, but as native title has been granted over much of this land during the last six months this may remove this impediment. The general consensus is that we are too early in this development of the 'new' species to have confidence that the species is commercially viable. Nicholas Thompson, Deputy Chairman of the Ipima Ikaya Aboriginal Corporation RNTBC, who is a prominent member of the NPA has praised the project's work to meetings of the Gudang/Yadhaykena Group and in writing: Thompson Lee and Burridge (2019; Sandalwood Region Forum), that development of a sandalwood development is one of the aspirations of his people, as it will provide employment, business and cultural opportunities. Publications and project report relating to this activity, showing successful delivery of this aspect of the project include: (Lee *et al.* 2019) (Australian Forestry), (Lee *et al.* 2020b) (Regional Sandalwood Forum) and Thompson et al 2019 (Regional Sandalwood Forum).			
4.2.3	Engage with private organisations and Traditional Owners about the potential for further developing sandalwood in CYP on a commercial basis.	Private organisations and Traditional Owners interested to engage in dialogue about opportunities.	Y2/M12 06.2017	Publications and project report relating to this activity, showing successful delivery of this aspect of the project include: Lee et al. 2019a (Australian Forestry), Lee et al 2019b (Regional Sandalwood Forum), Lee and Burridge 2017 (report provided to the leaders of the Gudang/Yadhaykennu Group and investors) and (Thompson *et al.* 2019) (Presented at Regional Sandalwood Forum).
	Quintis (the largest sandalwood plantation growing in Australia), was happy to establish a progeny trial to evaluate the species relative to the *S. album* they grow in their commercial plantations. However, they are not interested in developing plantations of this unknown species. In fact, they will not consider investing in *S. lanceolatum* further without a long term study of this species including appropriate benchmarking against their routine commercial *S. album*. As detailed in 4.2.1 and 4.2.2 over seven activities have been undertaken to engage private organisations and the Traditional Owners to assist with the commercial development of the species. As part of this, a four-page outline of what is needed to expand from *S. lanceolatum* trials to a small plantation industry in the NPA was sent to the Gudang/Yadhaykenu Group leaders and collaborators.			
4.2.4	Conduct workshop with interested parties to present CYP specific findings from Objective 2 and determine the potential for collaborative commercial development of sandalwood in CYP.	Statement of intent for potential collaboration outlining stakeholder objectives, parameters of engagement, lines of communications etc.	Y3/M06 12.2017	Publications and project report relating to this activity, showing successful delivery of this aspect of the project include: (Lee *et al.* 2019) (Australian Forestry), (Lee *et al.* 2020b) (Sandalwood Regional Forum), Lee and Burridge 2017 (report provided to the leaders of the Gudang/Yadhaykennu Group and investors), (Burridge and Lee 2020) (Sandalwood Regional Forum) and (Thompson *et al.* 2019) (Sandalwood Regional Forum).
	Workshops and reporting of the TOs of the NPA were undertaken as detailed in the previous sections with three specific workshops conducted over the duration of the project. These workshops were with Aputhuma Land Trust, members of the Ipima Ikaya Aboriginal Corporation RNTBC and the Gudang/Yadhaykena Group. Nicholas Thompson, a community leader involved in all of these groups said: "An industry based on *S. lanceolatum* has the potential to positively impact the lives, wealth and health of people in the NPA through development of nurseries, enrichment plantings, plantations and cultural activities."			
4.2.5	Review project engagement with and outputs for indigenous communities within the ACIAR research project.	Consolidated report on achievements, challenges, lessons and opportunities for engaging indigenous communities.	Y4/M12 06.2019	The review of the engagement is captured in a range of reports and publication associated with the project: (Lee *et al.* 2019) (Australian Forestry), (Lee *et al.* 2020b) (Sandalwood Regional Forum), Lee and Burridge 2017 (report provided to the leaders of the Gudang/Yadhaykennu Group and investors), (Burridge and Lee 2020) (Sandalwood Regional Forum) and (Thompson *et al.* 2019) (Sandalwood Regional Forum).

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
	Participatory domestication of sandalwood conducted in Cape York reflects a similar and successful approach to that implemented in PNG and Vanuatu. This included surveys of wild populations of sandalwood and identification of candidate trees producing heartwood oils of high quality. These were captured as the basis for an improved seed source available to small scale woodlots. Engagement with landowners in PNG and Vanuatu followed an iterative and practical approach to build relationships over time and demonstrate the unique silvicultural aspects of sandalwood production, particularly related to its host requirements. In PNG and Vanuatu, sandalwood plantings are typically established by individual family units as small agroforestry woodlots in which trees are planted among or adjacent to other garden and cash crops. On CYP, the sandalwood seed orchards and demonstration plantings have been established on country with help from public/community institutions (e.g. the local high school, land trust, prescribed body corporate and regional council) with the aim of providing the community with the greatest exposure to the concepts and methods for its production and commercialisation. Development of a sandalwood industry in the CYP will be with these public/community institutions as land is a community asset and not owned or managed by individuals. This means that the community needs to be more engaged than engagement of individuals within the community.			

Objective 5: To communicate and disseminate research outputs to improve uptake and impact.

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
5.1	Capacity Building and Communication			
5.1.1	Explore constraints to participation by women in tree planting.	Constraints to participation identified.	Y1/M06 12.2015	Outputs from the workshop on identifying constraints was reported in Page *et al.* (2020c). The workshops offered scope for exploring training needs and delivery preferences among participants which contributed to activity 5.1.2.
	Four workshops with women in ENB were conducted to identify the constraints to women's participation. The results show that women have a strong interest in establishing small woodlots, which is derived from their desire to address their own needs for timber (particularly house construction) as well as commercial sale to meet the shortfall in timber resources within the region. Despite this clear interest among women, the workshops showed that they are constrained primarily by (i) a lack of knowledge and access to information, (ii) competing responsibilities and associated lack of time, (iii) limitations to mobilise traditional sources of family or community labour and (iv) a lack of access to suitable land.			
5.1.2	Training Needs Assessment for nursery and silvicultural training needs, including those for women	Training needs documented.	Y1/M12 06.2015	See Below
	Training needs assessment and preferencing was conducted via three interconnected research activities: (1) a stakeholder (farmer) situation analysis was conducted to understand farmer needs, motivations (Jenkin 2019c) and competencies (2) a questionnaire of 96 landowners using 3 male and 2 female local enumerators (OISCA, PIP and PNG Missions) (PIP 2019a) and (3) the four women's workshops conducted in activity 5.1.2 (above) (Page *et al.* 2020c) and two farmer training events and semi-structured interviews (Page 2017a) (Page 2018; Page 2019a).			
5.1.3	Develop training resources to meet vocational training needs for the business of teak & sandalwood.	Teak and sandalwood specific training resources developed.	Ongoing	Training resources have been developed for smallholder growers and extension agents and two growers manuals for teak and sandalwood can be used for vocational training results. The results of activity 5.1.3 are related to activities 3.3.2 and 2.1.7 (see Section 7 Objective 5.1 for the resources produced.
5.2	Monitoring and evaluation			
5.2.1	Develop project specific monitoring and evaluation plan	Monitoring and evaluation of project	Y1/M6 12.2015	See below
	A project monitoring and evaluation (M&E) plan was developed by Jo Roberts at the commencement of the project, which was developed at the Planning for Monitoring and Evaluation Workshop. This workshop involved all project partners and was held on the on 12 August 2015. The information provided by project partners during the workshop contributed to the overall monitoring and evaluation plan (Roberts 2015). The monitoring and evaluation activities included: tree grower registrations, woodlot inspections, lead farmer interviews, Mission Base resource centre evaluation, landowner focus group discussions. The results of the M&E activities are presented in Section 7 Objective 5.2.			

No.	Activity	Outputs/ milestones	Due date of output/ milestone	Progress
5.2.2	Inception, mid project and final meeting	Progress and planning	Y1/M1 Y2/M11 Y4/M12	Inception, Mid-Term Review (MTR) and End of Project Review (EoPR) were conducted in both Port Moresby and East New Britain. ACIAR program manager Tony Bartlett attended the first two meetings and Nora Devoe and a review team attended the EoPR. All project partners attended the meetings and contributed to the direction of the project..

7 Key results and discussion

Objective 1 Advance the teak genetic improvement.

Overview

The project successfully advanced the genetic improvement of teak in PNG. It achieved this through the establishment of a diverse range of provenance plots as a source of individual tree selection and as a resource for conversion into seed productions areas. Phenotypic selection of high performing trees was conducted at UNRE provenance stands and captured through clonal propagation. These were used to establish clonal archives at UNRE and OISCA. Another clonal archive was established at FRI derived from clones sourced from a clonal seed orchard at Mt Lawes, and from phenotypic selections made from six planted sources (Kerevat-Vunapalading, Oomsis Forestry Station, Mt Lawes CSO, Kuriva, Erima (Madang) and East Sepik). At this stage the project partners manage the two sets of clones independently. For the development of teak in PNG there would be considerable advantage to bring the selected clones together into a single breeding population. This would increase the genetic diversity available for making long term improvements. Bringing the germplasm together will require co-operation among project partners.

Quantifying clonal performance has commenced for some of the UNRE clones, where two clonal test trials have been established. The clones (ramets) have demonstrated high vigour in the measured trial, reflecting the performance of the original mother tree (ortet). Furthermore the ortets have also continued to demonstrate their superiority in later measures (up to 5.5 years). This demonstrates an association between early and later growth. The FRI clones have been established in a clonal seed orchard, but there is need to test their superiority in a replicated trial. The FRI trees were selected without quantitative information on their performance; no records exist for Mt. Lawes clones and the single tree selections were based on visual assessment without knowledge of their age or management. Future trials should be established in both the seasonal and equatorial tropics to evaluate clonal performance over the two main environments in lowland PNG. This research could be supported through assessment of wood δ13C to identify fast-growing teak genotypes that also exhibit high WUE.

Clonal propagation protocols have been developed for capturing selected trees and replicating archived clones. Using the current nursery infrastructure the protocols are suitable for generating sufficient numbers of ramets for establishing trials. If the clones are to be replicated for deployment for operational plantings further investment would be required to upgrade nursery facilities and expand the clonal hedges. As an interim the most cost effective method of deploying improved teak will be through the establishment of replicate clonal seed orchards. This can be done through thinning of the clonal test trials once the performance of the clones have been quantified. Rapid development of improved sources of seed is central to addressing seed availability, since this is considered to be the primary constraint to expanding the smallholder teak estate.

1.1 Further develop existing provenance-progeny trials as first generation seedling seed orchards.

Clonal Provenance Trials (UNRE)

No significant difference was found for mean DBH at 3.5 years among any of the ten provenances evaluated in the clonal provenance trial 1a (2013). Significant variation ($P<0.05$) was found between provenances for each of the form scores, and it can be concluded that Jicaro was consistently the lowest performing. While an additional measure was recorded at 5.5 years the data for 3.5 years is used here, as it was used as the basis for early clonal selection.

At 3.5 years (May 2016) trees were selected in clonal provenance trial 1a and 1b based attaining a minimum score for each of the following:

(1) A stem diameter mean annual increment (MAI) of >4cm yr^{-1};
(2) Primary axis branches out in 3rd to 4th quarter or complete persistence (Paxis≥4);
(3) Primary axis straight to slightly crooked (StS≥4); and
(4) Branch diameter between ½ and less than ¼ of trunk diameter (BSz≥3).

Based on the selection criteria above a total of 91 individual trees representing 59 clonal genotypes were selected from trial 1a. Clones were selected from each of the ten provenances and the overall selection intensity was 15.8%. The selected clones were categorised as either:

(a) candidate plus clone, with 2 to 4 individuals of the same clone selected (denoted as 'p20') or
(b) selected clone, with only 1 individual of the clone selected (denoted as 's39').

Selection of clones in trial 1b resulted in one clone (K09) being upgraded from a selected clone (s39) to candidate plus clone (p20) based on its performance in clonal provenance trial 1b. A further 11 clones, representing a 7.5% selection intensity, were added to the candidate plus clone category.

The selection was conducted at 3.5 years after planting, which was supported by high positive correlation (R^2 0.88) for stem diameter between this and a later measure at 5.5 years. Tree form was assessed for four criteria at 1.7 and 3.5 years and there were significant differences and general increase in the values recorded over time. This demonstrates that teak form is not static and changes over time, particularly during early years of growth. It is proposed that tree rankings for stem straightness and branch size at 3.5 years may relate to final ranking at maturity, but this may not be the case for persistence of axis and branch mode. These may undergo further change as the trees mature. Further measures of selected clones over time are required to determine their performance at latter stages of development. The estimated standing volume at age 6 years was 171.1 m3/ha which represents a mean annual increment of 28.5 m3/ha/y (Jenkin and Minimulu 2019b).

Provenance Blocks Warrangoi (OISCA)

The provenance block plantings at OISCA in Warrangoi represent an important repository of genetic variation. From these multiple single-tree selections have been made to be captured through clonal propagation. A total of 11 seed sources have been planted as bulked block plantings totalling 2970 seedlings (Table 2).

Significant differences in diameter growth rates were found among the seed sources, with Mt. Lawes, Nambi and Penas Blancas demonstrating good growth (Figure 6). The younger (3yr) Mt. Lawes trees had a significantly greater diameter growth rate than the older (7yr) source indicating that thinning of the latter had occurred after the effects of competition. The form index for the trees ranged from 2.5 to 3.5 on a scale of 1 (Low) to 5 (High). This moderate mean score for form shows that the clonal approach to improving form is an important avenue for domestication.

Table 2: Eleven teak sources established as block provenance plantings at OISCA, Warrangoi ENB.

Source	Trees		Source	Trees
Mt Lawes	1078		Nambi	97
Laos	154		Penas Blanca	525
Thailand	42		Santa Cruz	303
China	364		Solomon Is.	26
Santa Alicia	28		Tanzania	99
Mansion	254		Total	2970

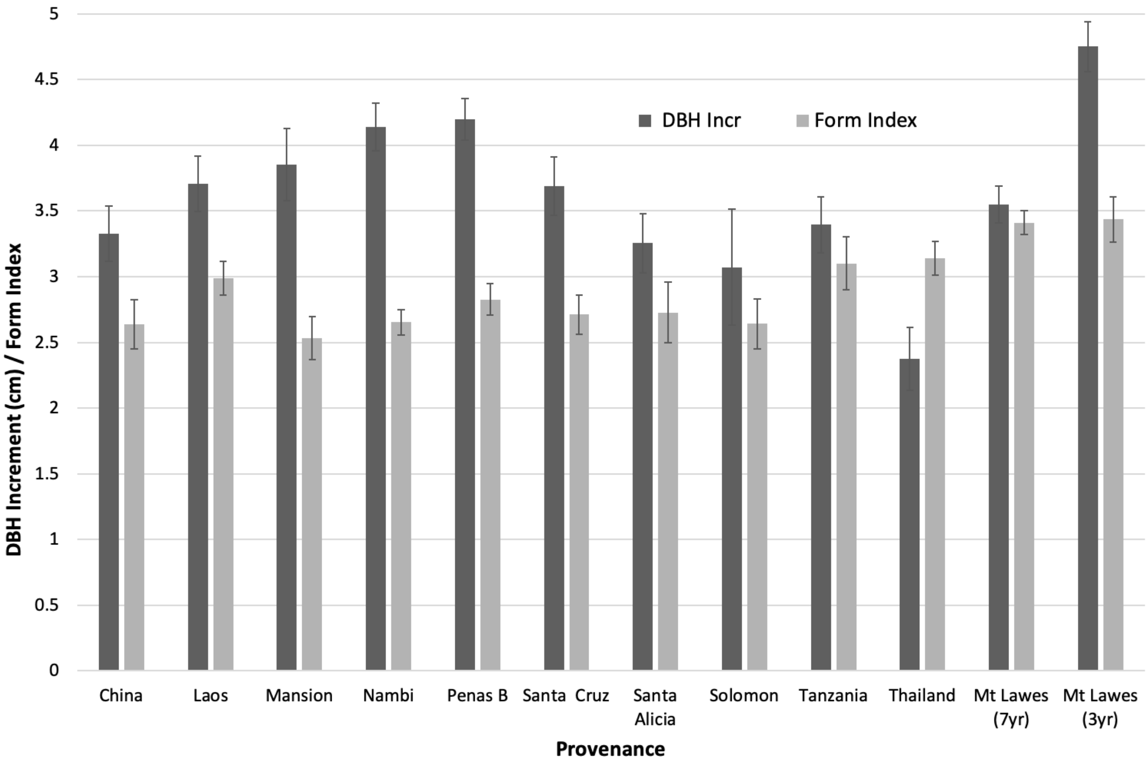

Figure 6: Mean annual increment for stem diameter (DBH) and form index (scale 1 Low to 5 High) across 11 seed sources tested at Warrangoi, East New Britain Province.

Provenance Trials Situm (FRI)

Teak Provenance Trial

The first teak provenance trial established at Situm in May 2015 comprising five provenances (Honduras, Santa Alicia, Jicaro, Laos, and China) was assessed each year for the first four years. Significant difference in stem diameter was found only between the fastest (Honduras) and slowest (China) provenances (Figure 7). The following site data at 4 years mean DBHOB (18.1cm) MAI (4.5cm.yr^{-1}), height (16.0m) and basal area (12.9 m^2). Mean basal area of the provenances followed the variation recorded for stem diameter. The mean basal area of the entire plot was 1.25m^2 at 12 months, 7.65 m^2 at 24 months, 10.55 m^2 at 36 months and 12.89 m^2 at 48 months. The mean annual increment peaked at 24 months for each of the provenances and was significantly greater than at 12, 36 and 48 months. This suggested that competition among the trees commenced at between 2 and 3 years.

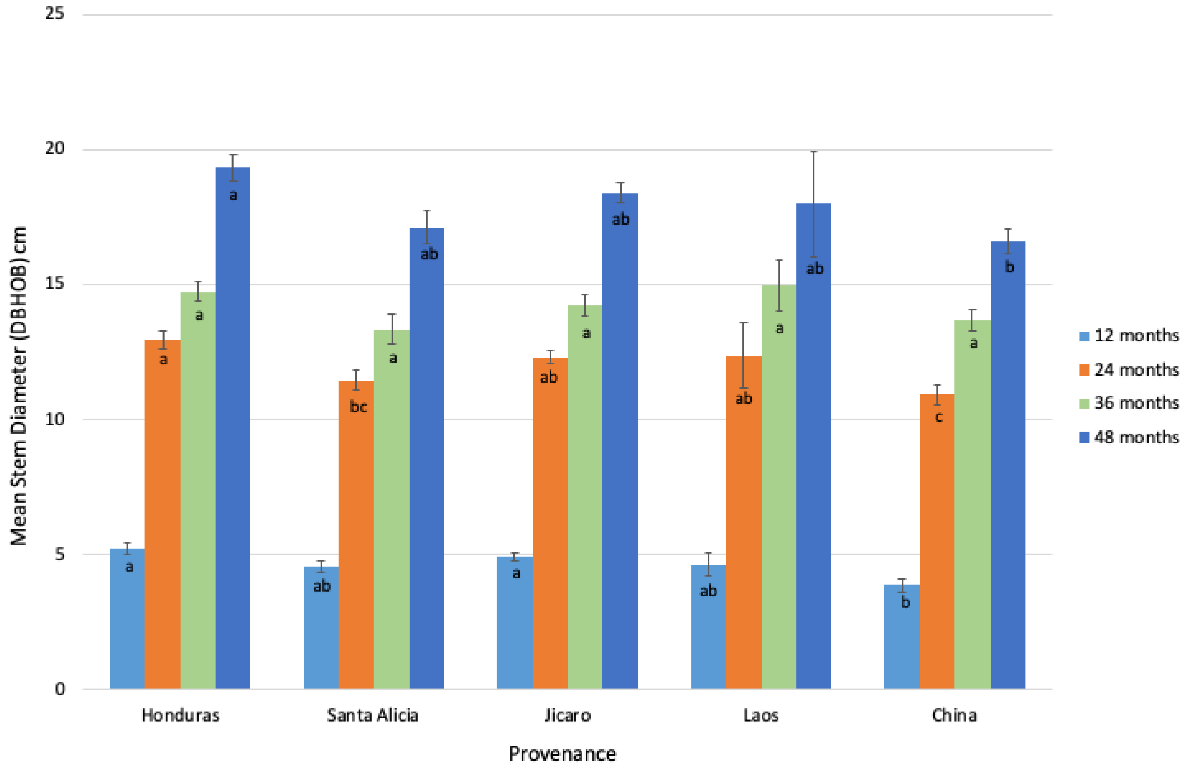

Figure 7: Mean stem diameter (DBHOB) for five seed sources tested at Situm, Morobe Province.

Teak Provenance Progeny Trial

Teak progeny-provenance trial was adjacent to the trial above in April 2016. Incomplete block design (IBD) was applied, with 8 replicates, 8 plots per replicate and 9-tree plots in an area of 1.03 ha. Initial spacing is 4 m x 4 m. There were 25 progenies (TG5: C1, C2, C5, C9, C13, C14, C15, C20, C24, C26, C27, C30, C31, C33, C35, C36, C40, C41, 1m16t, 1m15t and bulk, KU15, KU-UK and Omsis-T1) and 7 provenances (TG14-Mansion, TG15-Nambi, TG16-Penas Blancas, TG17-Santa Cruz, TG18-Nellicutha, TG25-Taliwas and TG29-Honjancha). A total of 584 seedling stumps were planted in the trial with 100 seedling stumps from Kuriva Tree number 15 (KU15) used as single-buffer planting. The trial was measured at year 4 (2020) but data was not available by the conclusion of the project.

1.2 Establish a network of seed orchards (CSO) and clonal hedges of plus trees.

Clonal test at UNRE

Performance of clonal selections

In trial 1a all teak was found to grow rapidly in the first 2½ years (mean current annual increment (CAI) of 6.7 $cm.yr^{-1}$), but with a sharp drop in CAI at 3½ years (2.2 $cm.yr^{-1}$). This suggests that at 4 x 4m the teak was beginning to compete for site resources from year 3 onwards. Therefore the first thinning intervention at year 3 to remove all small, poorly formed and damaged trees can ensure continued rapid growth of the remaining trees.

 

Figure 8: The teak clonal test trial (2a) at planting with nursery manager Sylvester Kulang (left) and after 2-years growth (right) at UNRE, Vudal, ENB, PNG.

The diameter growth performance of selected clones at 3.5 years (MAI 5.2 to 5.7 $cm.yr^{-1}$) was 12.6 to 16.3% greater than non-selected (MAI 4.7 to 4.9 $cm.yr^{-1}$) clones for clonal provenance trial 1b and 1a respectively. The rapid growth rate of the selected clones was confirmed at year 2 in the clonal test trial 2a with an MAI of 5.8 $cm.yr^{-1}$ with all 21 clones exceeding the original selection criteria of >4cm. This high growth rate reflects early measurement (2 years) of the trial, when the trees are yet to compete with each other for site resources. The MAI at 2 years for the clonal provenance trial 1a (7.2 $cm.yr^{-1}$) was significantly greater than that found for the clonal test 2a (5.8 $cm.yr^{-1}$). The difference was consistent across all the clones and therefore this difference likely represents site or environmental variation between the two trials. This demonstrates the need for a genetic gain trial, in order to examine the replicated performance of selected clones against unselected seed sources.

Based on mean stem diameter (DBH) growth in the clonal test 2a, the candidate plus clones (12.2 cm and 6.1 $cm.yr^{-1}$ respectively) significantly outperformed selected clones (10.9 cm and 5.5 $cm.yr^{-1}$ respectively) (Figure 9). Therefore phenotypic selection based on two or more individuals (ramets) is therefore a better indicator of clonal (genetic) performance compared with single tree selections. However this study demonstrated that single tree phenotypic selection followed by clonal propagation and testing can still identify genetically superior clones. A strategy for improving teak may include screening large numbers of single tree selections in clonal test trials with low replication (<10 ramets) followed by more rigorous testing of the highest performing clones in tests with higher replication (>20 ramets). This stepwise approach can efficiently identify large numbers of genetically superior (plus tree) clones following single tree selection within formal trials and provenance-based woodlots.

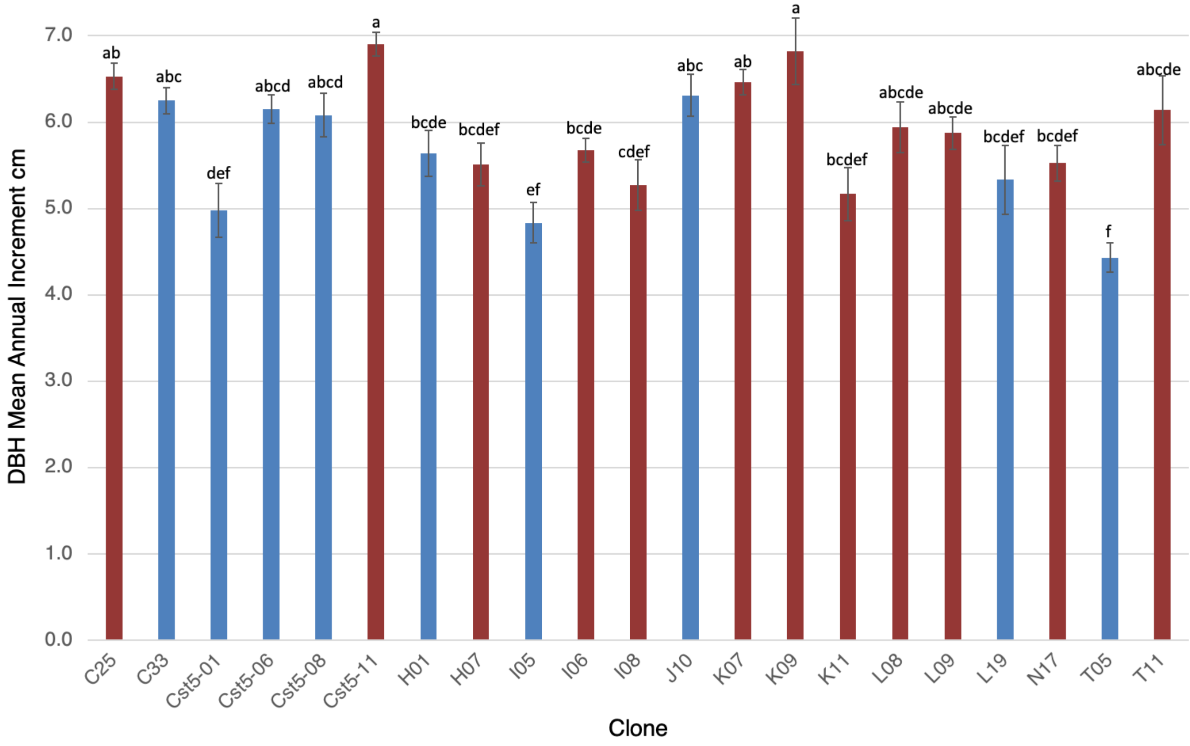

Figure 9: Mean annual increments for stem diameter (at 1.3m over bark) after 2-years growth for each of the 20 clones represented in the clonal test trial 2a. Red coloured bars are for candidate plus tree clone and blue are for selected clones. Vertical bars represent standard errors of the mean. Clones that share lower case letters are not significantly different at the 0.05 level.

Clonal test at OISCA

In August 2019 a replicate of the UNRE clonal test was established at OISCA in Warrangoi ENB (Figure 10). The trial was a randomized incomplete block design with 20 clones and nine replicates. The clones included in this trial included eleven candidates plus tree clones (C25, CST5-08, CST5-11, H07, I06, I08, J10, K02, L08, L09, T05) and nine selected clones (C33, CST5-01, CST5-03, CST5-06, I02, I05, K07, K09, K11).

Figure 10: Establishment of the teak clonal test with John Rabbie (left) and the OISCA-ACIAR team (right) at OISCA, Warrangoi ENB.

The study of leaf δ^{13}C‰ revealed a significant clone effect on WUE (P < 0.025) and no planting year effect (P > 0.10). The CST5-06 genotype was the least wateruse efficient (lowest leaf δ13C) in addition to showing large individual variation in this trait. The 'whiskers' for clone Cst5-06 in 2017 for instance extend up to 1.5 times the interquartile range of all the data (this clone was the most extensively sampled with 16 observations/ 16 individuals sampled). However, in contrast the T11 clone had similar leaf δ13C values to the Cst5-06 genotype, whilst the K11 and N17 lines as well as K09 showed the highest leaf δ13C indicating they were the most water-use efficient. The K11 and K09 clones were Kuriva selections while N17 is a Nambí, Guanacaste, Costa Rica selection. Balancing high WUE and high growth performance, the K09 and N17 genotypes would be judged superior (Figure 11). The Cst5-11 genotype may also be a good prospect in this regard, but there were not enough leaf δ13C samples for robust results. Three superior-performing genotypes (K09, K11 and N17) can sustain rapid stem growth while remaining water-use efficient. Genetic trait correlations are very useful for adopting reliable tree improvement strategies, considering the urgent need for improved quality, higher productivity and shorter-rotation period plantations whilst ensuring they remain resilient against variation in dry season length and intensity. Replication of these clones across an environmental gradient is important, in order to determine the effect of genotype by environment interactions on both WUE and growth rate.

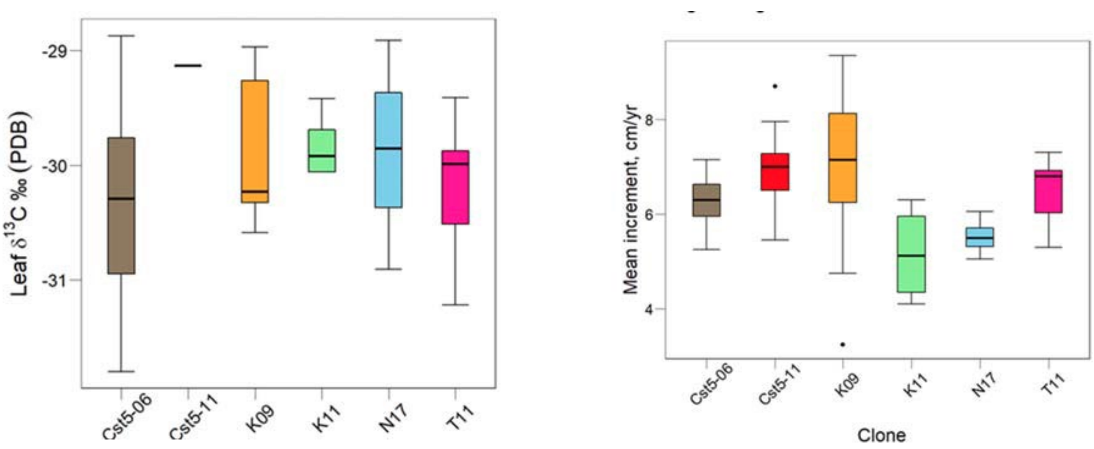

Figure 11: Clonal differences in WUE (δ13C‰), and mean annual increment for stem diameter sampled at 2 years from planting (2a clonal test trial) for select plus and elite tree selections. Different colours denote different genotypes.

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Clonal Archive FRI, Lae (Morobe Province)

A total of 43 genotypes of teak were secured in the teak clonal bank at FRI (Figure 12).

- 28 from Mt Lawes grafted seed orchard;
- 4 from Kuriva plantation;
- 1 from Vunapalading-Kerevat plantation;
- 4 from Erima teak woodlot in Madang; and
- 6 from teak woodlots in East Sepik Province

 

Figure 12: FRI Staff Anton Lata and Sonia Inu (left) and newly planted truncheon clone (right) within the teak clonal archive at FRI nursery in Lae.

Kuriva Clonal Seed Orchard

The clonal seed orchard was measured at year 2 (Figure 14). The best performers were clones K26, T05, T01, C29, K24 and C12. However, there were no differences among other clones from C27 to C14 (Figure 13). The stem diameter growth rate of the clones at 2 years grown at Kuriva (MAI <3.5cm.yr^{-1}) was substantially lower those at UNRE in Vudal (ENB) (MAI 5.8cm.yr^{-1}). Further replication of the clones between these two sites is required to determine the influence of genotype, environment and GxE. To facilitate this, a material transfer agreement (MTA) between project partners may be required.

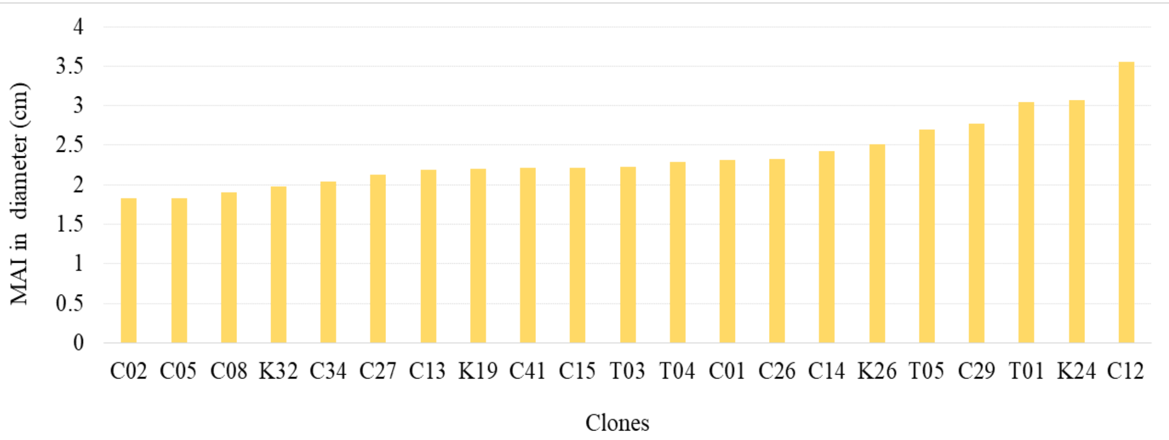

Figure 13: MAI in stem diameter (DBH) of teak within the clonal seed orchard at Kuriva, Central Province.

Figure 14: Left: Forest Authority staff planting teak clonal stump at Kuriva (From L to R Josephine, FA Officer, Winnie, Francis and Jacob). Right: Clonal teak at Kuriva 2-years after establishment.

1.3 Develop nursery protocols for commercial production and dissemination of improved teak germplasm.

Seedling production

Teak bare root seedling (stump) production has been refined for community use in PNG. The process involves sowing teak seed at consistent spacing (10 x10 cm) in a raised ground germination bed. Weekly weed removal for 4-6 weeks until the teak seed have germinated and growing rapidly. They are grown for up to 4-6 months until they attain a an average height of up to 1m. They are prepared as bare root stumps (Figure 15) and planted directly in the field. This simplified method of seedling production can be implemented by smallholders with existing tools: the beds can be prepared with a spade, the stumps prepared with a spade and bush knife and the planting hole prepared with a digging stick. This method was widely extended to smallholder farmers (Figure 16) and has captured their interest because it circumvents the need for establishing and maintaining a seedling nursery. The method has been documented in detail by Jeffrey (2019) and Jenkin and Page (2017b) for training of extension agents and smallholder farmers.

Figure 15: A prepared bare root teak stump (left) being planted in a hole prepared with a planning stick (Images Braden Jenkin).

Figure 16: Teak stump planting demonstration conducted across all 38 community nurseries. Attendance at these demonstrations was a prerequisite for receiving teak stumps from the project.

Clonal production

Clonal deployment of improved germplasm stands to deliver the greatest genetic gain to growers of teak. Experiments were conducted in both mist (Figure 17) and non-mist (Figure 18) propagation facilities. In both systems the regular maintenance of hedge plants to produce vigorous semi hardwood cuttings was essential to maximise rooting. At both FRI and UNRE these hedge gardens were maintained under full sun. Using the misting system teak cuttings with leaf area of 12cm^2 were treated with 0.3% IBA and propagated in cocopeat based commercial plugs (jiffy). These achieved 80% rooting and were used for routine propagation (Lata et al. 2016). For non-mist propagation the best results (40-80% rooting) were achieved with leafy stem cuttings propagated in a medium composed of 1:1 shredded composted coconut husks (coir) and sterilized topsoil. No rooting hormone has been used under the non-misting system. High rates of rooting up to 80% were achieved using both mist and non-mist propagators, but more consistent results was achieved with the former system. The reason the non-mist propagator has more variable results than the misting system is due to the ease of general hygiene maintenance of the misting system. The non-mist propagator is most applicable for smallholder clone production, but it is more challenging to maintain hygienic media over time, because changing the media is labour intensive. Typically the media was changed after 3-5 cycles of propagation, when the rooting percentage dipped below 50%. Ideally the media should be changed more regularly to maintain hygiene and rooting percentage. A protocol for the propagation teak truncheons and subsequent clone production was published by Lata (2019).

Figure 17: FRI teak clonal hedge garden (left) and stem cutting propagation in a misting propagator using commercial jiffy plugs (right).

Figure 18: UNRE teak clonal hedge garden (left) and stem cutting propagation in a non-mist propagator (right).

Objective 2 Develop smallholder appropriate silviculture.

Overview

The project has demonstrated a strong local market exists for teak thinnings (posts) and also for durable sawn timber in ENB. Approximately 1100 new permanent homes are projected on an annual basis from 2045 (based on 25 year rotation for teak). Smallholder grown teak has the potential to supply timber for this market. Based on assumptions of tree growth and timber recovery, this will require an annual planting rate of 184ha. Achieving this planting rate will require a functional service sector to support seedling production, extension, pruning, thinning and other services. There is a need for a functional coordinating organisation such as producers group (e.g. linked farmers) or an institutional processor (e.g. farmers as out-growers). The sustainability of the coordinating body will require a reliable funding model and an ethical framework to ensure it is trusted by farmers. This organisation and any associated service providers will require well informed and trained people. Regardless of the structure of the coordinating body there needs to be consideration of geographic spread of woodlots, and decisions are required as to which Wards/LLGs have sufficient land available to establish a concentration of smallholder woodlots to achieve an economy of scale. Areas such as Warrangoi and Vunapalading may be suitable, where land constraints are less obvious than many of the peri-urban areas around Kokopo and Rabaul. Consideration also needs to be given as to whether farmers are supported to undertake multiple plantings over a number of years or whether support will target new farmers each year.

Appropriately managed smallholder teak woodlots have potential to address immediate and long-term shortage of timber available for local house construction. Results from the spacing trials and demonstrations suggest that teak can be readily planted at close (2x2 m) and moderate (4x4m) spacing with trees rapidly capturing the site. At these two densities competition among trees was recorded at 1-2 years and 3-4 years at close and mid-spacing respectively. Interestingly when teak was planted at wide spacing (6x6 m) a higher level of tree mortality was recorded compared to closer spacing. The factors driving this mortality were not determined. Without refilling lost seedlings the large gaps resulting from the tree losses reduced the functionality of the woodlots. These trials demonstrate a range of options for smallholder growers (i) rapid site capture from 2x2m spacing (ii) a single rotation gardening at commencement of planting 4x4m and (iii) at the wider spacing of 6x6m, agricultural cropping can be conducted for at least 2-3 years post planting.

Proper thinning regimes have the potential for maximising mean annual increment of stem diameter from 3-4cm.yr^{-1} to 5-6cm.yr^{-1}. However pruning and thinning operations require significant inputs (labour and capital) and are more likely to be implemented when they produce products of commercial value or local use. For a 2x2 m spacing the thinning regime is critical to maintain tree productivity. Products from first few phases of thinning are likely to include narrow poles that can be used in local applications such as fence building. More research is required to determine if landholders consider the value of narrow poles sufficient to justify the inputs required for thinning. At 4x4 m there is a balance between the need for pruning and thinning, with pruning required annually in the first 3 years and first thinning required around 3 years. The pruning inputs are unlikely to yield any products other than fuelwood. The thinning products include posts for which there is a strong and lucrative market. It is likely that such a market would stimulate smallholder thinning from below. At 6x6 m pruning and weeding inputs will be dominant during the first 3-4 years. The weeding inputs can be offset through intercropping with agricultural crops during this time.

2.1 Identify appropriate establishment silviculture prescriptions

Survival

Survival of planted trees within replicates and between treatments within replicates varied (Figure 19). OISCA block 4 resulted in reasonably uniform survival at 80% plus, and this trial would be considered to have viable survival from an operational perspective. That is, there are adequate trees to grow on, select for thinnings and manage through to clear felling. OISCA block 3 had a higher degree of variability, with all treatments below a commercial threshold of survival. This site should be maintained to provide data on teak under very low spacing. While not ideal, this can make the best use of the current outcome. While not as low, survival at Gunanur is below operational targets, and, as with the OISCA block 3 site, this replicate should be maintained. The Napapar site had greater than 90% survival and will provide both useful data going forward and an exemplar demonstration of teak propagation. In general 6X6 spacing had the lowest survival, and further evaluation is required to determine the factors that may contribute to this result.

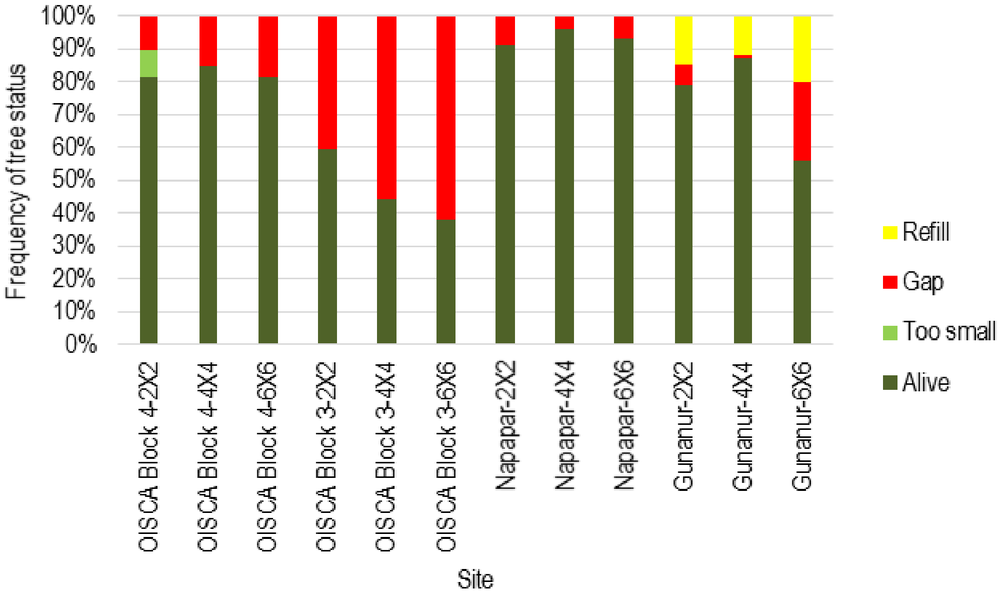

Figure 19: Tree survival and tree status across three planting density treatments (2 x 2, 4 x 4, and 6 x 6 m) across four planting sites (OISCA blocks 3 and 4, Napapar and Gunanur).

Figure 20: Three teak spacing treatments 2x2 (left), 4x4 (centre) and 6x6m (right) planted at OISCA block 4 spacing trial.

Growth rates

Tree DBHOB was measured at all sites, but OISCA block 3 and individual stem basal area was calculated based on individual stem DBHOB (Figure 21). OISCA block 3 and 4 and Napapar replicates were 17 to 19 months of age at assessment and Gunanur was 12 months old. OISCA block 4 and Napapar are of a similar age and both have 4X4 m and 6X6 m spaced trees with the same mean DBHOB, whereas trees planted at 2X2 m have a lower average DBHOB. Competition among teak trees commences at between 1.5 and 2 years for 2x2m and 2.5 to 3 years at 4x4m spacing. This competition defines when a woodlot manager should consider thinning: the close spaced trees would appear to require thinning at age c.17 months and mid-spacing at c 30 months. With continued assessment and data capture, it should be possible to determine when the 6 x 6m spaced trees commence competition and thinning is required. With a greater number of trees per hectare, but with slightly smaller DBHOB, the 2X2 m spacing replicates have the greatest basal area. Given that it is suspected that competition has commenced, it is proposed that a basal area of 5 to 7 m^2/ha may define when to commence first thinning. In comparison with other trials established under the project the timing of inter-tree competition and need for first thinning occurred at between 2 (~MAI 6.0 and BA 7m^2/ha) and 3 years (~MAI 4.0 and BA 10m^2/ha) at the Vudal (UNRE) and Situm (FRI) trials planted at 4 x 4m. While basal area range appears to be a low trigger for thinning, it is indicative of high growth rates associated with the high fertility and rainfall of these sites.

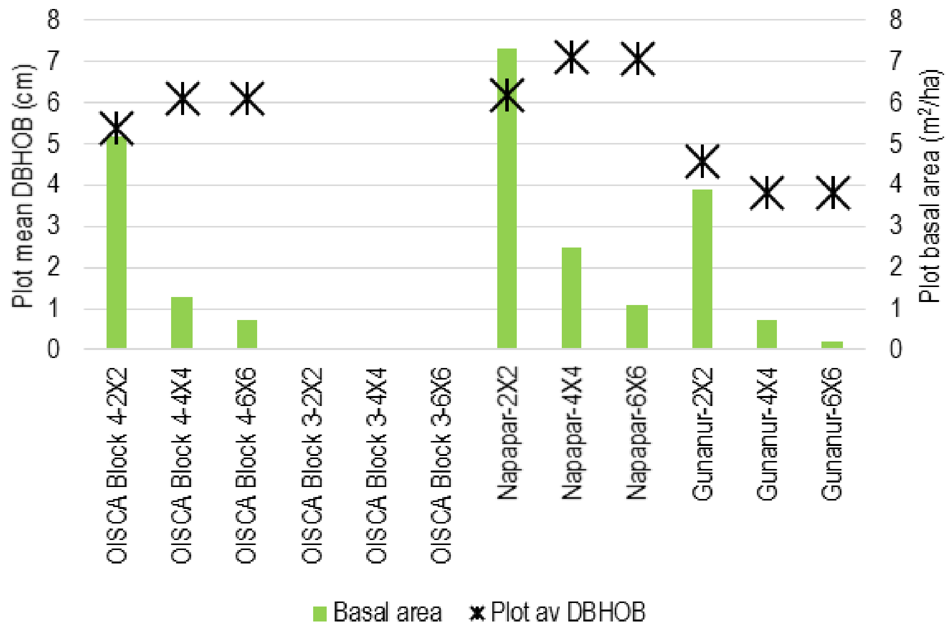

Figure 21: Treatment mean DBHOB and calculated basal area across three planting density treatments (2x2, 4x4, and 6x6 m) across three planting sites (OISCA block 4, Napapar and Gunanur). *note OISCA block 3 was not measured for growth prior to the end of 2019.

2.2 Define silvicultural systems that optimise economic returns.

Teak plantings in ENB and more widely across PNG have been documented. Teak woodlots were developed by the previous ACIAR project, by the UNRE and the PNGFA's Kerevat and Kuriva plantations. Importantly, we have identified a range of age classes and spatial arrangements to be included in the dataset. As other woodlots and plantations are identified and access is granted, these will be added to the project datasets. An Excel model has been developed to map and track woodlot inventory. The model also facilitates thinning decisions, by allowing the testing of a thinning prior to implementation. An individual model has been developed for 3 UNRE woodlots, the OISCA woodlot and a smallholder woodlot. All woodlots have been thinned from below and the data captured. The models have been developed with agreement from the UNRE that they will be maintained by the Forestry Department as part of the proposed revamped curriculum.

A subset of 58 thinned trees and 3 mature trees from the Kuriva plantations were assessed for stem volume in 1 m increments and at breast height (Figure 22). An Excel based stem analysis model was used to calculate volume under and over bark, and the resulting dataset was analysed. A single tree volume function was developed with diameter breast height over bark (DBHOB) as the "determinant variable" and stem over and under bark volume can be estimated with an R^2 of 93.8% and 93.1% respectively.

However, the model provides the capacity to develop estimates of standing volumes from routine assessment.

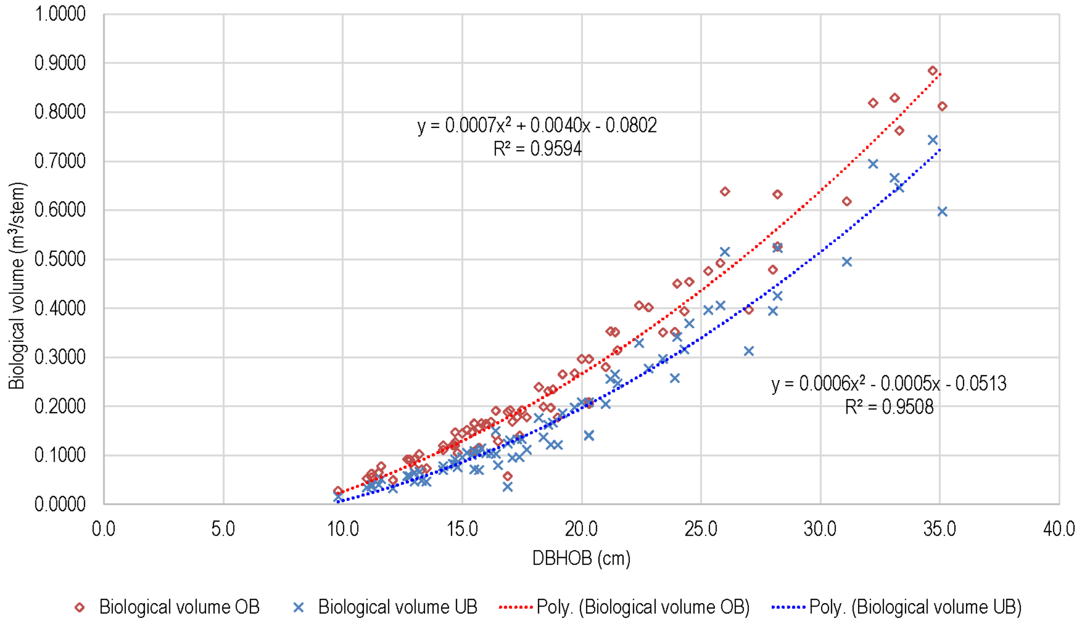

Figure 22: A teak tree volume dataset of 79 trees plotted to develop a one-way, single tree volume function.

The value of mature teak is driven by the attributes of the log wood, and in particular the percentage of heartwood. Currently teak logs exported from PNG are sold on a heartwood volume basis. A model was developed to estimate the volume of each component and this will be used to look at the relationship between heartwood percentage at set points as an estimate of overall heartwood volume. The teak volume model contributed to the development of a financial model for teak production. The financial model provides projections on woodlot and estate wood flows over time. It includes provision for calculating the number of domestic houses that a planted teak estate can support with a given annual planting rate. The model also includes provision for modifying the level of costs and benefits associated with the contribution of four main actors, including landholder, service provider, cooperative and investor. The model is useful for large-scale investors seeking to establish a nucleus estate for teak and/or partnerships with smallholder growers.

2.3 Model estate and marketing plan

A tree grower and the processors of the resulting logs must consider the target markets for their products. Log exports generate significant revenues for PNG: in 2018 exported logs returned K1.297 billion. The status quo of natural forest-sourced logs for export indicates a range of log fob prices from c.K145 to K356/m3 with the exception of kwila at K835/m3. Plantation grown logs achieved fob prices from K145 to K345/m3 with the exception of teak. Teak is sold on an under-sapwood basis with average log prices of c.K800/m3, but it is difficult to realistically compare price due the sales bias. Experience with demonstration teak woodlots allowed testing of the local and informal markets for thinned from below (e.g. smaller) trees at age nine years. Demand for the posts was significant with posts sold down to an over-bark SED of 9.0 cm (mean SED of 15 cm). The posts were sold on a linear metre basis for K5.00/ Linear m which equated to K433 to

K1,731/m3. The value of the trees thinned was K50.90 to K60.00/tree. Care is required to ensure that markets are not over-supplied, impacting demand and price. Where logs are processed into sawn timbers, there is the option to supply the domestic market (Table 3) or to export. Care is needed to ensure the best margin after all costs are accounted for. Data suggests that domestic market sawn timber prices were c.K1,000 to K2,000/m3, whereas the export market prices in the same year were on average (by sample) c.K1,000/m3 for mixed species.

Table 3: A summary of housing construction demand in 2045, sawn timber inputs and the area of woodlots required to supply the logs for processing. * MAI of 20 m^3/ha/y was calculated based on volume function of Figure 22.

House type	Attribute	Details	ENB
Traditional	Houses required in 2045		1164
Non-traditional	Houses required in 2045		1104
	Sawn timber (m^3/y)	At 10 m^3/house (demand)	11 040
	Log volume (m^3/y)	At 40% recovery (demand)	27 600
	Planted tree area harvest (ha/y)	At 25 years, an MAI of 20 m^3/ha/y*, less 25% volume as thinnings and clear fall volume 40% sawlogs (supply)	184
	Woodlot area per house (ha/house)	(supply)	0.2
	Sawn timber at year 25 (m^3/ha)	(supply)	60
	Planted tree estate (ha)	(supply)	4600
	Clear fall harvest residues (m^3/y)	(stemwood)	41 400
	Processing residues (m^3/y)	(solidwood off cuts)	16 560

Objective 3: Develop capacity to improve PNG Sandalwood.

Overview

With few regulations for and no monitoring of the sandalwood trade in PNG, the species has become rare in the wild. Through a systematic wild survey the project has demonstrated that PNG sandalwood has sufficient variation in which to base an improvement program. This is particularly evident for the extreme variation found for oil quality characters. Further research is required to capture selected individuals from the wild and establish a clonal archive. This would form the basis of future improvement in oil quality for this species. The identification of a new cryptic species in Western Province that is distinct from *S. macgregorii* is worthy of future research to determine its genetic basis.

Landholders are keen to restore their sandalwood resources through replanting in agroforestry systems. However with few trees remaining in the wild, sourcing sufficient quantities of seed can be challenging. The challenge in collecting substantial volumes of sandalwood seed relates to limited knowledge of the reproductive phenology, small seed crops, and logistics (high costs to collect from isolated individual trees). The project managed to work collaboratively with landholders to collect sufficient seed to establish functional *circa situm* sandalwood plantings. The *circa situm* participatory approach to tree domestication is characterised as a low-input strategy, and applicable where institutional resources to support more formal programs are lacking (Dawson *et al.* 2013; Bush *et al.* 2020). The *circa situm* sandalwood plantings established in this project will provide a sustainable and cost effective supply of sandalwood seeds to support new plantings. The caveat to this is that a system for seed exchange is required to ensure that new plantings are based upon a diversity of seed sources. Landowners are now aware of the value of seed as the basis of commercial exchange (Oa and Rome 2015). Seed exchange has already been demonstrated within the Kairuku area using existing mother trees within homestead plantings (Page and Oa 2017b). The project has also facilitated commercial seed exchange from a historical homestead planting established in the village of Gomore. Seed collections from wild populations in Western Province was not possible because of potential reproductive failure (Jeffrey *et al.* 2019).

The establishment of the species provenance trial at Kuriva represents an important future source of sandalwood seeds for commercial plantation development. The two surviving species include *S. album* and S. *macgregorii*. The intent was that the seed derived from this plot be made available to people planting sandalwood in areas such as the Markham where sandalwood is not native. Growers in Central province have however expressed their desire to plant Indian sandalwood, which represents a potential threat to the genetic purity of S. macgregorii populations. The potential proliferation of *S. album* into native areas of *S. macgregorii* is an issue that requires a consensus among stakeholders.

The development of a viable sandalwood sector in PNG, requires institution and regulatory support. In a review of existing regulations the following recommendations were made to support the industry: (i) establish a ten-year moratorium on the sandalwood trade to enable recovery of natural populations; (ii) develop a product grading and sales registry system to improve transparency and monitoring of trade; (iii) re-allocate tax revenues generated from sandalwood exports to the PNGFA to fund the monitoring of harvesting and trade and (iv) promote options for resource restoration through family garden, boundary and enrichment plantings. The sandalwood industry in PNG has the potential to be viable and sustainable if the proposed recommendations are adopted by stakeholders to manage the production and regulate the trade in the country and internationally.

3.1 Establish species/provenance sandalwood trials.

Seedlings were raised from imported and local seedlots at the PNGFA nursery. Germination rates of the seeds were very low (Table 4) owing to their low viability rather than nursery techniques during germination.

Table 4: Germination results for sandalwood seedlots sown at PNGFA HQ Nursery in 2016

Seedlot	Species	Collected	Date Sown	Sown	Germ	%
Hokua	S. austro	2015	14 Jul 2017	4500	495	11%
Mackay	S. album	2015	14 Jul 2017	3000	511	17%
Eterael	S. album	2016	14 Jul 2017	200	115	58%
Wiles	S. album	2016	14 Jul 2017	500	435	87%
Pronk	S. album	2013	14 Jul 2017	1000	0	0%
			Total	9200	1556	17%
Hokua	S. austro	2015	29 Sep 2017	2000	70	4%
Lava	S. mac	2016/09	29 Sep 2017	500	217	43%
Helalo	S. mac	2016/09	29 Sep 2017	500	412	82%
Gomore (Lava)	S. mac	2016/02	29 Sep 2017	500	265	53%
Kalio	S. mac	2015/05	29 Sep 2017	1000	185	19%
Kalio	S. album	2015/05	29 Sep 2017	1000	185	19%
			Total	5500	1334	24%
FRI Lae	S. album	2016 Bulk	02 Oct 2017	200	0	0%
FRI Lae	S. album	2016 RK	02 Oct 2017	200	10	5%
FRI Lae	S. album	2017 Bulk	02 Oct 2017	200	30	15%
Gomore (Helalo)	S. mac	2016/09	02 Oct 2017	2000	205	10%
Gomore (Mina)	S. mac	2016/02	02 Oct 2017	4000	35	0.8%
			Total	6600	309	5%

Kuriva

One-year-old sandalwood displayed 90 cm in height for local species (S. macgregorii) sourced from Kuriva and Gomore (70 cm) followed by *S. album* sourced from Mackay and Wiles in north Queensland. The least performing species were *S. album* originated from Eterael and Wiles (Australia) and *S. austrocaledonicum* from Vanuatu.

Survival was recorded in Jul 2018, and of 328 surviving sandalwood seedlings, 49.3% were measured as seedlings (normal seedlings), while 50.7% were classified as coppices. These coppices were developed mostly at the root collar from seedlings debarked or chewed by rats. Highest mortality was recorded in Ethereal source (84.4.%), caused primarily through rat and pig damage associated with their consumption of sweet potato that was planted in the area. In Vanuatu sweet potato has been used successfully as a companion planting that has been effective at reducing weed competition, but here it has been at the detriment of the young seedlings. Survival in all remaining provenances was between 68 (Wiles) and 88% (Mackay). The site was refilled again in mid-2019.

This trial can be used as a seed production area for the PNGFA and FRI (Figure 23) to distribute among growers nationally to enhance project impact from this activity. The site also offers a source of germplasm for clonal and family selection for superior growth.

Figure 23: Vigorous sandalwood seedling (left) at Kuriva are beginning to flower and set seed (right).

Situm, Morobe Province

A replicate sandalwood species provenance trial was established in Situm, Morobe Province. The seed sources and design were similar to that established in Kuriva. The trial established well with good survival after four weeks. However, over the following six months a high level of mortality (80-90%) was recorded and the trial was abandoned. The negative result for this trial was attributed to the high rainfall of the Situm area. Given that teak has established and performed very well at both Situm and Kuriva, it is evident that teak has a greater environmental range than sandalwood. Similarities between the Situm area and Gazelle Peninsula (ENB) has been noted, both with highly fertile volcanic soils and high and consistent annual rainfall without a dry season. The result of this trial therefore indicates that sandalwood would not be a recommended crop tropical regions with even annual rainfall.

In situ seed stands of S. macgregorii

Girabu Model Site 1: Rigo District, Central Province.

Land ownership rights for this site are vested with a single sub-clan. Clear ownership rights over the land was a prerequisite for the project to be established, to avoid disputes of any sort that would hinder the progress of the project activities into the future. The

Registration of Incorporated Land Group (*ILG Act)* was not achieved during the project due the requirements for birth certificates of all landowners within the ILG.

A one hectare plot was ploughed in 2015 using a community-owned tractor. Rows of vegetables, namely corn, cucumber, yam, aibika, watermelon, sweet potato and peanut were planted on the site followed by banana, pineapples, pawpaw and cassava (Figure 24). Crop production was recorded for all crops over the first four years and used to inform the financial model for this species. The mean value of the crops produced was PGK2,700 per annum. Growing and marketing of pineapples has continued to at least year 5 and vanilla was planted under each of the *Cassia* trees at age 3-4. These were not recorded in the financial model.

From December 2016 and for the next 7 months, sandalwood seedlings were planted among the vegetables at the project site. With the spacing designed at 5 m x 5 m, 13 rows of sandalwood were planted (221 trees). Six rows of *Cassia fistula* and 6 rows of *Leucaena leucocephala*, giving a total of 204 host trees planted in the project area. Twice annual applications of 25-50g of NPK fertiliser were applied to the sandalwood seedlings The mean annual increment for basal diameter at Girabu was 2.0cm.yr^{-1}.

Figure 24: Sandalwood agroforestry trial in Girabu (left) with Guduru Rome (PNGFA), Farm Manager Sebara (Girabu), Linden Oa (PNGFA) and sandalwood seed supplier Helalo Minima (Gomore). Sandalwood grown with pineapple (right) at the Girabu Model Site.

Iokea Model Site 2: Malalaua District, Gulf Province.

The project engagement with the Iokea site built upon a relationship established between the Gulf Province and a customary landowner group in the village of Iokea. This relationship was developed independent of the Iokea ward administration and as such the project worked directly with the Hasu Clan customary landowners. Wider community engagement occurred through the provision of seedlings for the sandalwood planting and technical workshops for sandalwood planting.

Sandalwood seed/seedlings were sourced from the multiple mother/seed trees growing within the Iokea village. Community members participated by commercial supply (K5/seedling) of sandalwood seeds/seedlings to the project. Seedlings were produced by individuals in small temporary nurseries as polybag stock in ground beds with low shade structures. The use of Alternanthera nana pots hosts was adopted by about half of the supplying nurseries.

A total of 500 sandalwood trees were planted on the project site in April 2015 (300) (0.5 ha) and June 2016 as infills (200) (Table 5). The spacing was designed as 6 m x 3 m, with a plant spacing of 3 m within rows and 6m between rows. After every 4 sandalwood trees a host was planted and the 1 hectare plot was designed to accommodate over 500 trees (Figure 25).

Table 5: Summary of sandalwood seedlings planted in April 2015 & June 2016 and their survival and growth in May 2017 and survival in November 2017.

Date	Planted			
Apr-15	300			
Jun-16	200			
Total Planted	500			
May 2017	Survival	Seedlings <2m	Seedlings 1-2m	Seedlings >1m
Frequency	192	58	67	67
Nov 2017	N	%	Mean Height	Mean Dia.
Unburnt	55		1.8 m	2.5 cm
Burnt	137	71% of May 17		
Dead	113			
Suckering	24	17.5% of Burnt		
Alive	79	15.8 % of 500 planted in 2015/16		

Although the site was suitable for agriculture, it was not ploughed due to mechanical issues with the tractor. Instead, the landowners manually cultivated an area within the site and planted peanuts, cassava, sweet potato and pineapples, but only for the first crop before the site was overgrown with kunai grass (*Imperata cylindrica*). These vegetables were used for own consumption and no records of sale recorded by the landowners.

The planting at Iokea had performed reasonably well up until June 2017 when the sandalwood were overgrown with kunai grass (*Imperata cylindrica*). A deliberately lit and uncontrolled grass fire in 2017 caused significant sandalwood mortality (Figure 26). A total of 79 surviving seedlings - 15.8% of those planted in 2015/16 (Table 5). Mean annual increment of basal stem diameter of the surviving plants was 0.74cm.yr^{-1} (Page 2017b).

Figure 25: Sandalwood and host trees planted at the Iokea sandalwood site

Figure 26: Sandalwood were affected by an uncontrolled fire from the north east in August 2017 (left), 71% of the surviving trees were affected and 17.5% of affected trees are beginning to sucker (right).

Kairuku Project Area, Model Site 3: Kairuku-Hiri District, Central Province.

The KPA covers several villages within Kairuku District in the Central Province. The villages covered are Biotou, Rapa, Babiko, Ipaipana, Mou, Nikura, Vanuamai and Eboa. These villages host a number of seed trees, either within household backyards or elsewhere on their land.

Within the Kairuku project area (KPA) an individual family-based approach to planting sandalwood was undertaken, which contrasted with the clan-based approach of Girabu and Iokea. The family approach involved nuclear families establishing small sandalwood blocks using seeds either produced from their own mother trees or supplied by the project. A rapid assessment of plantings across eight villages in 2018 identified 35 families planting an average of 45 seedlings each amounting to around 1,500 seedlings planted.

The area has a high population and families generally reside in their own blocks of up to 1ha. Plantings in the homestead are typically planted along boundaries or as ornamental specimens close to the house (Figure 27). These plantings are suitable for families that have limited seed and experience because the trees are easily maintained and seeds easily collected when they become productive. Sandalwood is also being established in small garden plots with a diversity of crops including pineapple, manioc, guava, banana, yam, citrus, mango, breadfruit, betelnut and moringa. The mean annual increment of basal stem diameter in Kairuku was 1.1 $cm.yr^{-1}$ at age 2 years.

Figure 27: Smallholder sandalwood woodlots in Babiko (left) and Eboa (right) within the Kairuku project area (KPA).

3.2 Characterise intra and inter population variation for S. macgregorii in PNG.

The survey conducted for *Santalum macgregorii* has confirmed a very low frequency of mature trees of commercial size. Trees can be considered to be commercial when their basal stem diameter is at least 15-20cm. To ensure sufficient trees could be sampled the study restricted sampled trees with a basal stem diameter of greater than 10cm, which were expected to contain heartwood but not of commercial quantities. Even with this small size threshold, it was challenging to identify a sufficient number of trees in each location to sample. Mean tree diameter was found to be 16.4cm at tree base (0.2m) and not significantly different among the five populations sampled. Trees from Kairuku were found to be larger in height and diameter than those from Iokea, Rigo, and South Fly, also with a greater bole length than the former two. The sample of four trees within the managed recreation at Kuriva were either intermediate between these two groups (diameter and bole length) or greater than the latter group (diameter). Given that the populations are highly modified by harvesting, planting and assisted natural regeneration, it is not possible to make generalisations regarding the relative sizes of trees between populations.

Evidence of historic harvesting was found where sampled trees were coppice growth from trees harvested some 15-20 years prior. This pattern matched the harvesting records in which a spike in national harvest export volumes was found in the late 1990s and early 2000s (Turia and Saliau 2019). The exception to this was South Fly where there was little evidence of historical harvesting of wild-occurring sandalwood. This evidence included landowner discussions, lack of patterned suckering around harvested stumps, and a low level of heartwood check damage. With a low harvesting pressure the trees in South Fly might be expected to be taller, with a wider stem diameter than the remaining populations. However, they were either equal to or lower than other sites where intense harvesting has been a feature. It is possible that the trees in South Fly represent a relic, with fire-affected small clonal copses that have limited capacity for sexual reproduction and seedling recruitment.

People are key to species conservation with over half (56%) of the trees sampled being established through planting or assisted natural regeneration (ANR). While people were found to tend trees, they were also the primary agent of damage, through the action of bark slashing, heartwood check and anthropogenic fire. A high incidence of bark slashing damage was found in trees that were proximal to the village, whereas heartwood check and trunk scald (associated with fire damage) was found more frequently in trees that were distant from the village. Heartwood rot was recorded in almost one in five trees, and even more frequently in trees with trunk scald damage.

Heartwood content and composition

Heartwood characters are the most important commercial traits for sandalwood and its development within the stem is crucial for its commercial value. In this study 21% of trees with a basal diameter of >10cm lacked heartwood. The percentage heartwood cross sectional area of PNG sandalwood in this study ranged from 0 to 61%. Despite this range, both mean heartwood diameter and percentage was statistically equivalent between the populations sampled (Figure 28). This difference in the species did not appear to be driven by tree size since the mean population basal diameters between the two species were similar; 14.4 to 22.6 in *S. macgregorii* and ~15.0 to ~22.0 in *S. austrocaledonicum* (Figure 1 within Page *et al.* (2010)). Significant variation was found within and between populations for oil composition (Figure 29). Rigo had lower levels of α- and β-santalol compared with the remaining populations. The South Fly population had elevated levels of *cis*-lanceol relative to the other sites. Tree-to-tree variation in α-santalol ranged from <1% to 51%, meaning there is significant scope for improvement in this important commercial character.

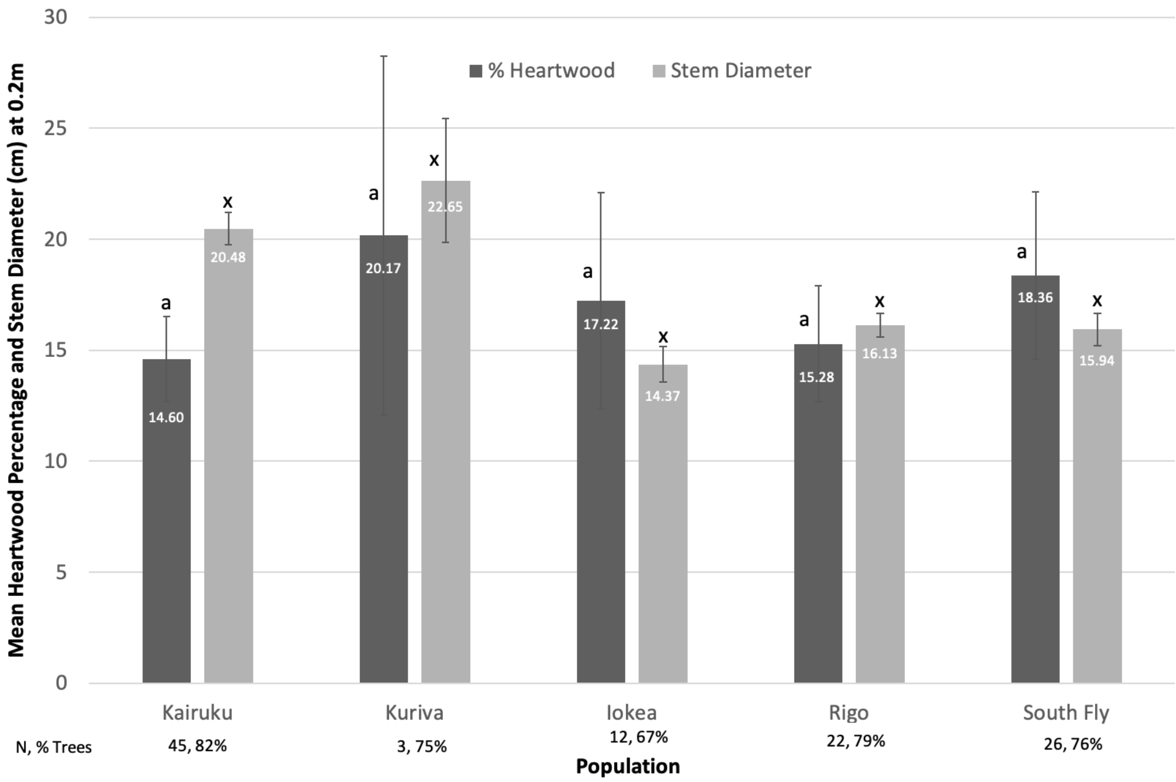

Figure 28: Mean heartwood percentage and stem diameter (0.2m from base) for those trees with heartwood present for five populations of *S. macgregorii* in southern Papua New Guinea. Vertical bars represent standard errors of the mean. Populations that share lower case letters are not significantly different for the individual trait. Figures below the x-axis denote N = sample number and % Trees = the percentage of trees within the population that contain heartwood.

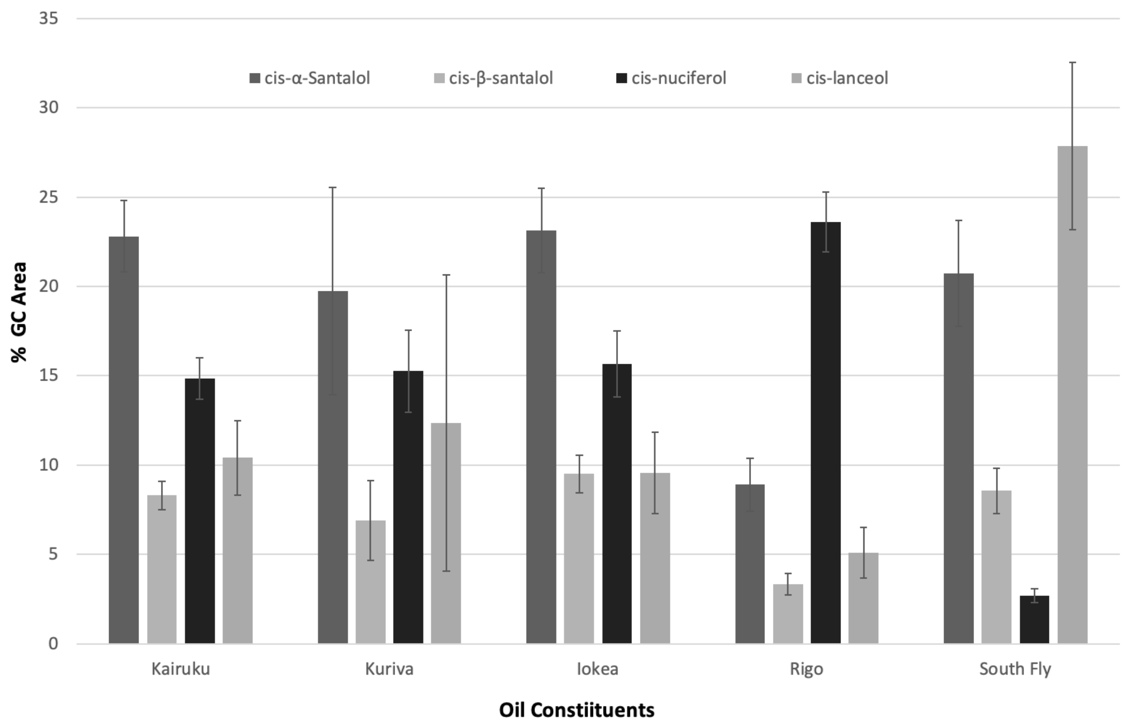

Figure 29: Percent area of gas chromatogram (GC) for four main heartwood heartwood oil constituents (*cis*-α-Santalol, *cis*-β-santalol, *cis*-nuciferol, *cis*-lanceol) for five populations of *S. macgregorii* in southern Papua New Guinea. Vertical bars represent standard errors of the mean.

Heartwood rot is a considerable problem that significantly reduces the volume of heartwood within a tree. Heartwood rot affected almost one in five trees sampled. All of the trees that were sampled would be considered to be unmanaged from the standpoint of limiting heartwood rot. This has implications for woodlots where ~20% trees can be expected to have heartwood rot if they are not managed. Heartwood rot can be introduced into the tree through damage to the bark that permits water entry into the main stem. This can be due to the direct action of people (heartwood check), fire or other biotic (pest) or abiotic (wind) damage to the branches and trunk. In this study we found that trees with trunk scald (fire/sun) had an elevated level of heartwood rot relative to the rest of the population. Interestingly trees with heartwood check damage had similar levels of heartwood rot to all remaining trees. Given the severity of both trunk scald and heartwood check it was surprising that many of the trees still did not have symptoms of heartwood rot at the base (0.2m). It is possible that any rot caused by damage had yet to reach the coring point at the base of the tree (0.2m). Within *S. album* plantings in Australia Barbour *et al.* (2010) found that wood rot fungi entered the trees either by the roots or where bark protection was lost through mechanical damage or trunk-scald. In the present study, we also found heartwood rot in outwardly healthy trees.

Reproduction and Recruitment

The measure of reproductive phenology provides only a snapshot in time. Interestingly, three of the populations (Kairuku, Iokea, and Rigo) exhibited a substantial proportion of trees with evidence of reproductive structures at different stages (buds, flowers, and fruits). In Kuriva the sample size (N=4) is not of a size to permit comparison with other locales. The trees in South Fly had a high proportion of trees with buds (66%) and a lesser proportion of trees with flowers (28%) but only very few with immature fruits (4%) and no observation of mature fruits (0%). This result may be indicative of seasonal conditions conducive to reproduction at the time of sampling. However, it is interesting because, firstly, it contrasts with all types of reproductive structures being observed in Kairuku, Iokea and Rigo and, secondly, landowners reported to have never observed mature fruits in the South Fly populations. These results are indicative of potential reproductive failure in this population, although more research is required to determine if this is the case. Sexual reproductive failure has been recorded in other species of sandalwood such as *S. lanceolatum,* resulting from population fragmentation and clonal reproduction, combined with self-incompatibility and pollen sterility (Warburton *et al.* 2000; Lee *et al.* 2020a). The contrasting flower colour between South Fly (white) and all remaining populations (red) confirms earlier reports of this distinction between these two non-contiguous areas of distribution (Bosimbi 2006).

Through the actions of harvesting and fire, people have been the primary cause of PNG sandalwood contraction over the past one hundred years. However, the present study found that people are also key to this species' ongoing survival and expansion. Over half (56%) of the trees sampled in the present study had established through planting or assisted natural regeneration (ANR). This was most prominent in Kairuku and Iokea, where approximately 80% of trees were regenerated by planting or assisted natural regeneration (ANR). Primarily this planting occurred within the village area as ornamental plantings or in adjacent garden areas. This high number of planted trees in the sample reflects the very low numbers of trees growing beyond the village areas in more natural settings. Resource owners suggested that most of the standing stock was removed during the early 2000s when there were high levels of trade in PNG sandalwood . In Rigo most sampled sandalwood trees (72%) were located beyond the immediate village area, with many having regenerated as root suckers from previously harvested mother trees. In South Fly all sampled trees were identified as being natural trees and only two instances were observed where trees had been planted, but not sampled as they were too small (i) transplanted root sucker and (ii) a small single tree within a yard which the children had removed during play.

Clonal recruitment through root suckering was found to be a prominent form of reproduction in *S. macgregorii* across all the sites. Seedling recruitment was found to occur in the populations of Central and Gulf Provinces (~20% of trees had approximately 10 seedlings each), but not in the isolated population within Western Province. Most seedlings were found within 5m of the mature seed tree and were primarily less than 1m in height. There was a distinct lack of saplings greater than 1m or any occurring beyond the seed trees. With frequent grass fires in natural sandalwood areas (i.e. beyond village areas) seedling recruitment in *S. macgregorii* was limited across its natural range.

3.3.Develop nursery capacity for production of wild-collected and improved sandalwood germplasm.

Sandalwood training and awareness workshops

Two technical workshops over two days covered sandalwood-specific content, with a classroom-based session on Day 1 (Figure 30) and a field-based session on Day 2 (Figure 31). The workshops were attended by 136 people across 10 villages in 2 districts (Iokea and Kairuku).

The following key learning areas were covered in the workshops:

- Sandalwood products and markets;
- Seed collection & processing;
- Potting media;
- Potting seedlings;
- Nursery management;
- Hosts; and
- Planting establishment & management.

Participants were asked to rate their understanding on the following 4-point scale.

1 I understand this topic well enough and could **train other people** in this task/topic.
2 I understand this topic well enough and could confidently complete the task/topic **without help.**
3 I am aware of the basic principles but **need further training** to complete the task/topic.
4 I am still **unclear** with this task/topic.

At the commencement of the workshop participants generally rated themselves between having a basic understanding of the topic to being unclear with a mean rating of 3.6 (Table 6). Participants' overall level of understanding of the eleven topics presented during the workshop improved by 1.7 points to a mean of 1.85, indicating that most thought they understood most topics and could confidently complete the task without further help. Most indicated that the practical sessions in the field helped to clarify some of the topics presented in the classroom. This result confirmed the feedback from the Training Needs Analysis in which landowners nominated face-to-face practical training as their most preferred method of training delivery(see activity 5.1.2).

Table 6: Mean scores across a 4-point scale (see above) for all workshop participants in Iokea & Kairuku. Lower scores indicate a better understanding of the topic.

Question	Before	After
1. Sandalwood products and international market demand for sandalwood	2.45	1.95
2. The correct practice of seed collection and processing	2.33	1.71
3. Crack test technique for testing seed quality	2.70	1.95
4. The components and ratios needed for a good potting media	2.81	1.83
5. The correct practice of potting seedlings	2.55	1.69
6. The consequences of incorrect potting of seedlings	2.57	1.85
7. The main factors determining seedling quality	2.67	2.10
8. The purpose and process of hardening seedlings in the nursery	2.76	1.89
9. The reason for planting sandalwood with other trees (hosts).	2.52	1.70
10. Selection and spacing of hosts with sandalwood.	2.63	1.80
11. The factors most important for successful planting establishment.	2.67	1.90
Mean	3.61	1.85


Figure 30: Workshop participants in Biotu (left) and Iokea (right) conducting classroom training on Day 1 of the workshop.

Figure 31: Sandalwood seed collection activity in Babiko (left) and participants with their collected seed (right) during Day 2 of the Biotu workshop.

Seedling Production

Girabu

A project site nursery was constructed and improved with the instalment of a 5,000 L water tank and shade structure. The nursery has germinated and raised significant numbers of sandalwood seedlings using seed sourced from both Gomore and Kairuku (Figure 32). Seeds were treated with gibberellic acid (0.1%) to improve germination, and resulting seedlings were raised in polybags in ground beds. The herbaceous plant *Alternanthera nana* was used as a pot host and introduced when the seedlings were at the 4-5 leaf stage. These were used to establish the project agroforestry plot and distribution to interested growers in Girabu.

Kairuku

A common nursery was established in Biotou, a central location in Kairuku. This nursery is a base for acquiring seeds and producing seedlings for the participants and to serve the area with the required nursery tasks as and when required. The project has also assisted families with technical input and equipment (polybags and shade cloth) to establish micro-nurseries for self-supply of sandalwood seedlings.

Iokea

Both a central project nursery (Hasu family) and smallholder micro nurseries (Figure 32) have been supported by the project. A survey of sandalwood seedling quality in smallholder micro-nurseries in Iokea between 2014 (8 nurseries) and 2018 (6 nurseries) revealed a substantial improvement in seedling quality (Figure 33). In 2014 an estimated 66% of seedlings were classified as having very poor quality and unsuitable for planting. In 2018 seedlings of similar poor quality represented only 12% of seedlings surveyed. Similar improvements were found in the proportion of nurseries using pot hosts with 25% in 2014 and 83% in 2018.

Figure 32: Smallholder sandalwood nursery owners in Iokea (left) and Girabu (Guduru Rome - PNGFA) (right).

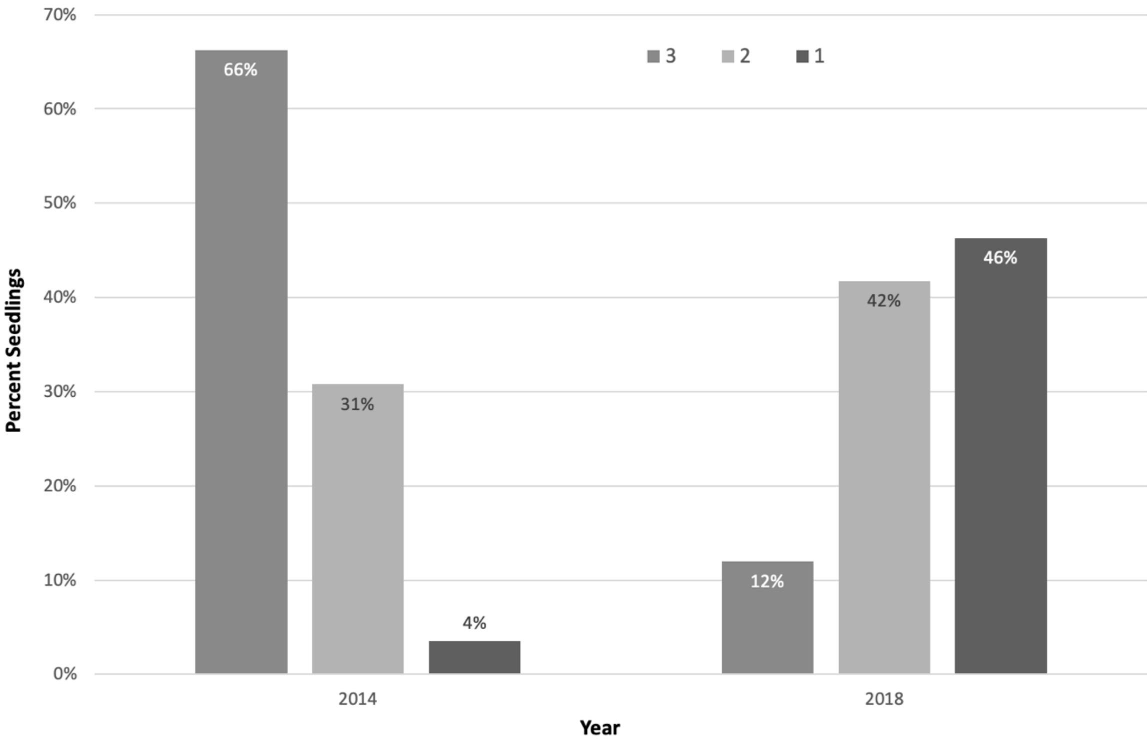

Figure 33: Sandalwood seedling quality assessment of micro-nurseries in Iokea in 2014 (8 nurseries) 2018 (6 nurseries). Seedling quality classes: 1) high quality ready for planting 2) of a quality requiring further growth or hardening, 3) are very poor quality seedlings and unsuitable for planting.

Objective 4. To advance the sandalwood genetic improvement program in Cape York Peninsula for use by local landowners.

Overview

CYP sandalwood offers excellent prospects for commercialisation owing to its high oil quality. Overall, the trials have been established, the growth of these species is promising and the Traditional Owners in the NPA are enthusiastic about the potential of sandalwood to bring regional employment, improved health and cultural activities for the people. The trials established in the NPA and Burdekin demonstrate the potential for this species to be produced under commercially-focussed silvicultural systems. The expansion of the clonal archive to include additional genotypes and establishment of progeny trials has improved the prospects for continued improvement in the species.

The biggest issue at the end of this project is that the oldest sandalwood trial was only 2.3 years old. There are significant challenges to starting a plantation program, in a greenfield location, based on a new species unknown to the market (last commercial harvest of wild sandalwood in the NPA occurred about 1937), with commercial partners who have to wait for a return on investment without detailed growth and oil production knowledge. Most tree based investments commence once detailed knowledge of the species is achieved at approximately 50% of a routine harvest age. At this age the potential growth, yield (in this case oil yield) and risks (pest diseases and adaptation to a plantation environment) can be considered and a sound investment made. The land tenure in the NPA was only clarified in 2019 when the Gudang/Yadhaykena Group was given Native Title over much of the area. Commercial development is of interest to both the Indigenous people of the NPA and private investors. However, it is too early in the development of the species for private investors to fund or assist with the establishment of plantations on this species without further research

With recent seed collections from the trials there is now sufficient seed on- hand to establish over 20 hectares of trials and/or commercial plantings of the species if additional funds become available. Trials of this scale are required to demonstrate proof of concept for further commercial investment. The trials are considered an important resource for developing and demonstrating capacity within community, determining the most appropriate host species mixes, and providing reliable commercial volumes of seed.

Outputs

All aspects of the project in the CYP have been delivered successfully.

- Two progeny trials have been established in the NPA with assistance from the staff and students of the Northern Peninsula Area State College and Community Development Program (CDP) workers (Figure 34). This has raised the profile of the work and help us build bridges with the broader community and the TOs in the region.

Figure 34: Establishment of the sandalwood progeny trials at the Northern Peninsula Area College (February 2017).

- Twelve new trees have been captured as grafted clones. This increases the number of sandalwood trees captured from the NPA to 30, providing the basis on an on-going tree improvement program of the species.
- Heartwood wood frass has been collected from eleven wild trees, with informed traditional owner consent, for oil evaluation. The oil profiles were analysed using GCMS. Seven of these trees had desirable oil profiles with santalol based oil profiles (the oils commonly found in Indian sandalwood) and four had less desirable lanceol based oil profiles. Lanceol is the most common oil found in 'typical' *S. lanceolatum*. These two groups of trees were significantly different from each other in overall oil profile, when tested by Analysis of Similarity (ANOSIM: Global R = 0.606, P = 0.001).

Some of these new trees have now been captured as grafted trees, securing the genotype and allowing these new genotypes to be included in future progeny trials.

- Viability of the seed has been found to be very high with viabilities in the 87% viability for the species (range 42% to 100% for individual families).
- Enough seed is held in the DAF Forest Science seed store to establish over 20 hectares of plantations.
- Two-year height growth in the NPA across the two trials was good with *S. lanceolatum* trees in the irrigated trial averaging 2.01 m height and 2.4 cm DBHOB (Figure 35). In the non-irrigated trial the *S. lanceolatum* trees averaged 1.75 m height and 0.9 cm DBHOB (Figure 36). This is similar to that reported elsewhere for young sandalwood.
- A trial has been established in collaboration with Quintis, the largest sandalwood plantation grower in Australia, to compare the growth and oil production of CYP sandalwood to the commercial Indian sandalwood they grow in their plantations.

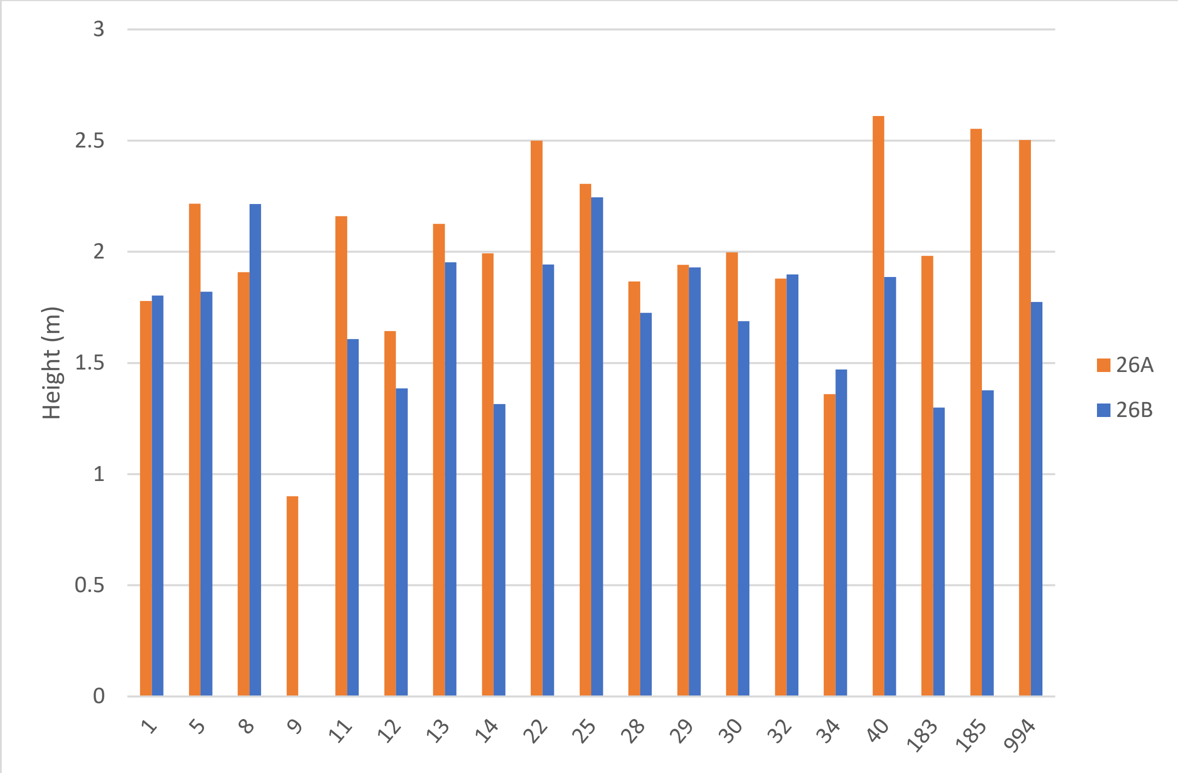

Figure 35: Two-year height growth in *S. lanceolatum* progeny trials at Bamaga. Trial 26A was irrigated and 26B was non-irrigated. Numbers along the x-axis are the family numbers to identify the progeny.

Figure 36: Two-year-old *S. lanceolatum* trees displaying good height growth in the irrigated (LHS) and non-irrigated (RHS) trials at Bamaga.

Objective 5. To communicate and disseminate research outputs to improve uptake and impact.

Overview

This objective has generated important findings that clarify farmers interests, constraints, training needs and training preferences. The project has found that both men and women alike are interested in planting trees for commercial and subsistence use. The primary constraint to adoption was one of knowledge and confidence since timber tree planting has not necessarily been part of agricultural production in the target areas. Despite this, many landholders have significant capacities for nursery and tree production associated with agriculture and cash cropping. Training activities for woodlot management should therefore commence through evaluation of existing participant knowledge. This can help determine the appropriate interventions required and any need for a differentiated approach to extension. Aspects that are specific to forest trees are likely to include tree spacing, pruning, thinning and harvesting and many landholders will require upskilling. Prospective growers are keen to learn and an overwhelming preference for practical training was recorded. This supports the projects use of extension and lead farmers to build capacity of woodlot owners.

Another constraint to planting was access to traditional forms of labour. Given the shared interest in tree planting among men and women The Family Farm Teams approach to agricultural extension in PNG (Pamphilon *et al.* 2017) would be applicable to address the needs for knowledge, practical based training and current perceived labour constraints. Smallholders have multiple existing family, agricultural, community, church and cultural commitments. Therefore there is advantage in delivering extension and training through existing upskilling programs with the church, ward and/or LLG. The project has established a resource centre at Mission Base in the Toma LLG where training can be conducted and resources from the Tree Growers Toolkit can be accessed. This approach to smallholder engagement and training has been well received and should be further expanded.

5.1 Capacity Building and Communication.

Explore constraints to participation by women in tree planting

The results indicate that women have a strong interest in establishing small woodlots, which has resulted from their desire to address their own needs for timber (particularly house construction) as well as commercial sale to meet the shortfall in timber resources within the region. Despite this clear interest among women, they are constrained primarily by (i) a lack of knowledge and access to information, (ii) competing responsibilities and associated lack of time, (iii) limitations to mobilise traditional sources of family or community labour and (iv) a lack of access to suitable land.

To address the lack of knowledge, the women provided preferences on training delivery. Face-to-face and peer-based training was preferred, but the duration of training interventions differed between participants, which appears related to their existing commitments. Participatory community-based training using female trainers was found to be important in addressing social and structural barriers to information provision for women smallholders. Preferencing of different types of media-based (ICT) information delivery (print, video, internet) varied between workshops, which may reflect differences in levels of literacy and access to internet between communities. Significant family and community commitments impacted in two ways. Firstly, commitments affected their capacity to attend organised training activities and, secondly, commitments affected their capacity to adequately maintain newly planted woodlots. The changing nature of access to traditional forms of labour exchange means that it will be challenging for women to address their time constraints with additional sources of labour. The limitation of land in this part of PNG can be expected given the relatively high population of the area. Tree plantings that complement existing agricultural land use and careful land use planning will need to be considered to incorporate trees within the landscape without causing disruption to existing livelihood activities.

Figure 37: Women participants in the workshop were involved in small group discussions (left) and prioritisation activities (right)

Figure 38: Following the consultative workshop participants engaged in a short practical activity (left) and were issued bare root teak seedlings (right).

Training Needs Assessment

Motivations

Teak growing by farmers in ENB is a relatively new activity and motivations were determined through earlier surveys, combined with the stakeholder situation analysis. A strong motivation for all tree growing is future cash returns, and also for house building materials. This result was confirmed among landowners in their responses to the questionnaires, in which products for sale and timber were prioritised most strongly. No significant differences for tree planting motivators were found between female and male participants for the priority index (Table 7). The importance of cash and timber as primary motivators for tree planting was further validated in the broad group discussions in the women's workshops and growers' training events. Training materials need to consider inputs (e.g. land; labour; capital) and expected outputs (e.g. log volume; log value; timing of returns) in combination with farmer timing horizons (Table 8).

Across all workshops and training events participants recognised the high demand and lack of local supply of hardwood timber required for building permanent houses and community buildings. There was a general awareness amongst the group of the ability to make use of the lower quality timber (thinning etc): stores, sack house construction as well as furniture. "*Furniture are very important to a family home, we need chairs and tables and also beds for family use*" (young female participant, 2018). Trees as a long-term investment, whether financial or for own-use, was also acknowledged in the workshops. *"I am a widow and getting old, but I am doing it* [planting trees] *for my grandchildren"* (female participant, 2016).

Table 7: Reasons for growing trees among 96 questionnaire participants in order of rank (priority index for each within parentheses). The priority index for male and female participants are also included. Priority index is based on weighting of 1st (x3), 2nd (x2) and 3rd (x1) most important motivators for planting trees.

Motivator	Rank (Index) All	Index Female	Male
Products for Sale	1 (0.325)	0.43	0.29
Timber	2 (0.258)	0.21	0.27
Environmental	3 (0.127)	0.15	0.12
Products for home & community use	4 (0.089)	0.08	0.09
Other	5 (0.088)	0.09	0.09
Fuelwood	6 (0.043)	0.02	0.05
Fruits & Nuts	7 (0.041)	0.02	0.05
Store Carbon	8 (0.021)	0.00	0.03
Boundary	9 (0.005)	0.00	0.01
Soil Fertility	10 (0.003)	0.00	0.00

Table 8: A farmer decision making matrix.

	Farmer time frames		
	Immediate future	Annual	Longer-term
Labour	Tree planting demands on labour compared to other commitments (e.g. subsistence gardens and cash crops).	Tree maintenance demands on labour compared to other commitments (e.g. subsistence gardens and cash crops). Such demands may appear of lesser importance (e.g. singling) as Teak trees are planted and growing, but can significantly impact on yield and value.	Longer term-tree maintenance demands on labour are limited to critical operations required (e.g. pruning and thinning).
Land	Tree planting demands on land compared to other commitments (e.g. subsistence gardens and cash crops).	Tree maintenance demands on land are fixed once planted, but can allow some inter-cropping (e.g. subsistence gardens and cash crops).	Tree maintenance demands on land are fixed once planted, with limited co-cropping after canopy closure. Teak can form part of a long-term garden fallow system and to mark boundaries
Capital	Tree planting demands on capital compared to planned commitments (e.g. school fees) and unplanned expenses (e.g. medical expenses).	Tree maintenance demands on capital compared to planned commitments (e.g. school fees) and unplanned expenses (e.g. medical expenses).	Potential cash returns from selling thinning and clear fall products planned to meet specific needs (e.g. housing, bride price, and/or educational needs).

Training Needs

Interest in planting forestry trees regularly occurred among questionnaire, workshop and training participants, suggesting forestry development interventions will have the potential to be adopted in East New Britain. With lack of knowledge identified as being a primary constraint to adoption, the development and delivery of training materials and information must be informed by the needs of farmers. A key point is that while farmers can articulate information needs (known unknowns), there are issues and information required that a farmer may not be aware of – the unknown unknowns. When growers are asked about what sort of knowledge they lack and need training, articulation of the need for assistance across all areas is usually communicated. A gap analysis comparing farmer skills in other crops with those required to manage woodlots was undertaken, in order to identify similarities (e.g. requirements to successful planting) and specific differences (e.g. a need for singling, pruning and thinning of a Teak woodlot). This process was reinforced by a range of farmer visits (informal and semi-structured interviews conducted during farm walks), observing the OISCA team's interaction with farmers and discussions with the OISCA team.

Plant nursery experience among women workshop participants was almost universal (97%) with particular emphasis on food crops (vegetables & fruit trees), cash crops (coconut, cocoa, betel nut) and ornamentals. Interestingly 14% of participants reported some experience with producing forest tree seedlings, even though only 7% recorded experience planting timber trees. East New Britain province has a vibrant galip nut (*Canarium indicum*) smallholder sector and some of the women may have produced galip nut seedlings as nursery stock.

Tree growing experience was widespread (78%) among women workshop participants, which included cash crops and fruit trees, but less so for forest/timber trees (7%). Much of the knowledge and skills associated with cash crop, fruit tree and ornamental nurseries and plantings are transferrable to forest tree management. Training and extension for forest tree nursery production can leverage existing knowledge among landowners to rapidly improve capacity and confidence among farmers. Furthermore, existing knowledge for site preparation, and planting can be relevant to forest tree production. Pamphilon *et al.* (2014) concluded that identifying and building from the existing knowledge and learning experiences of women can help agricultural extension to be more gender sensitive and culturally centred. Training activities for forest tree planting can include evaluation of existing relevant knowledge among participants. Aspects related to tree spacing, pruning, thinning and harvesting are unique to forest trees and will require specific knowledge transfer and upskilling.

Experience with timber tree growing was greater among men within the training events, with between 60 and 70% of participants having some experience. Almost all had confidence in being able to establish and maintain a woodlot, but considered the area of pruning and thinning to be an area where they required additional support. The timber trees that were most commonly included native species such as *Canarium indicum* (galip), *Calophyllum inophyllum* (calophyllum), *Eucalyptus deglupta* (kumerere), *Intsia bijuga* (kwila), *Homalium foetidum* (malas), *Pterocarpus indicus* (rosewood), *Pometia pinnata* (taun), *Castanosperum australe* (blackbean), *Octomeles sumatrana* (erima), and *Terminalia* species (talis). Exotic species included *Tectona grandis* (teak), *Gmelina aborea* (gmelina), *Swietenia macrophylla* (mahogany), *Ochroma pyramidale* (balsa).

The questionnaire respondents indicated some of the most important information required to assist them in their tree growing efforts. These included information on why to plant trees and which trees to plant (Table 9), which was interesting given that most considered they had experience in planting trees. 'Making money from trees' was an important area where growers considered that they required more information. When these results were presented to training participants they indicated that while they knew why they were planting trees, they were most interested in knowing which trees can produce good returns in terms of timber and cash for sale.

Table 9: The type of information identified by 96 questionnaire respondents to help them to grow trees.

Type of information	Percent of respondents
Why plant trees?	66%
Which trees to plant	84%
Where to plant trees	35%
How to grow trees	36%
How to grow trees with crops	28%
Making money from trees	74%
Protecting your environment with trees	29%
Slowing down climate change with trees	23%
Other	5%

Training Delivery

Forestry training can potentially be accommodated within existing programs including (1) women's program within the church fellowship and (2) ward (village) meeting. Both of these meetings occur weekly and the latter for an entire day, and training can be conducted as a component within them. Participants also considered scope for including forestry training within the 'community life skills training' that is delivered within the Local Level Government (LLG) activities.

Gender considerations related to training activities were raised by participants during the workshops. *"Training needs to include both women and men, because this is important to build trust*" (female participant 2016). This inclusive approach to training was further articulated to include all family members "*a family teams approach to training is a must*" (female participant, 2016). There was a recognition that because men are involved in family decision making, they too need to be involved in training and other activities to help them make an informed decisions.

Training Delivery Preferences

Face-to-face training is clearly the main preference for training delivery among the women participants, with lower preferencing of media-based training delivery (Table 10**.**). Across all workshops there was an enthusiasm for practical approaches to training, where people can directly observe and participate. There was a desire among some for landowner-specific advice "*I want someone to come to my block and tell me if teak is good for my block*" (Participant 2016). There was a general understanding amongst the participants that such practical training and/or personalised advice may not be cost effective to deliver to all farmers across the region.

Informal modes of training delivery, including the use of exemplars or lead farmers ,were well regarded across the workshops and many were familiar with the approach. *"WYiA are already using this method* [model farmers] *to disseminate knowledge within their work with the World Bank funded PPAP cocoa project they are involved with"* (WYiA representative 2016). The need for appropriate selection of or incentives for lead farmers was mentioned as being important. *"Farmer trainers need incentives to be encouraged to implement the training back in their communities – not to just keep the training for themselves"* (male participant 2016).

Community life skills training featured prominently as a training delivery preference among members of the third workshop (Priority Index 0.15) (Table 11). This training is organised by the Local Level Government (LLG), in order to disseminate general information and upskilling. Media-delivered training materials ranked the least preferred method, with similar priority indices being recorded for brochure and technical notes, video, internet, and radio. Some participants mentioned that short videos were the most appropriate for replicating the face-to-face training experience.

Videos can potentially demonstrate the works and be disseminated through popular social media platforms. It was discussed that whilst some did not have direct access to the internet or to expensive computers, most of the participants had someone within their family who had access to a computer, and they acknowledged that this could be a means to view instructional material. The third workshop highlighted a preference for internet-based training delivery, with some participants suggesting "*some of us on Facebook already*" (female participant, 2016). Media-based extension initiatives need to be delivered in local language since "some of the women are illiterate and language used needs translation from English to local languages" (female participant 2017).

Table 10: Women participant priorities for delivering tree planting training in order of rank (priority index for each within parentheses). The priority index for each of the four workshops (T1, T2 O3 & V4) are also included for each training delivery type.

Type	Priority (index)	T1	T2	O3	V4
Lead Forester (Farmer to Farmer)	1 (0.21)	0.36	0.38	0.05	0.04
In-field, hands on training (1 day)	2 (0.20)	0.30	0.30	0.04	0.17
Vocational / Technical Training	3 (0.11)	0.00	0.03	0.25	0.17
Friends/Wantoks/Family	4 (0.09)	0.12	0.12	0.09	0.04
Short Course (more than 1 week)	5 (0.08)	0.00	0.00	0.09	0.24
Government Extension/Agencies	6 (0.05)	0.06	0.09	0.03	0.04
Workshops (less than week)	7 (0.05)	0.00	0.00	0.09	0.11
Community Life Skills Training	9 (0.05)	0.00	0.05	0.15	0.00
Brochures & Technical Notes	10 (0.04)	0.06	0.02	0.03	0.05
Video	11 (0.03)	0.09	0.02	0.03	0.00
Internet (Facebook, YouTube etc.)	11 (0.03)	0.00	0.00	0.13	0.00
Radio	11 (0.03)	0.00	0.00	0.01	0.10
School Teachers	12(0.01)	0.00	0.00	0.01	0.04
Newspaper	12 (0.01)	0.00	0.01	0.00	0.01
University (UNRE etc.)	13 (0.00)	0.00	0.00	0.00	0.00

Develop training resources to meet vocational training needs for teak & sandalwood

Training resources developed under the project included technical notes (Figure 39) and manuals as well as videos (Table 11) with a focus on the two key species: teak and sandalwood. The target audience for these resources was primarily farmers, but also education and extension practitioners. The silviculture and growers' manuals for each species was aimed at education and extension practitioners. All these documents are provided on the PIP website: http://www.pip.com.pg/projects/completed-projects/185-improvement-and-management-of-teak-and-sandalwood-in-png-and-australia

Sandalwood Resources

- Teak Factsheet: Overview (Rollinson and Page 2019b)
- Teak Factsheet: *Making teak stumps* (Jenkin and Page 2017b)
- Teak Technical Note: *Tree assessment* (Page *et al.* 2018c)
- Teak Technical Note: Pruning (Page et al. 2018d)
- Teak Technical Note: *Benefits of planting improved teak* (Page *et al.* 2018d)
- Teak Technical Note: *Teak Tree Assessment*(Page *et al.* 2018d)

- Teak Technical Manual: *Clonal Propagation of Mature Teak* (Lata 2019)
- Teak Technical Manual: *Nursery Practices of Teak* (Jeffrey 2019)
- Teak Silviculture Manual (Jenkin 2019b)

Sandalwood Resources

- Sandalwood Factsheet: Overview (Rollinson and Page 2019a)
- Sandalwood Factsheet: Seed dormancy & treatment (Page et al. 2018e)
- Sandalwood Factsheet: Preparing a growing medium (Page 2017d)
- Sandalwood Factsheet: Potting up & raising seedlings (Page 2017c)
- Sandalwood Factsheet: Hosts & silviculture (Page and Meadows 2017)
- Sandalwood Technical Note: Seed collection & preparation (Page 2017f)
- Sandalwood Technical Note: Potting up & raising seedlings (Page 2017e)
- Sandalwood Technical Note: Sampling sandalwood (Page 2019b)
- Sandalwood Technical Note*: Sandalwood as a commercial investment* (Page *et al.* 2020e).

ACIAR Fact Sheet #S-03

Preparing a growing medium

Seedling Quality

The best potential financial returns from sandalwood comes from productive woodlots that produce trees of commercial value in the shortest possible time. Achieving a productive woodlot requires access to good seed and the production of high quality seedlings in the nursery. The quality of sandalwood seedlings is heavily influenced by the quality of the growing medium and the method of transferring seedlings from the germination tray to a polybag (potting-up). The importance of these steps should not be underestimated and diligence in following good practice in the nursery will be evident in the vigorous growth in the field for many years to come.

Healthy seedlings growing in good potting media

Potting Media Properties

Consider potting media as you would your garden soil; only fertile soil with good drainage will result in good food production. It is therefore necessary to pay very close attention to the quality of the potting medium, particularly the materials within.

Root systems need a balance of nutrients, air and water to supply the growing plant. In a garden soil a plant can use its roots to explore and find these important properties of life. Seedlings in polybags however, only have a limited volume of each property and their roots cannot explore beyond the polybag, because they are confined within the bag.

Preparation of good media takes time, but is the basis of good healthy nursery seedlings

Figure 39: Sandalwood pruning demonstration activity in Girabu (left) and sandalwood fact sheet on preparing a growing medium (right).

Table 11: Demonstration video content produced for management interventions for teak.

Topic, Feature, File Name, Video Location	Description
Motivation, Market, xtn01h, Morobe, PNG	The local market for round logs from thinning of teak stands, is an important source of mid-rotation cash for smallholder woodlot owners. Kevin is the customary landowner at Mare sell the trees from earlier thinning operations (at year 8 & 10).
Motivation, Personal, xtn01i Katakatai, ENB, PNG	Rodney speaks with ex-convict talk about his experience with teak timber during his time in prison, which sparked his desire to plant trees on his land after his release.
Seed Supply, Viability, xtn05a, OISCA East New Britain PNG	John Rabi and Inter Vinarut, of East New Britain in PNG, demonstrate a simple cut test of Teak seed to determine the percentage viability.
Seed Supply, Seed Pre-treatment, xtn06a, OISCA ENB PNG	Inter Vinarut of OISCA in PNG demonstrates the process of teak seed pre-treatment to break its dormancy before sowing into germination beds.
Nursery, Polytunnel Construction, xtn11e, UNRE, ENB, PNG	Jaupo Minimulu and Sylvester Kulang construct basic low shade house using irrigation polytube and shade cloth
Nursery, Media Prep. & Seedling Potting, xtn14a, PNGFA Port Moresby, PNG	Josephine Waine (PNGFA) describes the process of media preparation and transplanting of sandalwood seedlings into polybags
Woodlot Est., Teak Stumps, xtn52a, Madang PNG	Detailed account of the process used to establish teak stumps from a nursery bed to the field, includes discussion on spacing and maintenance.
Woodlot Maint., Fertilising Teak, xtn62a, OISCA ENB PNG	Inter Vinarut speaks about the conditions where fertiliser is needed, as well as the timing and method of application.
Woodlot Maint., Teak Issues (mixed species), xtn63a, OISCA ENB PNG	Inter Vinarut and Alex Kuariri inspect various issues associated with a smallholder teak woodlot and resolutions.
Woodlot Mgt, Sandalwood Agroforestry, xtn65a, Girabu, Central Province, PNG	Guduru Rome demonstrates a functioning sandalwood agroforestry system to bring both short and long term livelihood benefits
Pruning, Form Pruning Teak, xtn71a, OISCA ENB PNG	John Rabi of OISCA in PNG, demonstrates the pruning of teak at three different ages.
Pruning, Form Pruning Teak, xtn71b, OISCA ENB PNG	Gesley Rivan and Inter Vinarut of OISCA in PNG, demonstrate formative pruning of teak.
Pruning , Remedial Pruning Teak xtn71c, OISCA ENB PNG	Gesley Rivan of OISCA in PNG, demonstrates the pruning of a damaged tree to encourage it to regrow into a well-formed tree.
Pruning, Singling 1-year-old Teak xtn71d, ENB PNG	John Rabi (OISCA) demonstrates singling of teak
Pruning, Pruning Saw Review, xtn73a, ENB PNG	UNRE & OISCA staff review a range of handsaws purchased from local hardware supplies in Kokopo
Thinning, Teak Thinning Strategy, xtn76a, UNRE ENB PNG	Jaupo Minimulu & Inter Vinarut describe the reasons and demonstrate the process for thinning a 5-year old teak stand
Utilisation, Hauswin Construction xtn82a OISCA, ENB, PNG	Construction of a gazebo using exclusively teak from thinned trees of between 2 and 5 years of age
Harvesting, Teak Harvesting & Coppice, xtn90a Kuriva, Central Province, PNG	Franics Vilamur of PNGFA speaks about the management of coppice from the stumps of recently harvested teak trees at Kuriva, to bring about a second crop.

5.2 Project monitoring and evaluation.

The table below presents the progress made towards the project's intermediate (i.e. end-of-project) communication outcome: *Changes in access to knowledge and information and how that information is used* (see Project Monitoring & Evaluation Plan. August 2015).The project (1) measured the level of adoption of smallholder teak and sandalwood woodlots during project partner extension and engagement of lead farmers; (2) evaluated the transfer and adoption of knowledge related to management of woodlots; and (3) recorded the dissemination of extension materials.

Objective 1-2	
Desired Change	**Evidence**
Project partner staff and local leaders are competently conducting high quality relevant training workshops for nursery managers and forest owners. Nursery technicians are competently applying the knowledge and skills gained through training.	OISCA technicians worked closely with 38 smallholders to establish functional teak nurseries. These nurseries were established through in-field practical training activities with the nursery owner. The nursery then provided a hub for training of farmers interested in planting teak (see below). The results of the successful distribution, planting and maintenance of the teak smallholder woodlots demonstrates the appropriateness of this model of knowledge transfer from technician to lead farmer/nursery owner to farmer (Page and Vinarut 2017). OISCA and UNRE jointly hosted two formal lead farmer workshops on 29th March 2017 (21 farmers) and 3rd Aug 2018 (27 farmers). Lead farmers are those that extend the work back to the woodlot owners within their community. The response from these workshops were recorded in open discussion among participants at the conclusion of the workshops. The overall response for the content and the infield training component was positive. Recommendations included the need to include Ward Members and Church Leaders in the training events, as they have wider networks and resources. Group text messages were welcomed as a source of news and information on the project and upcoming events. The impact of the lead farmer approach on knowledge transfer and woodlot management is outlined in this table below (see "Forest owners are competently apply silvicultural knowledge and skills learned in effective extension and training").
More landowners have the skills and knowledge and confidence to establish and manage teak plantations	At the commencement of the project a total of 101 growers had established approximately 7400 teak trees. For landowners to access seedlings in this project they were required to prepare their own plots including clearing, field lining, planting and weed tending. OISCA technicians delivered training to smallholders at each of the 38 nursery sites at the time when the teak stumps were ready for planting. Landowners needed to have their site prepared prior to the distribution of the seedlings. Both OISCA technicians and nursery owners were responsible for ensuring landowners had met their obligations before seedlings were distributed. This approach enabled the distribution of over 22,500 teak trees, which were established with 500 growers (36 ha). This demonstrates that more landowners have knowledge, skills and confidence to establish and manage teak woodlots.
Project partner staff understand processes of forest genetics and silvicultural research	Project partner staff can articulate their understanding of the processes of selecting and propagating superior trees. Knowledge of selecting superior trees has been passed to the project partners through participatory assessment of trials at UNRE and OISCA (Page *et al.* 2016). The establishment of the clonal test plots with both these organisations has permitted staff to make comparisons between clones. Successful knowledge transfer has been demonstrated through a group tree selection exercise across the OISCA provenance plots. UNRE and OISCA staff have also successfully assessed the two clonal test plots independently. Knowledge of spacing and pruning has been successfully transferred to project staff. The spacing plots have provided a physical demonstration of the impact spacing has on tree growth and form. Based on project staff observations, the 4x4m spacing is considered to be applicable to most farmers for it (i) allows 1 garden rotation (ii) promotes good survival, (iii) reduces pruning inputs relative to 6 x 6m and (iv) produces products from first thinning (2-3 years) that include posts that have a strong market (PGK5 per linear meter) compared with 2 x 2 spacing (narrow poles - which are primarily subsistence use). Project staff carry out pruning independently and have extended this knowledge to smallholders by participatory pruning activities conducted with landowners and during the two lead farmer training workshops. The project has conducted participatory thinning activities with project staff and they have a conceptual understanding of why it is required. Further capacity building is required before staff can conduct independent thinning activities.

Objective 1-2	
Desired Change	**Evidence**
Appropriate group / selection of nurseries with a capacity to produce teak and sandalwood for market. Nursery industry governed by market forces	The project demonstrated a clear capacity for project partners and smallholders to establish plant nurseries and produce high quality bare root seedlings. A total of 38 nurseries were established that produced 22,500 plantable seedlings. According to UNRE the market price for a bare root teak seedling is PGK1 and polybag seedling is K2. This compares well with the range of market prices for other seedlings including PGK4 for grafted cacao to PGK0.5 for balsa. UNRE have made modest teak seedling sales (up to 500) and but OISCA have been enthusiastic to provide landowner with free seedlings to establish woodlots with the target communities. The woodlots have served as a demonstration for driving demand for teak seedlings. In a survey of 149 teak growers 72.4% indicated they required more teak seedlings to plant. While this data does not represent willingness to pay, it does suggest there is an underlying demand with existing growers. While plans were put into place to test teak stump sales at Kokopo market, these were not successfully implemented during the project. Several nursery operators that had been engaged with FST/2007/078 and FST/2014/069 increased their capacity and supplied seedlings commercially to the Erosion Control Project during 2015/16. OISCA have reported that smallholder farmers have a high demand for teak stumps. Landowner groups such as Run Creek Holdings and Wingmau and commercial organisations such as Farmset, Lihir Gold and Simberi gold mines have expressed interest or purchased teak stumps from project partners. For sandalwood, the smallholder nurseries have a capacity to produce a modest number of seedlings. In Iokea the number of seedlings produced from the combined central and smallholder nurseries was over 500 seedlings. In Kairuku a total of 35 micro-nurseries produced between 10 and 200 seedlings each for a total of over 1500 seedlings. In Girabu over 300 seedlings were produced in the central nursery. These were used in the demonstration planting and for distribution of small numbers of trees to interested growers. The cost of a sandalwood seedling is PGK5. The level of demand is yet to be quantified since most seedlings produced were planted in the demonstration plantings (Iokea and Girabu) or own smallholder woodlots (all three communities). Communities surrounding Girabu, (Gobuia, Londairi, Wasuma and Gomore) have been visited and over 1,000 sandalwood seeds were supplied and germinated by these communities. This informal extension-based training has increased local interest in planting sandalwood, resulting in increased demand for sandalwood seed and seedlings. A total of 1.5kg of seed was collected from the Girabu trial between May and July 2019, with 50% sold (K75/kg) and 50% used for local distribution (Sebara pers. comm. 2019). While this is a modest impact, it demonstrates that commercial seed supply offers income generation four years after establishment.

Objective 3:	
Desired Change	**Evidence**
Forest owners are competently applying silvicultural knowledge and skills learned in effective extension and training	The competent management of smallholder woodlots depends on the acquisition and application of knowledge. The effectiveness of the lead farmer training approach on knowledge transfer was determined through interviews with four lead farmers and independent focus group discussion with people from their community (Page and Vinarut 2017). The engagement of lead farmers was demonstrated to be an effective intermediary between project partners to smallholder farmers. OISCA have been active in identifying and selecting lead farmers based upon their existing community networks. From the four lead farmers interviewed the approach has worked well, with three in particular having prominent community presence and engagement. However, greater involvement of the Ward Committee was recommended in one community to ensure a greater sense of ownership in the selection of lead farmers. The level of knowledge transfer through the lead farmer varied depending on their engagement with the community. Focus groups expressed that most are now confident in establishing teak nurseries and woodlots. The application of this knowledge was confirmed during prior inspection and measurement of woodlots in the community. Pruning is an important input for these woodlots and both lead and participating farmers expressed they are constrained by capital (handsaw) and labour availability to implement pruning routines. In 2019 one lead farmer confirmed that he and others were collecting teak seeds from some of the older woodlots for their own planting purposes. This represents a small but important impact, which is expected to increase as more woodlots begin to produce seed.
PNGFA/FRI actively participated in model development and testing and are competently applying it,	In the development of the teak financial model PNGFA, OISCA and UNRE staff were key informants. Similarly for the sandalwood financial model PNGFA officers have contributed to the development of the sandalwood financial model through provision of information relative to production inputs, and yields of agricultural crops. The models

Objective 3:	
while being reliable custodians of the model. Plantation owners/ managers are able to access the model to inform their plantation planning and management decisions.	have been provided to PNGFA Forest Development Directorate and Policy and Planning Directorate for their use and engagement with industry. They have also been provided to FRI for research and extension purposes. The deployment of the models has been limited to project partners. Plantation owners can gain access to both the teak and sandalwood financial models through PNGFA, FRI and the PIP website and google drive folder. A technical note aimed to support the sandalwood financial model was developed for practitioners and has been made available through the PIP website.
Industries are considering teak and sandalwood plantation options.	A model estate and marketing plan was developed for teak in consultation with PNGFA staff within the Forest Development Directorate (Jenkin 2019a). With the government seeking to expand the planted timber estate, the plan contains information relevant to the industry to deliver timber to market. The 'growing a house' model for smallholders provides a market for initial growth of the estate, that can stimulate service providers and larger institutional plantings. Both smallholder and institutional growers (Simberi, Lihir, CPL, Wingmau, Run Creek) are interested in and already plant teak using germplasm provided by the project. A joint venture between a landowner group (at Puktas in ENB) and PNGFA is also beginning to plant teak with seedlings and technical input from OISCA. As a high-value and low-volume product, sandalwood can be harvested, processed and marketed by smallholders using existing resources. Growers communicated with project partners about the issue of transparency in marketing with respect to grading and relevant policies to guide them. Based on this feedback, a review of existing policies and procedures for harvesting and marketing of sandalwood was undertaken. The review was undertaken and led by PNGFA staff (Rome *et al.* 2020) . The results have shown that the improved rural road networks leading to Port Moresby offer scope for planting along prominent road corridors. Currently wood is transported via existing public transport options. While a broad estate and marketing plan was not developed, the review and the financial model provides important information to smallholder and institutional planters. Smallholders in all three target areas are seeking to expand their woodlots.
Landowners have the skills, knowledge and confidence to establish and manage sandalwood plantations.	Through monitoring and measurement of the woodlots established under the project, a spectrum of capacities exists between sandalwood growers. The planting with highest performance was the site at Girabu (MAI 2cm.yr^{-1}) where attention was given to establishing regular hosts, good site maintenance and fire control. In contrast, the sandalwood planting at Iokea had issues with maintenance and fire control, leading to significant loss and slow growth (0.742cm.yr^{-1})(Rome *et al.* 2020). Growers in Kairuku have applied knowledge gained in the workshop and follow-up extension activities. This has been demonstrated through the establishment of sandalwood within home gardens, where access to hosts and regular maintenance are most likely. In Iokea the capacity of sandalwood nurseries to produce high quality seedlings was assessed between 2014 and 2018. In 2014 an estimated 66% of seedlings were classified as having very poor quality and unsuitable for planting. In 2018 seedlings of similar poor quality represented only 12% of seedlings surveyed. Similar improvements were found in the proportion of nurseries using pot hosts with 25% in 2014 and 83% in 2018. The project has demonstrated that workshops and extension are effective methods for knowledge transfer in PNG, but that local circumstances influence knowledge application (Page and Oa 2017a).

Objective 4:	
Desired Change	**Evidence**
Trial sites established with long term landowner agreements & protected with institutional &/or community management arrangements	Sandalwood trials have been established on Traditional Land in the NPA as well as three external sites. A material transfer agreement has been ratified with the Aputhama Land Trust to include a clonal seed orchard at Gympie and Walkamin. An additional agreement covers the comparative growth trial (*S. lanceolatum* vs *S. album*) at Quintis in the Burdekin. For the progeny trials on Traditional Land (NPA Farm and College) a formal management agreement has not been necessary, as the plantings are maintained as part of the routine farm operations and school maintenance. The project was not funded to pay for Traditional Owners to manage the trials, so therefore setting detailed management prescriptions was considered counterproductive.
Forest owners understand the importance and intrinsic value of the remnant sandalwood mother trees.	The community is now aware of the locations of all the populations, while previously this knowledge was restricted to a few. Through site visits senior council managers are now aware of the impact of fire on the survival of sandalwood. They are aware of the value of these trees as an *in situ* source of sandalwood germplasm for ongoing improvement. Results from the genetic study have been provided and explained to the community and they are aware that it is a rare genetic resource, with only limited numbers of unique individuals for any given site, and high level of clonality. This understanding has been demonstrated by Community Leaders initiating and participating in an enrichment

Objective 4:	
	planting on important ancestral sites. The Community leaders have been actively monitoring and communicating with the project team on the tree's condition.
Project partner staff and local leaders are competently conducting high quality relevant extension and training workshops for provincial forestry officers, nursery managers and forest owners (women, men and youth). Landowners have the skills and knowledge and confidence to establish and manage sandalwood plantations.	Short workshops were held in conjunction with in-field training activities for building the capacity of indigenous participants within the NPA Farm staff and secondary school students. These training events included collecting heartwood samples, planting trees, measuring trees, pruning trees, and detailing host plant requirements and their management. The training activities have been positive in building knowledge and capacity. Staff are in communication with project staff regarding the maintenance activities and condition of the sandalwood trials. More capacity building is still required to build management and operational strategies. This is important if the project is to scale the plantings to a modest commercial planting. Discussion regarding the commercial potential of sandalwood was held during project staff participation in a Gudang/Yadhaykena Tribal Meeting and meetings with the Aputhama land trust. There is an appetite among Traditional Owners for scaling up and demonstrating commercial viability.
TOs (women and men) and research partners are confident in the opportunities available as a result of sandalwood research The CYP TOs are able to negotiate with potential investors about sandalwood related business opportunities based on sound evidence.	The traditional owners are clearly aware of the value of sandalwood in the international marketplace. They are also aware of the unique value of their species, based on their unique oil properties and indigenous connections with country. Negotiations with three commercial organisations have been positive but are still ongoing. The Aputhama Land Trust (covering the Gudang/Yadhaykena) is wanting a demonstration of proof of concept prior to entering commercial arrangements. Similarly the commercial organisations want further clarity on the pathway to commercialisation.
TOs (women and men) and research partners share Traditional Ecological Knowledge (TEK) and research based knowledge about sandalwood potential.	Following a number of meetings with the Community Leaders, the project team was invited to attend a cultural introduction to Community Elders. The cultural event involved the introduction of the project team to the Elders of the community. During this event there was a whole range of interactions regarding the scientific and cultural/medicinal significance of sandalwood and other important tree species in the region. For instance the leaves and bark of sandalwood are used in preparations for stomach upsets. The sandalwood bark is also used among other ingredients in a culturally confidential preparation. Elders are also aware of the unique and commercially significant properties of the heartwood oil. This dialogue has continued during field and other activities.

Objectives 5:	
Desired Change	**Evidence**
The Tree Growers Toolkit contains relevant material and is accessible and being used to inform nursery and silvicultural practice	The Tree Growers Tool Kit (TGTK) provides a one-stop source of information for tree growers and field workers in PNG. There are currently 537 files in 113 folders on the following topics: • Choosing the right trees; • Growing the best trees; and • Making money from trees. Monitoring the use of TGTK through the PIP website indicates average usage between 100 and 200 unique users per quarter (3 months) (PIP 2017; PIP 2018a; PIP 2018b; PIP 2019b; PIP 2019c; PIP 2019d). Under objectives 1-3, the Project's research activities led to the development of 21 specific resources to inform farmers and field workers about nursery and silvicultural best-practices (see Activity 5.1 Develop Training Resources). These multi-media resources have been arranged in the TGTK's Growing the Best Trees. These resource are freely available from the online platforms managed by Pacific Islands Projects (see Communication Report nos 2-6): • PIP Website: Resources / Tree Growers Tool Kit • PIP Website http://pip.com.pg/projects/completed-projects/185-improvement-and-management-of-teak-and-sandalwood-in-png-and-australia.html • YouTube / Videos for Tree Growers • Google Drive / Tree Growers Tool Kit • Mailchimp / Email news updates and alerts (345 subscribed members) • Facebook / Tree Growers Tool Kit and Agroforest Pacific

Objectives 5:	
	One Community Outreach Centre was set-up at PNG Missions in ENB Province to make it easy for over 100 nearby farmers participating with the project to access the TGTK's multi-media resources (see Outreach Centre Report: PNG Missions). Resources provided include printed technical notes (500 copies), laptop, tablet and printer. PIP Google Drive includes the a range of resources including the Bible Explorers Pack, Landowner Awareness Pack, School Teachers Pack TGTK and the Wood Processors Tool Kit. A total of 62 individuals have access to the Google Drive in addition to the organisations below. Within parentheses is number of communities that each organisation engages on development activities. • National Agricultural Research Institute (NARI) Sth. (26+). • Small to Medium Enterprise Corporation (SMEC) (26+). • PNG Missions Asia Pacific & Beyond Inc. (26+). • PNG Forest Research Institute (26+). • OISCA Eco-Tech Training Centre (26+). • ENB Provincial Administration (26+). • Angels Care Systems Limited (26+). • Rigo Early Childhood School (1). • Barakau Primary School (2-5). • Girabu Primary School (2-5). • Gomore Primary School (2-5). • Papalaba Primary School (2-5)
Appropriate pamphlets are available in the right locations	The Tree Growers Tool Kit contains pamphlets that help farmers to choose, grow and make money from trees. All pamphlets/brochures are designed for double-sided printing on a single A4 sheet (folded to A5). They can be easily accessed on computers and smartphones in the field (i.e. offline) using Google Drive. For example, the Outreach Library at PNG Missions (see above) has Google Drive installed on its laptop and tablets; allowing pamphlets to be viewed electronically, or printed out.
PNG Teak and Sandalwood Manual is prepared and being used by target audience	The PNG Sandalwood Manual has been prepared but is yet to be formatted/published for wider distribution among practitioners or farmers. The Teak Silvicultural Manual can be found on the PIP website http://www.pip.com.pg/projects/completed-projects/185-improvement-and-management-of-teak-and-sandalwood-in-png-and-australia

Objective 5:	
Desired Change	**Evidence**
Appropriate communication products (e.g. extension vs training materials) and processes support effective project implementation and management.	An evaluation of communication products and processes was undertaken at the Community Outreach Centre - PNG Missions - with 42 members of the Toma Valley community. An "Open-Day" approach was used to: • Test and identify training and extension tools and techniques that will improve the uptake and impact of the project's research outputs using the PIP's Resource Evaluation Form. • Understand landowner priorities, constraints, organisational arrangements and communication preferences, as well as existing land management systems and training/extension networks using the PNGFA's Landowner Registration Form. The Outreach Centre Report reveals that all Open-Day participants were impressed with the training and extension tools and techniques that were on display, and many welcomed the formation of a Community Outreach Centre at PNG Missions. Many respondents also indicated they were constrained by a lack of information. Whilst communication preferences suggested the most suitable training and extension resources were printed materials written in Tok-pisin, PNG Missions also has the capacity to share electronic resources on-site (e.g. training videos in Tok-Pisin).
Engagement planning and communication products and processes enable effective community engagement	

Farmer adoption of teak woodlots in ENB

The distribution and adoption of teak across East New Britain and six other provinces demonstrates a significant future local timber resource. At the conclusion of this project just over 30,0000 teak seedlings have been planted by smallholders in ENB (Table 12). This data includes the 101 growers that established approximately 7400 teak trees under FST/2007/078. The positive economic impact of these plantings is likely to be occur within the next 2 to 5 years when thinning products begin to be sold or utilised for local construction. A total of 600 families stand to benefit from the use of this developing resource.

Table 12: Teak distribution in the four districts of East New Britain Province and six other provinces of PNG. This data includes 101 growers that established ~7400 teak trees under FST/2007/078 and the 512 growers that established ~22,500 under this current project.

Gazelle District	Farmers	Trees	Ha
Toma/Vunadidir	350	17500	28
Livuan Reimber	30	1500	2.4
Central Gazelle	5	250	0.4
Inland Baining	2	100	0.16
Papalaba Primary School	1	100	0.16
Tauran Primary School	1	50	0.08
Vunalir Primary School	1	50	0.08
Sub total	390	19550	31.28
Kokopo District	Farmers	Trees	Ha
Raluana	15	750	1.2
Bitapaka	120	6000	9.6
Duke Of York	10	500	0.8
Kokopo/Vunamami	4	200	0.32
Tobera Primary School	1	50	0.08
Bitapaka Primary School	1	50	0.08
Kokopo Primary School	1	50	0.08
Sub total	152	7600	12.16
Pomio District	Farmers	Trees	Ha
Sinivit	50	2500	4
Warrangoi Primary School	1	50	0.08
Sub total	51	2550	4.08
Rabaul District	Farmers	Trees	Ha
Balanataman	5	250	0.32
Kombiu	3	150	0.32
Sub total	8	400	0.64
Other Provinces	Farmers	Trees	Ha
Bougainville Province (AROB)	4	250	0.32
Oro Province	1	50	0.32
New Ireland Province	4	200	0.32
Manus Province	1	50	0.32
Jiwaka Province	1	50	0.32
Milne Bay Province	1	50	0.32
Sub total	12	650	1.92
Total	613	30750	50.1

8 Impacts

8.1 Scientific impacts – now and in 5 years.

The project activities resulted in positive scientific impacts in the following areas: (1) water use efficiency (WUE) and growth in teak; (2) chemical composition of sandalwood heartwood oils in PNG; (3) genetic diversity of sandalwood in CYP; and (4) women's constraints to participating in smallholder forestry. Scientific publications include two published journal articles, two under review journal articles and seven conference papers.

Based on ^{13}C composition, leaf WUE is a good prospect for identifying superior performance of teak clones whilst retaining resilience against adverse climate conditions like drought. The study identified genotypes with both high water use efficiency and high wood growth. This knowledge permits stratified deployment of clonal germplasm in PNG. For instance genotypes with high WUE and high growth can be deployed for growing across a range of environments, whereas those with low WUE and high growth are more satisfactorily established in equatorial environments. This scientific understanding also informs clonal selection within genotype by environment interactions to determine climate resilience and adaptability of clonal germplasm in PNG. It also has broader scientific implications for the physiology of PNG-adapted germplasm relative to other environments internationally where teak is produced on a commercial scale.

The refined criteria for selection of teak mother trees promotes sustainable identification of phenotypically improved trees. With project partners using these trees for clonal and seed propagation it will improve the quality of teak germplasm in PNG. This is a simple but important scientific impact for both immediate and long-term improvement of the species. The combined effects of mother tree selection and adoption of project-developed protocols for seedling production improves teak establishment success among smallholder growers.

The project improved scientific understanding of sandalwood (*S. macgregorii*) diversity in PNG. The study demonstrated significant within-population diversity across a range of heartwood-oil traits. Species diversity was much higher than reported for other species of sandalwood. This result provides insight into why the market value of sandalwood is lower than found in other sandalwood producing countries. The study also demonstrated a distinct oil profile between the eastern populations (Gulf and Central populations) from those in Western Province. This contributes to the scientific evidence supporting a potential new cryptic species assemblage from Western Province to Cape York.

The variation in key oil traits permits a scientific approach to future germplasm collections and conservation of key resources. The molecular study of the CYP sandalwood highlighted this species was more rare in the wild than previously thought (55% of trees are clones). The result emphasises the imperative for *in situ* and *circa situm* conservation. Knowledge of the highly clonal nature of the stands informs the need to use trees from across its entire range to achieve genetic improvement. This study found that CYP sandalwood may be a new cryptic species, with it separating from typical *S. lanceolatum* and *S. leptocladum* in the microsatellite neighbourhood joining and genetic cluster analysis. This needs further investigation. This research will have scientific impact through more systematic evaluation of CYP, Torres Strait and Western Province PNG to better understand the taxonomy and phylogenetics of the species complex and determine how closely related these species are. This has implications for the conservation, breeding and commercialisation of the species.

The project has provided a new scientific understanding of the perspectives of farming women and their potential participation in smallholder forestry. This has led to an improved understanding of interests, constraints and avenues for improved engagement. Constraints related to knowledge and confidence are most prominent and can be easily addressed. This has broader scientific and social application for matrilineal land-tenure systems in general and for its contrast with the more common patrilineal systems. Scientific impact is likely through the contextualisation of the results of this study across different social systems within PNG and globally. This has the potential to broaden the social and economic impacts of smallholder forestry through more equitable systems.

8.2 Capacity impacts – now and in 5 years.

Significant development of capacity among project staff to understand and contribute to project activities has been achieved in this project. Substantial goodwill among project partner organisations and their staff has enabled collaboration and sharing of information to improve local institutional capacity and culture.

Key project staff in PNG

Sylvester Kulang (UNRE) completed his Graduate Certificate in Research Methods in Port Moresby (UTas) and graduated in early 2018. This was undertaken as part of the ACIAR funded project FIS/2010/055 (Capacity Building Research and Project Management Skills in Fisheries Staff in PNG). Sylvester's participation in this program as has improved his capacity to conduct and communicate scientific work. It has been a very valuable experience for Sylvester and this current ACIAR project has benefited greatly from Sylvester's improved capacities in this area. Our project has further supported Sylvester's application for a Commonwealth Distance Learning Scholarship and Masters in Research Methodology at Divine Word University, the latter of which he was accepted. During the course of the project Sylvester has been working in an unofficial acting role as Head of Forestry Department in 2018-19 during a period of significant corporate change. Through his actions the project has been able to sustain progress and engagement with UNRE.

Jaupo Minimulu (UNRE) completed his Post Graduate Diploma in Management at UNRE during the course of the project. Jaupo was essential to the establishment and maintenance of the clonal teak trials and implementation of the silviculture trials. Jaupo has sought to improve his research capability by commencing a research project exploring heartwood variation in teak trees. The project has worked to improve the monitoring of impacts and Jaupo has marketed teak products from the thinning of the UNRE teak trials and secured data on their value and acquired information about local demand. A strong working relationship between UNRE and OISCA has been strengthened by Jaupo and he continues to mentor OISCA staff on technical and research matters

Anton Lata (FRI) has been a significant contributor to the delivery of several ACIAR-funded projects. During this project Anton has further developed his capacity or independent research. Anton has supervised the implementation of teak clonal capture and establishment of a range of clonal and seed-based genetic trials. During the course of the project Anton has presented and published his research at the IUFRO small scale Forestry conference in the Sunshine Coast (Aust) in October 2015 and also presented at The Teak Smallholder Workshop in Luang Prabang (Laos) in November 2016.

Gedisa Jeffrey (FRI) completed his Masters study at SCU in Lismore during the course of this project as a John Allwright Fellow. Gedisa has made a positive contribution to the implementation and writing of the research related to the sandalwood population survey and presented the results at the Sandalwood Regional Forum in November 2019. The forum was funded as an SRA(FST/2014/024) and promoted information exchange and networking among sandalwood researchers and stakeholders.

Sonia Inu (FRI) conducted her traineeship at FRI under the ACIAR project and has submitted several reports on propagation work and assessment of the Situm teak provenance trial. Her ongoing training and engagement in the project represents mentoring of the next generation of PNG researchers in Forestry. Sonia's role at FRI is dependent upon the ACIAR funding of her position and so represents a direct and positive capacity impact for the project.

The project also contractually engaged with NARI technician Simaima Kapi to assist with the implementation of the women's forestry workshops. This engagement helped to build Simaima's research capacity in developing research questions, data collection and report writing. This was greatly assisted through the mentorship provided by Emma Kill (USC) and Brett Hodges (USC) who were based at NARI under ACIAR project FST/2014/099 (Private sector-led development of the Canarium (galip) nut industry in PNG). This demonstrates cross project collaboration for improving capacity among partner staff and contribution towards project objectives.

Forest Authority staff Guduru Rome and Linden Oa have a greatly improved understanding of the unique features and management of sandalwood seed collection, germination and planting establishment. This has led to improved confidence in providing extension to farmers and improved the quality of information provided. They both wrote up the research conducted as part of the sandalwood silviculture and extension research and presented this at the Sandalwood Regional Forum in November 2019.

A previous OISCA-ACIAR officer Charles (Wally) Suki worked with the project from 2012 to 2016 primarily as field supervisor. During that time Charles developed a strong knowledge of the establishment and management of teak woodlots at OISCA and with participating communities. Charles took a position with a UNDP conservation project in the Baining Ranges in Arabam from 2017 to 2019. Charles was a strong advocate for teak planting with the community of Arabam, to offer them an alternative income stream and reduced dependence on natural forest logging. With Charles' forestry skills developed under the ACIAR project and his continued links during this period facilitated the project to engage with the community of Arabam. Recently Charles has taken a position with Wingmau plantation (Warrangoi), which produces cacao as its main business. Already Charles has influenced decision makers at Wingmau to consider teak and galip for income diversification. Charles represents the positive and sustainable impact of capacity building among project staff both within and beyond their roles in the project.

OISCA have many key staff that have worked with the project to improve their capacity to deliver significant research and development outcomes for the communities in ENB. These include the Director Norbert Perry, who manages their budget allocations to ensure maximum funding reaches the ground. Norbert, together with Gesley Rivan, have managed to maintain project momentum beyond the end of the project using internal funds. John Rabbie and Inter Vinarut have further built upon their capacity to engage meaningfully with the community to promote tree planting and co-ordination of field extension and trial establishment at OISCA. Inter has been instrumental in collecting the necessary data to ensure the number of nurseries and farmers engaged in the project are recorded. Significant progress has occurred in the capacity of Alex Kuariri to implement field works, train and mentor OISCA staff and extend technical skills to community. Alex has also featured in several extension videos demonstrating key skills in the pruning of teak. Inter and Alex's standing in the region has been demonstrated in 2019 when they were appointed as members on the Ward Council of Wairiki 3, which is a community that is not home to either of them. This shows the deep relationships they have developed with the target communities and the respect the community shows for their knowledge and commitment.

Australia

Planting the two progeny trials in the NPA has increased interest in the species and the potential to develop the species as a long-term industry for the community. Training was an important aspect of these plantings with students from the high school and Community Development Program staff (Figure 40).

Training has been ongoing aspect of the project, with the high school students. We have discussed the work and shown the students how to measure and manage the trial near the school. Planting the species on Quintis land also enhanced the opportunity of the community to produce seed of the species or seedlings for a commercial plantation industry growing elsewhere.

Academic training of Aaron Brunton through his honours study was undertaken with the support of USC and ACIAR funding. This experience combined with publication of these research results has contributed to his development as a scientific researcher. He received an APA (Australian Postgraduate Award) based on his Honours Degree and is now undertaking a PhD in plant genetics.

Figure 40: Establishment of scientific trials in the NPA (CYP) offered opportunity for training of secondary students from the Northern Peninsula College (left) and CDEP workers at the Bamaga farm (right).

Sandalwood Regional Forum

The project funded four PNG project staff to attend and present at the Sandalwood Regional Forum (SRF) in November 2019 as part of ACIAR SRA (FST/2016/2014). These included Ruth Turia, Linden Oa, Guduru Rome and Gedisa Jeffrey. Four Australian project staff also attended and presented at the SRF, including Tony Page, David Lee, Tony Burridge and Nick Thompson. The Sandalwood Forum offered PNG and CYP project staff the opportunity to present their research work to an international audience and participate in discussions and networking (Figure 41). Several participants (Oa, Rome, Jeffrey, Page, Lee & Burridge) also attended the post-workshop study tour to Tanna. The study tour exposed delegates to the social and environmental conditions and production practices of smallholder sandalwood production in Vanuatu. It also offered more opportunity to interact with other sandalwood-involved scientists from other Pacific countries including Fiji, Tonga, Vanuatu, Indonesia, Australia and Timor-Leste. All participants presented papers with most being submitted for the proceedings. This was the first opportunity that PNG- and CYP-based project collaborators had a chance to interact and discuss common areas of development interest.

Figure 41: NPA traditional owner Nicholas Thompson presents work with sandalwood in the NPA, Cape York Peninsula (left) and Guduru Rome and Linden Oa (FA) with delegates from Vanuatu and Timor Leste during a field trip (right) at the Sandalwood Regional Forum (SRF) in Nov 2019.

8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

ENB

There are already some early economic impacts coming from the OISCA, UNRE and smallholder teak woodlots, through utilisation of the products from pruning and thinning. This includes indirect economic impact through the use of small round poles for constructing outbuildings, particularly market houses along the Warrangoi-Kokopo road (Figure 42). The use of the products in this way has been stimulated by demonstrating it at OISCA through construction of a 'haus win'. The economic impacts also include direct economic benefits through the market sale of these round posts (PGK5 or AUD2 per linear meter). The sale of these poles is currently being conducted at a very busy market junction at Baliora where traffic from both Kerevat and Warrangoi frequently passes (Figure 42). A total of 140 x 3m posts derived from the UNRE teak clonal trial (0.92ha) were sold for PGK2,100 (AUD835) at year 6. As trees begin to mature and set seed some families have the opportunity to accrue returns through commercial teak stump production.

Figure 42: The frame of the small market house is constructed from teak prunings from the OISCA teak woodlot (left). Products from teak pruning are just now being sold in small quantities along roadside markets (right).

Central

Through farmer extension activities and establishment of demonstration plots the project has stimulated local commercial demand for sandalwood seed (Figure 43). This has been clearly observed across all three project areas. This new market assigns an economic value to mature standing trees, with the potential for reducing the harvest pressure on the few remaining seed trees. At this stage most smallholder micro nursery owners are producing seedlings for establishing their own woodlots. As they complete their plantings they have the capacity to sell these to local growers, but also larger markets closer to Port Moresby. A older sandalwood woodlot in Gomore (Rigo District – Central Province) was established by the late father of the current owners. The trees range in age from 10 to 20 years and are very productive in seed. The trees are now providing the family with much needed income through the sales of sandalwood seed. Prior to the project there was no market for the seed. The project built capacity of the brothers to collect and prepare the seeds. These smallholders have been an important seed source for the project with payments of K200 per kg of seed being made. The brothers have since reported that they are now selling seed to others in the community. This example demonstrates that conservation of indigenous species on private land is possible and can result in income generation from seed sales. The stimulation of demand for sandalwood seedlings from this seed supplier in Gomore is a positive economic impact

A vibrant sandalwood seed/seedling market that supplements local income is an impact that is likely within the next five years as trees planted within this project begin to produce significant volumes of seed. Such an industry would create opportunities for upscaling woodlots, particularly around the transport corridors that radiate from Port Moresby. Entrepreneurs in each of the three target areas could potentially service new larger entrants with seed supplies, advice and management services.

Figure 43: The project has had a positive impact on the commercialisation of sandalwood seed supply. A sandalwood seed seller in Ipaipana (left) and small batch sandalwood seed sales conducted after the training workshop in Kariuku project area (right).

PNG National

The establishment of genetically diverse germplasm sources for both teak and sandalwood will have direct economic benefits within the next five years. As these stands produce volumes of seed it will permit the expansion of the national planted estate which is in line with PNG FA's tree planting initiative PGPD. The most significant economic benefits are likely to accrue beyond the five years when planted stands attain harvesting maturity, including producing products from thinning.

Work carried out with the growth data, water use efficiency and wood volume is of national importance for evaluation of teak performance against other candidate plantation species. This will have impact for national planning of the planted tree estate and permit reliable economic forecasting using the financial model produced under the project.

The conservation of improved genetic materials from Mt Lawes before it was clear-felled in 2019 is a clear and important impact of this ACIAR project (Figure 44). This can be classified as an environmental (genetic conservation) and scientific (further domestication) impact of the project. Ultimately, if the genetics are further developed and deployed to growers, it can have a significant economic impact for the communities that grow, process and market the resulting trees. Genetic material from Mt Lawes has been secured by the project at (a) FRI in Lae (Morobe) as a clonal archive, (b) Kuriva (Central) as a replicate clonal orchard (c) Situm (Morobe) as a progeny trial, (d) UNRE (ENB) as clonal progenies and (e) OISCA as bulk seedling progenies.

Figure 44: This ACIAR project has been the catalyst for the genetic conservation of improved teak genetics in PNG. The grafted seed orchard at Mt Lawes (est. 1960s) was harvested in 2019 (left). Jaupo Minimulu (UNRE) and Daniel Joseph (OISCA) stand next to a candidate plus tree originating from Mt Lawes established by the project (right – image Silva Systems).

CYP

The project has provided the necessary information for the community in CYP particularly the Gudang/Yadhaykenu Group (part of the Land trust and PBC) to stimulate interest in commercial development of the species. This has led to community engagement with potential investors to see if funding can be found to develop plantations of *S. lanceolatum* using the germplasm established under the project. The potential development has scope for providing positive business development and employment impacts within the community.

The project has also provided some work for CDP workers who are looking for jobs and they have developed skills planting trees that could potentially help them find jobs if investors / additional funding is provided to increase the size of the sandalwood plantings in the NPA.

8.3.2 Social impacts

ENB Teak Farmers

The out scaling of teak planting in ENB during the project has generated improved confidence among project staff at OISCA, but also with the group of Lead Foresters and the owners of the community woodlots. While this impact is currently difficult to measure, it will result in the continuation of out-scaling of woodlots beyond the life of the project. This positive social impact has led to a functional network of tree growers (Figure 45) that demonstrate a willingness to consider and adopt new forestry technologies. The positive social impact has also been demonstrated through the knowledge sharing between OISCA, UNRE, USC lead farmers and woodlot owners. OISCA staff have enabled the project to develop a sustainable peer-based network that has strong bonding and social capital among members and bridging social capital between farmers and project partners.

Figure 45: The project has contributed to positive social impact that has led adoption of new forestry technologies across many communities in ENB. Alex Kuariri demonstrates the virtues of different pruning saws (left) and meeting of lead farmers (right).

The engagement of women through the series of workshops identified that their interest in becoming involved with smallholder forestry is near universal (Figure 46). It was demonstrated that women seek to be involved within inclusive family-based forestry initiatives. This has made project partners aware of the opportunity for broader engagement beyond the vocal and prominent community members. A family-based approach also has the potential benefits for labour sharing. It limits the emergence of male-only tree planting, and supports matrilineal land tenure change. This has the potential for a more equitable decision making process and broader community benefits

Figure 46: The project has demonstrated a near universal interest among smallholder women in ENB to be involved in tree planting. Tree seedlings and bare root stumps were distributed among participants at the conclusion of the workshops held.

Sandalwood Farmers

Positive social change towards sandalwood planting has occurred in the target communities (Girabu, Kairuku and Iokea) during the project. The catalyst for this change in mindset was the Workshop in Dec 2017, which helped growers create an informal network. They are currently (2020) in process of formalising their association.

There have been positive social impacts in the three sandalwood communities, with people now being aware that it is possible to successfully plant sandalwood as a commercial forestry species. The project has contributed substantially to this change through community engagement with both Australian and PNG project partners. While it created only a small change in community perceptions, it can potentially form the basis of a sustainable effort at re-establishing the eroded natural resource. It is very likely that this awareness will persist beyond the life of the project. The project now has an opportunity to contribute to the transformation of this awareness into a genuine capacity to manage sandalwood woodlots over the long term.

CYP

People of the NPA are excited by the possibility of developing an industry based on the local sandalwood. This is having a positive impact on community spirit.

8.3.3 Environmental impacts

PNG

The planting of sandalwood seedlings in Iokea and Kairuku represents a very positive environmental impact. While the numbers of seedlings planted are modest, they are representative of a shift in the conservation prospects of this species. The project has given considerable attention to communicating the importance of maintaining genetic diversity through seed collection from many mother trees. Forest Authority officers are now keenly aware of this and this knowledge is being transferred to project collaborators in Iokea and Girabu and key sandalwood planters in Kairuku.

CYP

The species is locally endangered in the northern CYP and over 55% of the trees are clones so the population is much smaller than we previously thought was. Over the last five years 15% of the surviving trees known about before this project started have been killed by wildfires. Many of these trees now only occur in the clonal seed orchards. By capturing 30 trees from the wild across a wide area in the NPA we have ensured the genetics of this species will be conserved. The manuscript by Brunton *et al.* (submitted) makes recommendations on the steps to conserve this species.

8.3.4 Policy impact

PNG

The project has invested considerable time engaging with NAQIA to develop robust import protocols for both sandalwood and teak. While exotic sandalwood has been imported into PNG before, under current quarantine restrictions it was no longer permitted for import. The work conducted has resulted in a robust import and post-entry conditions for importing of any species of sandalwood from any country. This is obviously an important development for this project, but it also allows other reputable importers to bring sandalwood into PNG. Previously, for teak, only seed imported from Australia was permitted, this has meant all previous introductions have been imported through Australian quarantine procedures before being permitted to enter into PNG. This added considerable administrative and handling costs to importing teak seed into PNG. The new import protocols are now more stringent, in that they require both import and post-entry inspections; thus potentially limiting pest and disease entry. These import protocols were developed so that they can be applied to all new applications in the future, without the need for developing separate conditions for each new source country.

CYP

Land was secured with the NPA Regional Council for the sandalwood progeny trial. This land was going to be leased under general expressions of interest but following discussions between project staff and the Mayor, it has been leased to the Northern Peninsula Area College for a nominal fee for the next five years. This provides the school with a land resource for their horticultural and animal husbandry programs and provided us with a site that could be irrigated to establish one of the progeny trials.

8.4 Communication and dissemination activities

The 3 planned communication and engagement activities have been undertaken for all user groups (landowners, nursery operators, foresters, rural development workers and tertiary stakeholders). Project partners have:

- **Facilitated and guided project operations** with landowners through initial discussions with ward councillors, community meetings, training & awareness sessions, and ongoing site visits to ensure project awareness and participation.
- **Facilitated the rational use of project results** through the development of specific training resources for farmers and field workers that ensure awareness of project findings and user ability to make informed decisions. These resources have been incorporated into the Tree Growers Tool Kit, which is managed by Pacific Island Projects (PIP). Project partners have organised community meetings, training & awareness sessions, and meetings with lead farmers & nursery operators to communicate and disseminate project findings and resources.
- **Facilitated wider, post-project adoption of nursery production and tree planting** through the development of the Tree Growers Tool Kit's online communication platforms (PIP Website, Google Drive, YouTube, Mailchimp and Facebook) and the establishment of Community Outreach Centres (e.g. community schools and community-based organisations). Annual Communication Schedules were prepared to share project information and resources with project partners and stakeholders through the most appropriate communication platforms. Five bi-annual Communication Reports were produced to monitor user interactions on each platform.

The project communicates with teak smallholders in PNG through bulk text messages. The user group currently has grown to over 150 registered people from ENB, most of whom had attended an extension evert during the project. Text messaging is limited to short information briefs rather than building capacity or knowledge among recipients. Messaging through this service provides updates on community works were conducted within the previous weeks. Many users have commented that it is of interest and makes them feel like 'being part of something important'.

The project continues to maintain its Facebook site (Agroforest Pacific), with an audience of just over 1750. The audience is primarily professional and government workers in urban centres around the Pacific. This offers the project a vehicle to communicate significant outputs to a broader audience. The Facebook site has also been used to promote the work that project staff have been implementing, as it gives their work a wider exposure to a larger network.

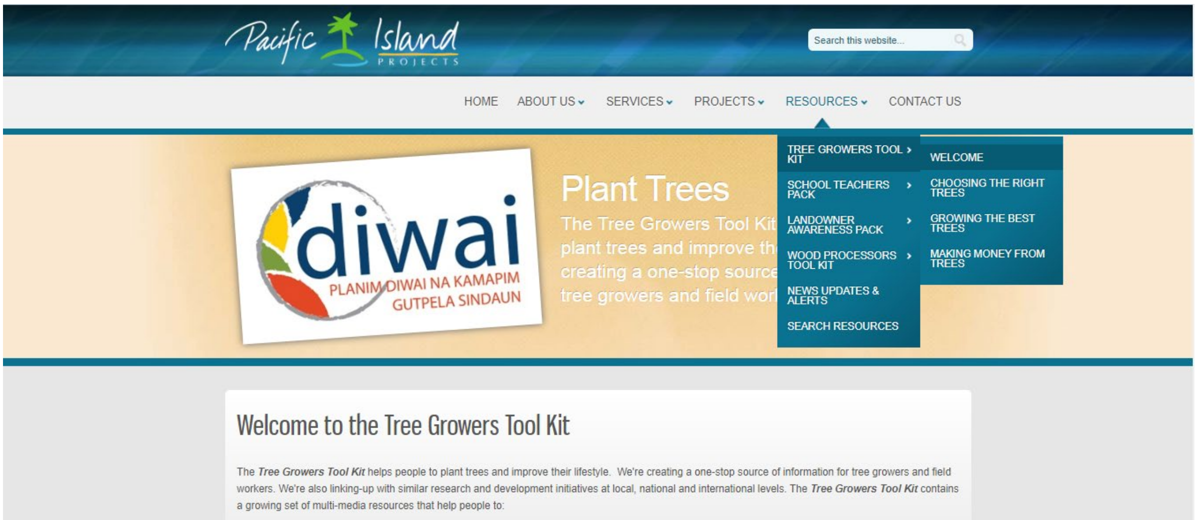

Figure 47: The Tree Growers Tool Kit's multi-media resources are freely available on the PIP Website

CYP

Strategic engagement

Meetings have been held with many indigenous people and groups in the NPA to promote and facilitate the project work. Specifically this included discussions with the NPA Council (Mayor, Deputy Mayor and Deputy CEO), Aputhama Land Trust, the Ipima Ikaya Aboriginal Corporation (who are the Prescribed Body Corporate that hold the native title over the NPA region) and the Gudang/Yadhaykenu Group, who are the traditional landowners for the land north of the Jardine River. We have discussed the project with the Traditional Owners and they are supportive of the work, as they see it could lead to employment opportunities for themselves and their children.

In addition we have engaged with Trility Water (the company that manages the town water and sewage treatment - Bamaga) and the Department of Infrastructure, Local Government & Planning (who own the water treatment and sewage plants in the NPA). This resulted in us securing free access to untreated irrigation water for the sandalwood progeny trial at the school. We are also working closely with several teachers at the Northern Peninsula Area College, who are including sandalwood work into their classroom activities (including helping with planting of the trials, maths (e.g. counting and estimating numbers of seed) and English.

Operational engagement & communication

We have run field days and training days for staff and students at the Northern Peninsula Area State College (six training events) and CDP (two training events) on the establishment and management of sandalwood plantations. We have had members of the Aputhama Land Trust and Ipima Ikaya Aboriginal Corporation work with us on the establishment and management of the trials and enrichment plantings in the NPA. We have also provided a document to the Gudang/Yadhaykenu Group (Lee and Burridge, 2017) that they provide to potential backers that are “looking into different opportunities to bring the investment to a funding stage”.

Project staff produced Lee D and Burridge A. (2017) Developing a sandalwood industry in the NPA 4pp. This was provided to the leaders of the Gudang/Yadhaykenu Group and to the investors they are talking to about sandalwood projects in the NPA.

9 Conclusions and recommendations

9.1 Conclusions

Both teak and sandalwood are financially viable options for smallholders to build long-term income stability and diversification. This project has clearly demonstrated that family-based forestry is an appropriate mode of forest resource restoration in PNG. As local adoption increases and cash returns are made from the products from thinning, it is likely to stimulate greater adoption and improve scaling out. Achieving widespread small woodlots is likely to address localised timber shortages, diversify incomes and improve livelihoods. The economic impacts can, however, be improved through a proportion of growers establishing more significant sized plantings. It is important to support local service providers that can deliver the inputs currently provided by the project and thus improve overall long-term sustainability. The family-based forestry approach is limited in its capacity to scale-up because individual families have limited resources to establish larger stands. Research is required to determine appropriate methods for scaling up, either at the family level, through unique forms of collective action, or by engaging private sector investors.

Great progress has been achieved in the domestication of teak in PNG and sandalwood in both PNG and CYP. The establishment of key genetic resource plantings within this project will provide long-term and sustainable benefits to participating organisations and communities. By its very nature domestication is a long-term activity, but short-term gains can be secured through continuation of the clonal approach to deployment. At this stage deployment of clonal teak is limited by the staffing and resource constraints of partner organisations that operate small-scale nurseries. Routine cutting propagation for operational deployment of clonal material for planting would require further staffing investments by project partners or engagement with a commercial nursery.

The next phase of improvement will need to continue to develop seed orchards both clonal (CSO) and seedling (SSO) approach, by substantial culling of underperforming phenotypes. Continuing the seed based deployment of improved material is important because of its low risk associated with the low input costs. However, further work is required to identify and develop commercial nurseries that can capitalise on market mechanisms for clonal deployment. OISCA understands the sustainability of market based methods for deploying teak materials, but are yet to demonstrate a movement towards seedling sales. Some of this may be explained by the close relationships OISCA have with stakeholders and the benevolent ethos of the organisation. OISCA have demonstrated the capacity to make sales to commercial organisations such as Simberi Ltd.

The works conducted to build growers' networks has made positive contributions to social capital and capacity to implement smallholder commercial forestry. While difficult to quantify, the substantial goodwill among project partner organisations and their staff has enabled collaboration and information sharing to improve local institutional capacity and culture. These networks are essential to continue research and development in this area. This project stimulated great interest among women smallholders, and there were few participant-nominated social barriers to adoption in ENB. These findings are an important contribution to new knowledge, but further work is required to test these findings. This can be done by engaging interested women through forestry networks established by this project, but also through existing women's agricultural and business networks that have been developed for cocoa germplasm. Evaluation of women's interest and constraints for involvement in sandalwood agroforestry is another research activity to address gender equity in PNG.

Significant community engagement in the NPA has helped Indigenous people build businesses based on their sandalwood. The components of this work that are limiting the commercialisation of the species are: scaling up the small plantings to a size (e.g. 5-10 hectares) where the investors and locals can see the potential of the species, and to gain knowledge on the growth, risks and potential benefits of sandalwood plantations. This will build the community capacity, as the people of the NPA have no agricultural or nursery experience. A viable and sustainable sandalwood industry in the NPA seems possible if further development work in the region is undertaken. This should lead to employment, health and cultural benefits for the Indigenous people of the NPA. These things can only be achieved with increased investment of knowledge and time.

The genetic diversity of the northern sandalwood (*S. lanceolatum*) populations is relatively low and much of the material in the natural stands is clonal, hence a conservative approach is required when selecting trees for inclusion in either a breeding program or conservation plantings. The growth of the sandalwood in the young trials is good, with trees growing faster in the irrigated trial than the non-irrigated trial. This growth is similar to that observed in other sandalwood species elsewhere. Sandalwood plantings on the NPA will be relatively large scale, as all land is a communal asset. Thus, plantings have to be at a size to benefit all members of the community, not just a single family or individual. Risks and impediments to sandalwood development in the CYP include: fire and cattle, the pests and diseases attacking the trees in their native environment, lack of facilitates (e.g. nurseries) and lack of a skilled labour force with agricultural experience. The other main impediment is the small scale of the plantings in the NPA. This means there is inadequate knowledge to guide economic modelling to encourage investors to fund sandalwood business development. This can be addressed by establishing larger scale demonstration plantings, collecting additional data through time and working and building capacity of the Indigenous people of the NPA, helping them develop the facilities, skills and knowledge to manage all aspects of a sandalwood agribusiness.

9.2 Recommendations

This ACIAR project has provided insights into how participatory domestication and smallholder tree planting can be implemented in PNG and CYP. However, constraints remain for further development and expansion of woodlots. Local seed supply needs to keep pace with the growing demand by smallholder and institutional growers. For teak, this project has been successful in establishing germplasm sources (clonal and provenance stands), but local seed supply has not kept up with demand. Further research is required to convert the germplasm sources into functional seed production areas to establish a sustainable supply. Sustainability of this approach will depend on identifying commercial means for exploiting these seed stands. Obviously this can be supported through commercial sale of seedings. With robust and cost effective nursery techniques, teak seedlings can be produced at an acceptable cost for smallholders. However further research is required to identify arrangements and/or stakeholders where seed supply can be sustained through commercial means.

The productivity benefits of clonal selection of teak has been demonstrated through clonal test trials. Currently there exists two sets of clones with one set selected for wet equatorial (UNRE) and the other selected for tropical savannah (FRI) environment. Further research is required to determine the adaptability of these clonal groups across the two different environments. This is important to ensure the germplasm is adapted across the tropical lowland environments of PNG. This will require cooperation among existing project partners for equitable germplasm share arrangements to ensure PNG stakeholders benefit from the research.

The project has been successful in facilitating the establishment of teak woodlots on customary land. The project worked at the nuclear family level to mitigate the potential social complexities associated with tree planting at the clan and community level. However, the long-term nature of tree planting presents potential land-tenure issues as the trees mature and increase in value. Furthermore trees planted by men on land with matrilineal tenure can be viewed as a land claim, potentially resulting in future land tenure conflicts. It is therefore important that future research explore the interactions of tree tenure, land tenure, social and gender issues more thoroughly. This is particularly important as the scale of tree planting increases, both in number of families involved and the size of the woodlots planted.

The smallholder teak woodlots established under this project provide a foundation for further expansion. At the current scale the commercial viability of the small woodlots is limited by the high transaction costs for maintenance, harvesting and marketing. Scaling up the size of woodlots or a physical aggregation of family woodlots offers scope to maximise their commercial potential. Research is required into social and land tenure dynamics to upscale family woodlots and/or work at the clan- and community- level. The issue of scaling of tree planting is important to inform PNGFAs vision under the PGPD tree planting initiative. Scaling and/or aggregation is also important to overcome an existing regulatory barrier to commercialisation, where an entity (Forest Industry Participant) must produce a minimum of 500 m^3/annum to legally trade and export timber.

The project has demonstrated the potential for a planted sandalwood sector in PNG through commercially viable smallholder woodlots. Preservation of the remaining wild trees remains a priority to maintain *in situ* genetic diversity, and serve as a source of germplasm to support long-term domestication. This can be achieved through the establishment of a ten-year moratorium on the sandalwood trade. To simplify smallholder decision making and improve sandalwood productivity the identification of best-bet hosts that can perform across a range of environments is required. While the project successfully characterised oil quality variation in PNG sandalwood, the selected individuals need to be captured and established as clonal seed orchards.

Research has found the potential for a cryptic sandalwood species, based on morphological similarities and shared oil chemistry of CYP and WP trees, which is distinct from their respective species. However, further research is now required to understand the true genetic relationships. Determining the existence of a new species is important from both a scientific and commercial perspective. Scientifically it is important to understand the process of sandalwood speciation across the natural distribution. The identification of a new high-quality sandalwood species can give it a unique identity within the international market. This can potentially offer marketing advantages and improve its prospects for commercialisation. To achieve commercialisation further capacity building is required so the NPA can be self-sufficient in their sandalwood seed and seedling production, as well as plantation / enrichment planting establishment and management. There is also a need for developing capacity for managing investments and joint ventures.

References

9.3 References cited in report

Barbour L, Norris L, Burgess T (2010) 'Heartwood Rot Identification and Impact in Sandalwood (*Santalum album*).' Rural Industries Research and Development Corporation, Canberra.

Bosimbi D (2006) 'Sandalwood Research, Development and Extension in Papua New Guinea.' National Tree Seed Centre, Bulolo, Papua New Guinea.

Bosimbi D, Bewang IF (2007) Report of Sandalwood Research, Development and Extension in PNG. In 'Proceedings of the regional workshop on sandalwood research, development and extension in the pacific islands'. Nadi, Fiji. (Eds L Thomson, P Bulai and B Wilikibau) pp. 57-61. (Secretariat of the Pacific Community)

Burridge AJ, Lee DJ (2020) Propagation of Santalum lanceolatum from Cape York Peninsula. In 'Sandalwood Regional Forum, 11-13 November 2019'. (Eds T Page and J Meadows). (Port Vila, Vanuatu)

Bush D, Thomas AL, Dutt S, Hamani S, Bolatolu W, Tauraga J, Mateboto J, Young E (2020) Domestication provides the key to conservation of Santalum yasi – a threatened Pacific sandalwood *Australian Forestry* **X**, 000-000.

da Silva JAT, Kher MM, Soner D, Page T, Zhang X, Nataraj M, Ma G (2016) Sandalwood: basic biology, tissue culture, and genetic transformation. *Planta* **243**, 847–887. doi:10.1007/s00425-015-2452-8

Dalsgaard S, Pedersen M (2015) The portable sawmill and other challenges to REDD plus in Papua New Guinea. *Asia Pacific Viewpoint* **56**, 128-139. doi:10.1111/apv.12086

Dawson IK, Guariguata MR*, et al.* (2013) What is the relevance of smallholders' agroforestry systems for conserving tropical tree species and genetic diversity in circa situm, in situ and ex situ settings? A review. *Biodiversity and Conservation* **22**, 301-324. doi:10.1007/s10531-012-0429-5

Eddowes PJ (1998) '*Santalum macgregorii*', Web Resouce Accessed: 02 September 2014, (<www.iucnredlist.org>).

Ellsworth D (2019) 'UWS Final Report for ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust.'.

Gunn B (2013) 'Facilitating the availability and use of improved germplasm for forestry and agroforestry in Papua New Guinea ' Australian Centre for International Research, Canberra.

Inu S (2019) 'Nursery Progressive Report.' PNG Forest Research Institute, Lae, Papua New Guinea.

IUCN (2012) 'IUCN Red List Categories and Criteria: Version 3.1. Second edition.' IUCN, Gland, Switzerland and Cambridge, UK.

Jeffrey G, Macdonell P, Oa L, Rome G, Page T (2019) 'Morphological and heartwood variation *Santalum macgregorii* in Papua New Guinea. Paper presented at the Sandalwood Regional Forum. 11-13 Nov 2019, Port Vila, Vanuatu.'

Jeffrey GK (2019) 'Nursery Practices of Teak in Papua New Guinea. Technical Manual #5.' PNG Forest Research Institute, Lae, Papua New Guinea.

Jenkin B (2019a) 'Model estate and marketing plan. Improvement and management of teak and sandalwood in PNG and Australia (ACIAR Project FST/2014/069).' Sylva Systems.

Jenkin B (2019b) 'Silviculture of Teak in Papua New Guinea and farmer requirements.' Sylva Systems.

Jenkin B (2019c) 'A training needs analysis in support of farmers as Teak growers. Improvement and management of teak and sandalwood in PNG and Australia (ACIAR Project FST/2014/069).' Sylva Systems.

Jenkin B, Minimulu J (2019a) 'Establishment and assessment of a teak silviculture trial to test initial spacing and a series of demonstration plots. Improvement and management of teak and sandalwood in PNG and Australia (ACIAR Project FST/2014/069).' Sylva Systems.

Jenkin B, Minimulu J (2019b) 'A second thinning of the UNRE 1A provenance trial and proposed seed orchard. Improvement and management of teak and sandalwood in PNG and Australia (ACIAR Project FST/2014/069).' Sylva Systems.

Jenkin B, Page T (2017a) 'Technical Brochure: Making teak stumps. Teak Project Fact Sheet.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Jenkin B, Page T (2017b) 'Technical Brochure: Making Teak Stumps.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Kanowski P, Blyth M, Essacu F, Holzknecht H, Jenkin B, Kuniata L, Mulung K, Rollinson S (2014) 'Value-adding to Papua New Guinea agroforestry systems. Final report for FST/2004/050.' Australian Centre for International Agricultural Research (ACIAR), 31/07/2014 ISBN: 978 1 925133 27 1, Canberra.

Kavanamur D (2010) 'Papua New Guinea Vision 2050.' National Strategic Plan Taskforce, Port Moresby, Papua New Guinea.

Kiapranis R (2012) Papua New Guinea. In 'Regional workshop on Sandalwood Resource Development, Research and Trade in the Pacific and Asian Region'. (Ed. L Thomson) pp. 27-31. (European Union, Secretariat of the Pacific Community, James Cook University and the Australian Centre for International Agricultural Research (ACIAR). Port Vila, Vanuatu)

Kulang S (2018a) 'Progressive Report on Cincture and Cuttings Propagation Method.' Forestry Department, Unversity of Natural Resources & Environment (UNRE), Vudal, ENB Province, Papua New Guinea.

Kulang S (2018b) 'Truncheon cuttings of selected teak clones in CSO in East New Britain.' Forestry Department, Unversity of Natural Resources & Environment (UNRE), Vudal, ENB Province, Papua New Guinea.

Lata A (2017a) 'Establishment Report: Clonal Seed Orchard of Tectona grandis (teak) at Kuriva, Central Province.' Planted Forest Program, Forest Research Institute, Lae, PNG.

Lata A (2017b) 'Site Preparation Report: Teak Clonal Orchard Kuriva, Central Province.' Planted Forest Program, Forest Research Institute, Lae, PNG.

Lata A (2018) 'Kuriva Trip Report: Establishment of Sandalwood species/provenance trial at Kuriva. February 2018.' Planted Forest Program, Forest Research Institute, Lae, PNG.

Lata A (2019) 'Protocol in Propagation of Mature Teak and Subsequent Clone Production in Papua New Guinea. Manual No. 3.' Lae, Papua New Guinea, PNG Forest Research Institute.

Lata A, Inu S, Wake Y, Jeffrey G (2019) 'End of Project Review PNGFA-Port Moresby. Results and milestones of research activities supported by ACIAR FST/2014/069 project at PNG Forest Research Institute.' PNG Forest Research Institute (FRI), Lae, Papua New Guinea.

Lata A, Kulang S, Howcroft N, Page T (2016) Clonal capture of mature Tectona grandis (teak) for improved germplasm deployment in Papua New Guinea (PNG). In 'Small-scale and Community Forestry and the Changing Nature of Forest Landscapes, Proceedings from the IUFRO Research Group 3.08 Small-scale Forestry Conference'. (Eds J Meadows, SR Harrison and J Herbohn) pp. 141-149. (Sunshine Coast, Australia 11-15 October 2015)

Lee DJ, Burridge A, Brunton A, Conroy GC, Ogbourne SM, Thompson N (2020a) Selection, breeding and development of Cape York Sandalwood. In 'Sandalwood Regional Forum, 11-13 November 2019'. (Eds T Page and J Meadows) pp. xx-xx. (Australian Centre for International Research, Canberra: Port Vila, Vanuatu)

Lee DJ, Burridge A, Brunton A, Conroy GC, Ogbourne SM, Thompson N (2020b) 'Selection, breeding and development of Cape York Sandalwood. Paper presented at Sandalwood Regional Forum, 11-13 November 2019, Port Vila, Vanuatu.'

Lee DJ, Burridge AJ, Page T, Huth JR, Thompson N (2018) Domestication of northern sandalwood (*Santalum lanceolatum*, Santalaceae) for Indigenous forestry on the Cape York Peninsula. *Australian Forestry* **82**, 1-9. doi:10.1080/00049158.2018.1543567

Lee DJ, Burridge AJ, Page T, Huth JR, Thompson N (2019) Domestication of northern sandalwood (*Santalum lanceolatum*, Santalaceae) for Indigenous forestry on the Cape York Peninsula. *Australian Forestry* **82**, 1-9. doi:10.1080/00049158.2018.1543567

MoTC&A (2016) 'Papua New Guinea Small and Medium Enterprise Policy.' Ministry Of Trade, Commerce And Industry,, Port Moresby.

Oa L, Rome G (2015) 'Brief report on Establishment of a Resource Site Centre & Identification of Seed Trees in the Surrounding Kairuku Areas in Central Province.' PNG Forest Authority, Hohola, Port Moresby, Papua New Guinea.

Page T (2015) 'Teak Nursery Workshop: Kokopo Village Resort Kokopo, East New Britain (ENB), PNG. Wednesday 15th October 2015.' University of the Sunshine Coast (USC).

Page T (2017a) 'Field Report: Implementation of teak activities in ENB & Sandalwood Farmer Meeting in Kairuku.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017b) 'Field Report: Sandalwood Awareness Activities.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017c) 'Technical Brochure: Potting up and raising sandalwood seedlings.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017d) 'Technical Brochure: Preparing a growing medium.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017e) 'Technical Note: Potting up and raising sandalwood seedlings.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017f) 'Technical Note: Sandalwood seed collection & preparation ' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2018) 'Field Report: Plus tree selection & Project Partner Meeting.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2019a) 'Field Report: Wild sandalwood survey, clonal teak (OISCA), C13 study, ITTO visit, Farmer Interviews.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2019b) 'Technical Note: Sampling sandalwood for heartwood development and quality.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Clarke B, Bush D, Thomson LAJ (2020a) 'Pacific sandalwood: growers' manual for sandalwood production in the Pacific.' University of the Sunshine Coast & CSIRO.

Page T, Howcroft N, Kulang S, Minimulu J, Waldi D (2018a) 'UNRE Teak Clonal Series.' University of the Sunshine Coast (USC), University of Natural Resources and Environment (UNRE), Maroochydore and Vudal.

Page T, Howcroft N, Kulang S, Minimulu J, Waldi D (2018b) 'UNRE Teak Clonal Series.' Report for ACIAR Project FST/2018/069 Improvement and management of teak and sandalwood in PNG and Australia.

Page T, Jeffrey G, Lata A, Kulang S, Minimulu J, Waldi D (2018c) 'Technical Note: Teak Tree Assessment ' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Jeffrey G, Macdonell P, Hettiarachichi D, Boyce M, Oa L, Rome G (2020b) Morphological and heartwood variation of *Santalum macgregorii* in Papua New Guinea. *Australian Forestry* **in review**.

Page T, Jenkin B, Rollinson S, Rabbie J, Vinarut I (2016) A Participatory Approach to Inventory and Extension to Improve the Management and Quality of Smallholder Woodlots in Papua New Guinea. In 'Small-scale and Community Forestry and the Changing Nature of Forest Landscapes, Proceedings from the IUFRO Research Group 3.08 Small-scale Forestry Conference'. (Eds J Meadows, SR Harrison and J Herbohn) pp. 196-205. (Sunshine Coast, Australia 11-15 October 2015)

Page T, Kill E, Kapi S, Inu S (2020c) 'Constraints for women to participate in small-scale forestry in a matrilineal society in Papua New Guinea.' University of the Sunshine Coast (USC), National Research Institute (NARI), PNG Forest Research Institute (FRI).

Page T, Meadows J (2017) 'Technical Note: Sandalwood Hosts in PNG.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Minimulu J, Rabbie J, Vinarut I, Kuariri A, Kulang S, Waldi D, Jenkin B (2018d) 'Technical Note: Pruning Teak.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Minimulu J, Vinarut I (2020d) 'Seed collection within Teak Provenance Blocks at OISCA. Technical Note for ACIAR project FST/2014/069 Improvement and management of teak and sandalwood in PNG & Aust.'.

Page T, Oa L (2017a) 'Sandalwood Growers' Workshops, Central & Gulf Provinces, PNG, ACIAR Project FST/2014/069.' Maroochydore & Port Moresby, University of the Sunshine Coast (USC) & PNG Forest Authority.

Page T, Oa L (2017b) 'Sandalwood Growers' Workshops, Central & Gulf Provinces, PNG.' University of the Sunshine Coast and PNG Forest Authority, Maroochydore & Port Moresby.

Page T, Rome G, Oa L (2020e) 'Sandalwood planting as a commercial investment in PNG. Technical Note for ACIAR project FST/2016/154 Improvement and management of teak and sandalwood in PNG & Aust.'.

Page T, Southwell I, Russell M, Tate H, Tungon J, Sam C, Dickinson G, Robson K, Leakey RRB (2010) Geographic and phenotypic variation in heartwood and essential oil characters in natural populations of *Santalum austrocaledonicum* in Vanuatu. *Chemistry and Biodiversity* **7**, 1990-2006. doi:http://dx.doi.org/10.1002/cbdv.200900382

Page T, Tate H, Tungon J, Tabi M, Kamasteia P (2012) Vanuatu Sandalwood: Growers guide for sandalwood production in Vanuatu. In 'ACIAR Monograph No. 151'. pp. 56. (Australian Centre for International Agricultural Research (ACIAR): Canberra, Australia)

Page T, Vinarut I (2017) Lead Farmer Knowledge Transfer & Smallholder Training Needs. Report for ACIAR project FST/2014/069 Improvement and management of teak and sandalwood in PNG and Australia.

Page T, Williams R, Trindade H (2018e) 'Technical Brochure: Sandalwood seed dormancy & treatment.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Pamphilon B, Mikhailovich K, Chambers B (2014) 'Training by Papua New Guinea women, for Papua New Guinea women': lessons from the development of a co-constructed course for women smallholder farmers. *International Journal of Lifelong Education* **33**, 721-736. doi:10.1080/02601370.2014.952358

Pamphilon B, Mikhailovich K, Gwatirisa P (2017) 'The PNG Family Farm Teams Manual. ACIAR Monograph MN199.' (Australian Center for International Agricultural Research (ACIAR): Canberra)

Paul JH (1990) The status of sandalwood (*S. macregorii*) in Papua New Guinea. In 'Proceedings of the Symposium on Sandalwood in the Pacific'. Honolulu, Hawaii. (Eds L Hamilton and CE Conrad) pp. 76-78. (USDA Forest Service)

PIP (2017) 'Tree Growers Communication Report #1.' Pacific Island Projects, Rabaul, East New Britain Province, Papua New Guinea.

PIP (2018a) 'Tree Growers Communication Report #3. January 2018.' Pacific Island Projects, Rabaul, East New Britain Province, Papua New Guinea.

PIP (2018b) 'Tree Growers Communication Report #4. 1 January to 30 June 2018.' Pacific Island Projects, Rabaul, East New Britain Province, Papua New Guinea.

PIP (2019a) 'Outreach Centre Report: PNG Missions, Toma-Vunadidir LLG.'

PIP (2019b) 'Tree Growers Communication Report #2.' Pacific Island Projects, Rabaul, East New Britain Province, Papua New Guinea.

PIP (2019c) 'Tree Growers Communication Report #5. 1 July to 31 December 2018.' Pacific Island Projects, Rabaul, East New Britain Province, Papua New Guinea.

PIP (2019d) 'Tree Growers Communication Report #6. 1 January to 30 June 2019.' Pacific Island Projects, Rabaul, East New Britain Province, Papua New Guinea.

PNG CoM&P (2017) 'PNG Resource Industry Economic Contribution.' PNG Chamber of Mines & Petroleum, Port Moresby. (www.pngchamberminpet.com.pg).

PNGFA (2014) 'National Strategies for Reforestation and Afforestation in Papua New Guinea 2015 - 2019.' Papua New Guinea Forest Authority, National Forest Service, Port Moresby.

PNGFA (2018) 'National Program & Strategies for Operation Panim Graun Planim Diwai incorporated with existing forest plantations: A conceptual approach.' Papua New Guinea Forest Authority, Port Moresby.

Roberts J (2015) 'Monitoring and Evaluation Plan: Improvement and management of teak and sandalwood in PNG and Australia FST/2014/069.' Strategy, Evaluation and Engagement for Development Pty Ltd.

Rollinson S, Page T (2019a) 'Choosing the Right Trees: Sandalwood (*Santalum macgregorii*).' Pacific Islands Projects, Rabaul East New Britain.

Rollinson S, Page T (2019b) 'Choosing the Right Trees: Teak (*Tectona grandis*).' Pacific Islands Projects, Rabaul East New Britain.

Rome G (2016) 'Incorporated Land Group (ILG) Awareness Activities in Girabu and Iokea. April 2016.' PNG Forest Authority, Hohola, Port Moresby, Papua New Guinea.

Rome G (2017) 'Progressive Report - Girabu Sandalwood Project Site, Rigo district in Central Province. 3rd May 2017.' PNG Forest Authority, Hohola, Port Moresby, Papua New Guinea.

Rome G (2018) 'Sandalwood Project Nursery Upgrading in the Pilot Project Sites in Central and Gulf provinces.' Hohola, Port Moresby, Papua New Guinea, PNG Forest Authority.

Rome G, Oa L (2019) 'Community Sandalwood Initiatives in Girabu, Kairuku and Iokea in the Central and Gulf Provinces of Papua New Guinea. Paper presented at Sandalwood Regional Forum, 11-13 November 2019.' Port Vila, Vanuatu.

Rome G, Page T (2018) 'Sandalwood Nursery Plan. Report for ACIAR Project FST/2018/069 Improvement and management of teak and sandalwood in PNG and Australia.'

Rome G, Turia R, Oa L, Saliau C (2020) Sandalwood Development in Papua New Guinea (submitted). *Australian Forestry*.

Sabuin T (2018) 'What is operation PGPD? Operation painim graun na planim diwai [PGPD] Landowner awareness package.' Pacific Island Projects, Papua New Guinea.

Saulei SM, Aruga JA (1994) The status and prospects of non-timber forest products development in Papua New Guinea. *The Commonwealth Forestry Review* **73**, 97-105.

SGS (2020) 'Log Export Monitoring Monthly Report 2019.' Société Générale de Surveillance (SGS) PNG Ltd., Port Moresby.

Terrain NCoSa (2009) 'Australian soil and land survey field handbook.' (CSIRO PUBLISHING)

Thompson N, Lee DJ, Burridge AB (2019) Aspirations for an indigenous led sandalwood industry on Cape York Peninsula. In 'Paper Presented at the Sandalwood Regional Forum, 11-13 November'. (Port Vila, Vanuatu)

Turia R, Saliau C (2019) 'Prospects for marketing sandalwood in Papua New Guinea (PNG). Paper presented at Sandalwood Regional Forum, 11-13 November 2019.' Port Vila, Vanuatu.

UNDP (2018) 'Development of future scenarios for private sector engagement in PNG's forest Sector. Working discussion paper: Planted trees and Plantations.' REDD+ Readiness Project – Forest Carbon Partnership Facility.

Warburton CL, James EA, Fripp YJ, Trueman SJ, Wallace HM (2000) Clonality and sexual reproductive failure in remnant populations of *Santalum lanceolatum* (Santalaceae). *Biological Conservation* **96**, 45-54.

9.4 List of publications produced by project

Journal articles

da Silva JAT, Kher MM, Soner D, Page T, Zhang X, Nataraj M, Ma G (2016) Sandalwood: basic biology, tissue culture, and genetic transformation. Planta 243, 847–887. doi:10.1007/s00425-015-2452-8

Lee DJ, Burridge AJ, Page T, Huth JR, Thompson N (2019) Domestication of northern sandalwood (*Santalum lanceolatum*, Santalaceae) for Indigenous forestry on the Cape York Peninsula. Australian Forestry 82, 1-9. doi:10.1080/00049158.2018.1543567

Page T, Jeffrey G, Macdonell P, Hettiarachichi D, Boyce M, Oa L, Rome G. (under review). Morphological and heartwood variation of *Santalum macgregorii* in Papua New Guinea. Australian Forestry.

Rome G, Turia R, Oa L, Saliau C. 2020. Sandalwood Development in Papua New Guinea (submitted). Australian Forestry.

Conference Papers

Burridge AJ, Lee DJ (2020) Propagation of Santalum lanceolatum from Cape York Peninsula. In 'Sandalwood Regional Forum, 11-13 November 2019'. (Eds T Page and J Meadows). (Port Vila, Vanuatu)

Jeffrey G, Macdonell P, Oa L, Rome G, Page T (2020) Morphological and heartwood variation Santalum macgregorii in Papua New Guinea. Paper presented at 'Sandalwood Regional Forum, 11-13 November 2019'. Port Vila, Vanuatu.

Lata, A., Kulang, S., Howcroft, N., and Page, T. (2016). Clonal capture of mature Tectona grandis (teak) for improved germplasm deployment in Papua New Guinea (PNG). Sunshine Coast, Australia 11-15 October 2015

Lee, D., Huth, J., Burridge, A., Oostenbrink, J. and Page, T. (2016) Breathing Life into Cape York Sandalwood. Sunshine Coast, Australia 11-15 October 2015.

Lee D, Huth JR, Burridge A, Oostenbrink J (2017) Developing Cape York Sandalwood for Indigenous Forestry. Tropical Forestry Innovation and Change in the Asa Pacific Region 'Developing Northern Australia Conference 19-20 June 2017'. (Pullman Cairns International) The Institute of Foresters of Australia pp27.

Lee DJ, Burridge A, Brunton A, Conroy GC, Ogbourne SM, Thompson N (2020) Selection, breeding and development of Cape York Sandalwood. Paper presented at 'Sandalwood Regional Forum, 11-13 November 2019'. Port Vila, Vanuatu.

Page, T., Jenkin, B., Rollinson, S., Rabbie, J., and Vinarut, I. (2016). A Participatory Approach to Inventory and Extension to Improve the Management and Quality of Smallholder Woodlots in Papua New Guinea. Sunshine Coast, Australia 11-15 October 2015.

Rome G, Oa L (2020) Community Sandalwood Initiatives in Girabu, Kairuku and Iokea in the Central and Gulf Provinces of Papua New Guinea. Paper presented at 'Sandalwood Regional Forum, 11-13 November 2019'. Port Vila, Vanuatu.

Thompson N, Lee DJ, Burridge AB (2019) Aspirations for an indigenous led sandalwood industry on Cape York Peninsula. In 'Paper Presented at the Sandalwood Regional Forum, 11-13 November'. (Port Vila, Vanuatu)

Scientific communication

Brunton A (2019) Population genetics of Santalum lanceolatum (Northern sandalwood). Honours Thesis, University of the Sunshine Coast.

Inu S (2018a) 'Growth Performance of Teak (Tectona grandis): Provenance effect in early growth at Situm. Morobe Province, PNG. 36 Months assessment report.' Planted Forest Program, Forest Research Institute (FRI), Lae.

Jenkin B (2019a) 'Business plan development: The prospects and markets for PNG timber products and plantation development.' Sylva Systems.

Jenkin B (2019b) 'Farmer needs, motivations and tree growing.' Sylva Systems.

Jenkin B (2019c) 'Model estate and marketing plan.' Sylva Systems.

Jenkin B (2019e) 'A training needs analysis in support of farmers as Teak growers.' Sylva Systems.

Jenkin B, Minimulu J (2019a) 'Establishment and assessment of a teak silviculture trial to test initial spacing and a series of demonstration plots.' Sylva Systems.

Jenkin B, Minimulu J (2019b) 'A second thinning of the UNRE 1A provenance trial and proposed seed orchard.' Sylva Systems.

Kulang S (2017c) 'Truncheon cuttings of selected teak clones in CSO in East New Britain. 23rd March 2017.' Forestry Department, University of Natural Resources & Environment (UNRE), Vudal, ENB Province, Papua New Guinea.

Kulang S (2018c) 'Truncheon cuttings of selected teak clones in CSO in East New Britain.' Forestry Department, University of Natural Resources & Environment (UNRE), Vudal, ENB Province, Papua New Guinea.

Lata A (2015a) 'Final Assessment and Thinning of Species Trial at Lae Botanical Gardens. Assessment Report December 2015.' Papua New Guinea Forest Research Institute, Morobe Province, PNG.

Oostenbrink J, Lee D (2017) 'Cape York Sandalwood (*Santalum lanceolatum*) Pollination Study Report.' University of the Sunshine Coast, Maroochydore.

Page T, Howcroft N, Kulang S, Minimulu J, Waldi D (2018a) 'UNRE Teak Clonal Series.' University of the Sunshine Coast (USC), University of Natural Resources and Environment (UNRE), Maroochydore and Vudal.

Page T, Kill E, Kapi S, Inu S (2020b) 'Constraints for women to participate in small-scale forestry in a matrilineal society in Papua New Guinea.' University of the Sunshine Coast (USC), National Research Institute (NARI), PNG Forest Research Institute (FRI).

Technical Communication

Jeffrey GK (2019) 'Nursery Practices of Teak in Papua New Guinea. Technical Manual #5.' PNG Forest Research Institute, Lae, Papua New Guinea.

Jenkin B, Page T (2017b) 'Technical Brochure: Making Teak Stumps.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Jenkin B (2019d) 'Silviculture of Teak in Papua New Guinea and farmer requirements.' Sylva Systems.

Lata A (2017d) 'Top cleft grafting techniques of *Eucalyptus deglupta* (Kamarere) in Papua New Guinea.' Papua New Guinea Forest Research Institute (PNGFRI), Lae, Papua New Guinea.

Lata A (2019a) 'The Nursery Training Manual for Community-based Nurseries.' PNG Forest Research Institute, Lae, Papua New Guinea.

Lata A (2019b) 'Protocol in Propagation of Mature Teak and Subsequent Clone Production in Papua New Guinea. Manual No. 3.' Lae, Papua New Guinea, PNG Forest Research Institute.

Lata A, Kulang S, Howcroft N, Page T (2016) Clonal capture of mature Tectona grandis (teak) for improved germplasm deployment in Papua New Guinea (PNG). In 'Small-scale and Community Forestry and the Changing Nature of Forest Landscapes, Proceedings from the IUFRO Research Group 3.08 Small-scale Forestry Conference'. (Eds J Meadows, SR Harrison and J Herbohn) pp. 141-149. (Sunshine Coast, Australia 11-15 October 2015)

Lata A, Page T (2017) 'Teak Clonal Orchard Kuriva (PNGFA).' PNG Forest Authority (PNGFA-FDD), PNG Forest Research Institute (FRI), Univeristy of the Sunshine Coast (USC), Australian Centre for International Agricultural Research (ACIAR), Lae, Papua New Guinea.

Lata AL (2019c) 'Growers' guide for Eaglewood (Gyrinops species) seedling production in Papua New Guinea.' PNG Foret Research Institute, Morobe, Papua New Guinea.

Lee D, Burridge A (2017) 'Developing a sandalwood industry in the NPA. 4pp.'

Page T (2017f) 'Technical Brochure: Potting up and raising sandalwood seedlings.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017g) 'Technical Brochure: Preparing a growing medium.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017h) 'Technical Brochure: Sandalwood Hosts in PNG.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017i) 'Technical Brochure: Sandalwood seed collection & preparation ' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017j) 'Technical Note: Potting up and raising sandalwood seedlings.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2017k) 'Technical Note: Sandalwood seed collection & preparation ' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T (2019c) 'Technical Note: Sampling sandalwood for heartwood development and quality.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Clarke B, Bush D, Thomson LAJ (2020a) 'Pacific sandalwood: growers' manual for sandalwood production in the Pacific.' University of the Sunshine Coast & CSIRO.

Page T, Jeffrey G, Lata A, Kulang S, Minimulu J, Waldi D (2018b) 'Technical Note: Teak Tree Assessment ' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Lata A, Jeffrey G, Kulang S, Minimulu J, Waldi D (2019) 'Technical Note: Benefits of planting improved teak.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Meadows J (2017) 'Technical Note: Sandalwood Hosts in PNG.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Minimulu J, Rabbie J, Vinarut I, Kuariri A, Kulang S, Waldi D, Jenkin B (2018c) 'Technical Note: Pruning Teak.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Page T, Oa L (2017a) 'Sandalwood Growers' Workshops, Central & Gulf Provinces, PNG, ACIAR Project FST/2014/069.' Maroochydore & Port Moresby, University of the Sunshine Coast (USC) & PNG Forest Authority.

Page T, Williams R, Trindade H (2018d) 'Technical Brochure: Sandalwood seed dormancy & treatment.' ACIAR project FST/2015/069 Improvement and management of teak and sandalwood in PNG & Aust., University of the Sunshine Coast: Maroochydore.

Rollinson S, Page T (2019a) 'Choosing the Right Trees: Sandalwood (Santalum macgregorii).' Pacific Islands Projects, Rabaul East New Britain.

Rollinson S, Page T (2019b) 'Choosing the Right Trees: Teak (Tectona grandis).' Pacific Islands Projects, Rabaul East New Britain.