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Final report

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Contents

Abbreviations and Acronyms

ACIAR	Australian Centre for International Agricultural Research
AusAID	Australian Agency for International Development
CSO	Clonal seed orchard
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Queensland Department of Agriculture & Fisheries
DBHOB	Diameter breast height over bark
DoF	Vanuatu Department of Forests
GSO	Grafted seed orchard
GxE	Genotype by environment interaction
IFP	Industrial Forestry Plantation land, near Shark Bay on the east coast Espiritu Santo Island
JCU	James Cook University
MTA	Material Transfer Agreement
NPA	Northern (Cape York) Peninsula Area
NPARC	Northern (Cape York) Peninsula Area Regional Council
SPC	Secretariat for the Pacific Community
2^{nd} gen	Second generation
SPRIG	South Pacific Regional Initiative on Forest Genetic Resources
SPRIG-2	Phase 2 of SPRIG project
SSO	Seedling Seed Orchard
TO	Traditional owner
USC	University of Sunshine Coast
VARTC	Vanuatu Agricultural Research and Training Centre

1 Acknowledgments

Our project partner, Vanuatu Department of Forestry (DoF), has contributed valuable resources to this project and we would like to acknowledge their significant role. Key Department personnel concerned with this project are co-authors of this report but many others, too numerous to be named here, were involved over time and their important contribution should be recognised.

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2 Executive summary

Vanuatu's forest sector is currently making a transition from an extractive-based industry to one founded on an expanding plantation resource. The Vanuatu Department of Forests (DoF) launched its reforestation program in 1994, with community participation in the program commencing in 2004. Since that time smallholder and community forestry has expanded, particularly for a few key commercial species. Further expansion and innovation in this sector will depend on development of improved germplasm to increase i) seed availability to growers ii) productivity of plantations and iii) market value of resulting products.

This project undertook research to improve and deploy genetic resources to maximise the potential value of the whitewood (*Endospermum medullosum*) and sandalwood (*Santalum austrocaledonicum*) industries in Vanuatu. Similar to Vanuatu, development of an improved form of sandalwood (*Santalum lanceolatum*) in Cape York (Queensland) affords the opportunity for indigenous communities to offer a high quality niche product to the international marketplace.

The project incorporated a range of activities to achieve these objectives, which included; the (a) advancement of seed orchard programs, (b) creation of advanced progeny trials, (c) establishment of gene resource populations, and (d) development of demonstration plots to guide current and prospective growers in key regions.

Activities and achievements for whitewood were: **(a)** thinning, following measurement, analysis and development of a selection index, of extensive (110 families of 15 provenances from five island origins) whitewood progeny trials established under SPRIG at IFP in Santo in 1998-99. Plus trees were marked and have provided an immediate source of improved seed (to date several thousand improved seedlings have been issued to farmers) for deployment within Santo and the other islands; **(b)** planting of three second generation whitewood progeny trials/second generation seedling seed orchards utilising plus-tree seed from IFP as a basis for production of highly genetically improved seed in the future. These were Bombua on Santo (1.4 ha), planted November 2011, 1,160 family-identified trees of 47 seedlots), Onesua on Efate (1.02 ha, planted January 2012, 384 trees of 25 seedlots) and Navota Farm on Santo (1.2 ha, planted October 2014, 1,296 family-identified trees from 66 seedlots). Fifty percent of trees were removed from the Bombua trial in February 2015 as part of the process of turning the trial into a second generation seedling seed orchard; **(c)** establishment at VARTC, Santo of a gene bank of new families and provenances not represented at IFP and; **(d)** planting of demonstration plots on Pentecost, Ambrym, Epi and two sites on Malekula.

Research undertaken on whitewood planted at the IFP site demonstrated significant and heritable provenance- and family-level variations in traits of economic significance (growth, form and wood density) confirming that a recurrent selection and breeding program should result in genetic gain in this species. An assessment of the conservation status of the wild stands of origin represented in the IFP trials, highlighted the importance to future breeding programs of in-situ and ex-situ conservation of whitewood genetic resources. Other research undertaken to underpin future breeding activities included a study of floral biology, seed storage methods and grafting and cuttings experiments.

Activities and achievements for sandalwood in Vanuatu were: **(a)** the successful replication of six sandalwood Grafted Seed Orchards (GSOs) in the northern islands of Vanuatu (Santo, Pentecost, Ambrym, Epi, Malekula and Efate). Each of these GSOs comprise largely of 18 superior clones replicated twice. Seed production has already commenced in most of the plantings and they already providing seed for establishment of a sandalwood progeny trial. DoF is now well equipped to continue the deployment of the clones to other areas of the country; **(b)** expansion of the sandalwood gene resource planting at Navota Farm (South Santo) that now comprises collections from all islands except Efate. A total of 853 trees from 15 populations are now well established on the site. Thirty-six candidate seed trees were identified based on their vigour and form. Further candidate seed trees can be identified from the remaining populations as the planting matures; and **(c)** establishment of a progeny trial at La Bouffa (Efate) representing 232 progeny from a limited (6+4) number of clonal genotypes from the GSO.

The replication of the GSOs in Vanuatu increases the security of this genetic resource and availability of improved seed for further breeding and supporting smallholder forestry. The Navota site represents a genetically important resource for broadening the genetic base of DoF's sandalwood improvement population and opportunity to select for form, vigour and heartwood development. It is recommended that the site be further renovated by host enrichment, pruning and fertilising to stimulate greater seed production for use in both domestication and operational forestry. The progeny trial represents the future for sandalwood development in Vanuatu. While the current size of the trial is relatively modest, further seed collections from both the GSOs and Navota gene resource planting can be used to expand the trial and increase its importance. This approach will rapidly broaden the genetic diversity available for second-generation selections, and permit longer-term improvement across a range of economic characters. All three strategic genetic resources (GSOs, Navota and La Bouffa) have been deliberately located in close proximity to DoF offices in Efate and Santo. This approach was taken to allow DoF to continue sandalwood improvement in the absence of external support.

Research associated with establishing the sandalwood genetic resources has resulted in improved scientific understanding of cutting propagation and reproductive biology within the genus. It has also led to a clearer understanding of likely hybridisation between *S. album* introduced within the natural range of *S. austrocaledonicum*. Introgression of *S. album* genes into the indigenous *S. austrocaledonicum* will present challenges when marketing Vanuatu sandalwood as something unique to the country. This feature, combined with research conducted into the wind-firmness and heartwood development, which showed *S. album* to be inferior to *S. austrocaledonicum* in these aspects, presents a potential risk for the domestication and silviculture of sandalwood in Vanuatu.

Workshops and training activities have been an important ongoing part of the sandalwood component of this project, including a series of sandalwood growers workshops in Malekula and Santo, several tree planting workshops in Santo, Malekula, Tongoa and the Shepherds islands. Grafting training conducted during the implementation of the project has led to a significant improvement in DoF capacity to clonally propagate mature sandalwood. An official event was conducted in early 2015 for the launch and distribution of the Sandalwood Growers Manual (ACIAR Monograph 149) and included a wide range of participants from education institutions, government departments, growers, and private and non-government organisations. Following the launch additional promotional events have been conducted by DoF staff, which include engagement with media outlets (Radio Vanuatu, Buz FM and Daily Post), festivals (Port Vila Trade Fair and World Environment Day) and forestry awareness training and field days. Five sandalwood-active DoF staff members participated in a study tour of the sandalwood industry in south-west Western Australia in April/May 2015. This activity highlighted Vanuatu sandalwood's natural competitive advantage, but also limitations to the future development of the industry. The tour culminated in a systematic evaluation of potential and constraints to sandalwood development in Vanuatu.

Domestication of *S. lanceolatum* in CYP could potentially underpin the development of small-scale forestry for indigenous communities in the region. The species is however under persistent threat from fire and grazing, with 19% of the original 31 wild trees killed by fire over the last five years. Protecting and conserving the species is therefore an important first step to realising the species commercial potential. A total of 17 wild sandalwood trees have been secured as grafted clones, from the Northern Peninsula Area Regional Council (NPARC). Ten of these trees are identified by their high relative oil quality, with the remaining trees selected to broaden genetic base of the clonal materials.

All work was undertaken with informed verbal and written consent, from traditional owners of the Adupthamu Land Trust. The grafted clones have now been established in two clonal seed orchards. One is on is on the Senior Campus of the Northern Peninsula Area College at Bamaga. This clonal seed orchard was planted with assistance from Year 8 students, who are now monitoring and watering the trees to ensure their survival. The other location is on Department of Agriculture and Fisheries land near Mareeba, to ensure survival of the germplasm in an ex situ conservation stand. Seed production has commenced in both clonal seed orchards and plans have been developed to test this material, in common garden experiments, to check if the species can be developed for the benefit of the indigenous peoples of the CYP.

The project has met most of its milestones despite the major constraints of working in remote areas in both Vanuatu and northern Australia with limited staff and resources. This is a significant achievement. Improvement of tree crops is invariably a long term activity requiring the host organisation to provide substantial on-going physical, human and financial resources to the program. A start to understanding the genetic diversity of Vanuatu whitewood was provided by the IFP provenance/family trials established under SPRIG 1996-2006, a project in five PICs involving a consortium of Australian research providers led by CSIRO and funded by AusAID. These trials provided a very useful start to the genetic improvement of whitewood and deployment of improved seed throughout the country, as undertaken in this project. Also for sandalwood earlier work by SPRIG and ACIAR facilitated the advances in domestication of this species made by this project However, much more can be done with further development of the seed orchard and clonal forestry components established by this project to ensure that highly improved germplasm of both species is available to growers in the future. DoF does not employ a research scientist with sufficient expertise in forest genetics to implement sophisticated tree breeding programs without some degree of external support. It is strongly recommended, therefore, that ACIAR consider funding a follow-on advanced breeding project for whitewood and sandalwood so that the genetic resources established in this project are further developed to the benefit of growers in Vanuatu. These crucial resources will be at risk if there is no follow-on project.

3 Background

The development of export industries can provide a basis for stimulating economic growth in Vanuatu. Both whitewood (*Endospermum medullosum*) and sandalwood (*Santalum austrocaledonicum*) have featured prominently in the export earnings from native forests in Vanuatu historically which has resulted in unsustainable harvesting of accessible natural stands. As both species are amenable to domestication as plantation species, the establishment of plantation industries was identified as the strategy to develop economically significant and sustainable forest industries.

A significant proportion of the Vanuatu's export earnings come from agriculture and exploitation of its timber resources and growth in the forestry sector will largely come from plantation establishment (AusAID 2006). Vanuatu has the capacity to source foreign exchange from processed timber exports and taxes (Bond 2006). Local value adding is a feature of the Vanuatu whitewood and sandalwood industries, with local production and export of sawn timber and panels (whitewood), powder and essential oils (sandalwood). However, as national timber volumes have decreased in Vanuatu over the past ten to 15 years so too have royalties available to the Vanuatu Government. This has led to a substantial increase in community and commercial production of both whitewood and sandalwood. This development has subsequently led to a greater awareness and demand for higher quality germplasm, which can help to reduce the length of the rotation and maximise market value. The germplasm resources established in this project can already support the expansion of the planted forest sector in Vanuatu and lead to economic growth for both local communities (increased income) and the national economy (increased employment and royalties).

In the Vanuatu Forest Policy (2013) the Vanuatu Ministry of Agriculture, Livestock, Forestry Fisheries and Environment reconfirmed an annual sustainable yield 68,000m^3 for logging from native forests originally set in the National Forest Policy of 1997. Since 1997 timber production peaked at just over 40,000m^3 in 1999 with a more recent decline to 5-11,000m^3 between 2005 and 2008. This abrupt drop in production was due primarily to the temporary departure of the largest sawn timber exporter based in Santo. Their departure then was due in part, to the exhaustion of commercial timber volumes in accessible areas and the associated high costs of harvesting timber in isolated areas. Importantly DoF reported that between 1990 and 2004, whitewood comprised 60-70 % of all logs harvested, but in 2008, it accounted for only 20% of the 10,973 logs harvested. To sustain the current forest industry's contribution to the national economy significant expansion of the national plantation estate is likely to be required.

The South Pacific Regional Initiative on Forest Genetic Resources (SPRIG) was an AusAID funded initiative (1996 – 2006) aimed at *strengthening the capacity of the participating Departments and Regional Organisations to conserve, improve and better promote the wise use of priority genetic resources in order to promote sustainable rural development.* The two-phase project involved Australia (CSIRO forest research, Queensland forest research and URS Sustainable Development) and five Pacific island countries (Fiji, Tonga, Samoa, Solomon Islands and Vanuatu). The core project components were: institutional strengthening in the conservation and development of priority forest and tree genetic resources; conservation and sustainable management of priority species; tree improvement and demonstrating linkages between conservation, tree improvement and enhanced rural incomes. In Vanuatu, SPRIG initiated capacity building activities in a wide range of forest genetic resources -related activities including development of vegetative propagation protocols for two priority species, whitewood (*Endospermum medullosum*) and sandalwood (*Santalum austrocaledonicum*), seed collection and seed handling technologies and experimental design and analysis. In-situ and ex-situ conservation strategies were developed for whitewood and sandalwood. Extensive seed collections of these two species were undertaken and provenance/family trials established at IFP on Santo. The whitewood trials were highly successful and are the base-populations for the tree breeding activities under this project. The environment at IFP was unsuitable for sandalwood and this planting was unsuccessful.

Harvest of sandalwood from natural stands was the first export industry in Vanuatu, commencing in the 1820s, and continues to be the major source of export revenue for many islands, although substantial depletion of natural stands has occurred. About 95% of the global supply of Indian sandalwood is currently sourced from India, but it has been predicted that existing Indian stands may be exhausted by 2020. With rising demand for sandalwood products in South-east Asia, there is an opportunity for plantation-based production.

This opportunity has been recognized by Australian investment companies, who have now established over 11000 ha of Indian sandalwood in Western Australia. Assuming expectations for this resource are met over the next 15 years, Indian sandalwood plantations in Australia could supply about 2400 tonnes of air-dry heartwood to the international market (currently totalling 6000 tonnes). A market shortfall due to depletion in India seems to offer considerable opportunity for other competitive suppliers. Significant potential exists for marketing Vanuatu sandalwood as a premium product based on the i) high quality of the oil produced from *S. austrocaledonicum*, ii) largely organic and natural production methods of smallholder growers, and iii) combined advantages of consumer values for designation-of-origin and fair-trade in some niche high-end market segments.

In Queensland, sandalwood (*S. lanceolatum*) has long been commercially exploited for its powdered heartwood and in Cape York harvesting occurred between after 1900 and the early 1930's. Many of the European sandalwood-getters relied heavily on the local knowledge and labour of Aboriginal people in each area to find and harvest the trees (Wharton 2005). While little commercial harvesting continues on Cape York today because of the scattered resource, indigenous communities may benefit from re-establishing the sandalwood resource to support local enterprise. The lower quality of *S. lanceolatum* oil compared with other commercial sandalwood species such as *S. album*, *S. yasi* and *S. austrocaledonicum* has limited the commercialisation of this species as cultivated sandalwood. However with the work of previous ACIAR project (FST/2002/097) and the identification of high quality *S. lanceolatum* in Cape York (Page *et al.* 2007) there is opportunity to develop this resource for commercial agroforestry plantings. Market potential exists for sandalwood produced in Aboriginal communities for similar reasons as Vanuatu sandalwood.

What was the project justification?

Access to improved genetic material is essential to any forest plantation program and was the basis of the research and development priorities for this project. The germplasm resources developed in previous projects (sandalwood FST/2002/097 and whitewood AusAID's SPRIG) were upgraded (whitewood at IFP converted to a seedling seed orchard (SSO); sandalwood gene conservation stand expanded to include northern island populations) and used to establish progeny stands and demonstration plots of whitewood and clonal seed orchards (CSO) of sandalwood. These existing and newly established assets are central to increasing the availability of improved seed for new plantations over the immediate-term, as well as providing sufficient genetic diversity to deliver improved material over the medium term. This combination of both short- and medium-term components to the project is already leading to significant local impacts.

The development of this project evolved from informal discussions and recommendations developed during previous ACIAR projects (FST/2002/057; FST/2006/118, FST/2007/057) and formal consultations between partner country and Australian project participants. The work conducted as part of FST/2007/057 highlighted significant livelihood opportunities from smallholder-established sandalwood agroforests with good internal rate of return (24%) and net present value (13.5 times that of market gardens) from a typical 1ha block

(Page, 2012). With the establishment of systems for germplasm deployment and subsequent provision of planting material across many islands, this project contributes directly to Vanuatu's plantation resource goal (National Forest Policy 1997). The policy sought to promote the establishment of at least 20,000 ha of commercial plantations between 1997 and 2022. With population pressures beginning to increase in many islands of Vanuatu there is also a need for integrating commercially significant tree crops within fallow, boundary and/or community land. The use of high-value, relatively short rotation indigenous forest trees such as sandalwood and whitewood can provide stability to family income and provide a buffer during periods of economic hardship.

This project specifically addressed an objective of the DoF Sandalwood Policy (2002) relating to the promotion and provision of superior sandalwood selections. Furthermore, the plantation approach for securing future sandalwood and whitewood supplies can potentially increase the total value of the industry since it has a number of advantages over the current wild-harvest industry.

- Integration of tree production within existing agricultural systems with only minimal additional costs.
- Reduce the incidence of resource disputes, since ownership of planted trees is rarely challenged.
- The planting of trees across a wider geographical area than the natural stands will facilitate improved distribution of economic impacts for smallholders across the country.
- Both whitewood and sandalwood have desirable qualities including
    - Production of high-value products within 15-20 years.
    - Have high degrees of cyclone resilience.
    - Have a combined natural occurrence across the Vanuatu archipelago, with complementary site requirements.
    - Strong market demand for their products
    - Strong seedling demand from farmers.

In Cape York there are often limited options for commercial development, but forestry provides one of the few promising opportunities. The potential to incorporate sandalwood within existing indigenous land management and further extend this into commercial plantings allows the opportunity to utilise an endemic tree species for economic development. While returns for these forestry trees are expected in the medium-term, management requirements are relatively minimal after the establishment years. Even during establishment, activities peak at certain periods, which allow other cultural, community and commercial activities to coexist with the enterprise. The substantial returns offered for sandalwood makes it potentially attractive for both community and investment forestry. Interest in establishing sandalwood plantations in north Queensland is increasing with the establishment of new investment plantations at the southern end of Cape York Peninsula. Previous ACIAR project work has identified populations of the local *S. lanceolatum* that will meet the international standard for sandalwood oil. This project has secured identified superior germplasm that will form the basis of ongoing improvement in the species. Continuing this improvement program can potentially provide the opportunity for indigenous involvement in and potential ownership of a north Queensland plantation industry.

4 Objectives

The primary aim of the project was to provide genetic underpinning for the emerging sandalwood and whitewood plantation industries in Vanuatu, and to provide a genetic base for future sandalwood plantings in northern Queensland. Achieving this aim involved three broad objectives with respective activities (Figure 1) and sub-activities. The intent underlying each of these objectives was to improve the capacity of Department researchers to implement a multifaceted domestication programme and community producers in Vanuatu and Cape York Peninsula (CYP) to establish and maintain plantings. While a specific capacity building activity exists for Objective 3, co-ordination and evaluation activities were intrinsic to the structure and implementation of all objectives in the project.

This project addressed the fundamental constraints related to the availability of and access to improved tree germplasm (seed and clonal materials). The overall aim of this project was to deploy an improved genetic resource to underpin the emerging sandalwood and whitewood plantation industries in Vanuatu, and to provide the genetic base for future sandalwood plantings in northern Queensland.

Project objectives:

- Advance the whitewood genetic improvement program in Vanuatu.
- Advance the Vanuatu sandalwood genetic improvement program.
- Establish the basic elements of a sandalwood genetic improvement program in northern Queensland.

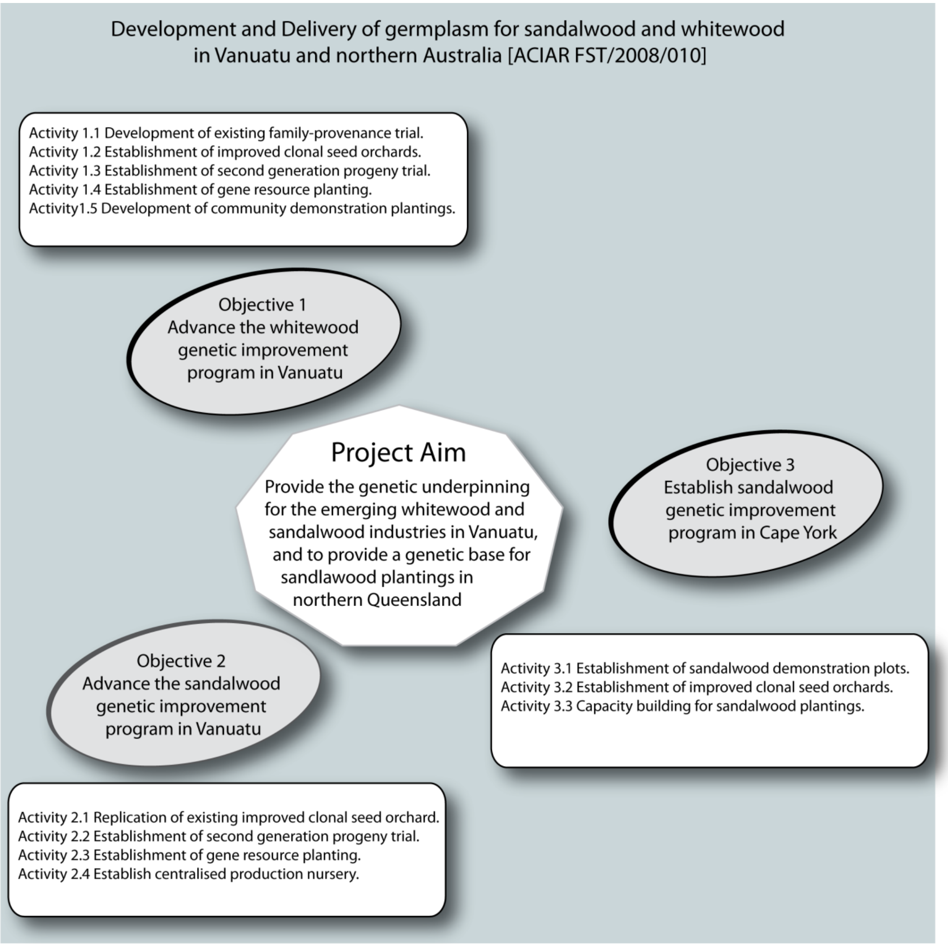

Figure 1: Project objective and activities that relate to the overall project aim.

5 Methodology

Project methodology:

The project encompassed a range of activities to improve the genetic resources of each species which includes the (a) advancement of seed orchard programs, (b) creation of advanced progeny trials, (c) establishment of gene resource populations, and (d) development of demonstration plots to guide current and prospective growers in key regions. The project was implemented with a broad action research-based approach involving participatory and iterative approach to problem solving and addressing research questions. This approach often required review and adaptation of methods based on operational experience, capacity of partners and the outcomes of initial activities.

This project aimed to address the following key issues:

Germplasm Development

To ensure the ongoing development and improvement of whitewood and sandalwood in Vanuatu the establishment of the following germplasm resources were established:

- Genetic resource planting to enable the conservation and use of existing natural variation for ongoing selection
- Second generation progeny trial to generate new genetic variation from individuals already selected for superior traits.

Given the larger size and greater complexity in establishing, maintaining and monitoring these trials relative to the seed orchards, a more centralised approach was adopted for its implementation.

The establishment of a second-generation progeny and a gene resource planting for both sandalwood and whitewood in Vanuatu was considered to provide the basis for the next phase of domestication. While such developments would be important in the development of *S. lanceolatum* in Cape York Peninsula, this project represented the first phase in implementation of a domestication programme. The establishment of demonstration plantings in Cape York Peninsula was considered of greater importance towards the purpose of generating interest and capacity building in the communities, rather than establishing complex breeding and conservation plantings.

The whitewood and sandalwood objectives in Vanuatu were administered and managed from Santo and Efate respectively. Structuring of the project in this way took advantage of the physical location of existing genetic resources for the respective species. Through the location of genetic resources at multiple locations, we sought to limit the risk to the domestication strategy associated with natural disasters, most notably cyclones. This strategy was justified with a severe tropical cyclone (Pam) affecting much of central and southern Vanuatu in March 2015. At this time the sandalwood genetic resources had been successfully replicated across the country and so while resources in Pentecost and Efate were affected, it was not an issue for the progression of domestication.

Germplasm Deployment

The deployment of improved germplasm was a feature all three objectives through the establishment of seed orchards. The deployment strategy for improved germplasm within this project took a decentralised approach, with individual seed orchards (clonal for sandalwood and seedling for whitewood) established on islands where bioclimatic and socio-economic factors are appropriate for plantation production. In Cape York Peninsula a clonal seed orchard was established in one of the two focal communities that were endowed with very high quality sandalwood.

While the deployment strategy was decentralised, the scaling-up of cloned individuals and seedlings to implement the activity occurred in centralised nurseries in Santo (whitewood), Efate (Vanuatu sandalwood) and Mareeba/Gympie (CYP sandalwood). This approach was taken to maximise propagation success given the close access to the selected plant material and the limited resources of the project and partners.

For sandalwood, the activities associated with replicating the seed orchards (promoting vegetative growth for producing high quality scions) limited the reproduction (flowering and fruiting) of the source selections and delayed the opportunity for undertaking the controlled crosses necessary for establishing the second-generation progeny trial. This activity was therefore scheduled in the later stages of the project.

Objective 1: Advance the whitewood genetic improvement program in Vanuatu

1.1 Further development of the existing family-provenance trial

Location: Two whitewood family-provenance trials on the Industrial Forestry Plantations (IFP) site near Shark Bay on the east coast of Espiritu Santo were established as part of the SPRIG project in 1998-99. **Design and condition in 2010:** The two trials (major and minor) covered a contiguous 7.3 ha and contained a total of 110 open-pollinated families from 6 islands. They were planted as 6-tree family line plots to latinised row-column designs. The major trial had been thinned twice with 1 and 2 trees remaining in each line plot for reps 6-8 and 1-5 respectively. No formal thinning regime was implemented for the minor trial (six replicates) but it had undergone substantial self-thinning between 1999 and 2010.

Method: A major growth assessment of the IFP trials was undertaken in mid-2010 when the trees were 11.4 years-of-age (c. half rotation age)(Doran et al. 2012). A combined statistical analysis of data demonstrated considerable island- and family-level variation in diameter (DBHOB) and form (straightness and branching habit). Trees with the fastest growth and best form were from Espiritu Santo provenances whilst the poorest performers were from Maewo and Forari on Efate. Growth and form trait heritability estimates were low to moderate, with moderate phenotypic variation indicating that a recurrent selection and breeding program should result in genetic gain. Another interesting observation was that DBHOBs at 11.4-years were very closely genetically correlated (r_A = 1.00 ±0.17) with measures at 4 years-of-age (Vutilolo *et al*. 2008) indicating the potential of early selection for diameter/volume growth in seedling seed orchards (SSOs).

A simple selection index, determined by summing the individual tree rankings for DBHOB and form traits at 11.4-years in these trials, was used to thin the trials to convert them to one large (7 ha) contiguous seedling seed orchard and assist in the selection of plus trees. Plots containing more than one tree were reduced to the best individual according to the index. The poorest performing families (18 families or 16% of the 110 families present in the two trials) were largely removed from the trials with only exceptional phenotypes retained. Amongst the 60 best performing families, superior individual trees (candidate plus trees) were marked for seed collection. Selection of plus trees also needed to cater for seeding periodicity amongst the females and the dioecious character of the species, as many of the selected trees were non seed-bearing males. This required the marking of four to seven top ranked trees within each family, from a maximum of 8 to 14 trees per family available after earlier thinning.

Whitewood is a light hardwood with an air-dried density of 365 – 450 kg/m^3 (Keating and Bolza 1982; Thomson 2006). An opportunity was taken in assessing the IFP trials to quantify genetic variation in wood density in this species and examine the potential for increasing density through selection and breeding**.** Doran et al. (2012) provided results of a preliminary study of density variation in one population. Variation between trees in estimated whole tree basic density was substantial ranging from 290 to 334 kg/m^3 and breast height was found to be the optimum sampling position to represent whole-tree density. This study was followed by two larger trials. Firstly a non-destructive acoustic method for indirectly estimating wood density was conducted. Ultrasound measurements were performed using a TICO Ultrasonic Testing Instrument, which is usually used to assess concrete (European Standard EN12504-4:2004, former BS 1881 Part 203, ASTM C 59). . In total, eight trees in each of 10 different families originally sourced from Kole and Pentecost. (Settle et al. 2012) were measured at a height of 1.3 m ($H_{1.3}$) over the course of 10 days. In 2011, when the trees were 12.4 years old, bark-to-pith cores at breast height were sampled from 10 families in each of two provenances (Kole from east-coast Espiritu Santo and Central Pentecost). The full results of this study are given in Settle et al. (2012). The key findings were moderate levels of phenotypic variation and narrow-sense heritabilities for this trait in the families and provenances studied indicating a potential to improve density through selection and breeding.

Participants: Field work was carried out by John Doran, Mesek Sethy, other DoF staff and trainees, David Lea, Mireia Torello Raventos, Damian Settle and Tony Page. Statistical analysis and manuscript preparation was carried out by John Doran, David Bush, Tony Page, Kevin Glencross, Mesek Sethy, Ioan Viji and Damian Settle.

1.2 Propagation of selections from the family-provenance trial into clonal seed orchards (CSOs)

Background: Establishment of a clonal, all-female seed orchard using the best trees at IFP was an aim of the original project proposal to maximise genetic gain. As this species is dioecious, the mature trees in IFP SSO1 allowed reliable selection of seed bearing female trees (as opposed to male trees). The trial at 11.4 years-of-age, or half rotation age, also allowed reliable selection of superior phenotypes for inclusion in the all-female orchard.

The trees at IFP were considered too mature to reliably produce coppice growth for cuttings and too large for safely establishing marcots in the canopy. Therefore the following approaches were evaluated during the project to determine their potential for generating clones of sexually mature whitewood selections. The experiments were conducted at the Department of Forestry (DoF) nurseries in Santo (all experiments) and Port Vila (budding only).

Grafting: The grafting techniques used in this trial under the supervision of David Lea include approach, top cleft and bud grafting. Scions were collected by 'Big Shot' from a total of 8 plus trees comprising 6 females and 2 males) in the IFP provenance/family trials. Grafts (2 approach grafts, 1 cleft graft and 7 bud grafts were undertaken on each of the 8 plus trees sampled) were then made on 1 m + tall stock plants that had been on-grown in Luganville Forestry nursery. Emphasis was placed on the bud grafts as these seemed intuitively to have the greatest chance of success. However, of the 56 bud grafts made only one survived and grew. Bud grafting training was provided to the Port Vila nursery staff in February 2013, where techniques to improve bud grafting success were presented by David Spencer. Subsequent attempts at bud grafting in Luganville under the supervision of David Dore also proved unsuccessful.

Grafting as a practical technique for vegetatively propagating mature whitewood at IFP was abandoned following the results of these trials.

Cincturing: A few of the trees that had been felled during orchard thinning in October 2010 produced basal coppice shoots. This unexpected outcome indicated that some 11 to 12–year–old whitewood trees are capable of providing basal coppice shoots that might then be collected as stem cuttings for clonal propagation. It was decided, therefore, to test a non-destructive coppice promotion technique developed for mango and being applied successfully to *Corymbia* hybrids in Queensland on whitewood at IFP. Five whitewood trees in the buffers at IFP were selected for test in November 2011. The technique is described in detail by Kelly (2009). It leaves a substantial squared scarf on the northern side of treated trees about 30 cm above the ground and to a depth of about one third of tree diameter. A plate is placed vertically below the bottom cut to prevent rapid healing of the wound. Only three of the treated trees presented with a few weak coppice shoots at least a year after treatment. This technique was deemed to be unsuccessful as a practical means of promoting vigorous coppice on mature whitewood trees.

Root Cuttings: Using the five buffer trees for the cincturing experiment at IFP, root severing and root cutting experiments were conducted. Adventitious roots that were observed in the 3 root severs and the root tips and that may have been of use for micropropagation had all died by October 2012. These techniques were also deemed to be unsuccessful as a practical means of promoting vigorous coppice on mature whitewood trees.

Revised clonal strategy: Success in propagating cuttings from coppice from stumps of 3-year-old trees using mist houses was well demonstrated by Walker & Haines 1995-96 and SPRIG-2 project 1996-2000. A return to this methodology utilising early selections in the Bombua 2nd gen progeny trial was undertaken. In 2013-14 propagation of cuttings from spontaneous and induced coppice at Bombua in a Non-mist Propagation Box (NMPB) built by the project in Luganville forestry nursery was tested but met with limited success (Dore et al. 2015). In 2014 a mist house was established in the nursery by the project and trials (containers, media, rooting hormones etc.) undertaken to re-establish the methodology. These trials were successful. In Feb 2015 when Bombua 2nd gen progeny trial was 3.25 years old, the best three trees of the best 12 families were coppiced for production of stem cuttings for rooting in the new misting facilities. They will be planted in clonal hedges once rooted and will be a future source of material for clonal orchards and plantations.

In an effort to collate and make accessible information on vegetative propagation of whitewood gathered over the last 20 years, Dore et al. (2015) prepared a report for DoF titled '**Synthesis of knowledge of vegetative propagation of whitewood, *Endospermum medullosum*'.**

Participants: Key personnel involved include Dave Lea (the SPC/FACT expert who assisted with the grafting), Mesek Sethy (project staff), David Spencer (trainer), Sero Isaiah (DoF staff member), Jean Marc (the Department of Agriculture's citrus budding technician in Port Vila), Tony Page and David Dore.

1.3 Controlled pollinations among selections and establishment of a second generation progeny trial

Background: Given the difficulty in vegetative propagation of sexually mature trees (see 1.2) and the lack of knowledge of controlled pollination methods in this species, it was decided to concentrate efforts on establishing seedling seed orchards rather than an all-female clonal seed orchard requiring controlled pollinations. Clonal orchards will be adopted later once the appropriate vegetative propagation techniques have been researched. The project initiated a preliminary study of floral biology of whitewood (see below) as a pre-requisite to developing controlled pollination techniques in the future.

Accordingly, the project has established three second generation progeny trials/seedling seed orchards, two on Santo (Bombua and Navota Farm) and one on Efate (Onesua). Seedlots used in these progeny trials were collected from the best available plus trees at IFP. Two separate collections were utilised: April 2011and February 2014 of three undertaken (February 2013). The seed crop collected in February 2013 failed to germinate sufficiently due to persistent rains during germination resulting in waterlogged germination media. Seed crops failed at IFP during 2012 due to persistent rains during flowering events presumably upsetting pollination.

1.3.1 Bombua trial site: genetic material and experimental design:

This second-generation whitewood progeny trial was planted in November 2011 at Bombua (latitude 15° 30.946' S, longitude 167° 14.987' E, elevation 40 m asl) near Luganville, the capital of Espiritu Santo Island. Existing vegetation on the site was mixed species secondary forest that was only partially removed before planting. Tree poisoning following planting reduced the overstorey further but this was curtailed because of damage to whitewood trees from falling limbs and whole trees. Therefore, some overstorey trees remain to compete with trial trees but fortunately the statistical integrity of growth data from the trial has not been compromised. The progeny trial comprises of 47 seedlots (treatments) or a total of 44 unrelated families. It was established to a latinised row/column design with six replications of 4-tree line plots. Spacing was 6 m between rows and 2 m between trees within rows. The 1.4 ha trial comprises 1,080 trees and is surrounded by buffer plantings.

1.3.2 Onesua trial site: genetic material and experimental design:

This second-generation whitewood progeny trial was planted in January 2012 at Onesua (latitude 17° 33.978' S, longitude 188° 26.905' E, elevation 110 m asl) in north-eastern Efate Island. The site was a mostly cleared paddock covered in guinea grass. It was planted after removal of some residual trees and deep ripping in two directions.

The progeny trial comprises of progeny of 25 seedlots (families) that were excess to the trial planting at Bombua. They were shipped from Luganville to Port Vila in early January 2012 followed by sorting in Tagabe forestry nursery and planting during 16-20 January 2012. It was established to a latinised row/column design with four replications of 4-tree line plots. Spacing was 6 m between rows and 4 m between trees within rows. A row of sacrificial whitewood seedlings was planted between the trial rows giving an initial spacing of 3 x 4 m, as recommended by the silviculture project (FST/2012/042). The 1.02 ha trial comprises 384 trees and is surrounded by buffer plantings.

The Onesua trial was directly impacted by Cyclone Pam in March 2015, with reported wind speeds in excess of 250 km/h.

1.3.3 Navota Farm trial site: genetic material and experimental design: This second generation whitewood progeny trial was planted in October 2014 at Navota Farm (latitude 15° 34.649' S, longitude 167° 00.375' E, elevation 50 m asl) west of Luganville on the south coast of Santo. The site was a mostly cleared paddock covered in wild geranium, needle grass and wild peanut. It was planted after removal of residual trees and spraying of the weed species with round up.

The progeny trial comprises of 66 seedlots (treatments) or a total of 56 unrelated families. It was established to a latinised row/column design with six replications of 4-tree line plots. Spacing was 4 m between rows and 2 m between trees within rows. The 1.2 ha trial comprises 1,296 trees and is surrounded by buffer plantings.

During the course of the project, various trials were undertaken by volunteer, David Dore, in collaboration with local staff, to better equip DoF for future tree breeding activities. Reports of this work include, 'Phenology of Whitewood Flower & Seed Development', 'Seed Preservation Experiment' and 'Stages in Development of Flowers and Seeds of Whitewood'.

Participants: Establishment of SSOs was carried out largely by Mesek Sethy, Rinnath Miltek, Olister Tarago, James Toa, David Silas, Mackense Naupa, Kipson Lokai, Roy Willie, John Doran and Tony Page. David Dore, assisted by Kipson Lokai and Roy Willie, undertook a range of trials to better understand whitewood flowering and seeding.

1.4 Establishment of a gene resource population

Background: The aim was to establish new gene resource plantings on Santo during the course of the project. This project component is extremely important to the breeding program to conserve genetic resources and provide new genotypes for infusion into third generation seed orchards. Populations from six islands were sampled and included in the IFP trials in 1998-99 (Doran et al. 2012). Collecting seed from islands not previously sampled became a priority for this project and included Ambrym, Banks Group, Epi, Erromango, Malo and Shepherd Is. For Islands that had been sampled previously (e.g. Malekula) every effort was to be made to collect seed from alternative populations.

Locations: Suitable sites for gene conservation plantings were identified at the Vanuatu Agricultural Research and Training Centre (VARTC) near Luganville.

Methods: From seed collection undertaken by DoF in early 2013, 80 Banks trees were planted in October 2013 at VARTC at 4 x 3 m spacing. In December 2013 this area was extended by the planting of 40 Malo trees. Further seed collections were made in January and February 2014 from South West Bay on Malekula Island and Malo, and again in April 2014 from Cooks Bay on Erromango Island.

Participants: Mesek Sethy, James Toa, David Silas, Kipson Lokai, Roy Willie, David Dore, David Lea and Tony Page.

1.5 Development of community-based, whitewood demonstration plots.

Background: While the export market opportunities for whitewood are strong, making it a viable commercial tree crop for smallholders in Vanuatu, many are unaware of this potential. The establishment of demonstration plots of genetically improved whitewood can serve as promotion and extension resources over the long term.

Locations: Demonstration plots have been established on Ambae, Ambrym, Epi, Malekula (Mapbest, Cornerpoint and Pinalum) and Pentecost in co-operation with local smallholders, in locally prominent and publicly accessible sites.

Methods: Seedlings from the maternal families represented at IFP that belong to various islands were propagated for use as demonstration plantings in those locations where possible. There were reasonable numbers of seedlings to be able to establish 'paired plots' on four sites, matching them with seedlings of trees with Santo origins in the IFP SSO ('Santo Bulk') for a comparison of growth. Details of the seedlings raised in Luganville forestry nursery for these trials are summarised in Table 1.

Table 1: The numbers of seedlings representing island-of-provenance collected from IFP and used for establishing demonstration plots throughout Vanuatu.

Maternal origin	Count 19/5/2014
Santo Bulk	585
Maewo Bulk	90
Ambae Bulk	330
Pentecost Bulk	390
Malekula (NE) Bulk	330
Malekula (SouthWest Bay) Bulk	31

Participants: Hanington Tate, Michael Tabi, Mesek Sethy, DoF island staff, and Tony Page

Objective 2: Advance the Vanuatu sandalwood genetic improvement programme.

2.1 Replication of the existing clonal seed orchard on other islands

Location: A total of seven CSOs have been established in the northern islands of Vanuatu. These include the following island locations

- Ambae (St Patricks College December 2013)
- Santo (VARTC February 2014)
- Pentecost (Whitewater March 2014)
- Malekula (Corner Point March 2014)
- Efate (Onesua, March 2014)
- Epi (Epi High School August 2014)
- Ambrym (Lalinda July 2014)

Methods: Sandalwood has a high propensity for cloning by grafting, provided both the rootstocks and scions have a high degree of health and vegetative vigour. Management of the scion stockplant garden was required to promote vegetative growth at the same time as when the rootstock seedlings are mature and vigorous. Greatest success was achieved using semi-hardwood scions from stems that were still actively growing. To ensure an almost perfect matching of the scion and rootstock cambiums, the scion stem needed to be assessed visually as being slightly larger in diameter than the rootstock stem. Rootstock needs to be cut at the selected graft point and all but two of the branches removed. Rootstock branches were retained to ensure maintenance of photosynthesis and sap flow. Scions were prepared ensuring that two whorls of buds would remain after the wedge of the scion was cut. All remaining leaves were removed by cutting, with care not to injure auxiliary buds. Highest success was achieved using a top wedge graft as described in Tate et al. (2006). Scions were prevented from drying out by applying petroleum jelly to cut surfaces and covering with a small clear plastic bag (75mm x 120mm). Grafted plants were placed under 75% shade and watered daily. The plastic bags were removed once the scion had developed two leaves on at least one bud. Once the bud had sufficiently hardened the plants were then transferred to 50% shade for a period of 2-3 weeks and then to full sun before being transported and established in the field. Each GSO comprised 18 plus tree clones replicated twice. Generally, each orchard consisted of 2 plus tree clones originating from each of Aniwa, Moso and Tanna and 3 plus tree clones originating from each of Aneityum, Erromango, Malekula and Santo. The GSOs are planted at a 5x5m grid and interplanted with intermediate host *Cajanus cajans* (36 individuals) and long-term hosts *Citrus* sp. (30 individuals) and *Acacia spirorbis* (7 individuals).

Results: Six month survival was determined for the following orchards at approximately six months: Onesua (100%), Malekula (98%) and Santo (75%). Under good management the seed orchards are very precocious and begin producing seed six months after planting. Survival of all CSOs following Cyclone Pam was determined in mid-2015 and the results are given below.

- Ambae (5%)
- Santo (55%)
- Pentecost (95%)
- Malekula (80%)
- Efate (98%)

- Epi (47%)
- Ambrym (78%)

Participants: Michael Tabi, Joseph Tungon, Samuel Bebe, Olister Tarago, Ray Kerry, Frank Joely, Taura Titus, Daniel Laeyang, Jobe Havo, David Spencer, Tony Page.

2.2 Controlled pollinations among selections and establishment of a progeny trial

Background: The aim of this activity was to undertake controlled pollinations among the grafted plus trees in the Tagabe GSO. This GSO was established within the DoF nursery compound primarily for reasons of security and proximity. The orchard was established at a spacing of 3 x 4m and *Glyricidia sepium* planted as the primary host. Initially growth and reproduction in the orchard was good, but this declined during the course of the project. Generally the GSO demonstrated a low level of flowering and seed production during critical phases of the controlled pollination work. The exact nature of the poor seed productivity has not been identified, but it is likely that it was influenced by the close spacing of sandalwood and the low numbers of mature woody hosts. Given that the GSO has remained secure during its replication (see 2.1) is testament to the appropriateness of the site. The project utilised other project resources as the source of seed for the progeny trial, including the Onesua replicate GSO and the Navota gene conservation stand.

Methods: Several clones within the grafted seed orchard established at Onesua were highly productive in seed from months 4-12 after establishment. A total of 280 seedlings from 10 clones have been produced in the Tagabe nursery and will be planted as a replicated progeny trial in 2016.

Trees at the Navota gene conservation stand for seed collection were prioritised as follows:

* Productive in both diameter and seed

* Productive in seed

This changed the nature of the progeny trial represents a first generation stand and comes with the benefit that it will further broaden the genetic base of the breeding population. This in turn will allow for later selections based on overall tree vigour, which was not a selection criterion for the sandalwood GSO. While this change was borne out of necessity (i.e. lack of seed in Tagabe GSO), it is considered that this compromise is preferential to the possibility of not establishing a novel breeding resource at all. The progeny trial will be established in 2016 at La Bouffa in Efate, a site owned and managed by the Vanuatu National Provident Fund.

Participants: Mesek Sethy, Michael Tabi, Joseph Tungon, Tony Page, John Doran.

2.3 Establishment of a gene resource population.

Location: The gene resource planting was established at Navota Farm (South Santo) because DoF had successfully established sandalwood plantings in cooperation with the Church landowners.

Methods: Seed were sourced from bulk collections made from the islands of Aneityum, Aniwa, Erromango, Futuna and Tanna under the previous SPRIG project and established at the commencement of this project in 2010. Seed from the Malekula and Santo populations were supplied by farmers that participated in the grower workshops (task 2.4). The latter approach was undertaken to increase the numbers of seed available, as it was difficult to source seeds during brief visits.

The supply of seeds from two populations in west coast Santo (Hokua, Penouru/Petawat) was secured in 2010. Seedlings from seed sourced from west Malekula (Tisvel) were also secured by DoF in Malekula, which were successfully established on the site in May 2012. Interestingly, DoF have only one contact with two productive seed trees in north Efate. This is indicative of the current, critically endangered state of the resource and the need for this gene conservation stand. Seedlings from Efate were not successfully established in the gene conservation during the period of the project.

It was recommended that the site be enriched with the long-term host *Acacia spirorbis* (namariu) in the many blank spaces that have been left by some of the dead sandalwood. Growth and vigour of some of the older trees at the sandalwood gene conservation planting at Navota has been declining with many of the trees remaining stressed. Despite the apparent stress, the trees are very productive in seeds, which is a primary source for local landowners who collect very regularly. A planting design for host enrichment has been produced and it was highly recommended throughout the implementation of the project, that the site be ‘renovated’ with spot weeding, pruning of dead branches and fertilizing all trees (200g NPKS per tree).

Participants Joseph Tungon, Taura Titus, Mesek Sethy, Michael Tabi, Presley Dovo, Russell Lovo, Tony Page.

2.4 Build capacity for and facilitate scaling-up germplasm delivery systems for whitewood and sandalwood

Location: At the inception meeting in April 2010 held in Port Vila, it was agreed among all DoF participants that a preference for general upgrading of all DoF forestry nurseries would be preferable to construction of a single greenhouse at Tagabe in Efate.

Methods: The Luganville nursery was upgraded with construction of germination boxes, standout beds and installation of a solar operated misting propagation system. The Tagabe nursery was upgraded with a 2m high chainmesh security fence and installation of a shade house facility to accommodate the sandalwood grafted clones. The nursery at Malekula was improved with a shade cloth installed across half of the standout beds. A seed storage facility was constructed within the Forestry Office block in Tagabe. The facility comprises a 3x3x3m cool room with a backup generator, which became operational in May 2011.

Training and extension activities were carried out in 2011, with a particular focus on the northern islands of Santo and Malekula. The workshops facilitated the establishment of a sandalwood growers association in Santo, which have been very proactive in establishing woodlots derived from Santo origin seed. Several individual producers are now supplying seed throughout the country and have been important suppliers for the establishment of the gene resource planting (see 2.3). The workshops had practical components that were recorded for contribution of an extension DVD that has been distributed widely to growers across the country with very positive feedback. The DVD has been copied and sold by local merchants.

Participants: Hanington Tate, Michael Tabi, Mesek Sethy, Joseph Tungon, Tony Page

Objective 3: Establish the basic elements of a sandalwood genetic improvement programme in northern Queensland

3.1 Establishment of sandalwood agroforestry demonstration plots in two communities in Cape York

Location: The Bamaga demonstration plot was planted on 26 July 2012 on a small (0.5 ha) plot at the Bamaga Community Farm and consisted of three *Santalum lanceolatum* provenances and one source each of *Santalum album* and *Santalum austrocaledonicum.*

The Lockhart River site was planted on 5 December 2012 on the Lockhart River Community Farm. The site had been prepared in mid-July by the farm manager; however some additional site preparation was done by John Huth and David Lee immediately prior to planting. The demonstration planting was set out on a small (0.1 ha) plot and consisted of three *S. lanceolatum* provenances along with one source of *S. album*.

Methods: As no commercially grown seed was available, the seed of *S. lanceolatum* was collected from natural stands or harvested from seed orchards. The seed of three provenances of *S. lanceolatum* was sourced from Hughenden, Cooktown Golf Club and Archer Point.

The sandalwood seedlings were raised in the Mareeba nursery by DAF staff. The *Acacia simsii* and *Pongamia pinnata* host plants were purchased from the Yuruga Nursery at Walkamin and the *Casuarina cunninghamiana* were grown in the Landcare nursery at Gympie.

Participants: David Lee (USC & DAF), John Huth and Mr Nick Kelly (both DAF) and Tony Page (JCU).

3.2 Establishment of two clonal seed orchards of selected sandalwood in Lockhart River and Injinoo.

Location: The gaining of Traditional Owner (TO) approval at Lockhart River has proved to be very difficult which delayed activities at this site. Traditional Owner consent was given to JCU in 2013 for the site at Injinoo. A Material Transfer Agreement (MTA) between JCU and the TO was signed.

Methods: Rootstocks for establishment of the CSO in Bamaga were initially raised in at the Walkamin Research Station. During the first two cycles of grafting, the only root stock available was large 12+ month old *S. album* seedlings. All scion material collected during the April and July 2013 trips were grafted onto this *S. album* root stock. The scion material collected during the April and July 2013 collection trips to Bamaga was all of poor quality being stunted and having a lot of visible insect damage along the stem. This may have be due to the poor wet season in both Bamaga and Lockhart River resulting in poor tree health with new flushes of vegetative growth.

Subsequent rootstock was raised at DAF Gympie from seed collected from 10+ *S. album* and two *S. lanceolatum* trees at the Walkamin Research Station (June 2013). The seed was sown after being treated with gibberellic acid (2g active ingredient/1 L water) for 24 hours and transferred to 10cm pots in early August 2013. From the above sowing the 29 *S. lanceolatum* and 249 *S. album* rootstocks suitable for grafting were grown. The seedlings take six months to reach a size where they are useful for grafting. Seed is sown on a regular basis to ensure a regular supply of suitable grafting rootstock.

A total of six cycles of grafting undertaken using the seed raised at DAF Gympie, with time of year, semi-lignified and lignified scion material and species of rootstock (*S. album*, *S. leptocladum* and *S. lanceolatum*) assessed for their impact on grafting success. Also, serial grafting from trees already captured was undertaken to bulk up the number of trees available for the grafted clonal seed orchards of this species.

Based on this study, collection of semi-lignified scion material collected in middle wet season was the most successful time to attempt grafting, along with use of *S. lanceolatum* rootstock. Collection of scion material in the middle of the wet season has limited the number of trees we have been able to access due to localised flooding. The other limiting factor for this work has been the access to suitable rootstock. We have collected only 9 seed from the wild in the Northern Peninsula Area (NPA) and this has produced only one usable seedling. Other sandalwood seed we've accessed also has low viability and takes up to six months to reach a stage where they can be used as rootstock. Once a graft union is formed we have not detected any incompatibility problems between *S. lanceolatum* scions with each of the three species used as rootstock (*S. album*, *S. lanceolatum* and *S. leptocladum*). Given this we have been very successful capturing 17 *S. lanceolatum* trees from the NPA and had enough grafts to establish two clonal seed orchards: one in the NPA (planted April 2015) and at Walkamin Research Station (planted October 2014).

Table 2: *S. lanceolatum* genotypes (tree number) that were successfully grafted during the April and July 2014 grafting activities.

Tree Number	Number Successfully Grafted
1*	8
5*	9
8*	6
9*	4
11*	4
12#	5
13	2
14	3
22	1
25*	1
28*	7
29*	9
32a	5
34	5
40b	8
47	1

* indicates the high oil content trees

# indicates moderate oil content trees

Participants: David Lee, John Huth, Tony Burridge and John Oostenbrink representative from the various Aboriginal Corporations (including Eric Cottis - Chairman of the Gudang/Yadhaykenu/Amung Aboriginal Corporation and Reg Williams - Chairman of Adupthama Lands Trust).

3.3 Community capacity building to establish and manage modest-scale sandalwood plantings

Location: Successful capacity building and awareness workshops have been held in both Lockhart River and Bamaga. A workshop was help at the Bamaga Farm (Northern Peninsula Area Regional Council) in the 25th July 2012, attended by 13 community members, including Uncle Shorty a traditional owner based at Injinoo. A workshop at Lockhart River was held on 28th November 2012. Local employment agency Jobfind promoted the workshop widely in the community prior to the day. Unfortunately a local elder had passed away the night before and the day of the workshop was a designated sorry day and three people attended. Both workshops covered necessary background on sandalwood as a product and potential plantation species, and culminated in the establishment of a sandalwood demonstration planting at each community farm.

Methods: During consultations and workshops in Lockhart River and Bamaga we attempted to identify potential candidates to participate in the proposed study tour in Vanuatu. After a series of consultations with the Lockhart River community, no candidate could be identified to participate in the proposed study tour to Vanuatu. In the Northern Peninsula Area, as part of the capacity building activities undertaken in the community, we assessed all indigenous persons working at the Bamaga Farm. Unfortunately the indigenous farm overseer was not interested in sandalwood and the farm labourers (Remote Jobs Community Program employees) only assist when available; no participant has been involved on more than one occasion when we've undertaken work on the Demonstration Planting.

Project staff also consulted (face to face, formal letters, numerous emails and phone calls) with the Northern Peninsula Area Regional Council, Apudthama Land Trust, Traditional Owners, and MyPathways in an attempt to identify persons that may be interested in inspecting sandalwood plantings and talking to the communities in Vanuatu about sandalwood. Unfortunately we have not had anyone nominated or had anyone express any interest in going to Vanuatu or to contributing to the sandalwood work on anything but an ad-hoc basis. Currently we have no "community champion" engaged in the sandalwood work that could be nominated to visit Vanuatu to bring back capacity from overseas. We hope that planting of the sandalwood seed orchard at the Northern Peninsula Area College Senior School we may be able to identify some students that could be convinced to 'champion' the sandalwood work in the NPA and be willing to undertake a sandalwood study tour. This however will not occur during this project.

Participants: David Lee (USC & DAF), John Huth (DAF), Nick Kelly (DAF)

6 Achievements against activities and outputs/milestones

Objective 1: To advance the whitewood genetic improvement program in Vanuatu

no.	activity	outputs/ milestones	completion date	comments
1.1	Advanced selections of whitewood identified by quantitative evaluation of productivity measurement. Further development of the existing family-provenance trial	Accessible genetic resource Data that quantifies relative performance of family lines. Method for cloning reproductively mature selections. Identification of superior family lines for inclusion in the domestication strategy.	31.05.2010 30.04.2010 3.04.2011 30.09.2010	The IFP (Santo) was renovated (thinned, fenced and weeded) in 2010-12 to enable access. Best performing unrelated family lines were selected based on tree height, bole length and stem diameters. Several attempts at grafting mature selections proved unsuccessful. A new strategy of clonal propagation by stem cuttings from 3-year-old selections was adopted (see 1.3). Two scientific papers were published in 2012 that documented the results from the comparative statistical analyses of growth and wood density traits within and between families (refer to scientific impacts).

1.2	Propagation of selections from the family-provenance trial into Seedling Seed Orchards in Santo (x2), and Efate	• Genetic resources ready for 2nd gen seedling seed orchard establishment. • Sites ready for 2nd gen seedling seed orchard establishment • Superior 2nd gen seedling seed orchards established • Continued survival and growth to capture sites • Identification of superior trees in 2nd gen breeding population • Sequential enhancement of genetic quality of trees in SSOs	31.12.2010 31.10.2011 18.11.2011 18.11.2011 6.12.2012 13/02/2015	Seed collection from superior trees (based upon growth, form and branching) at IFP (Santo) and propagation were routinely carried-out when seed crops were available. Sites in Santo (x2) and Efate selected by DoF in consultation with local communities and prepared for planting. Three 2nd gen progeny trials/SSOs were established: Bombua (Santo) in Oct 2011 consisting of 1,160 trees of 47 seedlots; Onesua (Efate) in Jan 2012 consisting of 384 trees of 25 seedlots; and Navota Farm (Santo) in Oct 2014 consisting of 1,296 trees of 66 seedlots. Generally the first two trials were well maintained with some issues with overstorey & vines at Bombua, and guinea grass & nutrient deficiencies at Onesua. At Navota Farm mortality (60%) and damage due to cattle incursion has totally compromised the objectives of the planting. Replanting is advised if possible. Trials have been assessed for survival and growth annually. Data from the latest assessment of Bombua in Oct 2014 at 3 years- of- age demonstrated fast growth of many trees/families, with larger trees approaching 10 m in height. Bombua was reduced to half stocking in Feb 2015 based on growth and form when the trees were 3.25 years old. Thinning will take place at Onesua when the trees have reached an appropriate size for selection.

1.3	Establishment of an all-female grafted orchard in Santo, controlled pollinations and establishment of a trial of controlled crosses in Santo and Efate to determine GCA and SCA effects	• Seedling rootstocks • Grafts for clonal seed orchard • Establishment of superior clonal seed orchard comprised of only 'female' selections • Seed and seedlings produced of known pedigree • Second-generation progeny planting • Continued survival and growth to *capture* site	10.04.2011 n/a n/a n/a n/a	1 m + tall stock plants were on-grown during 2010-11 in Luganville Forestry nursery. Of the three grafting techniques (approach, top cleft & bud) tried on IFP selections in April 2011 only one bud graft took. Efforts to repeat this modest success with bud grafting during 2011-14 failed. Cincturing and root cuttings were also tried in Nov 2011 but also failed to produce plant materials for propagation. Plans to establish an all female clonal orchard with controlled pollination during the course of this project were put aside and efforts directed at establishing 2nd gen SSOs. A revised clonal strategy was adopted (refer 1.2 methodology). Comprehensive studies of different types of cuttings material and different media utilising the NMPB method have met with limited success (Dore et al 2015). The change to a Mist Propagation system in 2015 has decreased the incidence of fungal attack and looks to be the way forward in clonal propagation of the selected trees at Bombua. Presently the felled selected trees are carrying coppice of 3 months-of-age and will be propagated shortly. The all-female clonal orchard concept is based on the assumption that selected male pollens will be introduced to the orchard through controlled pollination procedures. It was not possible to develop controlled pollination techniques for whitewood during the course of this project but as a pre-requisite floral biology studies were carried out and reported by Dore and Page 2015.

1.4	Establishment of a gene resource planting representing all islands with natural whitewood	• Written or verbal agreement between stakeholders, and host organisation • Short list for whitewood seed producer network • Gene resource conservation planting representing the species geographic distribution • Continued survival and growth to capture site	31.10.2013 n/a 31.10.2013 31.10.2013	Vanuatu Agricultural Research and Training Centre (VARTC) is the host of the Gene Resource planting. A seed producer network was not necessary, as effective collections were made by DoF officers. Banks and Malo natural whitewood was planted in October 2013. New material was collected from Malekula, Malo and Erromango and will be planted in June 2015. Maintenance of the VARTC site has been variable but despite times of intense vine competition trees have grown well.
1.5	Development of community-based demonstration plantings to assist with awareness and training activities.	• Written or verbal agreement between stakeholders, and host organisation • Collect seed from the selected families from the IFP family-provenance trial and establish seedlings in the nursery • Trained smallholders in whitewood silviculture • Demonstration planting established. • Whitewood silviculture demonstration.	1.1.2014 14.4.2011 18.12.2011 18.11.2011 23.10.2014	All hosts were successfully contacted and DoF made significant progress in finalising the landowner agreements. Seedlings from maternal families of various islands were propagated for use as demonstration plantings. There were enough seedlings to establish 'paired plots' on Pentecost and two sites on Malekula, matching them with 'Santo Bulk' seedlings for a comparison of growth. See below for count of seedlings available. This was undertaken during the establishment of the demonstration plantings. A total of seven whitewood demonstration plantings were established during the course of the project. Five of these are performing well at the conclusion of the project. Luganville nursery staff prepared a batch of 600 seedlings from the bulk sowings of IFP seed for shipment to a farmer on Malekula and another batch of 500 seedlings for a west Santo farmer.

Seedlings from the maternal families that belong to various islands were propagated for use as demonstration plantings, as below:

Maternal origin	Count 19/5/2014
SouthWest Bay Bulk	31
Santo Bulk	585
Maewo Bulk	90
Ambae Bulk	330
Pentecost Bulk	390
Malekula (NE) Bulk	330

Objective 2: To advance the Vanuatu sandalwood genetic improvement programme.

no.	activity	outputs/ milestones	completion date	comments
2.1	Replication of the existing clonal seed orchard on Santo (x2), Malekula, Erromango, Tanna, Pentecost, Ambae, Ambrym& Epi.	• Seedling rootstocks • Written agreement between stakeholders, and host organisation • Seed orchard secured in grafted clones • Sites ready for planting • Grafted seed orchards replicated	1.12.2014 31.5.2014 31.5.2014 31.3.2014 31.8.2014	Good maintenance of rootstocks by DoF staff in 2013/14 contributed to the high grafting success rate. All hosts were successfully contacted and DoF made significant progress in finalising the landowner agreements. Since the grafting training in 2013, the DoF nursery staff have successfully grafted 132 scions from 32 selections (mean grafting success of 69%). Seven sandalwood GSOs have been established at six sites across Vanuatu, including Santo, Ambae, Pentecost, Malekula, Ambrym, Epi and Efate..
2.2	Establishment of second generation sandalwood progeny of known pedigree established in a randomised trial in Efate.	• Written agreement between stakeholders, and host organisation. • Facilities established to achieve controlled crosses. • Seed produced of known pedigree. • Seedlings produced of known pedigree. • Site ready for planting. • Second-generation progeny planting. • Continued survival and growth to capture site.	30.10.2014 n/a 30.10.2014 Not yet Not yet Not yet	The progeny trial was going to be sited at Onesua in Efate, but Navota Farm was selected due to the variation in the trial to incorporate seedlots from a diverse range of mother trees. In 2012 the strategy was modified to collect open pollinated seed from the sandalwood GSO in Port Vila for the basis of the progeny trial. The selection of trees for seed collection from the GSO is being prioritised based on diameter and seed (as detailed below). The site will be prepared 1 month prior to the sandalwood seedlings being ready for planting. Not yet completed – dependent on Task 2.2.5 Not yet completed – dependent on Task 2.2.5

2.3	Establishment of a gene resource population comprising randomly selected seed lots across populations from all 'sandalwood' islands.	• Written or verbal agreement between stakeholders, and host organisation. • Supply chain to secure vulnerable populations of sandalwood • Seed resource representing the species geographic distribution. • Secure seed resource until plantation establishment • Seedlings ready for planting • Establishment of a conservation population • Continued survival and growth to capture site.	31.12.2010 31.5.2012 30.6.2011 30.6.2013 30.9.2013 30.9.2013	The gene resource planting was established at Navota Farm (South Santo) comprising seedlots from Tanna, Aniwa, Futuna, Aneityum and Erromango. Seeds from two populations on the west coast of Santo (Hokua, Penouru/Petawat) and seedlings from west Malekula (Tisvel) were secured and successfully established in May 2012. DoF utilised a contact to secure the supply of commercially sourced wild seed. Interestingly, the DoF only had one contact with two productive mother trees in Efate; indicative of the critically endangered status of this resource. Seedling planting is well progressed with the exception of one area awaiting Efate representatives. Completed in 2013 - performance of the older trees has been declining with many of the trees appearing stressed. Site still requires renovation through host enrichment, pruning and fertilising. Navota Farm has been a very good collaborator and maintained the planting.
2.4	Build capacity for and facilitate scaling-up germplasm delivery systems for whitewood and sandalwood	• Modifications to annual operating plans & domestication strategy • 2 Press articles per year • Nursery Facilities to propagate and grow whitewood and sandalwood • Facility to store whitewood and sandalwood seed • Publication of scientific articles, Final report and domestication strategy • Recommendations for future action	30.11.2013 2.5.2014 31.08.2014 31.5.2011 31.5.2015 31.5.2015	Project progress meetings were conducted annually throughout the project. Modifications to the project included (1) a change from controlled- to open-pollinated progeny for both the whitewood and sandalwood progeny trials. Several radio events have been conducted by DoF staff in association with the launch of the Sandalwood Manual (ACIAR Monograph 149) and the sandalwood planting initiatives. Refer to Community Impacts. An extension to the existing greenhouse was undertaken at the Tagabe (Port Vila) nursery to accommodate the sandalwood grafted clones. The remaining budget (about half) was allocated to the renovation of the DoF nurseries identified in the inception workshop. Facility constructed and operational in May 2011. The data from the 2-year measure at Bombua is currently being analysed and will form the basis of the projects next scientific paper. The initiative at Araki Island, using the Hokua (Santo) has had poor survival rates (of the 300 trees planted only 25% survived).

Objective 3: To establish the basic elements of a sandalwood genetic improvement programme in northern Queensland

no.	activity	outputs/ milestones	completion date	comments
3.1	Establishment of sandalwood agroforestry demonstration plots in two communities in Cape York utilised for awareness and training activities in Cape York.	• Written agreement between stakeholders, and host organisation	30.11.2012	Workshops were held in Bamaga and Lockhart River in 2012. Presentations by David Lee, John Huth and Nick Kelly demonstrated the history, conservation needs and silviculture of sandalwood.
		• Seed collection for demonstration planting and rootstock	25.7.2012	Seed of *S. lanceolatum* was collected from natural stands, harvested from seed orchards and sourced from Hughenden, Cooktown Golf Club and Archer Point.
		• Seedlings for demonstration planting	25.7.2012	The sandalwood seedlings were raised in the Mareeba nursery by DAFF staff. The other tree species were purchased from the Yuruga Nursery at Walkamin.
		• Sites ready for planting	25.7.2012	The Bamaga site was prepared in May 2012 and the Lockhart River site in July 2012. Seedlings arrived on site at this time.
		• Seedlings on-site ready for planting • Established demonstration plantings • Continued survival and growth to capture site	15.12.2012 15.12.2012 On-going	The demonstration planting at both the Bamaga and Lockhart River Community Farms are now well established. The sandalwood, acacia and casuarina have had good growth however the pongamia had been severely chewed by grasshoppers. Weed control was good at last visit.
3.2	Establishment of two clonal seed orchards of selected sandalwood in Lockhart River and Injinoo.	• Written agreement between stakeholders, and host organisation • Selections secured in grafted clones • Sites ready for planting • Seedlings on-site ready for planting • Established demonstration plantings • Continued survival and growth to capture site	Not done 30.6.2013 12.5.2015 12.5.2015 2.6.2015	Traditional Owner (TO) consent was given to JCU in 2013 for the site at Injinoo. The gaining of TO approval at Lockhart River has been very difficult, refer below for detailed activities. Progress was made on the grafted clones in Bamaga during 2013. Raising of rootstock was conducted in June 2013 at the Walkamin Research Station. The October 2014 field visit to Bamaga found that funding was no longer available from the Torres Strait Regional Authority to maintain the water supply at Bamaga farm, which was needed for the Clonal Seed Orchard. Two clonal seed orchards were later established, one each at i) Walkamin Research Station (Oct 2014) using 14 clones and ii) NPA College (Jun 2015) with 12 clones.

3.3	Community capacity building to establish and manage modest-scale sandalwood plantings	• Individual links established • Trained community participants • Trained project leaders	30.11.2012 On-going On-going	Successful workshops have been held in both communities as detailed in the results section. Identifying locally-based individuals that are interested in the project has proved challenging, although recent linkage with the NPA College (secondary school) has opened potential to work more collaboratively with staff and students. There may be opportunity to identify interested individuals to work more intimately with future projects.

PC = partner country, A = Australia

7 Key results and discussion

Objective 1: To advance the whitewood genetic improvement program in Vanuatu

Results from the further development of the existing family-provenance trial

Doran et al. (2012) give a full account of the methods, results, discussion and conclusions of the major assessment of growth traits in the whitewood provenance/progeny trials at IFP at 11.4 years-of-age. On the basis of this assessment the trials were thinned based on a simple selection index to become one contiguous Seedling Seed Orchard. The key findings are given below.

Island, provenance and family rankings

Results from the IFP provenance/family trials at age 11.4 years showed that variation amongst islands was significant for growth traits (DBHOB, stem straightness and branching habit), indicating that island-level selection at IFP will result in some genetic improvement. Families from Espiritu Santo had the best diameter growth at 11.4 years while those from Maewo and Forari on Efate were the poorest. It should be noted, however, that the trial site is on Espiritu Santo and the magnitude and practical implications of GxE interaction in this species are still unknown. Form scores for the Espiritu Santo families were mostly better than the other islands while the reverse was true for branching score. The very high genetic correlation for diameter growth between the 4-year and 11.4-year measures bodes well for early selection for growth traits which is directly associated with volume production in future seedling seed orchards.

An assessment in 2012 which was reported in the paper of the conservation status of the wild stands of origin included in the IFP trials showed a sorry state of depletion of wild populations of whitewood. Nine of the fourteen wild populations sampled are no longer known to exist.

Genetic parameters

Single-site heritability estimates were moderate to low for growth (0.16) and form (0.10) traits at 11.4 years, similar to estimates for these traits reported in other species. This coupled with moderate coefficients of phenotypic variation indicate that prospects for genetic improvement by recurrent selection and breeding are promising. Precision of estimation was moderately high in all but the 4-year DBHOB. As the data are drawn from a single site only, upward bias in these estimates is expected as the environmental (genotype-by-site, GxE) component of variation cannot be quantified. Plans to establish second generation progeny trials across a range of sites from the selected individuals in this study will provide a future opportunity to quantify GxE interactions.

Diameter at breast height over bark at the 4- and 11.4-year measures were very closely correlated (genetic correlation of 1.00 ±0.17). Similar age-age genetic correlations were found for growth traits in other species. This correlation is encouraging as early selection for diameter/volume growth and early thinning in seedling seed orchards can be incorporated into the breeding strategy. Growth and form traits were not strongly correlated (-0.10±0.28 for branching and 0.10±0.29 for form) though they had high standard errors of correlation. Given this low correlation it is possible these traits can be improved independently of one another. Similarly, branching and form traits were only moderately correlated (0.40±0.30).

Thinning of IFP trials to become a first generation seedling seed orchard (SSO1)

A simple selection index, determined by summing the individual tree rankings for DBHOB and form traits at 11.4-years in these trials, was used to thin the trials to convert them to one large (7 ha) contiguous seedling seed orchard and assist in the selection of plus trees.

At the family level, those from Espiritu Santo dominated index rankings with one family from West Ambae being the only exception in the list of the top 18 families. The poorest performing families (18 families or 16% of the 110 families present in the two trials) were largely removed from the trials with only the odd exceptional phenotype retained.

On the individual tree level, plots containing more than one tree were reduced to the best individual according to the index. Amongst the 60 best performing families, superior individual trees (candidate plus trees) were marked for seed collection. Selection of plus trees also needed to cater for seeding periodicity amongst the females and the dioecious character of the species, as many (41% as determined later) of the selected trees were non seed-bearing males. This required the marking of four to seven top ranked trees within each family, from a maximum of 8 to 14 trees per family available after earlier thinning to one tree per plot. In all 280 trees were selected and marked (painted Red for best-in-family, Blue for second, Pink for third and Green for fourth).

Variation in wood basic density

Results from the preliminary study at IFP

A preliminary investigation of variation in wood density in one provenance from a bulked seedlot was undertaken to inform the sampling strategy applied in any larger study. Basic density was found to decrease with increasing stem height. The best linear relationship between whole tree density and density at the various sampling heights was with the samples taken at breast height (r^2=0.99) but with an upward bias indicated of about 6% at this age. Breast height non-destructive coring in any latter studies, apart from its convenience, can also be justified as it represents the density of the butt log which is the most valuable part of any tree and perhaps more so in young whitewood. In this study, most samples (n=19 samples/trees) were taken at breast height where basic density ranged from 284-364 kg m^{-3}, with a mean (±standard deviation) of 330 (±21) kg m^{-3}. This is an almost identical range to that given in the literature for mature trees. There was no evidence in this data of a relationship between growth rate and wood basic density in whitewood trees of 11.4 years-of-age.

Results of the larger study based on cores

Settle et al. (2012) quantified mean basic density, radial variation in density and trait-trait correlations for *E. medullosum* for the first time based on core samples from two provenances at IFP. *Endospermum medullosum* produced a low density timber (345 kg m^{-3}), which varied significantly between individuals (range of 143 kg m^{-3}) and populations (328 and 361 kg m^{-3} for Pentecost and Kole populations respectively). Radial variation in wood density was also found to be significant with a 16.5% increase in wood density from the inner to outer wood. Moderate heritability estimates for wood density ($\hat{h}^2$ 0.49±0.24) in this species enables this trait to be considered as a potentially desirable breeding objective in future breeding efforts in Vanuatu.

Results from acoustic estimations of wood density

Temperature (T_a) and wetness of the surface contact area had a significant effect on pulse velocity (*V*). High *V* was found for all measurements where (a) T_a was >30 °C (0.17 cm $\mu s^{-1} < V < 0.32$ cm μs^{-1}) and (b) the surface of the bark was wet due to rain (0.17 cm $\mu s^{-1} < V < 0.36$ cm μs^{-1}) (Table 3). Compared with such conditions, the mean *V* for measurements carried out at T_a< 30 °C and in dry conditions was significantly slower ($p < 0.05$), with a range of 0.12 cm $\mu s^{-1} < V < 0.14$ cm μs^{-1}.

Table 3: Summary wood density (*ρ*) and acoustic velocity (*V*) for *E. medullosum* trees examined at different temperatures (T_a< 30 °C & > 30 °C) and relative bark wetness (wet vs. dry)

Location	Bark	Temp. (°C)	No. trees	No. meas.	*Wood density (ρ)* (kg m-3) [a]			*V* (cm µs -1) [a]		
					Avg.	Min.	Max.	Avg.	Min.	Max.
Plantation	Wet	$T_a < 30$	22	132	310	260	360	0.24	0.17	0.36
Plantation	Dry	$T_a > 30$	50	300	310	260	360	0.23	0.17	0.32
Plantation	Dry	$T_a < 30$	15	45	310	260	360	0.13	0.12	0.14
Buffer	Dry	$T_a < 30$	1	6	400	380	410	0.14	0.14	0.14
Buffer	Dry	$T_a < 30$	1	6	380	340	420	0.13	0.13	0.13
Buffer	Dry	$T_a < 30$	1	6	450	420	490	0.14	0.14	0.14
Buffer	Dry	$T_a < 30$	1	6	400	370	440	0.14	0.14	0.14
Buffer	Dry	$T_a < 30$	1	6	490	480	500	0.15	0.15	0.15

[a] Values are means of a number of measurements.

Buffer trees

Measurements from the buffer trees at T_a < 30 °C on dry days present ranges of 0.13 cm μs^{-1} < V < 0.15 cm μs^{-1} and 340 kg m^{-3} < wood density (ρ) < 500 kg m^{-3}. These results indicate that the buffer trees had a higher density than the trees within the experimental sites.

Radial measurements of both acoustic velocity and wood density were carried out at different tree heights of $H_{1.3}$, $H_{1/2}$, and $H_{3/4}$ for the buffer trees in the tree plantation (Table 4). A decrease in V at each higher point along the stem corresponded with a decrease in measured density. Measurements at $H_{1.3}$ and $H_{1/2}$ had a range of 0.13 cm μs^{-1} < V < 0.15 cm μs^{-1}. The range of densities was 340 kg m^{-3} < ρ < 500 kg m^{-3}. At $H_{1/2}$, the range of densities was 300 kg m^{-3} < ρ < 350 kg m^{-3}. At $H_{3/4}$, the range of V was 0.10 cm μs^{-1} < V < 0.14 cm μs^{-1}, and the range of densities was 310 kg m^{-3} < ρ < 330 kg m^{-3}. The means of V along the stem between $H_{1.3}$ and $H_{1/2}$ and between $H_{1.3}$ and $H_{3/4}$ were significantly different (p < 0.1), although no statistical differences were found between $H_{1/2}$ and $H_{3/4}$.

Table 4: Summary of the buffer tree species *E. medullosum* for the number of trees sampled, the number of measurements done, and the maximum, minimum, and coefficient of variation for velocity ($C.V._V$) for all the sampled trees in Vanuatu.

No. trees	No. meas.	V (cm µs^{-1}) $H_{1.3}$	ρ (kg m^{-3}) $H_{1.3}$	V (cm µs^{-1}) $H_{0.5}$	ρ (kg m^{-3}) $H_{0.5}$	V (cm µs^{-1}) $H_{0.7}$	ρ (kg m^{-3}) $H_{0.7}$	$C.V._V$ (%) $H_{1.3}$ - $H_{0.5}$	$C.V._V$ (%) $H_{1.3}$ - $H_{0.7}$
1	6	0.14	450	0.12	330	0.12	330	0.12	0.14
1	6	0.14	390	0.12	320	0.11	320	0.11	0.16
1	6	0.14	380	0.12	320	0.11	320	0.09	0.19
1	6	0.13	380	0.13	330	0.12	320	0.03	0.09

[a] Values are means of a number of measurements.

Tree-to-tree variation in acoustic velocity and wood density

Measurements of wood density in *E. medullosum* varied by ~30 % with a range of 310 kg m^{-3} < ρ < 510 kg m^{-3}. The results showed a positive relationship (R^2 = 0.66) between V and ρ for both the buffer trees and the experimental trees in the tree plantation (Fig. 2.5). Figure 2.5 shows that the tree species *E. medullosum* in Vanuatu presented a wide range of V when measurements were taken at T_a > 30 ºC (♦), or when the outer part of the tree was wet due to precipitation. Under such conditions, the relationship between V and ρ was not significant (p > 0.001). In contrast, a moderate positive relationship (R^2 = 0.66) between ρ and V was evident when measurements were taken on dry bark at T_a <30 ˚C.

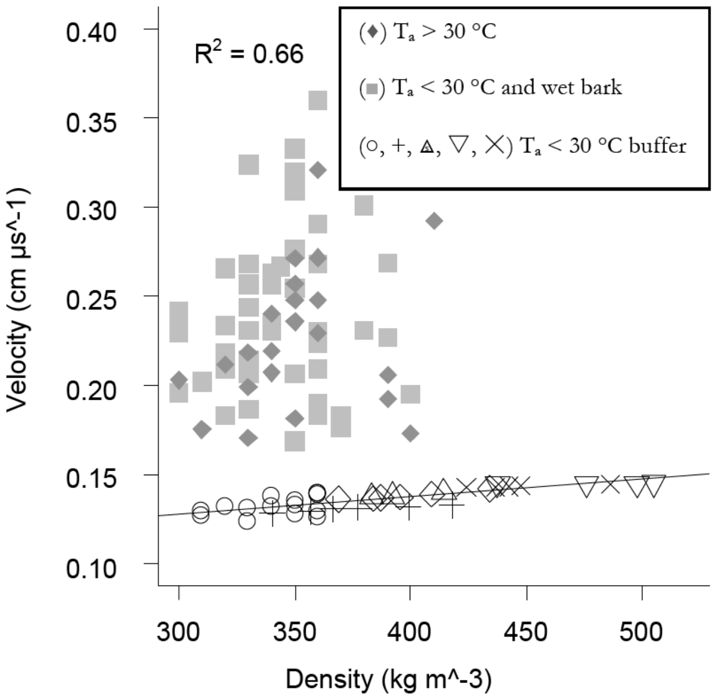

Figure 2: Intra-specific variation of wood density and acoustic velocity to explain the influence of T_a and bark moisture on V of *E. medullosum* in Vanuatu. Coefficient of determination is 0.66, and fitted equation is y=0.09865x + 0.09798.

Concluding remarks on the IFP trials

Considerable island- and family-level variations in traits of economic significance in *E. medullosum* were demonstrated such that both island- and family-level selection in a recurrent selection and breeding program should result in genetic gain. This was the strategy adopted in thinning the trial to become one contiguous 7 ha seedling seed orchard. Two hundred and eighty best-trees (candidate plus trees) of 60 families were marked to be the seed trees for immediate deployment and the basis for second generation seedling seed orchards. To date several thousand improved seedlings from the IFP SSO have been issued to farmers for deployment within Santo and the other islands and the seed from the IFP candidate plus trees have been used to establish second generation seedling seed orchards on three sites.

The IFP study has also underlined the importance of genetic conservation of a wide range of genetic material of this species. In this study, material from highly threatened subpopulations (e.g. Sara, which is now entirely depleted, see Doran et al. 2012) have performed well. Though conducted on a modest scale, this breeding program is an important means for conserving the genes of this subpopulation. Maintenance of genetic diversity in wild populations through a conservation strategy is recommended to ensure the availability of germplasm for long-term improvement.

Confusion surrounds the lease of the IFP site, which no longer rests with DoF. Continuing access of DoF personnel to the IFP SSO1 is of paramount importance and needs to be negotiated with the traditional owners as a matter of urgency. Access to this source of improved seed will be required for several years until project 2nd gen seed orchards produce commercial quantities of improved seed. Failure of DoF to secure on-going access to IFP SSO1 to allow orchard maintenance, further genetic advances to be made and improved seed to be collected and deployed would be a major setback to the domestication of whitewood in Vanuatu.

Results from trials to vegetatively propagate whitewood selections into Clonal Seed Orchards

Grafting of mature trees to allow establishment of an all-female seed orchard

Grafting (approach, cleft and bud) was tested as a means of vegetatively propagating IFP whitewood and thus facilitating the establishment of an all-female clonal seed orchard. Bud grafting showed a little promise from the first trial as one of 56 bud grafts bonded to the stock plant and grew. All the other grafts failed. Repeated later attempts to successfully bud graft IFP whitewood also failed. On the basis of the difficulties experienced in vegetatively propagating whitewood, the idea of a clonal seed orchard incorporating selected females from IFP was replaced in this project by the aim of establishing a network of second generation open pollinated seedling seed orchards (see 1.3).

Immature trees

A return to rooting stem cuttings from coppice from stumps of 3-year-old whitewood, as pioneered by Walker and Haines and SPRIG-2 in the 1990s, and utilising early selections in the Bombua 2nd generation progeny trial, was undertaken. In 2013-14 propagation of cuttings from spontaneous and induced coppice at Bombua in a Non-mist Propagation Box (NMPB) built by the project in Luganville forestry nursery was tested but met with limited success (Dore et al. 2015). In contrast a few marcotts tried in the Bombua trial were highly successful in inducing root formation. In 2014 a mist house was established in the nursery by the project and trials (containers, media, rooting hormones etc.) undertaken to re-establish the methodology. These trials were successful. In February 2015 when Bombua 2nd gen progeny trial was 3.25 years old, the best three trees of the best 12 families were coppiced for production of stem cuttings for rooting in the new misting facilities. They will be planted in clonal hedges once rooted and will be a future source of material for clonal orchards and plantations.

Results from second generation progeny trials/SSOs

Second generation progeny trials were established at Bombua (Santo) in October 2011, Onesua (Efate) in January 2012 and Navota Farm in October 2014. Like the IFP trials they combine the base, breeding and propagation populations in a single plantation. These plantations serve sequentially as progeny tests of trees selected in the first generation, as a resource for selection and breeding for the next generation and finally as commercial seed orchards. They also provide estimates of genetic parameters (e.g. heritabilities, G x E interactions, age-age correlations) and may be used to identify material to place in a vegetative propagation program.

The Bombua SSO consists of 1,160 trees of 47 family seedlots. It has received three annual measures: DBHOB at 1 year; DBHOB, height and form at 2 years and DBHOB and form (5 levels with 5 excellent and 1 extremely poor) on 28-29 October 2014 when the trees were nearing 3 years-of-age. There were significant difference between seedlots in growth traits at all measures but not in form. Form scores have been disappointing with many trees scoring 2 (poor tree) and 1 (extremely poor tree). Contributing factors here include: a) 'speed wobbles' attributed to the very fast growth of trees; and b) kinks (usually low down on the stem) and broken tops caused by vines and falling limbs and trees from the overstorey. We can expect that trees will grow out of the speed wobbles and minor kinks over time, but on this site there is sure to be the inevitable and unfortunate damage to and loss of good trees because of the overstorey. On the other hand, the growth rate of trees at Bombua has been very good with larger trees in the trial approaching 10 m in height and 18 cm in DBHOB in just 3 years from planting. Growth data at 3-years for three seedlots, treatment13 [maternal grand mother MS47] ranked third for diameter growth, 37 [MT38] which was ranked 13th and 7 [MS40] which was ranked 37th out of 47 seedlots, are given in Table 1.

Table 5: Family averages for DBHOB, height and form for three families at Bombua at three years and relative growth rate since the 2-year measure. (G.mother = Grandmother)

Trt No.	Maternal family	Origin of G.mother	DBH (cm)	Ht (cm)	Form score	Dia (cm) increment in 12 mo	Ht (m) increment in 12 mo
13	MS47	CE Santo	13.5	7.5	2.5	3.7	1.1
37	MT39	W Ambae	12.6	7.2	2.4	4.4	1.2
7	MS40	CE Santo	10.3	6.0	2	3.2	1.3

There was evidence in the data that growth rates had slowed during the third year with increments for that year in diameter and height averaging about 3.8 cm and 1.2 m respectively. In February 2015, when the trees were 3.25 years from planting a thinning was undertaken to reduce plot stocking to two trees per plot from the four originally planted. Thinning was based on a trees phenotypic performance in diameter growth and with a consideration of spacing and form.

The Onesua SSO consists of 384 trees of 25 family seedlots. It has received two annual measures: DBHOB at 1 year and DBHOB and height at 2 years. Survival and growth of trees on the site has been reasonable overall, but highly variable because of site effects (grass competition and gardening in one part that has promoted vigorous tree growth). No statistically significant differences in seedlot performance have been detected at Onesua because of the site variation. For this reason also, a cross site analysis (Bombua cf Onesua) to study GxE interactions cannot be supported statistically at this stage.

While more comprehensive evaluation of the impacts of Cyclone Pam (a category five storm that passed over the trial site) will be conducted in 2016 it is evident that whitewood has a high degree of tolerance to extreme winds. Initial inspections in the months following the cyclone indicated that while most tree canopies were damaged, with varying degrees of broken tops the primary bole remains intact. The estimated proportion of trees that were leaning or windblown was low (~5-10%). Obviously a more detailed evaluation of the extent of the damage and long term recovery will reveal the true extent of whitewood's resilience to cyclonic winds.

The growth of trees at Onesua has been slower than at Bombua, Thinning is not advised until the trees have fully occupied the site. Thinning might not take place for another year or two depending on how fast the trees recover from the damaged sustained by Cyclone Pam.

The Navota Farm SSO consisted of 1,296 trees of 66 family seedlots at planting on 23-24 October 2014. Unfortunately, later in 2014 cattle gained entry to the site and caused very significant damage (all leaves eaten and some trees trampled) to the trial. Some trees were found to have coppiced in a February 2015 assessment of tree mortality/survival and height growth to ascertain if the trial was still of any use. There had been 55% mortality due to cattle damage at this point and another 5% of trees were wilted and unlikely to survive much longer. A determination of survival within plots showed 17% of plots with no surviving trees, 31% with one tree surviving, 31% with two surviving, 15% with three surviving and only 6% with all four trees remaining. Trees that have coppiced have created a new leader, usually down the stem from the old leader, meaning form will be adversely affected so selection for this trait will not be possible for many years. The trial purpose has been totally compromised.

A final seed collection was made from IFP in April 2015, and sufficient replicate seedlings exist to re-establish this trial in 2016. The modest amount of project funds remaining at the conclusion of the project has been allocated to ensure that this trial will be established and maintained beyond the life of the project.

Results of whitewood gene bank establishment

The gene conservation stand at VARTC comprises of seedlings from Vanua Lava of the Banks group of islands, Malekula, Malo and Erromango (Table 6).

Table 6: Summary details of the seedlings established in a gene bank at VARTC during the course of the project

Population	Date Collected	Collection Type	Date Sown	Percent Germination	Individuals Planted	Survival
Vanua Lava (Banks)	Sept 2013	Bulk	29thOct 2013	50%	80	60
South West Bay (Malekula)	28th Jan to 3rd Feb 2014	13 Trees DS 1-13	6th Feb 2014	40%	102	100
Malo Island	13th – 14th Feb 2013 17thDec 2013 1st Feb 2014	11 trees 3 trees Malo 1-3	13th – 14th Feb 2013 17thDec 2013 3rd Feb 2014	20% 0 30%	40 0 60	25 0 55
Cooks Bay (Erromango)	10th Apr 2014	Bulk from 2 trees	20th Apr 2014	0	0	-

All the plantings represent populations new to the breeding program and will be a valuable source of infusions to the third generation progeny trials as well as serving a gene conservation purpose.

Results in developing of community-based demonstration plantings to assist with awareness and training activities

Demonstration plots were established during 2014 and 2015 on the islands of Ambae, Pentecost, Ambrym, Epi and three sites on Malekula in co-operation with local smallholders, in locally prominent and publicly accessible sites (Table 7). Seedlings from the maternal families represented at IFP that belong to various islands were propagated for use as demonstration plantings in those locations. 'Santo Bulk' was planted on all sites, but there were a reasonable numbers of seedlings from mother trees representing other islands to allow the establishment of 'paired plots' on three sites (Pentecost, and two sites at Malekula) for a comparison of growth.

Table 7: Summary details of the demonstration plantings established under the project

Location	Date planted	Area and spacing	Number of seedlings	Comments
Ambae (St Patrick College)	Jan 2014	2ha 6 x 6 m	122	30-40% survival, poor survival due to lack of maintenance, site no longer viable.
Ambrym	July 2015	6 x 8m	159	70% survival, impact from 2015 El Nino (dry) period, survivors growing well in 2015
Epi	July 2015	6 x 8m	140	80% survival, good maintenance, survivors growing well in 2015
Malekula (Mapbest)	Sept 2011	6 x 4m	400	20% survival, poor initial maintenance, survivors now growing well in 2015.
Malekula (Corner Point)	Feb 2015	6 x 8m	60	African snail damage severe, widespread losses, site no longer viable.
Malekula (Pinalum)	Jan 2015	6 x 8 m	107	57% survival, moderate cyclone damage, survivors growing well in 2015.
Pentecost (Crosspoint)	Jan 2015	6 x 8m	150	30 - 40% survival, heavy impact from TC Pam and 2015 El Nino (dry) period.

Objective 2: To advance the Vanuatu sandalwood genetic improvement programme.

2.1 Replication of the existing clonal seed orchard on Santo (x2), Malekula, Erromango, Tanna, Pentecost, Ambae, Ambrym& Epi.

The replication of the existing CSO represents an important achievement of the project with six functioning CSOs, from the seven that were established (Table 8). All of the remaining GSOs have begun to produce seed during 2015, although protocols for recording the distribution need to be implemented by DoF. Clear systems should be feasible in Santo, Malekula and Efate where the orchards are proximal to DoF offices. In Epi liaising with Epi High School about collecting distribution information is certainly feasible. In Ambrym the GSO is established in the Lalinda Community and provisions for recording distribution would need to be made with a reliable community member. Collation of seed distributed from the six GSO will need to be managed by the Research Section of DoF. This information can then be used in any future studies into the performance and quality of the progeny under a range of smallholder managed systems.

Table 8: Location and descriptors for the seven sandalwood grafted seed orchards (GSO) established in Vanuatu. Clone island of origin are denoted by the prefix letters Ani=Aniwa, Ayn=Aneityum, Err=Erromango, Ma=Malekula, Mo=Moso, S=Santo & T=Tanna. Replicates of each clone are represented in parentheses.

Location	Date planted	Area & spacing	Clones	Survival
Ambae (St Patricks)	Dec 2013	5 x 5m	Ani01(x2), Ani05(x2), Ayn09(x2), Ayn20(x2), Ayn21(x2), Err37(x2), Err44(x1), Err57(x2), Ma02(x2), Ma14(x3), Ma27(x2), Mo01(x2), Mo13(x2), S08(x2), S18(x2), S27(x2), T11(x2), T22(x2)	5%
Santo (VARTC)	Feb 2014	5 x 5m	Ani01(x2), Ani05(x2), Ayn09(x2), Ayn20(x2), Ayn21(x2), Err37(x2), Err44(x2), Err57(x2), Ma02(x2), Ma14(x2), Ma27(x1), Mo01(x2), Mo13(x2), S08(x1), S18(x2), S27(x2), T11(x2), T22(x2)	50-60%
Pentecost (Whitewater)	Mar 2014	5 x 5m	*Ani15 (Ani01)(x2), *Ayn18 (Ayn09)(x2), *Ayn19 (Ayn21)(x2), *Err41 (Err57)(x2), *Err73 (Err37)(x2), *Ma19 (Ma27)(x2), *Mo02 (Mo13)(x2), *Mo21 (Mo01)(x2), *S15 (S18)(x2), *S23 (S27)(x2), Ani05(x2), Ayn20(x2), Err44(x1), Ma02(x2), Ma14(x3), S08(x2), T11(x2), T22(x2)	95%
Malekula (Corner Point)	Mar 2014	4 x 5m	Ani03(x2), Ani05(x2), Ayn09(x2), Ayn18(x2), Ayn19(x2), Err37(x2), Err44(x2), Err73(x2), Ma10(x2), Ma14(x2), Ma16(x2), Mo01(x2), Mo13(x2), S06(x2), S27(x2), S29(x2), T04(x2), T11(x1), T22(x1)	88%
Epi (Epi High Schl)	Aug 2014	5 x 5m	Ani03(x2), Ani05(x2), Ayn09(x2), Ayn18(x2), Ayn19(x2), Err37(x2), Err04(x2), Err68(x2), Ma16(x2), Ma14(x2), Ma02(x2), Mo13(x2), Mo21(x2), S08(x2), S27(x2), S26(x2), T04(x2), T11(x2), Ayn19(x1), T20(x1)	47%

Ambrym (Lalinda)	Jul 2014	5 x 5m	Ani01(x2), Ani05(x2), Ayn09(x2), Ayn20(x2), Ayn21(x2), Err04(x2), Err41(x2), Err68(x2), Ma10(x1), Ma16(x2), Ma23(x2), Ma27(x1), Mo21(x2), Mo23(x2), S08(x2), S15(x2), S27(x2), T04(x2), T11(x2)	78%
Efate (Onesua)	Sept 2014	5 x 5m	Ani03(x2), Ani15(x2), Ayn18(x2), Ayn20(x2), Ayn21(x2), Err44(x2), Err57(x2), Err73(x2), Ma10(x2), Ma14(x2), Ma19(x2), Mo02(x2), Mo13(x2), S18(x2), S23(x2), S26(x2), T04(x2), T22(x2)	98%

Sandalwood Grafting Procedure

Using the grafting method explained in Section 5, the mean rate of successful graft unions, across four regular grafters, was 57%. A total of 43 genotypes were replicated using this method, which were used for the establishment of the seven GSO replicates across Vanuatu (Table 8).

Sandalwood Cutting Propagation

To develop an effective method for vegetative propagation for producing clonal sandalwood (*S. austrocaledonicum*) a series of four experiments were conducted. In these experiments the effects of cutting (genotype, type of cutting, leaf area,) and environmental (exogenous auxin, rooting media, and light intensity) treatments on adventitious root initiation (%rooting) and development (mean root number and length) in leafy stem cuttings using non-mist propagators were evaluated. The results demonstrate that *S. austrocaledonicum* seedlings can be successfully propagated by cuttings. Island of provenance and genotype were clearly found to influence the rooting percentage and root development. Cuttings taken from genotypes from the island of Erromango outperformed those from Tanna. Significant variation was also found among genotypes from Erromango with several genotypes having greater cutting success. The studies demonstrated optimisation of the propagation environment is required for individuals and/or groups of genotypes. The cost of optimising the propagation environment for small numbers of genotypes, means that cutting propagation would only be feasible if the genotypes were superior, which is recognised by the market for sandalwood seedlings, where growers would be willing to pay a premium.

This research found that *S. austrocaledonicum* seedlings can be readily propagated by cuttings using the following method. Stockplants need to be healthy and actively growing at the time of cutting collection. Cuttings should be taken from the apical and medial stem position using soft to semi-hardwood stem material. Cuttings should be prepared with two nodes and a combined leaf area of 400 to 800mm2. Two node cuttings are preferred as leaf retention in the propagation environment is essential to cutting success. Therefore having a cutting with two leaves reduces the chance complete leaf shedding compared to single node cuttings. The application of the exogenous auxin (0.3, 0.4 & 0.8% indole-3-butyric acid) is not required for *S. austrocaledonicum* as it was found to have no statistical effect on any measure of rooting success. Rooting medium can be comprised of a range of sterile organic (peat or coco-peat) and mineral components (gravel, pumice, vermiculite or perlite) with good success found across a range of media provide it has a air-filled porosity of between 30 and 40%. The non-mist propagators need to be managed with attention to maintaining i) hygiene (removal of all dead or diseased cuttings), ii) the water-table within the media vessel, iii) integrity of the polythene film to ensure high humidity, iv) position under 50-75% shade.

2.2 Establishment of second generation sandalwood progeny of known pedigree (half-sib) in a randomised trial in Efate.

Progeny trial at La Bouffa (Efate)

The progeny trial will consist of progeny from six superior clones, which were collected from the Onesua GSO replicate.

Table 9: Number of seedlings from each sandalwood clone that represented in the 2nd Gen progeny trial at La Bouffa (Efate). Clone island of origin are denoted by the prefix letters Ani=Aniwa, Err=Erromango, Ma=Malekula, Mo=Moso, S=Santo. No representatives from Aneityum, Efate or Tanna are represented.

Clones	Seedlings
Ani-03	41
Ani-15	35
Err-44	4
Err-57	1
Err-73	2
Ma-19	15
Mo-02	38
S-18	56
S-23	1
S-26	39
Total	232

The La Bouffa planting could be a very important genetic resource for future improvement of sandalwood in Vanuatu. The site is currently owned by the Vanuatu National Provident Fund (VNPF). Written agreements between DoF and VNPF have not yet been ratified and given the strategic importance of this resource, a high priority should be assigned by DoF to finalising a written agreement for this particular trial prior to establishment. In short the agreement needs to contain information pertaining to ownership of the trees by VNPF at maturity, which in return should guarantee DoF access throughout the rotation to collect performance data, clonal materials and seed. The agreement should also include management responsibilities and basic silviculture. Importantly the agreement should include provisions for the removal of adjacent *S. album* trees, so that cross-pollination with the progeny trial is not possible.

Reproductive biology of *S. austrocaledonicum*

While the development of a full-sib progeny trial was not possible within the scope of this project, its delivery depended upon undertaking controlled pollinations among selected genotypes. This required a knowledge of the species reproductive biology with respect to floral phenology and breeding system. The project made significant contributions to a wider study conducted as part Hanington Tate's Masters thesis. The results specific to the work conducted in Vanuatu for *S. austrocaledonicum* are presented, with additional results to those reported in Tamla *et al.* (2010).

Floral Phenology

The flowers of Vanuatu sandalwood persist for a mean 2.46 days before either setting fruit or falling off. The flowers open rapidly over 3-4 hours typically in the morning. The flowers close again between 24 and 48 hours making them unavailable for pollination by large insects, although small ants and thrips may still access the flowers. No visual changes in stigma morphology were detected and the timing and duration of stigma receptivity requires further investigation. It is likely that *S. austrocaledonicum* is either slightly protandrous (pollen shed before stigma receptivity) or pollen shed and receptivity occur simultaneously. This is suggested since pollen shed occurs throughout the period where the tepals are open and the stigma is available for pollination. Furthermore the upper part of the style is abscised concurrently with the floral tube, so the stigma is only available for pollination by 'large' insects during the opening of the tepals.

Pollination

The flowers of *S. austrocaledonicum* were tended by ants, bees, beetles, butterflies, flies, ants and thrips. Ants were, however, often found to chew and remove the style at its base, and while the purpose for this behaviour was not clear, it rendered the flower no longer available for pollination. It is not clear whether thrips would be effective pollinators, since they were of such small size that they could easily access the floral tube without coming in contact with the stigma.

Controlled pollination can be effective by pollinating buds just prior to opening. This approach is necessary since the flowers begin shedding pollen immediately at the opening of the tepals. Therefore, if the flowers are permitted to open, spontaneous self-pollination is possible. Bud pollination can be achieved by cutting of the floral tube just under the position of the stamens, so that the entire androecium is removed with the upper-part of the floral tube. The excision of the floral tube in this way was not found to affect the development of the fruit since the ovary is inferior to the floral tube and after fertilisation, the floral tube abscises from the pedicel. Pollen was best collected from opening flowers, and used on the same day as collection. Viable pollen can be stored at ambient conditions (22-25°C) in a desiccator for a short period (2-3 days) and used to achieve fertilisation as shown in preliminary studies. We however, conducted all comparative controlled pollination studies with fresh pollen so as to avoid any potential issues with a potential reduction in viability. Further studies into pollen viability, longevity and propensity for storage are required to determine the feasibility of using stored pollen in a breeding programme.

The isolation of sandalwood flowers from sources of foreign pollen using bags proved problematic, since the bags often damaged the small and delicate flowers. A range of paper and mesh bags were examined with the lighter mesh bags being more effective, although still not suitable for use in operational breeding. Isolation of entire plants was used in this project to restrict pollen transfer. We used a range of temporary structures constructed of either timber or steel and covered with insect and/or quarantine mesh. This approach required the use of pruned trees to reduce the overall size. Pruning the trees often had the effect of promoting vegetative growth. Temporary isolation structures were also prone to being damaged on windy days and more substantial steel structures were cost prohibitive for isolating a large number of trees for operational breeding. The most efficient way to isolate a number of plants was to use potted (>300mm) grafted plants under a single isolation structure. Grafted plants have a propensity for early flowering and their small size in the pots allows for isolation of many individuals. This approach proved most successful for controlled pollination studies. It is important to note that all methods of flower isolation failed to limit access by ants, which were subsequently controlled by pesticide application to the base of the stem.

Sandalwood breeding system

Self- and intraspecific cross-compatibility was examined in 13 genotypes of *S. lanceolatum* and interspecific cross-compatibility between *S. lanceolatum* with each of *S.*

austrocaledonicum and *S. album*. *S. lanceolatum, S. austrocaledonicum* and *S. album* were found to be cross compatible. While the number of controlled pollinations using S. austrocaledonicum was not sufficient for comprehensive statistical analysis, the following results can be reported: *S. austrocaledonicum* has a capacity for self-pollination with 12.5% of flowers producing seed. This was equivalent or greater than the percentage seed set in flowers pollinated with intraspecific (12.5%), *S. lanceolatum* hybrid (8.7%) and *S. album* (11.5%) pollen. The germination rate of the resulting seed however, was lower for self' seed (50%) compared with intraspecific (78%), *S. lanceolatum* hybrid (63%) and *S. album* hybrid (83%) seed. All resulting seedlings were grown and observed for a period of 3 years without any evidence of late acting incompatibility. The results of this study demonstrate that *S. austrocaledonicum* has no, or incomplete barriers operating to restrict selfing or hybridization with either *S. lanceolatum* or *S. album*.

Sandalwood domestication and conservation

The propensity for Vanuatu sandalwood to freely hybridise with at least two other tropical sandalwood species (*S. lanceolatum* and *S. album*) raises issues about the conservation and domestication of the species. The introduction of *S. album* into Fiji has already resulted in its hybridization with the indigenous species *S. yasi* (Bulai & Nataniela, 2007). Therefore, the introduction of *S. album* within the natural range of *S. austrocaledonicum* will likely result in uncontrolled gene flow between them. This is likely to have significant implications on genetic structure and diversity of the local species (Vila *et al*. 2000; Ellstrand 1992).

The lack of reproductive barriers between Vanuatu and Indian sandalwood opens the potential for introgression of desirable traits between species and/or the development of hybrid cultivars. With *S. album* generally producing a consistently superior oil to *S. austrocaledonicum*, the hybrid approach to sandalwood domestication may be seemingly desirable. The superior oil of *S. album* was one reason that some industry representatives began to import Indian sandalwood seed for planting in Vanuatu.

Considerations of other characters of *S. album* may however, negate the advantages of superior oil. Evidence exists that *S. austrocaledonicum* may have a propensity for early heartwood formation under favourable conditions, where at 16 years a tree can yield an average of 22kg (Page, Hannington*, et al.*, 2012) compared with 5.8kg for *S. album* (Brand *et al.*, 2012). This may result in a potentially shorter rotation of 15-20 years (Page, Hannington*, et al.*, 2012) compared with 25-30 years for *S. album* (Sen-Sarma, 1977; Doran *et al.*, 2005; Brand *et al.*, 2012). While much debate exists in the commercial sector as to likely rotations, unrestricted natural hybridization between *S. austrocaledonicum* and *S. album* may influence the timing of heartwood development in resulting progenies. This is important since the rate of heartwood development heavily influences the commercial viability of planted sandalwood (Brand *et al.*, 2012).

Another important consideration is the apparent lower tolerance of *S. album* to cyclonic winds relative to *S. austrocaledonicum*. Following category five cyclone Pam in March 2015, Tungon and Tabi (2005) assessed its impacts on Vanuatu's main plantation tree species on Efate. Based on their assessments they rated each species on a scale of 1 (Very wind-firm) to 5 (Very susceptible to stem-snap or not wind-firm) and found that *S. austrocaledonicum* was rated as category 2 (wind-firm) and *S. album* as category 5. Given the high frequency of cyclones in Vanuatu, the tolerance to high winds was a factor in determining the DoF priority plantation species. With such a substantial difference in the tolerance of high winds between these two species, any domestication based on their hybrids would be considered risky.

Apart from the potential biological issues of hybrid sandalwood they may also be undesirable where the genetic integrity of the species is important for cultural and/or marketing reasons. Consumers of sandalwood are sensitive to differences in product qualities that are associated with different species. For instance the two major plantation companies in Australia (Santanol and TFS) are committed to producing Indian sandalwood, since its heartwood oil qualities are associated with a market premium (Tropical Forestry Services (TFS), 2015) (http://santanol.com/about-santanol/ accessed 7th April 2015). In Pacific Island Nations such as Fiji and Vanuatu many industry participants view their indigenous sandalwood as having niche market opportunities, and a point of difference to the larger industrial plantations of *S. album*.

2.3 Establishment of a gene resource population comprising randomly selected seed lots across populations from all 'sandalwood' islands.

The gene resource planting of about 880 sandalwood trees at Navota Farm (South Santo) represents sandalwood populations from all islands except Efate (Table 10). The site allows for the assessment of growth and performance of sandalwood from different origins. Candidate seed trees have been identified from the earlier 2008/09 plantings, based on their performance (growth rate and form).

These additional trees offer a potential for broadening the genetic base of the current breeding population (based on 43 superior clones) and including trees selected based on their relative vigour. As the later plantings from Malekula and Santo are of a suitable age, further seed trees may be identified. The site also offers the potential for assessing heartwood development through a coring study, to determine any relationships with island of origin and growth rates. This information could be carried through any progeny testing of the parents.

The research and development potential of this site would be maximised by undertaking rejuvenation activities, particularly within the earlier plantings. This would include enrichment with hosts such as *Acacia spirorbis*, pruning and fertilising. Project funds were allocated to this rejuvenation throughout the implementation of the project. Based on the relative simplicity of this task, full-responsibility for completion of the rejuvenation was given to the DoF. The rejuvenation of the Navota trial was not completed during the life of the project, although Forestry staff have given assurances that it will be conducted post-project using monies reserved for this purpose.

Table 10: Summary details of the sandalwood gene conservation stand at Navota Farm

Population	Planted	Collection Type	Surviving (2014)	Seed Trees
Aneityum				
Analgahat	2008	Collection from 3 individual Trees	7	6
Anware	2008	Bulk Collection	9	4
Aniwa				
Aniwa	2008	Individual Tree collection from Isavai Itangutu & Itangutu and family collection from Imale	203	NA
Erromango				
Antiock	2008	Bulk Collection	11	3
Tamsal	2008	Bulk Collection	15	1
Tamsal	2008	Single Tree Collection	1	1
Tamsal	2008	Family Collection	3	1

Population	Planted	Collection Type	Surviving (2014)	Seed Trees
Futuna				
Futuna	2008	Bulk Collection	12	2
Malekula				
Tisvel	2012	Bulk Collection	199	NA
Santo				
Hokua	2012	Bulk Collection	57	NA
Penouru	2012	Bulk Collection	56	NA
Westcoast	2010	Bulk Collection	216	4
Tanna				
Lamanaburuan	2008	Bulk Collection	4	1
Lataus	2008	Bulk Collection	19	6
Latun	2008	Bulk Collection	12	2
Laukaueria	2008	Bulk Collection	11	4
Whitegrass	2008	Bulk Collection	18	1
		Total	853	36

2.4 Build capacity for and facilitate scaling-up germplasm delivery systems for whitewood and sandalwood

A refrigerated seed storage facility (27m^3) with backup generator was established at the DoF offices in Tagabe. While this facility is still operational, it is yet to deliver the anticipated benefits. DoF have cited that the cost of operation (i.e. electricity) currently exceeds budgetary allowances. The DoF Director Hanington Tate has been investigating potential avenues to share the facility with other Government Departments and Private organisations. Sharing the space by installing lockable internal cabinets may offer efficiencies and divide operating costs.

Whitewood: Training in seed collection techniques by David Lea on Santo and project sponsorship of five island-based staff to a CSIRO/AusAID course resulted in well-documented seed collections at IFP and, for the first time, from Banks, Malo and Erromango. Upgrading of germination beds at Luganville forestry nursery resulted in more efficient and reliable production of seedlings from improved seed from the IFP SSO. Growers are increasingly demanding IFP seedlings as information on the availability of genetically improved germplasm disseminates, as evidenced by distribution of improved seedlings to growers on Santo and Malekula during the course of the project. This trend is expected to continue as the results of the whitewood demonstration plots on five islands become evident. The project also established a robust solar-powered misting facility at the Luganville nursery, to enhance the success of cuttings propagated from coppiced plus-trees at the Bombua whitewood trial. This facility has enabled the DoF to produce the first batch of cuttings from these trees, which will lead to the establishment of plus tree hedges. The system was designed so that it can be easily extended as the clonal program expands.

Sandalwood: Upgrades to DoF nursery facilities at Tagabe were undertaken as part of the project and included installation of a perimeter security fence, shadehouse, greenhouse roof replacement, tree isolation structures and rejuvenation of the sandalwood GSO. The perimeter security fence was essential to reduce seedling theft from the facility, as well as unrestricted public seed collection and associated tree damage from the sandalwood GSO. The security fence all but eliminated these issues from the early part of the project and enabled DoF staff to undertake research activities without theft and vandalism affecting progress. Both the renovation of the greenhouse and construction of shade house created areas suitable for the grafting of the sandalwood, used within and beyond the project for production of grafted clones. The isolation structures were important additions to the study of sandalwood reproductive biology and could be used for further controlled pollinations. The rejuvenation of the GSO was essential to ensuring grafting success and improved productivity of the GSO so that it began producing significant seed crops towards the end of the life of the project. The rejuvenation demonstrates that, with appropriate management interventions, poor performing sandalwood plantings with insufficient hosts can regain productivity.

The sandalwood genetic resources established by the project are already being used for seed supply to DoF and its stakeholders (farmers). Seed collections by local communities are being conducted within the gene resource planting and provided further rejuvenation continues (see activity 2.3 above) this will produce seed of high genetic diversity and with further selection high vigour. The GSOs have been replicated across six sites (see activity 2.1 above) and while this is a good start, further replication at other sites is still needed to meet the expected demand for improved seed. With the facilities and expertise gained through this project the DoF has a capacity for further deployment of the GSOs to other locations. DoF partnerships with commercial sandalwood enterprises to assist with the deployment of improved germplasm throughout the country may be considered. This could help to accelerate further deployment and develop an economy of scale for high quality Vanuatu sandalwood.

Industry and market development of Vanuatu sandalwood

Five DoF staff members toured parts of Western Australia (Perth, Wheatbelt and Goldfields areas) in April/May 2015 and met with various sandalwood industry stakeholders. These included organisations such as Wescorp, TFS, Paperbark Co., FPC and growers in the Wheatbelt. The aims of the tour were to enlighten DoF personnel concerned with Vanuatu sandalwood to i) the demands of the market and consumers and prospects for Vanuatu sandalwood, ii) the status of improvement for other species and market potential for hybrids, iii) product grading for specific markets and real market value of products, and iv) current constraints to market development of Vanuatu sandalwood. The results of the study tour have been outlined in Tabi et al. (2015) and the main findings are summarised in a SWOT analysis for Vanuatu sandalwood (Table 11).

Table 11: SWOT Analysis of the Vanuatu sandalwood industry developed from lessons learned during the DoF Perth Study Tour in April/May 2015.

Strengths
• Vanuatu sandalwood is recognised in the marketplace as a very high quality product. • Vanuatu has marketing advantages associated with its location and traditional way-of-life. • Vanuatu sandalwood has rapid growth and heartwood development compared with other species, particularly *S. spicatum*. • Smallholder farmers have a capacity to grow sandalwood trees. • Vanuatu has a genetic improvement program aimed at ongoing improvements.

Opportunities

- There is a clear market for oil and Vanuatu sandalwood generally produces a very high quality oil.
- The prices paid to landowners in Vanuatu can be increased in-line with current market prices.
- Tribal/Fair Trade marketing of sandalwood demonstrating a chain of custody from farmer to consumer to add value.
- A sandalwood oil library can be used to identify origin of sandalwood.
- Improvement in productivity and product quality can be achieved through improving silviculture. Growing products (silviculture) vs. growing trees (wild).
- Industry restructure including single point marketing of sandalwood can attract a greater number of international buyers to Vanuatu.

Weaknesses

- The Vanuatu sandalwood industry suffers from fragmentation with many small producers, making it difficult to access the broader international market.
- The legality of sandalwood from Vanuatu is unclear to the international marketplace.
- The DoF has limited resources to adequately administer and regulate the sandalwood trade.
- Lack of in-country capacity for processing and value adding

Threats

- Significant volumes of sandalwood to come onto the market from *S. album* plantings in Western Australia.
- Illegal removal of trees and farmers not being paid.
- *S. album* introgression with *S. austrocaledonicum* that potentially leads to a reduction in wind firmness and an increase in rotation due to slowing of heartwood development.

Objective 3: To establish the basic elements of a sandalwood genetic improvement programme in northern Queensland

3.1 Establishment of sandalwood agroforestry demonstration plots in two communities in Cape York utilised for awareness and training activities in Cape York.

The Bamaga demonstration plot was planted in July 2012 on a 0.5 ha plot and consisted of three *S. lanceolatum* provenances and one source each of *S. album* and *S. austrocaledonicum*. Survival is approximately 50% (46%, 56% and 80% for *S. album*, *S. austrocaledonicum* and *S. lanceolatum* respectively). Survival for the hosts was 25%, 80%, 100% for *Sesbania formosa*, *Acacia simsii* and *Milettia pinnata* (pongamia) respectively. Many of the trees were damaged due to weed growth and over zealous brush-cutting. Weed control was completed by the farm in May 2014 (after prolonged wet weather) however the damage had been done.

The Lockhart River demonstration site was planted in December 2012 on a 0.1 ha plot and consisted of three *S. lanceolatum* provenances (Davies Creek, Walkamin and Delta Downs) along with one source of *S. album*. Intermediate host species *Acacia simsii* and two long-term host species *Casuarina cunninghamiana* and *Pongamia pinnata* were established. All plants were were established on a 2 x 3 m grid with a host to sandalwood ratio of 3:1. David Lee inspected the site in July 2014 and the survival of both hosts and sandalwood was 80% and the sandalwood had grown up to 3 m tall. An issue of partial ringbarking of trees due to brushcutter use was discussed with the farm manager during the visit. The site continues to experience low intensity fires during dry periods.

3.2 Establishment of two clonal seed orchards of selected sandalwood.

Walkamin Grafted Seed Orchard

A grafted clonal seed orchard containing fourteen clones from the Northern Peninsula Area has been successfully established on secure government land (with traditional owner approval) at Walkamin Research Station. The seed orchard was established in an existing *Milettia pinnata* (syn. *Pongamia pinnata*) provenance trial, as the leguminous pongamia trees can act as hosts for the grafted sandalwood trees. The pongamia trees in the areas where the sandalwood trees were being planted were pollarded at 1.0 m to ensure the grafted sandalwood trees had sufficient light and space to grow. This planting secures the resource and will act as a backup source of the germplasm in the event of a natural disaster killing the trees in the wild. It can also be expanded as we capture additional genetic resources of this species.

Bamaga Grafted Seed Orchard

The October 2014 field visit to Bamaga brought some bad news. The pump had broken down and funding from The Torres Strait Regional Authority (TSRA) was exhausted. Requests for further funding were unsuccessful and all work at the farm ceased in 2014. Therefore, the planting of the grafted seed orchard was delayed. The most promising alternative to the Bamaga Farm was the Senior Campus – Northern Peninsula Area College. The Head of the campus was receptive to collaboration and a CSO was established in 12 May 2015. Twelve clones (most with multiple copies) from across the NPARC (Injinoo region) were planted at the school with assistance from year eight students, who are now monitoring and watering the trees to ensure their survival. During the planting day another workshop was held to ensure that the TO's and the students understood the history, conservation and potential of sandalwood for their communities future. To prevent damage from brush cutting a novel tree guard, fashioned from the pots of the trees, were installed. Site was inspected on the early June 2015, with all clones coping with the hotter environment of the NPA compared with Gympie, due in part to the twice weekly watering and some follow-up rain at the school.

Grafting method development

The impact of season, semi-lignified and lignified scion material and species of rootstock (*S. album*, *S. leptocladum* and *S. lanceolatum*) was investigated to evaluate the impact of each component on grafting success. Based on this study, collection of semi-lignified scion material during the middle wet season, along with use of *S. lanceolatum* rootstock, was found to be optimal for this species. Once graft unions had formed, no incompatibility problems were detected, irrespective of the species of rootstock used.

Traditional Owner consent at Lockhart River

The gaining of Traditional Owner (TO) approval at Lockhart River has proved very difficult. At the end of the project, although an agreement with the Land Corporation was signed, the consent from all of the TOs had not been provided. The project team has made numerous attempts to get this finalised but getting the TOs to all agree has been time consuming and has limited additional work in this community. A condensed timeline of attempts to get the MTA signed was provided in the 2014 annual report.

3.3 Community capacity building to establish and manage modest-scale sandalwood plantings

The most significant activity to build capacity to manage sandalwood plantings was the workshops held and demonstration plantings established at both Bamaga (story covered by the NPARC Newsletter No 39 July 2012) and Lockhart River in 2012. The workshops covered the following topics:

1. History of sandalwood harvesting from wild trees in Cape York Peninsula from approximately 1865 until the mid 1940s. The importance and prominence of indigenous people from the region working in the industry during that time. The current wild harvesting of sandalwood from is now mainly focussed around the basalt walls near Richmond and Hughenden.
2. There are six sandalwood species of commercial value and that local Queensland sandalwood (*Santalum lanceolatum*) may have a potential to be developed into a commercial crop in Cape York. These studies have also found that there was little regeneration due to fire and grazing so there is a need to protect the Cape York sandalwood resource.
3. To realise the commercial potential of *S. lanceolatum* however there is a need to protect the trees in the wild (conservation), test how the species grows in plantations conditions (silviculture) and start a tree improvement program (domestication) that will provide a reliable source of seed for the community. As resource owners, Indigenous Communities have an opportunity to commercialise sandalwood, to produce a sustainable source of income.
4. Basic background on domestication and why wild sandalwood trees need to be 'captured' as grafts (to capture clones with high oil yield that will produce seed earlier than seedlings) and how trees are grafted.
5. Sandalwood silviculture including seed collection and seed pre treatment, the parasitic nature of sandalwood and associated requirement for host plants. Potential hosts such as nursery (*Alternanthera nana*), intermediate (*Sesbania formosa*), and long-term (*Pongamia pinnata* and *Acacia simsii*) species were discussed and used for the demonstration planting.
6. Establishing sandalwood plantings, watering, fertiliser, pest control and management and pruning of sandalwood to maximise value of sandalwood trees. Establish a sandalwood planting evaluating a range of sandalwood species and provenances on the community farm.
7. Local indigenous knowledge of sandalwood and its use in the community.

In the final year of project implementation the project established a working linkage with the Bamaga Senior Campus of the Northern Peninsula Area College. This linkage was made possible by educator Ms Jody Warbrick, has been proactive collaborator with the project and facilitated the approval and establishment of the sandalwood GSO. It is likely that any future project will continue the relationship with NPA College to potentially identify students interested to be involved with the project and participating in capacity building activities. The sandalwood activities of the College were featured in the Torre News (1st May 2015), which highlighted the conservation benefits, commercial potential and student engagement.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Whitewood scientific publications

Two scientific papers were published in 2012 that documented the results from the comparative statistical analyses of growth parameters between provenances and families of whitewood (*Endospermum medullosum*) in the IFP provenance-family trials at 11.4 years-of-age:

- Settle D.J., Page T., Doran J., Bush D., Sethy M. and Viji, I. 2012. Basic density, diameter and radial variation of Vanuatu whitewood (*Endospermum medullosum*): potential for breeding in a low density, tropical hardwood. International Forestry Review 14: 463-475.
- Doran J., Bush D., Page T., Glencross K., Sethy, M. and Viji, I. 2012. Variation in growth traits and wood density in whitewood (*Endospermum medullosum*): a major timber species in Vanuatu. International Forestry Review 14: 476-485.

These papers confirmed the superior growth rates and form found in trees from Espiritu Santo Island when planted in their home island. Heritabilities for key commercial traits were low to moderate and coupled with reasonable levels of additive genetic variation support the desirability of undertaking a recurrent selection and breeding program to capture genetic gain in those traits.

The paper by Doran et al. (2012) demonstrates clearly the loss of wild populations of whitewood in Vanuatu over the past decade and the urgent need for in-situ and ex-situ conservation measures. This paper has been cited several times in other scientific papers.

Whitewood technical reports

A series of experiments conducted during the project under the direction of David Dore build further scientific understanding of the basic biology of the species

Reproductive Biology

It was not possible during the course of this project to undertake controlled pollinations amongst selected trees to generate seed of full-sib pedigree. A prerequisite to applying controlled pollinations in a breeding program is a thorough knowledge of flowering phenology of the target species. This knowledge did not exist for whitewood in Vanuatu so basic studies were initiated in this project to monitor the development of flowers on a female tree and a male tree planted alongside the Luganville Forestry Nursery. This study will guide any future efforts in developing controlled pollination procedures in this species.

The aims of the study were to

- Identify and document the stages of bud, flower and seed development of whitewood.
- Record the duration of each phase in the phenology of whitewood seed.
- Record a photographic record of the wasp parasitism of whitewood seed.

The results were included in the report, **'Stages in the Development of Flowers and Seeds of Whitewood, *Endospermum medullosum*'**. Eleven stages in the process from bud initiation to seed fall were identified. Most stages were photographed but further documentation is needed for Stage 8 (seed closure), Stage 9 (seed swelling) and Stage 11 (seed fall). Photos of the wasp that causes damage to the whitewood seed are included. The length of time from bud emergence to mature seed was just over 5 weeks (39 days in this study). The factors that affect the magnitude and frequency of seed crops of whitewood are yet to be fully identified but may include lack of water stress, interval since last crop and the duration and intensity of rains during anthesis, when pollen needs to be circulated. The study did not include work on pollen collection, storage and viability, which are amongst many gaps in knowledge that will need to be addressed in future work on the species.

A practically relevant aspect of the reproductive biology and seed handling research was knowledge that the timing of seed collection can significantly affect the viability of the seed. It was found that seed must be collected at the peak of its ripeness to ensure that seed viability is optimised. Given that the seed crop ripens rapidly, attention to the logistics of seed crop monitoring and collection is an important practical consideration for developing this species in plantation forestry. The process of seed cleaning and preparation was documented, which is of critical importance to reduce seed loss due to parasitism and fungal infection, to ensure maximum germination. This new knowledge enables the DoF staff to improve the efficiency of their tree seedling production system through the enhanced germination rates.

Phenology Notes

The development of information relevant to the reliable identification of large male and female trees can improve the capacity for identifying candidate seed trees for later seed collection. As whitewood is dioecious and has very small flowers it can be difficult to visually distinguish male and females trees. A technical note was prepared titled **'Determining tree gender in mature whitewood (*Endospermum medullosum*) populations and notes on seed ripeness and handling'** to outline the best way to identify seed crop development and the sex of the tree, which is observable during the short flowering window that occurs. The purpose of the technical note is to enable observers to identify whether trees - which can be as tall as 40m - are male or female from ground observations. Local staff and trainees are now skilled in identifying male and female trees from the ground.

Seed Processing and Storage

The notes on seed ripeness and handling in the above report, outlines the process of examining seed viability through a flotation test, which is essential to discriminate between viable seed and those affected by wasp larvae. A seed storage experiment was also conducted, with initial tests using refrigeration or freezing of both whole drupes and cleaned seed. The results clearly demonstrated that both storage treatments were ineffective at extending seed viability of the seed. From the germination rates of the fresh seed it appears that seed viability in whitewood is characteristically low (13%); this is not a major operational issue as the species can produce copious amounts of seed. Further testing of seed storage procedures is warranted as lean seed years can disrupt the annual planting program for this species.

Vegetative Propagation

The vegetative propagation studies culminated in a technical note **Synthesis of knowledge of vegetative propagation of Whitewood, *Endospermum medullosum*** ad provided information on the amenability of the species to be cloned by a range of techniques. Cutting propagation using shoots of mature trees is problematic, with very low survival. While it is technically possible for mature whitewood to be propagated by grafting/budding, the difficulty and generally low level of success renders it practically irrelevant. While coppicing is possible after tree felling, not all matures trees produce coppice shoots, making it unreliable for producing clones of mature selections. Attempts to encourage coppicing in standing trees by cincturing and root severing were not successful. Cuttings and layering using very young material (~12 months) and cuttings from coppiced saplings (<3years) were most successful. This work on vegetative propagation, combined with the knowledge of the close genetic correlations measured in growth and form between young and old trees, offers the potential for selecting and cloning plus trees from a relatively young age (3-years).

Sandalwood scientific publications

Sandalwood floral phenology data has been published as a conference paper. It was presented by the lead author at the Sandalwood Symposium in Hawaii in October 2012.

- Page T., Gabriel E., and Tate H.2012. Floral phenology in three species of sandalwood (*Santalum album*, *S. austrocaledonicum* and *S. lanceolatum*). Paper presented at the International Sandalwood Symposium, East-West Center, University of Hawai'i, Manoa, Honolulu, HI, 21-24 October 2012.

The paper provides a comparative account of both the morphology and phenology of three different sandalwood species. This information is of particular importance to understanding the factors that may influence successful seed set in these commercially important species as well as informing plant breeders of the floral characteristics that will affect controlled pollination.

Sandalwood reproductive biology was published during the project by Hanington Tate, Jonathan Cornelius and Tony Page.

- Tamla H.T., Cornelius J. and Page T. 2011. Reproductive biology of three commercially valuable *Santalum* species: development of flowers and inflorescences, breeding systems, and interspecific crossability. Euphytica 84: 323-333.

This paper is of significance to the conservation and domestication of three tropical and commercial sandalwood species. Given the hybridisation of the species it highlights the importance of considering intercrossing when introducing an exotic sandalwood species within the range of an existing native species. The findings indicate that self-compatibility varies between genotypes, which confirms some earlier anecdotal observations of some trees producing seed in isolation of other sandalwood trees. Another contribution is that some trees have a much higher fecundity than others, which supports the folklore varieties identified in Vanuatu as 'man' or 'woman'.

8.2 Capacity impacts – now and in 5 years

A) Enhanced capacity via publication and dissemination of technical information

A series of training notes, books, video clips and toolkits have been published to support this project, developed in collaboration with partners and distributed to community nurseries. The titles are:

- Page T., Tate H., Tungon J., Tabi M. and Kamasteia P. 2012. Vanuatu Sandalwood: Growers guide for sandalwood production in Vanuatu. ACIAR Monograph No. 151. Australian Centre for International Agricultural Research, Canberra.
- Page, T., Tate H., Tungon J., Tabi M. and Kamasteia. 2013. Sandelwud blong Vanuatu: Gaed blong planem sandelwud long Vanuatu. ACIAR Monograph No. 151a. Canberra: Australian Centre for International Agricultural Research.
- Multi-media toolkit includes relevant content for smallholder Pacific Forestry, much of the video content from the extension DVD is included in the kit (www.pip.com.pg)

The publication of a Vanuatu Sandalwood growers guide as part of the ACIAR Monograph series (English No. 151 and Bislama No. 151a) has been important in building greater capacity for local landowners to establish and maintain high quality sandalwood plantings.

To improve the effectiveness of the dissemination of the technical information on growing sandalwood, this ACIAR monograph was prepared in both English and Bislama language versions. The Bislama version was printed on waterproof paper to make it more durable in tropical village settings. The DoF received 4,500 copies of the Bislama language version of this monograph, of which 2,400 were distributed by June 2015. The recipients of the monograph include farmers, government departments, educations institutions, private companies, and non-government organisations. With the remaining 3,100 to be distributed, a further focus on distributing to areas with vibrant sandalwood farming sectors such as Tafea, Malampa and Sanma is recommended.

Table 12: Number of sandalwood growers guides distributed by island.

Province	Island	Total
Banks (90)	Vanua Lava	90
Malampa (90)	Malekula	90
NA (9)	NA	9
Penama (499)	Ambae	495
	Pentecost	4
Sanma (405)	Santo	405
Shefa (1032)	Efate	983
	Epi	1
	Nguna	1
	Pele	45
	Tongoa	2
Tafea (275)	Aneityum	90
	Erromango	91
	Futuna	2
	Tanna	92
	Total	2400

Sanma Province hosts a Sandalwood Field Day

The Sandalwood Forestry Field Day was conducted at South Santo on the 28th of July 2014 at the Karai Boro Conference Area. The sandalwood field day targeted the off shore islands of Sanma province and 30 participants attended the workshop, of which 10 were female. The field day was a one day event mainly for farmers with already established plants or those interested in future planting.

Participants were provided with classroom teaching sessions and demonstrations in the field. The day was a success with the participants receiving briefings on sandalwood propagation in the nursery, planting in the field and basic silviculture. On completion of the workshop the Sandalwood Growers Guide was distributed to the participants as a completion gift. The general feedback on the field day from participants was very positive. The success of the day was concluded with positive comments from three participants broadcast live on the National Radio of Vanuatu.

The shortage of planting materials such as seeds, seedlings or wildings was highlighted as a challenge for most participants at the sandalwood field day. During this discussion, the new manager of Navota Farm welcomed farmers to access seeds or wildings from the Navota Farm sandalwood gene planting to use at their own farms. An inspection of the Navota sandalwood planting during the end of project review revealed that local landowners were regularly harvesting the sandalwood seed from this site.

B) Enhancing DoF capacity to deliver improved sandalwood and whitewood germplasm

Capacity building of DoF staff

This project worked closely with the DoF Research Section, particularly with staff members Michael Tabi and Mesek Sethy, in collaboration with Research Manager Joseph Tungon. In-house training in practical aspects of the project was conducted including vegetative propagation of whitewood, grafting propagation of sandalwood, establishment of randomised trials and demonstration plots and measurement of tree growth and form. The project also worked with Joseph Tungon to elevate the management capacity of the research staff. Michael Tabi was appointed as in-country project leader in mid-2013, after changes to DoF senior management and the appointment of the previous Project Manager, Hanington Tate, as Director of DoF. The project worked closely with Michael, who oversaw great advances in sandalwood grafting and establishment of the GSOs throughout 2014 and early 2015. Michael demonstrated a very high capacity for management and implementation of practical elements of the project. Project staff continued to work with Joseph Tungon and other senior management to build Michael's capacity for staff management and engagement. This has included the 2015 appointment of forestry trainee Samuel Bebe as a junior researcher within the Research Section.

Project staff also worked closely with Mesek Sethy, who was central to the multiple outputs of whitewood component of the project. Mesek developed and improved his capacity for implementing complex seed collection strategies from whitewood at IFP through the capacity building activities conducted by project staff John Doran and David Lea. This culminated in a fully independent collection made by Mesek and more junior staff members Rinnath Miltek, James Toa, David Silas, Mackense Naupa, Kipson Lokai and Roy Willie. Mesek continues to build an impressive management and practical skill set in the establishment, maintenance and measurement of research trials. His skills, knowledge and work ethic is greatly valued by ACIAR projects operating with DoF in Santo. To ensure departmental retention of this knowledge it would be judicious of DoF management to consider a planned approach to the transfer of Mesek's knowledge and skills to emerging younger staff members.

Establish a seed storage facility with the capacity for long-term storage of orthodox seeds and pollen

DoF has experienced periods when seed of their priority species like sandalwood and whitewood is scarce and this effects annual planting programs. It would be a great advantage if seed from seasons when crops are large ('mast years') could be stored in the medium to long term to cover seed shortfalls in poor seasons. To aid the ability of DoF to store seed, a seed storage facility was constructed within the Forestry Office block in Tagabe, Efate with funding from the project. The facility is 3x4x3m cool room with backup generator. The cool room became operational in May 2011 but DoF has not been able to run the facility because of the costs of power and fuel.

Following the devastating effects of Cyclone Pam on the forests of southern Vanuatu with and estimated 80% of timber trees damaged or destroyed, seed production of key forest tree species is expected to be hampered for several years. In order for nurseries and production to be restored, DoF plans to collect seed from unaffected islands for redistribution to affected areas and use the project cool room for short to medium term storage of this seed. DoF and Department of Agriculture have made a joint submission to the 'Medium and Long Term Recovery and Rehabilitation Strategy 2015-2017' of Risk and Resilience Unit Cyclone Pam, Ministry of Agriculture, Livestock, Forestry, Fisheries and Biosecurity for funding to operate the cool room for this purpose. The outcome of this submission will be decided during 2016.

Upgrading of DoF nursery facilities

At Tagabe forestry nursery, a chain-lock security fence was constructed around the nursery to reduce sandalwood seedling theft, which had become unmanageable. The fence was very effective and losses due to theft were negligible throughout the project. A small shade house was constructed for the initial placement of sandalwood grafts.

At Luganville forestry nursery, concrete germination beds overhead plastic film and shade were constructed to protect germinating seed from heavy rain. This followed the disastrous whitewood sowings of 2013 when most germination beds were washed away by heavy rains. Concrete barriers were constructed around all standout beds in the Luganville nursery, which replaced the high-maintenance wooden barriers used previously. These standout beds were still in good condition at the conclusion of this project. A small solar-powered misting facility was constructed towards the end of 2014 for rooting whitewood stem cuttings. It was used successfully in this project and will serve as an important facility for the DoF.

In the Malekula nursery a shade structure was installed over half of the standout beds to protect developing seedlings in the nursery.

Training in seed collection and vegetative propagation

The training of DoF staff in whitewood seed collection using the ‘Big Shot’ catapult and most importantly the documentation to accompany such collections was provided by David Lea in 2011 and 2013. DoF’s Luganville staff are now competent whitewood seed collectors and carried out the individual plus tree collections at IFP in 2015 independently.

The project funded the participation of five DoF officers to attend the CSIRO, AusAID-funded Tree Seed Technology Training Course in Port Vila in April 2012. This led directly to the successful whitewood seed collections at Malo and Banks, which was of great benefit to the project.

The training in grafting sandalwood provided by David Spencer at Tagabe forestry nursery in 2013 and again in 2014 was highly successful. Following this training, DoF staff were able to carry out the grafting needed to establish the GSOs at several sites with a high level of success, producing approximately 300 grafted sandalwood plants during the project. The grafting training provided for whitewood by both David Lea and David Dore was not successful and led to a change in clonal strategy away from grafting using scions from mature trees to striking stem cuttings from coppice shoots from trees selected at 3 years-of-age.

8.3 Community impacts – now and in 5 years

The project has facilitated some important community initiatives, which will have a positive impact on their capacity for high value smallholder forestry in the future. The significance of replicating the Sandalwood GSOs on five northern islands of Vanuatu cannot be understated. Communities from these islands have had very little opportunity to participate in the lucrative sandalwood industry in the past because of the difficulty in obtaining seed. The sandalwood industry is largely one confined to the southern province of Tafea. The establishment of the GSOs deliver positive benefits in terms of the in-field community training conducted at the time of planting and subsequent maintenance activities as well as the opportunity to plant sandalwood from the seeds expected to be produced from the trees in the coming years.

The gene conservation planting at Navota Farm is now producing significant volumes of seed, which are being collected by the students of the farm, as well as community members surrounding the planting. In addition, wildings are now being observed in the secondary regrowth vegetation in the area, a development that is viewed very positively by local residents.

In whitewood, seedlings propagated from seed of plus trees at IFP have been distributed to farmers in Santo and Malekula. In addition, improved seed from this source has been used by the ACIAR Whitewood Silviculture Project (FST/2012/042) as well as in the seven whitewood demonstration plots established by this project. The anticipated faster growth and better form of the improved seedlots in these trials is expected to increase farmer interest in establishing whitewood plantations based on the improved IFP seed. IFP will be the main source of improved seed for several years to come until replaced by second generation SSO seed from Bombua and Onesua.

The work on cloning by stem cuttings the best selections at 3 years-of-age from Bombua offers exciting scope post project to increase genetic gain by deployment of best clones and establishment of clonal seed orchards.

Northern Island Farmer Training

The project conducted farmer extension in June 2010 with farm visits at Vinmavis, Tautu, (Malekula), Wusi, Penouru (Santo), Saratamata (Ambae), Baravat (Pentecost), Port Vato (Ambrym), Lamen Bay and Brisbane (Epi). A three-day growers workshop was held in each of Tisvel (Malekula) and Hokua (Santo). The workshops covered the current state of knowledge for sandalwood production in Vanuatu from seed collection to harvesting and marketing, largely following the content in which the ACIAR monograph was based. The workshops also contained field demonstrations and record video content (peer-to-peer) for the production of an extension DVD. The DVD was distributed widely among grassroot networks across Vanuatu during the implementation of the project. The DVD was duplicated by local vendors and sold into local markets. While it was not possible to determine the full extent of distribution, it is believed to reach well beyond the extension networks of DoF. The workshop was received very positively among the participants and in Hokua culminated in the establishment of the Wunmaho Sandalwood Growers Association. The Australian Project Leader maintained regular contact with members of these communities throughout the course of the project and noted a reported spike in sandalwood planting. Several progressive farmers are now distributing seed commercially throughout Vanuatu, including clients as far as Tanna, the DoF and ACIAR projects. The livelihood of these farmers has improved considerably through the sale of seed and elevation of their status within their community. This development has positive impacts to both community forestry and conservation of the Malekula and Santo provenances (with known high-oil quality). The project leader considers this single extension activity to have had a high impact and worthy of follow up to determine the extent of this perceived impact. Consideration may also be given to establishing a development project to implement a national training and extension program that aims to engage directly with farmers and training providers. Such a project may aim to build capacity of individuals to establish productive sandalwood plantings, training institutions to deliver research informed training and industry leaders to build local and national support networks.

Radio press coverage of sandalwood and whitewood

Several radio events have been conducted by DoF staff in association with the launch of the Sandalwood Manual (ACIAR Monograph 149) and the tree planting training days. A radio interview was conducted for the Panita tree planting to allow farmers to express what the plantation means to them and what impact it will have on their lives. There was a live broadcast by the National Radio of Vanuatu on the Sandalwood Forestry Field Day at South Santo, with three participants expressing their learning outcomes from the day. An additional Sandalwood training workshop was conducted in Santo by DoF as part of their promotion of the sandalwood monograph (see ABC Rural in March 2015). Joseph Tungon and John Doran had a radio interview during the planting of the Onesua whitewood progeny trial in 2012 to build awareness of the project and potential community benefits.

Panita tree planting, 2 May 2014

A tree planting in the village of Panita (Tongoa and the Shepherds islands) went ahead in May 2014. It was held at the Presbytery Women Mission Union hall and with opening speeches from the Vice Chairman of the community council Mr. Robert Andrew and Deputy Director Watson Lui.

In Panita, fishing has long been an important source of income for the community, however in 2014 the whole village (>100 people) rallied instead for a tree planting. The central idea was for each of the 33 households to plant 10 sandalwood trees that year and when the trees are harvested in year 20, one tree will be allocated to the Church, one to the village council and the rest to the farmer. The main focus of the plantation was on sandalwood and mahogany – due to their high economic returns – however other local species were promoted for use as roundhouse materials (culturally significant structures designed to withstand cyclones).

Panita village is the main port of entry for Tongoa and over the years, there has been evidence of severe coastal erosion resulting in some households moving further inland. It was suggested some years ago that the village would need to relocate inland as a precautionary measure from any major tsunami. To manage some of the environmental impacts on the community, the tree planting raised awareness of three practises; (1) the promotion of roundhouses to withstand storms, (2) keeping fruit trees low for easy access and to prevent damage to households and (3) replanting sandalwood and mahogany for economical purposes.

The whole community demonstrated their support by participating in the tree planting and a mini nursery was established where the seeds were sown. The community also committed 30,000 Vatu (~$350 AUD) as part payment towards the sandalwood seedlings in Port Vila. There are plans to nominate an annual celebration of the tree planting to commemorate the initiative and raise awareness in future generations.

8.3.1 Economic impacts

The positive economic impact of the wide distribution of the book entitled “Sandelwud blong Vanuatu: Gaed blong planem sandelwud long Vanuatu” is already evident with reported evidence of many new smallholder nurseries being established after receiving the book. Tree nursery initiatives have typically relied on the interventions of Extension Officers from the DoF, but now many farmers in Efate and Ambae have been sourcing and sowing sandalwood seeds in their own nurseries without external assistance. While the potential increase in planting activity associated with this guide is yet to be quantified, early evidence indicates that it is stimulating greater activity in this area. It is apparent that this ACIAR supported publication is already having a positive economic impact by stimulating greater smallholder participation and improving nursery and woodlot management.

The economic impact of germplasm deployment is not yet adequately quantified, as it was not monitored during the implementation of the project. Knowledge of the gains achieved by breeding distribution of the improved germplasm is essential to determine the economic impact of the research.

DoF management needs to consider establishing systems to adequately record the distribution from the key sandalwood genetic resources. This is important so that the benefits of the research can be quantified, as well as provide to the market the deployment of and location of plantings established with improved sandalwood genetics.

The process for quantifying whitewood deployment is relatively straightforward, since DoF reports that IFP is the single most important seed resource. DoF has estimated that over 90% of national whitewood seeds would be currently sourced from IFP. With highly improved seed becoming available within the next five years from the second generation SSO at Bombua and later from the Navota SSO, the DoF represents a single source for genetically improved whitewood seeds in Vanuatu. DoF have also identified that around 100 hectares of whitewood are currently being planted annually using seed from IFP. Detailed records of farmers, locations and numbers of seedlings established are yet to be provided to the project.

Quantifying the distribution of sandalwood from the improved resources, particularly the Tagabe GSO, has been problematic. Since the establishment of the original GSO in 2007, DoF has provided anecdotal information as to the seed productivity of the orchard and no information as to the distribution of the seed. DoF has indicated on several occasions that the orchard has not produced significant volumes of seed and at times of production this seed has been lost due to theft. Good seed crops (both developing and mature) have been observed by visiting scientists on several visits and the earlier issue of theft of seedlings has been resolved with the installation of the security fence. It is recognised that the GSO rejuvenation conducted during this project increased vegetative vigour (for scion collection) at the expense of flowering and fruiting. Towards the end of the project however the trees entered a more physiologically mature stage with a high propensity for flowering and seed set.

With the high value of the seed it is possible that DoF workers and technicians have been actively collecting seed for planting in their customary lands. While project management does not have any objection to this kind of distribution strategy, it is important that it is adequately documented by DoF.

It was not practical during the course of this project to establish realised genetic gain (yield) trials to more realistically quantify the levels of improvement in economic traits for whitewood and sandalwood due to breeding activities. This was because improved seed sources were still being developed. DoF and ACIAR should now consider establishment of such trials as a matter of priority as this knowledge is needed to accurately quantify economic impacts of the research and to provide information that will assist in determining future breeding strategy with these species.

8.3.2 Environmental impacts

Conservation of genetic resources

The importance of the ex-situ conservation of whitewood genetic resources in progeny trials and gene banks cannot be overstated. The IFP family-provenance trial/SSO1 now contains the only germplasm of nine of the fourteen island wild populations included in the trial. The nine populations have been lost from the wild due to harvesting and clearing.

Conservation of sandalwood populations at Navota is also of considerable importance now functions as a repository for a representative sample of Vanuatu sandalwood. This stand is a readily accessible resource that can be used for further research purposes, as well as being a source for seed for community plantings in South Santo. The lack of representation from populations from north Efate is still of concern. This stems from the small numbers of reproductively mature trees currently in this region. The securing of seed and establishing a plot from trees of north Efate depends on logistical considerations rather than investment of significant resources and it would be judicious for the DoF to follow up this for the conservation of Vanuatu sandalwood.

8.4 Communication and dissemination activities

Formal communications with ACIAR

- 4 Annual Reports
- Trip reports by Australian personnel visiting Vanuatu and Cape York Peninsula

In country project communication

- Inception meeting at commencement of project involving DoF and representatives from Australian agencies
- Six monthly field visits by project leader (Tony Page) with field reports distributed to project collaborators

- Three monthly reports from Mesek Sethy (DoF) to project collaborators
- Six monthly field trip reports from John Doran (Forestry Consultant)
- Periodic seminars by project staff held at DoF with field site visits
- Regular email and phone exchanges between Vanuatu and Australian personnel

Scientific Publications

- Settle D.J., Page T., Doran J., Bush D., Sethy M., and Viji I. 2012. Basic density, diameter and radial variation of Vanuatu whitewood (*Endospermum medullosum*): potential for breeding in a low density, tropical hardwood. International Forestry Review 14: 463-475.
- Doran J., Bush D., Page T., Glencross K., Sethy M., and Viji I. 2012. Variation in growth traits and wood density in whitewood (*Endospermum medullosum*): a major timber species in Vanuatu. International Forestry Review 14: 476-485.
- Page T., Gabriel E. and Tate H. 2012. Floral phenology in three species of sandalwood (*Santalum album, S. austrocaledonicum* and *S. lanceolatum*). Paper presented at the International Sandalwood Symposium, East-West Center, University of Hawai'i, Manoa, Honolulu, HI, 21-24 October 2012.
- Tamla H.T., Cornelius J. and Page T. 2011. Reproductive biology of three commercially valuable *Santalum* species: development of flowers and inflorescences, breeding systems, and interspecific crossability. Euphytica 84: 323-333.
- Page T., Southwell I., Russell M., Tate H., Tungon J. et al. 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.
- Page T., Potrawiak A., Berry A., Tate H., Tungon J. et al. 2010. Production of sandalwood (*Santalum austrocaledonicum*) for improved smallholder incomes. Trees and Livelihoods 19: 299-316.

Other publications

A series of training notes, books and toolkits have been published to support this project, developed in collaboration with partners and distributed to community nurseries. The titles are:

- Page T., Tate H., Tungon J., Tabi M. and Kamasteia P. 2012. Vanuatu Sandalwood: Growers guide for sandalwood production in Vanuatu. ACIAR Monograph No. 151. Australian Centre for International Agricultural Research, Canberra.
- Page, T., Tate H., Tungon J., Tabi M. and Kamasteia, P. 2013. Sandelwud blong Vanuatu: Gaed blong planem sandelwud long Vanuatu. ACIAR Monograph No. 151a. Canberra: Australian Centre for International Agricultural Research.
- Page T., Tate H., Bunt C., Potrawiak A. and Berry A. 2010. Opportunities for the smallholder sandalwood industry in Vanuatu. Technical Report No.79. Australian Centre for International Agricultural Research, Canberra.
- Torello-Raventos M., Ford A., Page T., Metcalf D., Saiza G., Lloyd J. and Bird M. (in prep) Non-destructive, in-field determination of wood density in tropical forests.
- Multi-media toolkit includes relevant content for smallholder Pacific Forestry, much of the video content from the extension DVD is included in the kit (www.pip.com.pg).

- Tabi, M., S. Bebe, M. Sethy and J. Tungon (2015). Western Australia Sandalwood Industry Study Tour Report. Port Vila. Vanuatu Department of Forests.
- DoF Internal Technical Reports
- Dore, D. 2014. Whitewood seed preservation experiment.
- Dore D., Page T. and Doran J. 2015. Synthesis of knowledge of vegetative propagation of Whitewood, *Endospermum medullosum.* May 2015.
- Dore D. and Page T. 2015. Stages in the development of flowers and seeds of whitewood, *Endospermum medullosum*. February 2015

8.5 Conclusions

This project addresses the existing constraints to tree germplasm supply by developing and deploying an improved genetic resource to underpin the emerging sandalwood and whitewood industries in Vanuatu, and to provide a genetic base for a future sandalwood industry in northern Queensland.

In whitewood, existing progeny trials at IFP established under the AusAID SPRIG project in 1998/99 have been thinned to become one large contiguous first generation seedling seed orchard (SSO1) providing seed for general deployment and for second generation progeny trials. This SSO1 should be Vanuatu's primary source of whitewood seed for establishing plantation and agroforestry plots for several years ahead until second generation seed orchards produce even more highly improved seed.

Three second generation progeny trials have been established and initial thinning to half stocking of the oldest (3.25 years) trial at Bombua took place in 2015. The 2014 planting at Navota was decimated (60% mortality) by cattle and will need to be replanted by DoF. A new genebank has been established incorporating seedlots from provenances not previously included in the breeding program and demonstration plantings were established at six locations with four currently functioning well as demonstrations (Pentecost, Ambrym, Epi and Malekula (Pinalum)).

Project research on variability and heritability of key economic traits, the serious erosion of genetic resources in the wild, floral biology, seed storage and clonal propagation will underpin future breeding and conservation efforts in this species.

For Vanuatu sandalwood, the GSO has been successfully replicated across six sites, and with only modest inputs DoF has the capacity to continue further replication across the country. The completion of the gene resources planting at Navota potentially offers an easily accessible resource for DoF to undertake further selections based on tree vigour, form and heartwood development. This, combined with further seed collections made from the replicated GSOs can be used to expand the progeny trial at La Bouffa. This approach will rapidly broaden the genetic diversity available for second-generation selections, and permit longer-term improvement across a range of economic characters. All three strategic genetic resources (GSOs, Navota and La Bouffa) are located in close proximity to DoF offices in Efate and Santo, which will permit cost-effective continuation of improvement of this species. The planting and expansion of La Bouffa should be considered as a very important strategic resource for sandalwood development in Vanuatu. Given this consideration, it is of utmost importance that the DoF enter into a binding agreement with the landowners (VNPF) to ensure DOF long-term access and use of this resource. Such an agreement should survive any change in ownership and considered to be essential to ongoing sandalwood improvement and attracting future research and development funding.

For sandalwood in Cape York Peninsula, two grafted clonal seed orchards have been established on secure government land (with traditional owner approval) at Walkamin

Research Station and at Northern Peninsula Area College. These seed orchards represent an important first step to the conservation and domestication of this species, and they will quickly become a source of seed. Given the embryonic stage of the species development, the priority for this seed should be to establish a genetically diverse progeny trial. It would be recommended that it be established as a family-line plot trial and progressively thinned according to tree vigour and form to become a productive seedling seed orchard.

Despite the early stages of the development of sandalwood in CYP, consideration should be given to explore the commercial potential of the clones and seed derived from the CSO. This is important to demonstrate the prospective economic value of commercialising the germplasm, and sandalwood production. Such opportunities could be explored by facilitating communication between Traditional Owners and interested commercial partners. It is important that ACIAR maintain a presence with sandalwood development in Cape York Peninsula since productive collaborations in Indigenous communities requires continuity. This current project represents the first genuine engagement with communities on indigenous sandalwood and although challenges were encountered it was clear that some momentum had been gained towards the end of the project. While great opportunity exists for developing sandalwood in Cape York Peninsula, it depends on building trusting relationships over time.

Sandalwood demonstration plantings were established at Lockhart River and Bamaga community farms in cooperation with community members. These demonstration plots provide an avenue for further engagement with and training within these communities. The development of closer linkages with the NPA College towards the end of the project was important for the establishment of the grafted seed orchard and offers the potential for more meaningful engagement with prospective project participants and future generations of Indigenous people.

A major strength of the project has been the quality of the project leadership, in both professional and personal terms. DoF and Australian project staff have participated enthusiastically in all aspects of the project. The weaknesses of the project are, of course, those common to most development projects namely lack of adequate resources of personnel, funds and facilities. One specific weakness – some deficiencies in the administrative procedures related to transfer of project funds from Head Office to the field offices for project operations – should be addressed in any future projects. This problem frequently stopped or seriously delayed crucial field operations, which were time- or seasonally-bound. The project has met all of its milestones for whitewood and most for sandalwood, despite the major constraints of working in remote areas in both Vanuatu and Australia with limited staff and resources.

The DoF already implements development activities to support the forestry plantation sector and distributes improved germplasm of whitewood, sandalwood and other priority species. The DoF should genuinely consider putting simple systems in place to i) capture this important information, as it will provide the basis for further donor funding and support and ii) assist the plantation sector to better understand the nature and quality of its resource. Marketing should be enhanced by such insights.

Genetic improvement of tree crops is invariably a long-term activity requiring the host organisation to provide substantial on-going physical, human and financial resources to the program. This project has provided a very useful start to the improvement of germplasm of whitewood and sandalwood in Vanuatu and deployment of improved seed throughout the country. However, much more can be done with further development of the seed orchard and clonal forestry components established by this project to ensure that highly improved germplasm of both species is available to growers in the future. DoF, which is a very small government agency, will be hard pressed to make the required inputs of staff, vehicles and finances to see the program continue at full strength into the future. It is strongly recommended, therefore, that ACIAR consider funding a follow-on advanced breeding project for whitewood and sandalwood so that the genetic resources established in this project are further developed to the benefit of the whitewood and sandalwood growers of Vanuatu. These crucial resources will be at risk without a follow-on project.

8.6 Recommendations

One of the most important measures which needs to be incorporated into future assistance projects (of any type) to DoF is emphasis on and practical help in storing, both electronically with back up and in hard copy, trial information including reports, maps, data, statistical analyses etc. At present there appears to be no formal way of doing this in-country and there is a high risk of information being lost over time.

It is recommended that the proposed follow-on tree breeding project (see conclusions) addresses the following issues/activities:

For whitewood –

- Continuing access of DoF personnel to the IFP SSO1 is of paramount importance and needs to be negotiated with the traditional owners as a matter of urgency. This source of improved seed will be required for several years until project 2nd gen SSOs mature and start to produce improved seed in quantities.
- Replanting of Navota 2ndgen progeny trial that has suffered 60% mortality due to cattle damage be undertaken as a priority activity.
- Establish a genetic gain (yield) trial as soon as possible. This is needed to quantify the genetic gain actually realised in improved plantations and the financial return on the investment in breeding.

For sandalwood (in Vanuatu) –

- Continue replication of the grafted seed orchard to many more islands/sites.
- Consider formal linkages with private growers to assist with the deployment of improved germplasm.
- Domestication activities to include scope for selection for and improvement of vigour, form and early heartwood formation.
- Ensure a binding agreement is entered with VNPF prior to establishing the La Bouffa progeny trial, to secure long-term maintenance and DoF access to trees for data and propagule (stems & seed) collection.
- Implement the renovation at Navota Gene Conservation stand as planned, to include host enrichment, pruning and fertilising.
- Identify candidate seed trees from later-planted provenances (Aniwa, Santo & Malekula) at Navota.
- Collect seed from Navota and GSOs and continue to expand La Bouffa progeny planting.

For sandalwood (in CYP) –

- Increase the number of clones represented in the clonal seed (50+) orchards to broaden the genetic diversity, with priority to high oil quality forms.
- Establish sandalwood progeny trial trials using seed collected from the grafted clonal seed orchards, and where possible, wild populations.
- Explore opportunities for commercialisation of the CYP germplasm, and sandalwood production.

9 References

In this section, list references used in the report as well as providing a list of all project publications.

9.1 References cited in report

AusAID (2006). Pacific 2020: Challenges and Opportunities for Growth. Canberra, AusAID.

Bond, A. (2006). Pacific 2020: Background Paper - Forestry.

Doran J., Bush D., Page T., Glencross K., Sethy M., and Viji I. 2012. Variation in growth traits and wood density in whitewood (*Endospermum medullosum*): a major timber species in Vanuatu. International Forestry Review. 14: 476-485.

Dore D. and Page T. 2015. Stages in the development of flowers and seeds of whitewood, *Endospermum medullosum*. Internal Technical Report to DoF, February 2015.

Dore D., Page T. and Doran J. 2015. Synthesis of knowledge of vegetative propagation of Whitewood, *Endospermum medullosum.* Internal Technical Report to DoF, May 2015.

Keating, W.G., Bolza, E., 1982. Characteristics, Properties and Uses of Timbers. Vol. 1. Southeast Asia, Northern Australia and the Pacific. Inkata Press, Melbourne.

Kelly N. 2009. *Corymbia* hybrid non-destructive clonal coppice promotion techniques. Internal Report Queensland Primary Industries and Fisheries, September 2009.

VDoF (1997). National Forest Policy Statement. Port Vila, Vanuatu, Vanuatu Department of Forests. Ministry of Agriculture, Livestock, Forests, Fisheries and Environment. Government of the Republic of Vanuatu.

VDoF (2002). Sandalwood Policy. Port Vila, Vanuatu, Department of Forests Vanuatu, Ministry of Agriculture, Livestock, Forests, Fisheries and Environment. Government of the Republic of Vanuatu.

VDoF (2013). Vanuatu Forest Policy: 2013 - 2023. Port Vila, Vanuatu Department of Forests. Ministry of Agriculture, Livestock, Forests, Fisheries and Environment. Government of the Republic of Vanuatu.

Settle D.J., Page T., Doran J., Bush D., Sethy M., and Viji I. 2012. Basic density, diameter and radial variation of Vanuatu whitewood (*Endospermum medullosum*): potential for breeding in a low density, tropical hardwood. International Forestry Review. 14: 463-475.

Tate, H., Sethy, M. and J. Tungon, J. 2006. Grafting of sandalwood in Vanuatu. Sandalwood Research Newsletter. 21: 7.

Thomson, L.A.J., 2006. *Endospermum medullosum* (whitewood) Euphorbiaceae (spurge family). Permanent Agriculture Resources (PAR), Holualoa.

Tungon, J. and Tabi, M. 2015. Rapid assessment report: Cyclone Pam's impacts on main plantation tree species on Efate. Port Vila, Vanuatu Department of Forests. Ministry of Agriculture, Livestock, Forests and Fisheries. Government of the Republic of Vanuatu.

Vutilolo I.V.N., Tyagi A.P and Thomson L. 2008. Genetic variation in growth traits in whitewood (*Endospermum medullosum* LS Smith) in Vanuatu. South Pacific Journal of Natural Sciences. 26: 1–10.

Walker S. and Haines R. 1996. Melcoffee hardwood plantation project in Vanuatu: Current status and future directions. Pacific Islands Forests and Trees December 1996.

9.2 List of publications produced by project

Settle D.J., Page T., Doran J., Bush D., Sethy M., and Viji I. 2012. Basic density, diameter and radial variation of Vanuatu whitewood (*Endospermum medullosum*): potential for breeding in a low density, tropical hardwood. International Forestry Review 14: 463-475.

Doran J., Bush D., Page T., Glencross K., Sethy M., and Viji I. 2012. Variation in growth traits and wood density in whitewood (*Endospermum medullosum*): a major timber species in Vanuatu. International Forestry Review 14: 476-485.

Page T., Gabriel E. and Tate H. 2012. Floral phenology in three species of sandalwood (*Santalum album, S. austrocaledonicum* and *S. lanceolatum*). Paper presented at the International Sandalwood Symposium, East-West Center, University of Hawai'i, Manoa, Honolulu, HI, 21-24 October 2012.

Tamla H.T., Cornelius J. and Page T. 2011. Reproductive biology of three commercially valuable *Santalum* species: development of flowers and inflorescences, breeding systems, and interspecific crossability. Euphytica 84: 323-333.

Page T., Southwell I., Russell M., Tate H., Tungon J. et al. 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.

Page T., Potrawiak A., Berry A., Tate H., Tungon J. et al. 2010. Production of sandalwood (*Santalum austrocaledonicum*) for improved smallholder incomes. Trees and Livelihoods 19: 299-316.

Page, T., Tate, H., Bunt, C., Potrawiak, A., Berry, A., 2012. Opportunities for the smallholder sandalwood industry in Vanuatu. Australian Center for International Agricultural Research (ACIAR), Canberra.

Page, T., Tate, H., Tungon, J., Tabi, M., Kamasteia, P., 2012. Vanuatu Sandalwood: Growers' guide for sandalwood production in Vanuatu. Australian Centre for International Agricultural Research, Canberra.

Page, T., Tate, H., Tungon, J., Tabi, M., Kamasteia, P., 2013. Sandelwud blong Vanuatu: Gaed blong planem sandelwud long Vanuatu. Australian Centre for International Agricultural Research, Canberra.