

PROCEEDINGS of the
REGIONAL WORKSHOP on SANDALWOOD
RESEARCH, DEVELOPMENT and EXTENSION
in the PACIFIC ISLANDS

28 November - 1 December 2005
Nadi, Fiji

Edited by
Dr Lex Thomson
Mr Sairusi Bulai
Ms Bale Wilikibau



Australian Government
AusAID

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Growth Through Knowledge

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CONTENTS

Foreword	7
Abbreviations	9
Workshop Proper.....	11
Major Recommendations of the Workshop.....	16
Group Session Findings	17
PART A – COUNTRY PAPERS	20
Cook Islands.....	21
Fiji	27
French Polynesia.....	35
Indonesia	43
New Caledonia.....	51
Papua New Guinea.....	57
Vanuatu	63
PART B - TECHNICAL AND DEVELOPMENT PAPERS	72
Sandalwood (<i>Santalum insulare</i>) Planting Efforts in French Polynesia.....	73
Chemical Variability of Sandalwood Populations in New Caledonia.....	81
Indian Sandalwood (<i>Santalum album</i> L) Variation in Sesquiterpenoid Composition and Possible Biogenetic Pathways	87
Development of the Indian Sandalwood Industry on the ORD River Irrigation Area.....	93
Chemical Variation in the Oils of <i>Santalum macgregorii</i> (PNG Sandalwood).....	101
Sandalwood Phylogeny; Insights for Biogeography, Conservation and Classification.....	109
Vanuatu Sandalwood - An Industry Perspective from Tropical Rainforest Aromatics Limited	115
Evaluation of Heartwood and Oil Characters in Nine Populations of <i>Santalum Austrocaledonicum</i> from Vanuatu.....	123
Evaluation of heartwood and oil characters in seven populations of <i>Santalum lanceolatum</i> from Cape York	131
APPENDICES	137
A - Workshop Programme.....	138
B - Working Session Groups.....	140
C - Participants List	142
D - Workshop in Pictures	147





FOREWORD

Sandalwoods (*Santalum* species) have considerable cultural and economic importance to many communities in the Asia - Pacific region. It is for this reason that conservation of the species in the genus is an important issue and needs special attention to ensure its sustainable management. The high economic values of sandalwood species coupled with their amenability to cultivation, in agroforestry systems and in plantations, give them a vast potential to make a significant contribution to rural economies.


Sandalwood was heavily exploited in the Pacific during the first half of the 19th Century. However its first recorded sandalwood trade commenced much earlier, with the introduction of Buddhism into China from India. This occurred in the first century A.D. and with it came the practice of burning sandalwood incense in temples. Later the trade expanded to the Pacific when Americans and Australians began trading with China. This trade led to the discovery of sandalwood in the Pacific, including Hawaii, and Australia. Sandalwood has also been used and traded in Indonesia for over 1000 years, and it is possible that sandalwood was introduced from Indonesia into India or vice versa.

As most of the native sandalwood stands have been heavily exploited throughout the Pacific, there is concern now for its survival and the also the habitats in which it grows. The natural regeneration or artificial establishment is dependent on suitable host plants as well as a suitable forest and/or agroforestry environment. As *Santalum* species usually grow in drier open forest and woodland communities, their conservation and management will determine the conservation status of many of the *Santalum* species in Asia-Pacific. *Santalum* is generally vulnerable to fire and grazing animals, both of which have been increasing in its habitats. For this reason, greater research and input into ways of improving stand management, introducing sandalwood in agroforestry systems, and policy requirements to conserve both the species and its habit are required.

Over the last decade, CIRAD-Forêt in New Caledonia, ACIAR in Australia and Indonesia, CSIRO/SPRIG in the Pacific region and several other Pacific Islands Countries (PICs) have been carrying out research and undertaking field plantings of sandalwood. In August 1994, a regional workshop was organised by the South Pacific Forestry Development Programme in association with CIRAD-Forêt and ACIAR in Noumea, New Caledonia to provide “hands-on” training on sandalwood seed, nursery and planting technology. In 2002, SPC, with the support of CSIRO/SPRIG, ISSS/AusAID, CIRAD-Forêt – France, CIFOR and IAC – New Caledonia, organised a regional workshop on sandalwood which brought together participants from sandalwood-growing countries in the Asia-Pacific region. The main aim of this workshop was to review existing sandalwood research and development activities and to determine future prospects.

These proceedings report on the regional workshop on sandalwood held in Nadi, Fiji, from 28th November to 1st December, 2005. The workshop was organized jointly by the SPC LRD, Ensis/SPRIG/AusAID, SPC/GTZ-PGRFP and IAC. More than 40 participants from sandalwood-growing countries and territories of the Asia-Pacific region attended the workshop. This workshop was organised to provide an opportunity to share and discuss the progress in sandalwood research and development and extension, how these results could be applied to support efforts towards sustainable rural development, and to strengthen and explore opportunities for regional and international collaboration.

It is hoped that these proceedings will serve as a useful reference for those in the Asia-Pacific region and elsewhere who are actively involved in sandalwood research and development.





Participants of the Regional Workshop
on Sandalwood Research, Development and Extension
in the Pacific and Asia,
28 Nov-1 Dec 2005, Fiji Mocambo Hotel, Nadi, Fiji

Sitting: L-R – Dr T Page - Australia, Ms C de la Torre, Mr J-F Butaud, Dr. P Raharivelomanana,- French Polynesia, Ms B Clarke - Australia, Rev V Daunabuna - Fiji, Dr J Doran - Australia, Mrs N Kaur - India, Mr S Bulai - SPC, Mr C Jones - Australia, Ms D Harbaugh - United States of America, Ms T Kalsakau - Vanuatu, Ms T Mokoia - Niue, Mr D Bosimbi - Papua New Guinea, Ms C Espigole - SPC

Standing: L-R – Dr P Stevens - Australia, Ms B Wilikibau - SPC, Mr T Koroa - Cook Islands, Mr O Tangianau - Cook Islands, Mr W Lui - Vanuatu, Mr P Bulai - Fiji, Dr R Blank - SPC/GTZ, Mr N Denmark - Solomon Islands, Dr D Xu - People's Republic of China, Mr S Defranoux - French Polynesia, Mr A Marav - Vanuatu, Mr K Robson - Australia, Mr M Havea - Tonga, Mr T Hanington - Vanuatu, Dr L Thomson, Mr C Done - Australia, Mr S Napa'a - Tonga, Dr P Murphy, Mr T Coakley, Mr P Kimber, - Australia, Dr A Rimbawanto - Indonesia, Mr E Simanu - Samoa, Mr H Likiafu - Tonga, Dr M Hunt - Australia, Mr T Pouli - Samoa, Dr L Huang - Australia, Mr I Wainiqolo - Fiji, Mr I Bewang - Papua New Guinea.

ABBREVIATIONS

ACIAR	-	Australian Centre for International Agricultural Research	IAC	-	Institut Agronomique Néocaledonien (Noumea, New Caledonia)
AusAID	-	Australian Agency for International Development Assistance	IFAD	-	International Fund for Agricultural Development
CIRAD Forêt-		Forestry Division of the Centre for International Cooperation in Agriculture Research for Development (Montpellier, France)	IP	-	Intellectual Property
CIFOR	-	Centre for International Forestry Research (FutureHarvest Centre)	IPGRI	-	International Plant Genetic Resources Institute (Future Harvest Center)
COSMECAL-		A firm dealing with fragrances and its name is derived from COSMEtique and CALedonie	IRD	-	Institut de Recherche pour le Développement
CRGA	-	Committee of Representatives of Government and Administrations (SPC)	ISO	-	International Standard Organisation
CSIRO	-	Commonwealth Scientific and Industrial Research Organization, Australia	ISSS	-	International Seminar Support Scheme (AusAID)
CSO	-	Clonal Seed Orchard	ITTO	-	International Tropical Timber Organization
CCSO	-	Containerised Clonal Seed Orchard	JCU	-	James Cook University
DFSC	-	DANIDA Forest Seed Centre (Denmark)	NFT	-	Nitrogen-fixing tree
DNA	-	Deoxyribose Nucleic Acid	NGOs	-	Non-Government Organisations
EU	-	European Union	NLTB	-	Native Land Trust Board (Fiji)
FAO	-	Food and Agricultural Organisation of the United Nations	NPK	-	Nitrogen/Phosphorus Potassium (fertilizer)
FCSO	-	Field Clonal Seed Orchard	NTFPs	-	Non-timber Forest Products
FFEM	-	Fond Français pour l'Environnement Mondial (French Fund for World Environment)	NTT	-	Nusa Tenggara Timor (Indonesian Province)
FFP	-	Forestry and Forest Products (Division of CSIRO)	PCA	-	Principal Component Analysis
FOGER	-	Département Forêt Gestion de l'Espace Rural (Department of Forestry and Rural Zone Management)	PGRFP	-	Pacific German Regional Forestry Project
FPCD	-	Foundation for People and Community Development	PICTs	-	Pacific Island Countries and Territories
FSP	-	Foundation of the Peoples of the South Pacific International	PNGFA	-	Papua New Guinea Forest Authority
F&TP	-	Forests and Trees Programme (SPC, Suva)	PNGFRI	-	Papua New Guinea Forest Research Institute
GC	-	Gas chromatographic	PRS	-	Provenance Resource Stand
GEF	-	Global Environment Facility (of the World Bank, UNDP and UNEP)	QFRI	-	Queensland Forest Research Institute
GTZ	-	German Agency for Technical Cooperation	RAPD	-	Randomly Amplified Polymorphic DNA
HoF	-	Heads of Forestry (of Pacific Islands)	R & D	-	Research and Development
			RDCPF	-	Research and Development Centre for Plantation Forest, Indonesia
			RRA	-	Rapid Rural Appraisal
			SAPA	-	FAO's Pacific Sub-regional Office (Apia, Samoa)
			SDR	-	Rural Development Department (French Polynesia)
			SFM	-	Sustainable Forest Management
			SPAs	-	Seed Production Areas
			SPC LRD	-	Secretariat of the Pacific Community's Land Resources Division

WORKSHOP REPORT

▶ Executive Summary

The workshop was organised and jointly sponsored by the Secretariat of the Pacific Community Land Resources Division (SPC LRD), South Pacific Regional Initiative on Forest Genetic Resources (SPRIG), AusAID/International Seminar Support Scheme (ISSS), SPC/GTZ-Pacific German Regional Forestry Project (SPC/GTZ-PGRFP) and IAC (NC).

The Director for SPC Land Resources Division, Mr Aleki Sisifa, officially opened the workshop. More than 40 participants attended the workshop, including Government, non-government, university and private sector representatives from Australia, Cook Islands, Fiji, French Polynesia, India, Indonesia, New Caledonia, Papua New Guinea, People's Republic of China, Tonga, Samoa, Solomon Islands, United States of America and Vanuatu, and representatives from SPC LRD, SPRIG, IAC, SPC/GTZ-PGRFP and Ensis. A full list of participants is given in Annex 1.

The workshop included presentations on regional and international programme initiatives, country reports, technical papers, group discussions and a field visit to Colo-i-Suva and Vunimaqo. Details of the programme are included in Annex 2.

There were two sessions of group discussions. The first session involved participants meeting in five groups, with each group discussing issues and strategies relating to the conservation and management of the main species of sandalwood:-

- *Santalum album*
- *Santalum macgregorii*
- *Santalum austrocaledonicum*
- *Santalum insulare*
- *Santalum yasi*

During the second session, participants also formed into five groups to discuss the following thematic areas:

- Legislation and certification
- Exchange of germplasm and IP issues
- Replanting, extension and awareness
- Inventory - methodologies
- Heartwood assessment and chemistry and genetic assessment - methodologies

Records of the plenary and group discussions are given in Annex 3. These highlighted some of the main issues of concern on the various topics discussed, and those requiring actions, both nationally and regionally.

▶ Recommendations

On the basis of its observations and discussions, the workshop has made the following major recommendation for action.

This workshop recommends that SPC, in close consultation with member Pacific Islands Countries and Territories (PICTs), develop and co-ordinate a regional sandalwood research, development and awareness program *that aims to maximize the potential of sandalwood to contribute to sustainable rural livelihoods in the Pacific Islands.*

It will be an inclusive program that aims to effectively involve key stakeholders, including Governments, private sector, research organizations, NGOs and donors, to the maximum extent possible. This program will be based on the discussions and recommendations of the working groups to this workshop.

Specifically SPC is requested to assist member PICTs:

1. To develop appropriate regulatory and certification regimes to ensure that sandalwood resources are sustainably developed with maximum benefits to land owners and national economies.
2. To exchange and sharing tree germplasm and information, especially sandalwood, to maximise economic benefits from growing trees whilst ensuring biodiversity values are maintained. This may include SPC assisting member countries in developing benefit sharing arrangements supply of sandalwood germplasm.
3. Capacity building in their identified priority areas, especially related to inventory, conservation, management and development of sandalwood resources.
4. Developing research partnerships to:
 - Understand, conserve and utilize genetic diversity;
 - Value add;
 - Understand heartwood development and chemistry, and
 - Improved silviculture especially in local agroforestry and farming systems
 - Standardize approaches and methods for assessment.

► Other Recommendations

1. This workshop notes and supports James Cook University's intention to electronically publish the Sandalwood Research Newsletter (SRN). Given the need for hard copies of SRN it is requested that JCU liaises with SPC to facilitate distribution of hard copies to interested Pacific Islanders.
2. It is recommended that SPC organize a follow-up regional sandalwood meeting in 2008.

► GROUP SESSION FINDINGS

Santalum album

- Standardization and improvement of sandalwood inventory methods
 - Standard method of inventory is available, adoption of the standard has not been done (inventory program is not in place)
 - Who should be doing the inventory?
- Genetics
 - Need to know the diversity of the remaining populations of *S. album*; collaboration/network with research agencies has to be formed
 - Legal issue on information and germplasm exchange would be an issue and need to be addressed
- Seed technology and propagation
 - Seed storage technology for conservation of germplasm
 - Vegetative propagation is well developed (macro- and micro-propagation)
- Silviculture
 - Two silviculture systems i.e. agroforestry and industrial scale; each has different issues
 - On host-plant relationship mostly empirical; lack of understanding of the underlying process of the relationship
- Breeding strategy
 - Appropriate breeding strategy has not been developed; most of the breeding strategy currently being adopted is based on phenotypic characteristics which are not necessarily linked to the formation of heartwood formation and oil content, more research on fundamental aspects of heartwood formation need to be done

- Technical advice
 - SPRIG should continue to take the role of providing technical advice
 - Sandalwood industry in Australia is in a better position to share the information on various aspects of sandalwood management and utilization

Santalum austrocaledonicum

1. Ways to minimize movement of seeds between the southern and northern populations of Vanuatu
 - Certification of flow of seeds,
 - Restrict or avoid mixing of germplasm
2. Ask SPRIG or SPC to coordinate sending of samples to Danica,
3. Test hosts through an agro-forestry system,
4. To promote combining results of genetic studies to get a clearer picture on the diversity of genetic materials and oil components between CIRAD and ACIAR projects,
5. Finding funding for sandalwood inventory in Vanuatu – should develop standardization of sandalwood inventory system,
6. Standardization of laboratory extraction for all future GC analysis,
7. Need to reconcile error between ethanol extracted oil and bulk steam distillation from the industry.

Santalum insulare

Work done since the last workshop

Cook Islands

- a sandalwood workshop has been held on Mitiaro, mainly on *S. insulare*
- trial on vegetative multiplication of *S. insulare* (still in progress)
- production of *S. austrocaledonicum* and *S. album* seedlings

French Polynesia

- end of the inventory of all the populations of *S. insulare*
- definition of provenances by the mean of botanical, chemical and genetic studies
- establishment of conservatory stands for 3 provenances (Moorea, Nuku Hiva high elevation, Nuku Hiva low elevation) and of several plantation of production (Nuku Hiva high elevation)
- sale of *S. insulare* seedlings to the population of Nuku Hiva

Main objectives

- Inventory of *S. insulare* on Mitiaro
- Maintain the integrity and diversity of *S. insulare* populations
- Vegetative multiplication to gather sterile material
- Production and collection of seeds on natural stands
- Implementation of ex situ conservatory stands
- Exchange of experiences and results between French Polynesia and Cook Islands

► Recommendations

- Production/Conservation: Until now, the main works done were relative to conservation of *S. insulare* because the species is endangered. For production purposes, the question of which species must be used has to be answered. Hybridization between species or provenances must be avoided. Separation of the conservation of the local species and the production of introduced species can eventually be discussed
- Policy: Discuss and incorporate the eventual promotion/production/utilisation of introduced species in the legislation/regulation. Is it pertinent to introduce other species or *S. insulare* is it suitable for production?

The promotion of sandalwood must stay low until the forest department can produce seedlings in each provenance to avoid mixture of provenances or species.

Santalum macgregorii Papua New Guinea

The main constraints that are faced in sandalwood development in Papua New Guinea include:

- The extent of the sandalwood resource base not known
- Awareness not reaching the right audience
- Greedy middlemen only concerned with “getting rich quick” and
- Lack of financial support for sandalwood development.

Priority activities to be implemented

The four main activities described above in national plans and strategies will form the core activities in sandalwood development in Papua New Guinea in the next three years. These are to:

- Carry out a physical assessment of the sandalwood resource base,
- Collect wood samples for more testing of its oil contents,
- Establish an ex-situ seed production orchard with germplasm collected from across the three provinces and
- Establish model plantations in the country.

Santalum yasi Fiji

Inventory

In Fiji: status of existing resources – the inventory need for extent to outer island such as Koro, Nausori Highlands, Ono-i-Lau, only Kandavu where proper inventory has been done.

Research

Established seed orchard, collection and exchange of seed, vegetative propagation need to be continued such as Juvenile cuttings of young seedlings can be rooted but not mature trees, past trials affected by watering problems and lack of maintenance, gene conservation have not started yet, Mating system should be done, nothing done on genetic structure of the species, control pollination technique need enough information to continue (need expertise to do that) in order to moving genetic around and wounding of sandalwood research should be done on that.

Silvicultural research

Still continuing with the planting and use medium and long term hosts, problem with the fungus, agroforestry system should be combining with Sandalwood, Extension nursery should be moved to the dry area e.g. Vunimaqa. The sandalwood is highly depleted need more work on that, Research, development and tree improvement continues under the 5 year forest research development plan, Their main focus is mainly on *S. yasi*, *S. album* and *F1 hybrid*, the interest on sandalwood increasing after a SPRIG workshop on sandalwood in Fiji, more than 10,000 seedlings supplied to the public in the last 3 years and there is significant increase in number of people planting sandalwood. In field planting lines cut through bush and Sandalwood planted at 4m spacing with intermediate hosts planted beside each sandalwood. The natural regeneration needs an effective management system

The work has been done on *yasi*

Seed Production Area, Selection of plus trees, Clonal Seed Orchard, Family Trial and Gene conservation

The work has been done on *album*

Work on *S. album* limited due to some reason including narrow genetic base, *S. album* regenerations invading the Drasa area, within the vicinity of the original trial plot.

The work has been done on *F1 Hybrid*

Recognized this species is more vigorous, faster-growing, and more adaptable, and produces oil faster than the parents

Tonga**Inventory**

Inventory in Tonga likewise haven't done any no inventory of Tongan resource. Forest resource knowledge is based on the National Forest Resource Inventory. Such data become out of date and need verification from actual harvesting data. Detailed forest inventories for individual forest areas do not generally exist. The country's biodiversity is poorly understood. Ha'apai problem with the fungus host plant name Foui, public awareness is mainly focus on planting technique and use of agroforestry system,

Research

Continuation of propagation and distribution of seedlings in outer islands forestry nurseries especially 'Eua, Ha'apai and Vavau, protection and management of sandalwood population remaining in Ha'apai Group, Small-scale replanting of sandalwood on 'Eua forest estate, Small-scale field trials on Foa Island and 'Eua, establishment of potted seed orchard in main Island nursery and establishment of landowner demonstration plots in Tongatapu, 'Eua, Vava'u and Ha'apai.

National Plan

Plan for National Forest Policy in Tonga is a major problem, Amend Forests Act and Regulations to provide greater control over sandalwood harvesting.

Extension and Awareness

Landowner demonstration plots need to be continue, Field days and producing pamphlets in Tongan language should be done as soon as possible.

Other Issues

Heimuli such raise the major problems is facing with Tongan farming system is becoming increasingly threaten by threaten by; Rising population, growing encroachment of non-agricultural development into agricultural lands; increasing allocation of land for monocrops; and increasing monetary expectations and aspirations of the people from farming. Government is the main backbone of development for any issues but it seems that the government issues such as over regulation and poor enforcement, poor monitoring and evaluation, lack of strategic planning and policy, poor coordination of services. Lack of forestry capacity, technical knowledge and skills causes ineffective forestry extension service and is caused by lack of budgetary support and resources.

Niue

Need proper inventory. Niue is not part of the SPRIG Phase 1 and 2 but they have offered some assistance in terms of securing seeds for a seed orchard. Needs to have a complete inventory of the stand, measuring and mapping especially the very small sandalwood natural stand which is a seed orchard where these seedlings will be planted have been planted with citrus (mandarin) as a host plant.

Problems they came up with including: Financial assistance, lack expertise, shortage of manpower, viable seeds from the naturalized sites and cyclones.

Research

Need ongoing research development, extension in developing a Sandalwood seed orchard. Need ongoing awareness for the landowners to grasp the importance of this valuable tree species. The Government is the key for the promote conservation and sustainable development concepts agroforestry development and intercropping will be encourage and promoted, Niue Forestry Division start to promote the planting of Sandalwood using the local provenance and develop joint management with landowners to ensure sustainable management ,need regional assistance for more Sandalwood seeds for the local seed orchard.

Major Recommendation

This yasi group recommends some of the key development issue to be highlight inorder to contribute to sustainable rural livelihoods in the Pacific Islands.

- *Inventory: need to be done as soon as possible.*
- *Conservation: seed, grafting in order to exchange and sharing tree germplasm and information.*
- *Genetic evaluation and assessment in term of heart wood materials.*
- *Policy and regulation: need to have a good policy.*
- *Research programme: to be continue the good work on Sandalwood especially on stimulating heartwood formation, grafting, micro-grafting.*
- *Agroforestry system: need to be practice in the PICs.*
- *Public awareness and educational: strengthening and upgrading the research information on Sandalwood.*

Other Recommendations

- *Harvested restricted: need a limited ages trees.*

Exchange of germplasm and IP issues

Many of the current exchanges of forestry tree germplasm between south Pacific countries are made under SPRIG “Code of Conduct for Sharing Tree Germplasm”. Sandalwood germplasm exchange has mainly occurred for *S. yasi* from Fiji to Niue and Samoa and also *S. album* from Australia to Fiji and Tonga.

It is recommended that germplasm exchange for research purposes be allowed to continue between South Pacific countries aided by the SPC through the development of co-ordinated agreements to facilitate legal exchanges of not only sandalwood but also other commercial forestry species.

There is a need for the development of IP provisions at the legislation level for the exchange of germplasm purely for commercial purposes. Such legislation is required to ensure the benefits of germplasm export from PICT’s to other more developed countries (with the capacity to produce sandalwood on a much larger scale) return to the exporting nation.

Strict quarantine procedures need to be in place to restrict the movement of pests and diseases during germplasm exchange, which needs to be included in any legislation or agreements.

There is a need to reconcile the competing interests of

- Germplasm exchange and planting of improved germplasm and
- Gene pool conservation

Distinction between natural and improved populations (plantations) and separate them physically to limit cross-breeding and uncontrolled alteration of the both gene pool types

Need for further understanding of interspecific breeding systems to determine the fertility of F₁ hybrids and possibility of long distance dispersal through pollen transfer and/or seed spread.

Need to identify the genetic diversity of each commercial sandalwood species and identify populations that have particular importance for their conservation. Development of hierarchy of conservation values for populations, which recognises that some populations may have a greater importance to the conservation of the species than others.

Extension, Awareness and Replanting

1. Feasibility study to be carried out in the communities to ascertain if there is interest in Sandalwood in order for the Forestry Department/institutions to be made aware and then for further extension work to continue.

2. SPC to facilitate or encourage each country to establish commercial plantation or woodlot establishment for attractive sandalwood investments as a commodity.
3. Encouragement of agroforestry practice or other appropriate land management practices in the smaller island Nation, for example. Niue and Tonga, using other commercially nut timber trees or other non-timber forest products for example noni and citrus etc.
4. SPC to seek/provide funding to conduct regional and national field days focusing on the promulgation of Sandalwood for a set period within the Pacific Islands.
5. More establishment of sandalwood demonstration plots in countries where sandalwood is not widely considered as an important commodity. The demonstration/model plots can then be used for awareness and guidelines to be established for interested stakeholders.
6. Each country should regulate the trading of the Sandalwood seeds as a commodity.
7. Include sandalwood as a priority species in each country and to be included in the academic curriculum concentrating in Elementary/primary education.

Heartwood essential oil chemistry, physiology and genetics working group

Key findings and recommendations

Heartwood assessment: It was recommended that *standardisation of heartwood assessment* be adopted. This includes wood sampling, both destructive and non-destructive. If mature (>15 cm DBH) trees are to be removed for either commercial harvest or scientific purposes, it would be desirable *to gather as much anatomical, physiological and chemical information as possible*. This includes chemical analysis of sapwood, transitional heartwood and central heartwood from discs cut from various heights. Compositional data should be collected from as many trees, at as many heights as practical. The main deficiency in heartwood/oil data is a lack of appropriate replication and number of trees. Core sampling through the diameter should also be performed on as many trees as practical, using either 22 mm inner core drills or increment boring tools. Again, information such as heartwood content, colour, and oil composition should be collected. Cores from *at least two heights* should be taken to further explore within-tree compositional differences. It was also recommended that physiological data such as water use, sap flow, wood density and heartwood extractive properties (pH etc.) be compiled so as to gain a greater understanding of heartwood formation. *Further work on oil biosynthesis, heartwood initiation and the genetic and environmental factors which control it is needed*.

Chemical analysis: With respect to analysis of wood samples, standardisation is required. Solvent extraction is appropriate for small samples (non-destructive). Previous research has suggested little difference between solvents; hence choice of solvent is not important. Distillation of larger samples of wood may also be performed to identify yields, and comparison to solvent extraction should be conducted to maintain consistency. It was agreed that essential oil composition should be analysed by gas chromatography (GC) using medium-high polarity capillary columns (DB-5, HP-5, AT-WAX). Ideally two columns of varying polarity should be used in parallel to positively isolate minor components. Detection by flame ionisation (FID) is suitable for known compounds with appropriate standards, and positive identification using mass spectrometry (MS) should also be endorsed. *Area quantification of all detectable compounds in the essential oil profile* should be done. These minor compounds are integral to the overall nature of the oil, and may be central to reliable chemotaxonomic and quantitative co-occurrence studies. Co-occurrence data should be collected all oil-yielding species of *Santalum* and compiled. These properties may be very useful for further work on oil biosynthesis within the genus. *Collaboration between countries and laboratories* on this subject is paramount to the success of such investigations, and is strongly encouraged.

Genetic assessment of sandalwood: Ascertaining the genetic role in heartwood quality is absolutely essential to the improvement of sandalwood. *Comprehensive genotyping of as many individuals in as many different populations is required*. Reliable techniques such as restriction fragment length polymorphisms and microsatellite primers should be used, while amplified fragment length polymorphisms techniques should be avoided. Sharing of knowledge of appropriate primers and probes is encouraged to allow genetic studies to proceed without hindrance. *Accurate GPS coordinates for*

sample locations are essential for any comprehensive genetic studies. Access to genetic information from sandalwood populations should be allowed, while a nations' right to gain from that germplasm should be respected. *Co-operation with all stakeholders* is encouraged so as to allow the most rapid scientific advances in understanding heartwood formation in sandalwood.

Multi-locational provenance/family and clonal trials need to be established so that the extent to which genetic and environmental factors influence heartwood formation can be determined. This should first be undertaken on one member of the genus, with an aim to eventually include other sandalwood species. Chemical phenotype data should also be compared to genotype data, and collaboration between groups is required to ensure the success of this project.

Chris Jones; rapporteur December 1st 2005.

Legislation and Certification

Group members:

S. Bulai, Watson, Blank, Wainiqolo, Coakley, Tate, and Kaur

Strategy: The strategy is to first place emphasis on legislation as certification will be dependent on appropriate legislation.

Inventory Survey: It was noted that it is difficult to collect reliable data in India, including due to different state interests. Inventories require national co-ordination by Government, but may need to be initiated by other institutions such as SPC.

Options/Proposals (Better management regime):

Legislate;

- Diameter size limits for Pacific island countries; (e.g. Vanuatu - 15 cm minimum diameter at 50 cm height above the ground).
- Product specifications (grades/portion of wood versus prices). The main challenge lies in the implementation of harvesting regimes, with the most viable solution being to properly educate both resource owners and buyers.
- Enable sharing of materials (seeds) – through mutual understanding (MoU/CoC) for research purposes and appropriate access and benefit regimes.
- Registration of common/trade names e.g. Vanuatu and New Caledonia – *S. austrocaledonicum*; Fiji, Tonga and Samoa – *S. yasi*; Fiji, Australia, India, Indonesia – *S. album*, and
- Development of legislation requires the involvement of all stakeholders.



Part A:
Country Papers

Otheniel Tangianau and Teuanuku Koroa

Sandalwood Resource Base

Santalum insulare is the only sandalwood species that is indigenous to the Cook Islands. It is found in the makatea areas on the island of Mitiaro, which is situated about 200 km north-east of Rarotonga, the main island of the Cook group. A proper inventory of the *S. insulare* populations has yet to be carried out, but it appears to occur in three small sub-populations as follows:

1. Vaiai - >100 stems
2. Kaapoto- 10 stems
3. Vaitamaroa – 7 stems.

Mitiaro sandalwood is a small multi-stemmed shrub, 1 to 4 meters tall. It produces light green and yellow flowers and reproduces solely by root suckering.

An exotic species of sandalwood, *Santalum austrocaledonicum* was introduced into the country in the early 1990s. It was brought in for trial purposes, to test its ability to grow and develop in the Cook



Fig. 1. *Santalum insulare* in flower (Mitiaro)



Fig. 2. Coppice coming from damaged roots (Mitiaro)

Islands particularly on the makatea islands. The species was raised in the nursery at Rarotonga by the CIRAD-Forêt as seedlings. These seedlings were distributed for field evaluation on Rarotonga at the Totokoitu Agriculture Research Station and in trial sites on the makatea islands of Mangaia, Mitiaro, Mauke and Atiu.

In 1994, the Forestry Division of the Ministry of Agriculture in Mauke raised approximately 800 seedlings. During this period the seedlings raised were used to establish field trials. The rest of the seedlings were distributed to interested households for out-planting on their properties and in their food and flower gardens. Considerable variation in tree performance has been observed both within and between all sites where the species has been trialed in the Cook Islands. Key observations on species performance are as follows:

- There are strong links between sandalwood trees and permanent hosts, meaning that sandalwood species surrounded by certain hosts perform better in terms of growth. Nitrogen-fixing trees appear to make the best hosts for sandalwood.

- Sandalwood can grow in almost any area, but prefers fertile, well-drained sites to rocky dry sites. Seedling growth improves with site fertility and young plants do not compete well with weeds during the early years of their life. Sandalwood trees are now being tested for growth on infertile, upland fernland sites and results so far are encouraging.
- There is a high level of variability between individual trees in every site where the trees have been grown. This means when planting out seedlings it has to be expected that poor and good quality trees may develop next to one another. Since this is controlled by the genetic make up of individual seedlings, it is difficult to predict the final form and size of the trees until these are at least one year old.



Fig. 3. - *S.austrocaledonicum* in school planting



Fig. 4. Plantings on rocky coastal sites

Trade and Industry

Cook Islanders have traditionally used sandalwood (*S. insulare*) especially its shavings as a remedy for problems associated with severe headaches and migraines as well as problems associated with breathing both with infants and adults. The Cook Islands does not export sandalwood or sandalwood products.

Research and Development

Research related activities have been undertaken in the country for about 15 years. Some of these, as mentioned previously include:

The establishment of sandalwood trials in makatea sites on the five islands of Mangaia, Atiu, Mauke, Mitiaro and Rarotonga. This work was initially done and piloted by CIRAD-Forêt. To date the trees in these trials are generally performing well in terms of tree growth and form. It is pleasing to note that the trees have blended in well with the natural forests in the areas where they have been established. The problem is, for most of these trials, the growth data generated in the early years of the program has been lost.

A trial work to test if sandalwood can be successfully multiplied using cuttings was carried out on Mangaia. This work was done in 1998/1999. From the tests, it was found that while the cuttings were able to callus and produce roots, they could not continue to remain alive and establish after the roots have developed. It was difficult to identify what was causing the seedling to degenerate after the roots had established. Rooting hormones were used to promote rooting in the cuttings.

Sandalwood seeds once they fall to the ground can germinate within 14 to 30 days. As part of our work on sandalwood, the Forestry unit has increasingly been using seedlings for potting up that have already germinated in the field. This is because the pre-germinated seeds develop more rapidly and reliably.



Fig. 5. Plantings around home surroundings



Fig. 6. Fruit damaged by rats

Rats have been causing considerable damage to seeds in the seed production stands. Measures have now been implemented to limit rat predation of the seeds which are required for planned expansion of the *S. austrocaledonicum* estate on Cook Islands .

Santalum album seed has been received from Australia via the SPRIG program. A limited amount of seedlings from this seedlot have germinated and are now being cared for by the Forestry unit on Mangaia. These will be transplanted into the field once the seedlings have reached a suitable size and following hardening.

Seedlings collected and germinated from a single *S. album* tree grown in Kaumata village (Mangaia) have also been performing well. So far they seem to out perform the *S. austrocaledonicum* seedlings in terms of growth rate and in general vigour.

National Plans and Strategies

Government attention is presently focused on tourism, environment and other areas that will bring immediate benefits to the country. It is difficult to promote sandalwood as a new plantation species in a country where national priorities are not highly placed on forestry. To make matters difficult there is no forestry-related issue of significant proportion in the country to shift and direct the attention of Government towards the forestry sector.



Fig. 7. Metal bands for rat control

Fig. 8.. *S. album* in home garden, Mangaia

However, while sandalwood production is not on the top of the list of priorities for government it has been mentioned in the country's report to the World Summit on Sustainable Development (WSSD). It is also gaining recognition as an important future resource for development on Mangaia Island by the Mangaia Local Government which is the political entity managing the affairs of Mangaia, an island located 176 km south-east of Rarotonga.

Sandalwood has been planted and promoted on a small scale on Mangaia since 1996. In 2000, the Mangaia Island Council gave its approval to the establishment of plantations of sandalwood on all lower coastal areas on the island, an area totaling about 1,100 hectares. This strategy was adopted because it was recognised that the relatively large area of the island constituting coral pinnacles with small pockets of soil was not giving its owners any economic returns (due to its rocky, non-arable nature). Rather sparse, native forests currently cover these areas and sandalwood can establish within these native forests and hence increase their value. Establishing income-generating resources like sandalwood also improves the value of this otherwise unproductive land making their management, development and protection much easier and meaningful for the island communities.

The Council's offer of establishing sandalwood plantation has not been vigorously taken up because of the following reasons:

- Limited resources,
- Management unit lacking leadership,
- Management arrangement and partnerships were not developed, and
- Limited options for raising the required quantity of seedlings.

There are clear lessons from earlier trials and now enough information to allow successful establishment of sandalwood as plantation on the Makatea sites of at least four outer islands in the Cook Islands. The biggest hurdle is the ability to access sandalwood seed and raise the required seedlings.

At present 2,500 seedlings have been planted in different areas on Mangaia Island. They appear to be growing well. The Mangaia Local Government believes if adequate seeds can be collected the island can operate a small annual planting program of 10,000-12,000 seedlings per annum.

Extension and awareness

In the past three years extension and awareness activities have been initiated on Mangaia and also on Mauke. The main activities undertaken include:

- Presentation of local sandalwood program on TV Mangaia (in 2000).
- Sandalwood workshop in Mangaia for all Southern Island participants (in 2001).
- Sandalwood workshop in Mitiaro (in 2004).
- Out planting of new stocks in Mitiaro (in December 2004) and,
- Article in the national newspaper on sandalwood in Mangaia.

In the Cook Islands, as elsewhere, extension and awareness programs will only be successful if you are able to show success stories/sandalwood plantings and demonstrate clearly the benefits to your stakeholders.

Four priority areas for Implementation

The Cook Islands, in particular the Mangaia Local Government, considers the following as crucial and important for the advancement and development of sandalwood in the country.

- Plantation will not proceed fast if technology for increasing planting materials for example, cuttings development or perhaps tissue culture is not refined or enhanced. Therefore further work into sandalwood rapid multiplication activities is needed.
- The research work on refining plantation establishment activities will need to be an on-going one. Research information from research institutions will complement and feed into progressive plantation development.

-
- There are stocks of sandalwood trees on private owned properties. Most are doing extremely well. Management regimes for a complete rotation will need to be circulated to prospective growers.
 - Fast track the establishment of a *S. album* seed collecting stand.
 - Develop seed production stand(s) of the putative *S. austrocaledonicum* x *S. album* hybrid.
 - Vegetative propagation of *S. insulare* on Mitiaro and develop a planting programs for sandalwood in villages and surrounds.

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Research, Development, and Tree Improvement of Sandalwood in Fiji

Ponijese Bulai

Introduction

Santalum yasi or 'yasi' in Fijian is the only native sandalwood in Fiji. It is one of the most valuable sandalwood timbers in the world but is highly depleted due to heavy exploitation in the early 19th century and more recently in the 1980s (Shineberg, 1967; Jiko, 1993; Bulai, 1984; Tuisese *et al.*, 2000). Very few harvestable trees remain and probably with a narrow genetic base. However, economic prospects for yasi remain highly attractive and sustainable measures are being undertaken to conserve, manage, and develop the resource in Fiji.

The current research and development, and tree improvement of sandalwood in Fiji is implemented under the Forestry Department's 5-year research program from 2002 to 2007. The aim is to undertake research to assist in the scientifically sound conservation, management and development of sandalwood genetic resources. This program focuses on three sandalwood taxa namely *S. yasi*, *S. album* and F1 hybrid between *S. yasi* and *S. album*.

Significant progress has been made during the last three years. More knowledge has been acquired on seed technology, nursery, and field planting. Germplasm of more than 100 individuals have been vegetatively propagated. Newly established seed production areas, including a grafted clonal seed orchard, have started bearing fruit. However, of most significance is development of the natural F1 hybrid (*S. yasi* x *S. album*). It is much more vigorous, faster growing and highly adaptable to a wider range of environments compared to the parental species. This has raised the prospects for a rapid increase in both quantity and quality of the sandalwood resource in Fiji within the next 15-20 years.

However, large knowledge gaps on sandalwood development remain. These include development of an effective mass multiplication system for cuttings, progeny testing of half-sibling families derived from selected base populations, improve management practices for clonal seed orchard, and complete germplasm collection and preservation of remnant populations in isolated areas.

Research and Development

The Forestry Department's Silviculture Research Division implements its research and development program on a 5-year cycle. This includes a research focus on the most pressing problems preventing the successful plantation silviculture and genetic conservation and improvement of sandalwood.

Flowering and Fruiting

S. yasi appears to be predominantly out-crossing, freely hybridizing naturally with *S. album*, but it also apparently self pollinating as isolated plants may set heavy fruit crops. Fruiting may occur sporadically throughout the year but the peak period is during the wet season from January to March and again from October and November, with light fruiting in the cooler season from June to August.

Seed Processing and Germination

The ripe fruit is collected from the crown or from the ground and soaked in water for 1-3 days to soften up the fruit pulp. It is then cleaned and the seed air-dried at room temperature for a number of days

before sowing, or dusted with fungicide and cold stored at 3-4°C. Seed is sown in mahogany compost, peat moss, fine river-sand, or ready-made commercial potting medium. Due to the high cost, seed pre-treatment is not undertaken even though nicking and total removal of the endocarp significantly enhances germination. Fresh seed has viability in excess of 60%, and normally commences after about 2 weeks.

Seedling Production

Seedlings are pricked out at the 2-4-leaf stage into poly-pots (16cm x 6.5cm) with *Alternanthera* cuttings used as a pot host. Potting mix includes forest soil (67%) and fine river sand (33%) amended with 2 - 3 kg NPK fertilizer per cubic meter of potting mix.



Fig. 1. Raising *S. album* seedlings in the extension nursery at Lautoka



Fig. 2. Germination of *S. yasi* under the mother tree in Lekutu, Bua

Seedlings are ready for field planting after about 6 months, when their height exceeds 30cm. However, it is now becoming more common to raise bigger seedlings in larger pots. This allows for an extended hardening and culling process, and a longer pot-stage for yasi to develop a strong and sustainable hemi-parasitic relationship with host plant. Only the strongest and fittest seedlings survive the extended nursery cycle to be planted out in the field. This system stops weaker plants from being planted in the field, and thus eliminates high mortality that normally would occur during the establishment stages of field planting. This also eliminates the costs of beating-up and replanting involved and leads to development of fully stocked and highly productive sandalwood plantations.

Wildings are also used to supplement seedling derived planting stock. For production of wildings it is best to clear and cultivate the undergrowth to induce germination of fallen seed. Young regeneration is pricked-out and transplanted into pots, and raised under partial shade. This method is best on sandy, well-drained soils and suitable in areas where sandalwood exists.

Field Planting

Planting lines are cut through existing bush, and sandalwood planted together with intermediate hosts of *Calliandra calothyrsus*, with existing trees on site used as final hosts. The over-shade is gradually reduced to about 50% by cutting and girdling of large, less desirable trees over duration of 1-2 years.

In open areas such as old garden sites and grassland, permanent field host such as *Citrus reticulata*, *Casuarina equisetifolia* (nokonoko), *Acacia richii* (qumu), *Gliricidia sepium*, *Pongamia pinnata* (vesi wai), *Gymnostoma vitiense* (velau), *Samanea saman* (vaivai mocemoce), *Serianthes vitiensis* (vaivai ni veikau) and *Pithocellobium dulce* must be introduced. Only well-hardened and vigorous seedlings with

associated, surviving healthy pot hosts should be planted out into the field. After planting, the pot host (*Alternanthera spp*) must be managed and cultivated properly so that it could persist longer and sustain the sandalwood for at least 1-2 years until it attaches itself to the field hosts.



Fig. 3. Line planting of sandalwood through existing bush



Fig. 4. Line planting of sandalwood in open area

Vegetative Propagation

While seed remains the main source of improved genetic material for planting, vegetative propagation is able to capture non-additive genetic gains (Shelbourne, 1992). At the moment, only juvenile shoot cuttings of young *S. yasi* seedlings are able to be rooted under mist. Recent advances in biotechnology in the form of cell and tissue culture of *S. album* in India shows great promise for *in vitro* mass multiplication of sandalwood and production of disease resistant materials (Parthiban *et al.*, 1998; Sanjaya *et al.*, 1998; Lakshmi Sita, 2002; Rao and Ozias-Akins, 2005).

Tree Improvement

Santalum yasi

The general, low-input, strategy for improving *S. yasi* involves the selection of superior phenotypes in each generation, which are then allowed to naturally cross to produce the next generation. (Shelbourne *et al.*, 1986, Eldridge *et al.*, 1997).

Seed Production Area (SPA)

Four small SPAs have been established with more than 1,000 seed trees. About 4 % of trees had started fruiting after 3 years, and it is increasing each year. In 2004 only 3 kg (green wt) was collected, but it increased to about 10 kg (green wt) in 2005. However, actual fruit/seed borne on trees were more than double these figures as birds take most of the seeds. Covering the crown canopy with fishing net to keep away birds works effectively with shorter trees but is impractical for taller ones. One method being investigated is to pick the mature fruits (greenish with red markings) before they turn fully red as birds normally take well ripened, softening fruits.

Natural regeneration in the SPAs is also being raised and managed as future seed trees. It is a promising alternative method for raising sandalwood forests in villages, and an effective silviculture management system need to be developed and promoted. Usually, thousands of regenerations would sprout from the ground but many would die and only a handful of seedlings persist. Natural selection favours only the fittest plants, especially those which have managed to secure a good host plant, and development of host relationships may be under genetic control.



Fig. 5. 3-year old natural regeneration at Galoa



Fig. 6. Newly established SPA in Lololo, Lautoka

Selection of Plus Trees

More than 100 *S. yasi* candidate plus trees have been selected in natural areas such as Bua Province in Vanua Levu, Nausori Highlands in Viti Levu, and Lakeba in Lau Group; as well as in SPAs and individual trees in Viti Levu (Serua, Naitasiri, Nadroga, and Tailevu). Some have been non-destructively sampled for heartwood with results indicating considerable variation in oil content.

Clonal Seed Orchard (CSO)

More than 50% of selected plus trees have been grafted in the CSO for conservation of germplasm and mass-production of good quality seed. Trees in this orchard have started fruiting lightly and about 2 kg (green wt) of seed was collected in 2004. Two systems of CSO are currently in use:

Containerized Clonal Seed Orchard (CCSO)

Grafted clones (with hosts) are grown in large plastic containers. This system is easy to manage, requires less space, and is highly maneuverable. The containers can be moved around easily and could facilitate breeding activities such as crosspollination, hybridization, or development of in-bred lines. They could also be used as mobile seed sources for use in villages that have no sandalwood.



Fig. 7. Containerized Clonal Seed Orchard with potted yasi graft (V5 clone) at Colo-I-Suva nursery

Field Clonal Seed Orchard (FCSO)

All clones in the CCSO are being duplicated in the FCSO for long-term preservation. Also, overgrown grafts in the FCSO will be transferred into the FCSO. Observations showed that grafted trees planted directly on the ground fruit more heavily compared to those in containers.

Family Trials

Two small family trials (0.2ha) have been established, consisting of Lakeba and Bua seedlots. These have a spacing of 4 m x 2 m with intermediate field hosts of *Calliandra calothyrsus* and permanent host of *Citrus reticulata*. The objective is to rank the performances of individual families and determine best families for seed production, and for second-generation selection. The trials also act as demonstration stand and seedling seed orchard.

Santalum album

Tree improvement work on *S. album* is limited due to its narrow genetic base. All stocks of *S. album* in Fiji originate from a single plot established in the 1980s at Drasa near Lautoka. The species is well adapted to the drier western part of Viti Levu, as shown by the large numbers of natural regeneration now invading the logged-over pine areas within the vicinity of the original *S. album* trial plot.

Our main seed source has been a small SPA of about 100 trees established with seed from Drasa. Some of the seed trees have been grafted in the CCSO to hybridize with *S. yasi* for production of F1 hybrids. However, the genetic variability of *S. album* in Fiji is likely to be increased with the importation of two seedlots from SPRIG/CSIRO Australia. Seedlings are currently being raised in nursery for establishment of seed production areas.

S.yasi x *S. album* F1 hybrid

Interspecific hybridisation between *S. yasi* and *S. album* produces F1 hybrid that are more vigorous, faster-growing, more adaptable to a wider range of environments, and less dependant on hosts, compared to the parents (Bulai and Nataniela, 2002). In the CCSO, the grafted clones are brought together to naturally cross-pollinate and produce spontaneous hybrids. An effective multiplication system for cuttings is necessary to bring selected highly desirable F1 hybrids into mass use.



Fig. 5. 3-year old natural regeneration at Galoa



Fig. 6. Newly established SPA in Lololo, Lautoka

Discussion

Research, development and tree improvement for sandalwood in Fiji has made significant progress in the last 3 years. A higher number of germplasm materials have been vegetatively propagated and managed centrally in very accessible areas. This means that the genetic variability of *S. yasi* in Fiji is being protected and conserved for the future. However, more germplasm of remnant populations in isolated areas still needs to be collected. These include Kadavu, Ono-I-Lau, Macuata in Vanua Levu, and Nausori Highlands in Viti Levu.

After 3 years of the program, newly established seed production areas and clonal seed orchard have started fruiting. This has significantly raised seed supply and reduced problems associated with procuring seed from isolated seed sources. However, evaluation through progeny testing remains a bottleneck due to difficulties in collecting seed from distant places. This is further exacerbated by scarcity of suitable land under lease by the Department of Forestry for establishing trials.

Finally, production of F1 hybrid between *S. yasi* and *S. album* is a very exciting outcome. Its fast growth, vigor, and higher adaptability to a wider range of environments raises the prospects of a significant expansion of the resource in the next few years. Development of an effective mass production technique would ensure the full realization of the genetic potential of the hybrid. This however, does not rule out the opportunity for research in cell and tissue culture as powerful tools for rapid multiplication of desired clones.

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Sandalwood (*Santalum insulare*) Program in French Polynesia

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This report is designed as a supplement and update to a similar report (Butaud and Tetuanui, 2005) presented in 2002 during the international meeting on sandalwood in New Caledonia.

Sandalwood Resource base

Eastern Polynesian sandalwood (*Santalum insulare*) is the only sandalwood species native to French Polynesia. It can also be found in the Cook Islands (Mitiaro Island) and Pitcairn Islands (Henderson Island) and so is endemic to eastern Polynesia. Nine botanical varieties corresponding in general to non-contiguous geographical areas have been identified by taxonomists (Fosberg and Sachet, 1985) and their validity is currently being studied as part of a multidisciplinary work effort for the species.

Three other sandalwood species have been introduced into French Polynesia:

1. *Santalum album* or East Indian sandalwood, introduced about 50 years ago and occasionally used in reforestation efforts. This species is grown on several islands and now also grows wild in dry areas on Tahiti and Moorea.
2. *Santalum yasi* or Fiji and Tonga sandalwood, introduced a few decades ago. There are a few isolated trees left on Tahiti.
3. *Santalum austrocaledonicum* or New Caledonia sandalwood, introduced to the Marquesas Islands in 1998, with a few dozen specimens remaining as ornamental trees.

Beginning in 1998, an inventory of sandalwood resources was conducted throughout French Polynesia. Although it was still incomplete during the last sandalwood conference (Butaud and Tetuanui, 2005), it is now relatively comprehensive.

It shows that Eastern Polynesian sandalwood can currently be found on 10 islands spread throughout the three island groups shown in Table 1. It seems to have disappeared from another three islands during historical times (i.e. from 1800 to present) as it could not be found there even though both literature and island residents mention it.

So through the work of the local

Islands	Populations	Trees	Status
Nuku Hiva	27	1180	Declining
Ua Pou	4	71	Endangered
Ua Huka	0	0	Extinct
Hiva Oa	8	125	Endangered
Tahuata	13	246	Endangered
Fatu Hiva	3	42	Critically endangered
Marquesas	55	1664	Declining
Tahiti	23	248	Endangered
Moorea	4	241	Endangered
Raiatea	3	85	Endangered
Society	30	574	Endangered
Tubuai	0	0	Extinct ?
Raivavae	20	2340	Declining
Rapa	2	14	Critically endangered
Austral	22	2354	Declining
Makatea	0	0	Extinct ?
Tuamotu	0	0	Extinct ?
French Polynesia	107	4592	Endangered

inhabitants, SDR (Rural Development Service) personnel and botanists, involving through systematic prospecting of favourable environments, it was possible to identify more than 100 populations consisting of nearly 4600 trees.

The original sandalwood populations have not been able to recover from

several centuries of over exploitation and the introduction of numerous harmful species (both animals and plants) and are now counted by the number of trees rather than on an area basis. This is an endangered species over the vast majority of its natural distribution range, although four islands do still have more than 1000 trees.

For those reasons, the commercial sandalwood resources of *S. insulare* are best considered as non-existent. All the remaining trees must be preserved so as to allow conservation of this species, both by *in situ* means as part of protected zones or specifically for the species, and *ex situ* in gene conservation stands and seed orchards needed to provide the seed that will be required to establish future production plantations.

Trade and Industry

French Polynesian forestry regulations require that anyone who wants to cut down a tree, on either private or public lands, must submit a request to the government for a tree-cutting permit. Any tree-cutting that is not authorised by the government and township authorities is, then, illegal. Since several varieties of the Eastern Polynesian sandalwood (var. *insulare* on Tahiti, var. *marchionense* and *deckeri* in the Marquesas Islands, and in the near future var. *margaretae* on Rapa) are protected by the 'Resolution to promote the preservation of nature' (Orders 296/CM dated 18 March 1996 and 471/CM dated 10 April 2003) and the fact that sandalwood is generally considered to be endangered by forestry officials, no cutting of sandalwood trees is authorised. All cutting is, then, illegal and considered 'poaching'. Accordingly the only recent statistics are for illegally cut and seized wood in the Marquesas Islands: 47 logs for a total volume of 0.2 cu. m on Nuku Hiva in 2002 and 10 logs with a volume of 0.07 cu. m in 2004.

Whilst there is no legal trade in sandalwood, handicrafts made from sandalwood are tolerated due to the possible use of wood cut before the legal protection measures were put into effect and the traditional nature of these crafts.

In fact, many traditional uses do exist in medicine, cosmetics, and handicrafts in the strict sense of the word. At the markets or during craft shows, one can find small sandalwood sculptures, hair combs, sandalwood powder, unprocessed branches, crowns made of wood shavings, and most often, sandalwood-perfumed coconut oil (monoi ahi or pani puahi) and sandalwood powder. Sandalwood monoi is now the main use of Eastern Polynesian sandalwood, due to its frequent use in traditional medicine and/or in body care. Accordingly, due to the many different traditional uses, Eastern Polynesian sandalwood is still cut down illegally and a reasonably constant, low level illegal trade continues.

Research and development

French Polynesia's sandalwood programme commenced with a research phase carried out through collaboration among various research agencies (Rural Development Service [SDR], University of French Polynesia, CIRAD) and a second phase run by the SDR based on the conclusions of the first phase. These two phases have, in part, been carried out simultaneously on certain island groups with practical work such as setting up demonstration plots and producing Eastern Polynesian sandalwood plants.

In terms of research, the following work has been undertaken:

- An inventory of Eastern Polynesian sandalwood populations throughout French Polynesia,
- A study of the current dynamics of the species on all the islands,
- Development of nursery techniques for propagating Eastern Polynesian sandalwood,

- Creating and monitoring conservation stands/seed orchards,
- Chemical characterization of Eastern Polynesian sandalwood in relation to the quality of other sandalwood species worldwide,
- A study on the chemical variability of wood components throughout French Polynesia, and
- A study of genetic diversity in Eastern Polynesian sandalwood.

In terms of development, the following actions have been taken:

- Training for nursery farmers in seed propagation of Eastern Polynesian sandalwood,
- Creating demonstration stands on several islands,
- Monitoring these stands so as to determine the silviculture of Eastern Polynesian sandalwood, and
- Formulating conservation and sustainable development strategies for Eastern Polynesian Sandalwood.

National plan and strategies

French Polynesia's sandalwood program is based on two complementary conservation and development approaches: conserving the diversity of existing stands (*in situ* and *ex situ*) and developing higher quality varieties through specific stands (*ex situ*).

4.1. Preserving existing diversity

Legislation

Forestry regulations and the 'Resolution to promote the protection of nature' are two legislative tools that can be invoked to enable conservation of existing sandalwood stands. In fact, due to the directives issued by forestry officials, no permits to cut down sandalwood trees are being granted at the present time. In addition, as mentioned above, three varieties of Eastern Polynesian sandalwood are now protected and a fourth is in the process of being classified for protection. Such protection, as part of the 'Resolution to promote the protection of nature', prohibits all types of damage not only to the species but also to its natural environment. Mandated SDR agents are in charge of enforcing this legislation. Over the long-term, it is advisable that all the natural stands of the various varieties be protected in this way with appropriate waivers authorising SDR or Environment Department officers to collect seeds or plant material (cuttings, layers, scions, and meristem) from mother trees to supply sandalwood nurseries.

Genetic diversity

Recent surveys have shown significant genetic differentiation in *S. insulare* between the various island groups, between islands in the same group and sometimes even on the same island (Rives, 2004; Butaud *et al.*, 2005a; Lhuillier, 2005). For that reason, the sandalwood's distribution area has been divided into distinct provenances that must be managed and treated separately so as not to lose certain local characteristics. A conservation plan adapted to the context of each provenance needs to be formulated (Butaud and Meyer, 2004) including a proposal to prohibit the introduction of any sandalwood foreign to the site in question.

The distinct provenances recognised at this time are as follows:

- var. *margaretae* on Rapa (Austral Islands),
- var. *raivavense* on Raivavae (Austral Islands),
- var. *raiateense* on Raiatea and Moorea (Society Islands)¹,
- var. *insulare* in the low altitudes on Tahiti and var. *alticola* in the high altitudes on Tahiti (Society Islands): there is still a problem as genetic and taxonomic differences do not coincide,
- var. *marchionense* in the high altitudes on Nuku Hiva (Marquesas Islands),
- var. *marchionense* in the low altitudes on Nuku Hiva (Marquesas Islands),

¹Although little differentiation exists on the genetic level, the populations of these two islands are treated separately by SDR agents

- var. *marchionense* on Ua Pou (Marquesas Islands),
- var. *marchionense* on Hiva Oa and Tahuata (Marquesas Islands)¹,
- var. *marchionense* on Fatu Hiva in the Marquesas Islands.

The variety *deckeri*, poorly defined botanically in the Marquesas Islands and in our opinion just a part of the var. *marchionense*, has been deliberately excluded in this categorization.

Chemical diversity

It has been possible to identify many different qualities for the heartwood of the Eastern Polynesian sandalwood. Two main chemotypes have been identified (Butaud *et al.*, 2002). The most common is the santalol chemotype, of higher quality, which corresponds to the current world market. It can be found in all the island groups whereas a second chemotype (with nuciferol) of poor quality is restricted to a few populations on the islands of Nuku Hiva and Hiva Oa in the Marquesas Islands and, to a lesser degree, on Raivavae in the Austral Islands. This second chemotype, rare and not in demand at the moment should nonetheless be the target of a conservation plan. Accordingly, it is already treated separately on Nuku Hiva and a specific plantation has been created.

In this way, two new provenances were identified based on these biochemical criteria:

- low altitude populations in Maaau and Vaiteheii on Nuku Hiva (that match the provenance identified on a genetic basis in the low altitudes on Nuku Hiva, with the exception of the stand at Motuhee), and
- a low altitude population in Hanaavao on Hiva Oa.

Certain trees on Raivavae may also show a nuciferol chemotype but it is not possible to characterise them geographically or ecologically.

An active approach to conservation

Regulations for protection of sandalwood stands will not, by themselves, be adequate in most cases to preserve the remaining sandalwood stands. In reality, factors other than human damage are involved, such as browsing by herbivores or the trees being overgrown by invasive plants. Conservation plans will, wherever necessary, determine which populations need to be protected by fences; whether or not herbivores and/or rats need to be destroyed on certain islands, or when invasive plants need to be controlled, as has been done in the plans formulated for sandalwood on the Austral Islands (Butaud *et al.*, 2005b).

Ex situ conservation populations and *in situ* reinforcement planting

Sandalwood nurseries (germination, layering, propagation by cuttings, etc.) will be set up in each provenance's geographical area and will make it possible to produce local sandalwood plants. Seeds or plant material will be harvested from mother-trees by authorised agents, using, where necessary, rat poison so as to eliminate rats throughout the fruiting season.

The plants produced will make it possible to initially create conservation stands on public and township lands and in accessible, easily-manageable sites. These conservation plantations will bring together trees from different populations that belong to the same provenance and serve as seed orchards to provide the seeds required to produce the seedlings needed for development of new stands. Some of these plants will also be used to enrich depleted natural populations that may suffer from a lack of fructification due to their limited genetic diversity and resulting inbreeding.

In short, the conservation strategy is as follows:

- legislative protection of existing natural populations,
- defining provenances based on botanical, genetic and chemical criteria and managing them separately,
- formulating conservation plans for each of the provenances, and
- separate *in situ* and *ex situ* conservation actions for each of the provenances identified.

All this work will need to be done by French Polynesia's government or public agencies or under their supervision.

4.2. Managing and developing sandalwood resources

There are no plans to exploit existing resources given the current status of sandalwood populations but rather to manage and develop them. Development of new stands will be done wherever possible by using local sandalwood resources and respecting the distinct provenances that have been identified. The quality of the heartwood of Eastern Polynesian sandalwood is generally the same from one provenance to another (except for the nuciferol chemotypes) and so there is no justification for introducing seeds from one provenance to another in order to improve the wood quality.

Production stands will be created mainly with seeds from seed orchards or from conservation plantations and, to a certain degree, from selected natural populations. As is already the case on Nuku Hiva, plants raised from wild seeds can be sold to the community once conservation stands have been created. These plants are designed to raise awareness in the community about sandalwood conservation and about the species' ecology (hemiparasitism, fructification, etc.) and they will allow the community to regain a sense of ownership for this traditional and emblematic species.

With regards to selection of the plants to be disseminated, chemical studies have, to a certain degree, identified the most interesting trees for wood quality in each provenance. These trees can then be targeted for future propagation with a view to producing high-quality wood: harvesting seeds to have descendants or taking cuttings, layers, meristem cells and grafts to make clones. This work will be conducted in each provenance region so as not to introduce exotic provenances, but rather to conserve local sandalwood populations and traits.

Production of selected plants will be done at private or public nurseries using modern propagation techniques. Appropriate silviculture methods will have to be identified to maximise growth in sandalwood trees. Finally, French Polynesia authorities will have to set a good example for private citizens by creating medium-size production stands on public land as part of its local species reforestation program. An incentive policy will be implemented to encourage private plantations, e.g. technical advice on nursery work, planting and silviculture, providing seed or plants free of charge or at a low cost. French Polynesia's administrative departments and public agencies will also have to be ready to provide an adequate number of sandalwood plants or seeds to meet current or future needs.

In short, the development strategy is as follows:

- identifying the best individuals (oil quality and quantity) in each provenance,
- sexual or plant propagation of these sources,
- identifying appropriate silviculture techniques, and
- implement an incentive policy for creating sandalwood stands on private, public and township lands.

Most of this work can be done by private individuals or companies using seeds provided by government, either free of charge or through sales.

Extension and awareness

In the absence of appropriate conservation, management and development strategies, in a few years from now, sandalwood could become an almost mythical plant known only through tradition. In fact, the vast majority of the French Polynesian population does not know sandalwood directly, has only seen finished products during craft shows and is not aware of the threats to this endangered species.

So efforts have been made by the SDR to raise awareness among the general public with French Polynesian young people as the target group. Talks have been held during Tree Days, training has been provided to nature walk guides and presentations have been made in the agricultural high school and other educational institutions. Documents have been published describing sandalwood and the threats to it. Sandalwood plants produced by the SDR nurseries have been sold to the community so that

people regain a sense of ownership of this species, which is emblematic on several islands. Symbolic plantations have been established in the vicinity of town halls and schools.

Other agencies/programmes in the sandalwood development sector

The sandalwood programme in French Polynesia is the result of the collaborative efforts of several different local and national agencies, particularly through a number of research programmes. In addition to the Rural Development Service, the following two agencies are involved:

The University of French Polynesia's (UPF) Laboratory of Natural Substances is working on Eastern Polynesian sandalwood characterisation and chemical variability. CIRAD-Forêt (CIRAD's Forestry Programme) participated in formulating seed propagation methods for the Eastern Polynesian sandalwood and is currently studying the species' genetic diversity for the purposes of both conservation and development.

Collaboration between these three agencies began with a technical assistance volunteer (VAT) position in the Marquesas Islands between 1998 and 2000 funded by the development contract between the French Government and the Territory for the period 2000-2005 and then continued after 2001 as part of research projects by the French Ministries of Overseas Affairs (MOM, 2001-2003) and the Environment (MEDD, 2002-2005), in particular with a doctoral student in chemistry (2001-2006) at the UPF serving as the link between the various work themes. The main results of these collaborative efforts are presented in Section 3 of this report.

Four priority national activities to be implemented

With the work conducted since 1998, significant progress has been made in terms of information on the status of Eastern Polynesian sandalwood populations, the threats to conservation, propagating this species, the quality of its wood and its genetic diversity. With the aid of this recently-acquired knowledge, new actions appear necessary for establishing and implementing conservation and development strategies.

Nursery propagation

Sandalwood seed propagation techniques have been identified and shared (Butaud, 2001) but no work on vegetative propagation has been completed yet. Research needs to be carried out on cutting, layering, grafting and *in vitro* culture techniques so as to be able to propagate plant material from high-quality trees or those that are not producing any seeds. In addition, the SDR nurseries need to have appropriate equipment such as automatic sprinklers, protected germination beds and bottom heat beds.

Identifying silviculture techniques

Very few data exist on the performance of *Santalum insulare* in plantations. Silvicultural research needs to be conducted in order to identify preferred host plants, spacing, trimming and growth rates. In this way, a sandalwood silviculture manual can be written to provide advice to public agencies and private individuals on how to create the best sandalwood plantations possible.

Impact of edaphic conditions on wood quality

Genetic and chemical studies have not uncovered any real link between wood quality and genetic diversity, perhaps partly because of the highly variable ecological conditions. Plantations including sandalwood trees from different origins should be created in different ecological zones to assess the influence of genotype and environment on wood quality.

An active Eastern Polynesian sandalwood replanting policy

French Polynesia's government and public agencies need to stimulate and encourage efforts to grow sandalwood in the various island groups by several means. These include producing a large number of seedlings in SDR nurseries, widespread dissemination of sandalwood production and silvicultural

techniques, the sale of plants or seeds at a low cost, giving priority to planting sandalwood on public lands and providing technical and financial assistance to private plantations. The main factors currently limiting sandalwood replanting are difficulty in collecting seeds or plant material from the remaining natural stands, low germination and propagation in *ad-hoc* nurseries. These are the areas where concentrated efforts need to be made.

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Sandalwood (*Santalum album* L.) Resources in Indonesia

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Sandalwood Resource Base

It has been realized for a long time that biodiversity constitutes an essential asset for sustainable development. Indonesia is rich in biodiversity. This richness is not only limited to the species level - covering wild as well as domesticated and cultivated, native as well as introduced species of plants and animals - and to a certain extent, the microbes - but also at the ecosystem and gene/genome levels. With the high degree of diversity at all levels, especially the species and ecosystem levels, Indonesia has good options in sustainably utilizing the components in these levels of biodiversity.

Sandalwood trees are amongst the myriad of biodiversity that Indonesia has been blessed. Sandalwood belongs to the order *Santales*, family *Santalaceae*, subfamily *Santalinae* and genus *Santalum*. There are several species of sandalwood, but the species *Santalum album* L. is believed to have originated from the Timor region. Two varieties of *S. album* are recognised in the Timor region, i.e. *S. album* var. *album*, which is characterised by small leaves, and *S. album* var. *largifolium*, which has larger leaves (Harisetjono and Suriamihardja 1992). In Indonesia, sandalwood (*S. album*) is primarily found in eastern Nusa Tenggara (NTT) and west Timor. The three main islands of NTT are Timor, Flores and Sumba (formerly known as "sandalwood island"). The name reflects the long history of utilization of sandalwood trees on Sumba Island. The island of Timor is the largest and easternmost of the Lesser Sunda Islands, and part of the Nusa Tenggara archipelago. The long narrow island is 34,200 sq. km with parallel mountain ranges spanning its length. Average rainfall is about 1,250mm per year mostly falling during the monsoon season from December to March. Timor has sparse natural vegetation due to its poor soil, although it does contribute valuable timber such as eucalyptus, teak, bamboo, rosewood and sandalwood to Indonesia's economy.

Apart from NTT, the species also has restricted distribution to the highland regions of Sulawesi, Moluccas and eastern tip of Java in Bondowoso district. The exact origin of *S. album* is not known. However, it has been suggested that the species is native to Timor and Sumba islands (Harisetjono and Suriamihardja 1992). It is often speculated that it was introduced into India about 2,000 years ago from west Timor (e.g. Yusuf 1999). However, Fox *et al* (1995) found no clear evidence of an origin for *S. album* in either India or Indonesia.

Indeed, since the 10th century sandalwood has been commercially traded in Timor by Chinese traders to Malaya and India. During the 15th century following the colonization of Portugal in Timor, western traders were attracted to sandalwood, although the earliest records of sandalwood trade from Timor date back to the 3rd century AD (Husain 1983).

Sandalwood is light-demanding and can be easily shaded and suppressed by faster-growing taller species. Cultivation techniques now involve the use of *Capsicum* and *Acacia villosa* as host plants. Cultivation of sandal in NTT has had limited success. Sandal trees freely produce seed and natural regeneration occurs both via seedlings and through root suckers after trees have been uprooted and the stump removed from the ground. Yield of oil is highest from the roots and lowest from wood chips derived from branch wood.

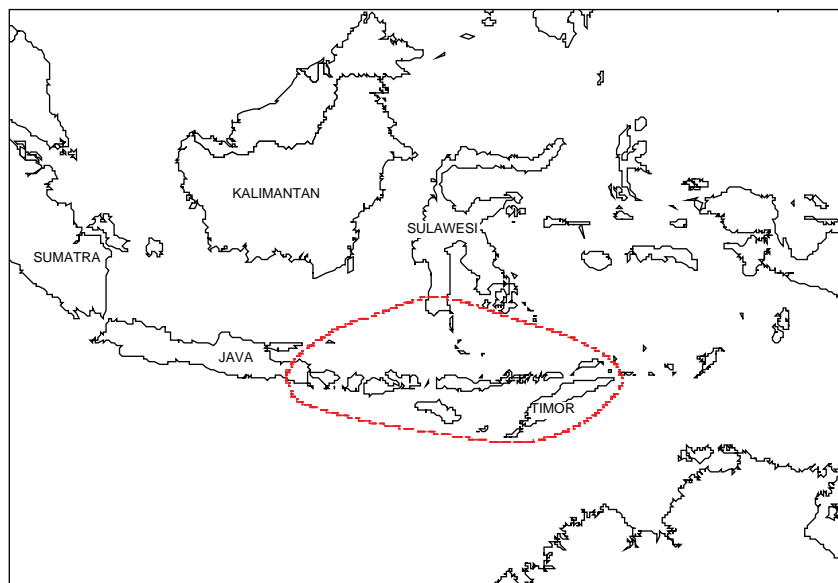


Fig. 1. Distribution of *Santalum album* in Indonesia (circled area).

The cultivation or planting of sandal as a short- or medium-term source of income is unattractive because the oil is only obtained from the heartwood of mature trees and the tree is slow growing. Almost all of sandalwood timber in NTT is harvested from naturally regenerated trees..

In Indonesia continuous harvesting without replacement regeneration (due to fires, shifting cultivation and cattle grazing) has caused a serious decline in wild populations. McKinnell (1990) had warned that under the existing conditions sandalwood resources in west Timor would only last for 10 years. Subsequently it would have severe adverse economic and social impacts on the Province. Latest statistics from the essential oil market in London showed that sandalwood oil from Indonesia has disappeared from the market since March 2002. This probably reflects the diminishing resources of sandalwood trees in west Timor.

The rapid decline of sandalwood resources on Timor Island is illustrated in the inventories carried out by the Provincial Forestry Service in which during the 10 years period from 1987 to 1997, the number of sandal trees dropped almost 50% from 544,952 trees to 250,940 trees. The most serious decline was found in east Sumba where 27,900 trees in 1990 has declined to only 3,253 trees in the latest 2001 inventory. Sandal has become extinct on smaller islands in NTT such as Adonara Island and Lomblen Island.

Outside NTT, planting of sandalwood is being pursued, most notably was the planting at Wanagama, Gunung Kidul Yogyakarta by the Faculty of Forestry University of Gadjah Mada. Although this planting was for genetic trials it has demonstrated that the species is suitable from growing in the area.

Trade and Industry

Sandalwood production in Timor is derived mostly from natural regeneration. Although efforts to establish plantations first started in the early part of the twentieth century, today no plantations exist.

Sandalwood utilization can be grouped into three categories: a. oil extracted from the heartwood used for perfumery, cosmetics and aromatherapy; b. powder used for incense; and c. wood for furniture and handicraft. Sandalwood oil from West Timor is exported mainly to USA and Europe, including France, Netherlands and the United Kingdom (BPEN 1993).

The sandalwood oil industry is a major consumer of sandalwood raw material. The largest and oldest oil-distilling factory is located in Kupang and had a processing capacity of about 800 tonnes of wood per annum. The average recovery of sandalwood oil is between 2.62% and 2.84% (Rohadi *et al* 2000).

The oil recovery is far below those reported in India. One possible reason for the low recovery is the premature harvesting of the wood in Indonesia. Barret (1985) reported that oil content increases significantly with tree age.

In earlier times nearly 30% of the world production of sandalwood and sandalwood oil was exported from the ports of Kupang and Dili, with the majority coming from southern India (Yusuf 1999).

Towards the end of 1960s about 30 tons of sandalwood oil and an equivalent amount of sandalwood were exported annually from Timor. Between 1989 and 1994 the production had declined significantly to an annual average of 12 tons oil and 680 tons heartwood (Yusuf 1999). Data on export of sandalwood oil from NTT between 1987 to 1992 are presented in Fig. 2.

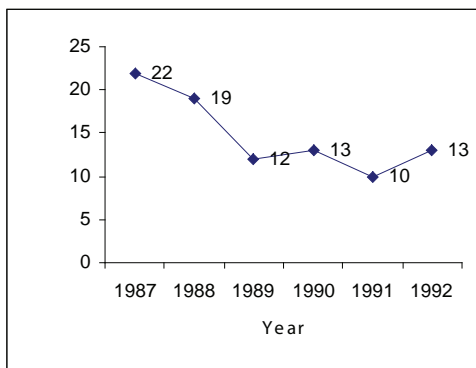


Fig. 2. Export volume of sandalwood oil from NTT (FAO 2002)

Sandalwood oil and joss stick have traditionally been locally produced in NTT and logs were traded between islands particularly to the neighboring island of Bali for woodcarving. With the diminishing supply of sandalwood logs from NTT this home-based industry is struggling to survive.

Figures from 2000 showed the total wood intake of the sandalwood industry in West Timor was around 4000 tons per year (Rohadi *et al* 2000). The main products in West Timor included sandalwood oil, joss sticks and handicrafts. All of the factories are located in Kupang, the capital of NTT.

Sandalwood is an important commodity for the Province of NTT contributing significantly to the local economy. Between 1986 and 1991, sandalwood contributed up to 40% to the total income of the Province. Since then it has declined steadily reaching a low level of 16.5% in 1997 (Rohadi *et al.* 2000). In 1998 more than 1000 people were directly employed in sandalwood-related industries. It is believed that these figures would be lower nowadays. Despite the economic importance of sandalwood to the local economy, there has not been any significant effort by the provincial government to rehabilitate the dwindling sandalwood resources.

Research and Development

Sandalwood is referred to as a hemiparasite (or semi-root parasite) and requires a range of suitable host plants for its nutrition and moisture requirements (Radomiljac 1998). The ecology of natural sandalwood production in Timor (and elsewhere) is therefore complex and accounts for significant variation in growth characteristics and heartwood development throughout the range of the species. Although there has been significant research on the ecology and silvicultural aspects of the tree, a full understanding of ecological dynamics of sandalwood has yet to be developed (Barret, 1989).

3.1. Genetic research

Considering the depletion of genetic resources of *S. album* in West Timor, conservation of the remaining genetic diversity is of the highest priority. Unsustainable harvesting has put the genetic diversity of the species at risk. The remaining trees in West Timor, Sumba and Alor are scattered in solitary patches. It is believed that the genetic diversity of the species in west Timor is narrow as most of the adult trees

have been cut out. Work to examine the genetic diversity of the remaining trees/populations would be an important step both for conservation purposes and new plantation establishment.

Effendi *et al* (1995) reported that four seed production areas (SPAs) have been identified in west Timor. However, it is unclear if these SPAs remain. Similarly, phenotypically selected plus trees have been identified in various districts across west Timor. In total 108 trees have been selected and used as materials for breeding and genetic improvement works (Effendi and Surata 1993).

In recent years R&DCPF has been conducting a study on the genetic aspects of sandalwood. Using DNA markers we are currently conducting a study to examine the genetic diversity of sandalwood in several populations from Alor, Timor and Sumba islands. Germplasm from 17 populations has been collected and used to establish *ex situ* conservation plots at Gunung Kidul Yogyakarta (central Java).

Ex situ genetic conservation of sandalwood commenced in 2002 at Gunung Kidul near Yogyakarta. A plot of 2.5 ha containing 17 provenances (10 from Timor, 3 from Sumba, 3 from Alor and one land race from Java) has been planted. Seed collection from populations in Rote, Pantar and Solor has been carried out recently and will be used to establish a gene conservation stand.

The slow development of heartwood from which sandalwood oil is derived limits its attractiveness as a short or medium-term source of income. Under natural conditions in the forest, sandal is slow-growing tree. Growth rate may be increased by improvement of soil fertility and other measures but vigorous growth is often associated with later onset of heartwood formation. Assuming that existing propagation and cultivation problems can be overcome, opportunities for utilizing sandal as anything other than a long-term cash crop are likely to depend on the identification of faster-growing elite trees with earlier heartwood formation as a source of material for planting. This in turn requires the establishment of a wide-ranging screening program to search for such trees.

3.2. Seed technology and propagation techniques

In Timor sandal trees flower between December and January and fruits are harvested from March till April. Extracted seeds can be air dried for 4 – 5 days, out of the sun, or until moisture content reaches 5 – 8%. A suitable storage condition is in sealed containers at 4°C.

Vegetative propagation by tissue culture has been developed and applied at operational scale. Culture media for initiation and multiplication is MS based whilst for rooting it is WPM base. Although the protocol for multiplication is well established, rooting success is not high, around 60%.

3.3. Flowering biology

Sandalwood flower is a protandrous hermaphrodite with, low pollen quantity. It has low seed set and high selfing rate. A study carried out by the Faculty of Forestry, Gadjah Mada University, Yogyakarta is in progress to enhance pollination effectiveness and increase outcrossing rate through inter-provenance crosses by hand pollination. Controlled crosses gave the highest value of pollination effectiveness and seed set (29.0% and 16.6% respectively) compared to those of selfing (12.5% and 12.0% respectively) and open pollination (1.8% and 0.92% respectively).

3.4. Silvicultural research

Research on nursery techniques has focused on finding the most suitable conditions (treatment, media, and host plant) for germination and seedling growth. Soaking the seeds in water for 12 hours is the standard practice for germination. Suitable host plants in the seedling stage are *Althernanthera* sp., *Desmatus virgatus* and *Crotalaria juncea* (Surata 1993). Light shading is required for up to 6 months and seedlings should be ready for planting at 8 months old.

Suitable host plant in the plantation has also been studied. Surata (1993) reported host plants for mid term are *Acacia villosa*, *Leucaena leucocephala* and *Sesbania grandiflora* and for long term are *Casuarina junghuniana*, *Cassia siamea* and *Dalbergia latifolia*. Mungbean, maize and rice are suitable cash crops for intercropping with sandal trees.

Studies on other aspects of silviculture, propagation, and seed technology have also been carried out.

In conclusion, more data and information on various the technical aspects of cultivating sandalwood will be needed to support a successful plantation program. The lack of success in planting sandalwood, particularly in NTT is also adversely impacted by non-technical aspects, especially regulations regarding the share of benefits between local government and community.

National Plan and Strategies

Under the National Indonesian system of classification for forest resources, sandalwood falls into the category of a 'minor forest product'. This designation reflects the institutional bias towards timber (major forest product) within the Indonesian forestry sector. Considering the importance and the strategic position of sandalwood in the international market, a national strategy on sandalwood resource management is urgently needed.

Since 1999 the provincial government of NTT has relinquished its rights over the harvesting of sandalwood trees and given back to communities the right to manage and derive benefits from trees found on their private land. A small portion of the sale price goes to the local district government. The provincial government remains responsible for the management of sandalwood trees in public land.

Various agencies with an interest in sandalwood research and rehabilitation are not working in a coordinated manner. With limited resources, it is most desirable that a comprehensive plan for sandalwood recovery be developed. The issue of sandalwood however, is not restricted to technical issues but equally important are the administrative regulations governing the management of sandalwood in the province. Lessons learned from former policies clearly demonstrate that government policies on sandalwood that marginalize the rights of individuals to benefit from sandalwood trees will have a detrimental effect on the sustainability of sandalwood resources.

1. Extension and Awareness

Historically, under traditional law sandalwood was appropriated by the ruling class (Ormeling 1955). Similar rules were maintained by the government in which the biggest benefit was taken by the government while farmers or individuals who plant trees on their own land only received 15% of the sale of the products. This regulation has now been revised giving a greater share to landowners.

Ineffective local government policies that tend to neglect community rights and thus discourage villagers from participating in the maintenance of sandalwood regeneration have been identified as one of the root problems of the declining resources of sandalwood in NTT (Rohadi *et al* 2000, McWilliam 2001). Participation by local communities will be crucial to the recovery of the greatly diminished Indonesian sandalwood resource,. Local communities should receive a fair share of their efforts to attract them in the cultivation of sandalwood trees.

It is commonly said that growing sandalwood is difficult and that the trees would grow by themselves. Attempts to plant sandalwood were often received with a pessimistic view by the public. Accordingly public perception of the difficult nature of growing sandalwood also needs to be addressed.

The involvement of NGO's to encourage local communities to grow sandalwood would be an important step given the repressive approach by government authority in the past. These efforts should also involve agriculture extension workers as they often well-developed networks in rural communities.

Other Agencies/Programmes in the Sandalwood Development Sector

Rehabilitation of sandalwood resources in NTT has been carried out by forestry agencies (Provincial Forestry Services and Forestry Research and Development Centre in Kupang). In recent years Indonesian Science Institute (LIPI) is also active in developing suitable technology for sandalwood cultivation. Some local NGOs are also believed to be also active in supporting local community to plant sandal trees.

The efforts to rehabilitate sandalwood resources in NTT would be most effective when all organizations interested in sandalwood could work in a coordinated program. The adoption of national program on sandalwood rehabilitation and utilization would be an important step that would prevent the species from disappearing from Timor islands landscape.

Four Priority National Activities to be implemented

The crisis in the sandalwood resources and industry across NTT has reached a point where the viability of the species on the islands is at risk. The failure of the government to sustainably manage sandalwood resources in NTT was due mainly to a policy that gave the State control over a forest resource that was mainly cultivated and managed by local farmers and communities on their own land.

In order to restore the genetic resources of sandalwood the following activities need to be treated as priority.

- a. Conservation of genetic resources both *in situ* and *ex situ*.
- b. Establishment of model plantations.
- c. Mass propagation of sandalwood seedlings.
- d. Regulations that encourage community participation.

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This paper provides an update on the communication that was presented during the regional Workshop on Sandalwood research held in Nouméa, New Caledonia, in 2002 (Tassin *et al.*, 2005).

1.0 Sandalwood Resource base

1.1. Recent inventories

The sandalwood resource is still largely based on the inventories undertaken by the *Centre Technique Forestier Tropical* (now known as CIRAD-Forêt) on the three Loyalty Islands of Lifou, Maré and Ouvéa in 1987, and on the Ile des Pins in 1988. A second survey was carried out in 1994 at Isle des Pins to update data, to investigate sandalwood population dynamics, and to determine sustainable levels of exploitation. This second inventory, a six-month study, was supported by Province Sud and conducted by CIRAD-Forêt. It concluded that a significant increase in regeneration had occurred in the inventoried area between 1988 and 1994. Available data show that between 30 and 45 tonnes per year of heartwood could be sustainably harvested in Isle of Pines or in Loyalty Islands. Following these inventories, the criteria used to assess whether sandalwood trees are able to be harvested is as follows: (i) stem girth over 70 cm and sapwood width under 3 cm at 20 cm above ground level; (ii) all trees with a girth over 100 cm being allowed to be cut down.

In 2004 and 2005, sandalwood inventories were undertaken using a new methodological framework developed by IAC (Tassin, 2003ab; Tassin; 2005; Tassin *et al.*, 2005). On the request of the Province des Iles Loyauté, an inventory has been undertaken in Loyalty Islands, in Mare (Brinkert, 2003), then Lifou and Ouvéa (Steierer, 2004). The main objective was to prevent overexploitation of sandalwood resources. We wanted to make sure (i) that the current exploitation of 45 t a year of heartwood was sustainable and (ii) that the demography of sandalwood was not altered (that is to maintain a supportable level of regeneration and a balanced distribution of tree age classes/sizes). Yet, we considered that a supportable level of exploitation monitored at the island level might be irrelevant at lower spatial scales, if not disastrous. Accordingly, using a new methodology package of inventory of sandalwood resource based on an exhaustive sampling of the whole island, and considering different spatial scales, we investigated contrasting situations to examine showing questions of sustainable harvesting at lower spatial scales.

We developed an efficient method of evaluation, using (i) square plots instead of line transects, (ii) a systematic covering of the island through a sampling netting. First, we divided the islands into grids of 500 m x 500 m, each one of which we positioned a central plot. Secondly, using available maps of vegetation (soil utilization, vegetation and pedology), we excluded all grids in following zones : primary forest, degraded lands highly invaded by *Schinus terebenthifolius*, and areas inventoried in 1988 that showed a very low density of sandalwood ($d \leq 5$ trees / ha). This selection has led to a mapping of Inventory Areas, that yielded important information on a fine scale. A 50 m x 50 m central plot was geo-referenced and studied in each mesh within the Inventory Areas. We recorded sandalwood data (circumference at 20 cm and 130 cm upper soil level) and environmental data (type of vegetation,

vegetation composition - invasives or native vegetation, height of canopy). Using this method, the workload has been reduced to one-fifth of that required for the 1988 inventory.

We undertook a statistical study to analyse (i) links between vegetation and sandalwood densities, (ii) distribution of circumference classes at the island level and in each one of the Inventory Areas, and (iii) computation of heartwood exploitation quota. For this third point of the statistical analysis, we used different regression models (Nasi, 1984).

(i) We found that the distribution of circumference classes was linked to the composition of vegetation. Sandalwood is mainly linked to the presence of anthropogenic vegetation (63 % of the trees on Maré, 59 % on Lifou, and 64 % on Ouvéa) but is rather scarce in primary forests (4 % on Maré, 0.2 % on Lifou, 2 % on Ouvéa).

(ii) We did not find a significant difference of densities of sandalwood between 1988 and 2003, with the exception of class 10-20 cm, which is reduced on Maré in 2003 from an unknown cause(s). We computed a new exponential model, based on data gathering 2531 sandalwood trees: $N = 2071 e^{-0.0802 C_{1.30}}$ ($r^2 = 0.910$), N the number of individuals, $C_{1.30}$ the circumference (cm) at 1.30 m. Then, we compared this model to the distribution of circumferences in each one of the different zones. On Maré, we identified situations of overexploitation and/or insufficient regeneration in 40 % of sandalwood areas (18 % on Lifou, and 43 % on Ouvéa).

(iii) We determined that sandalwood exploitation needs to be reduced to a more sustainable level per year (10 t on Maré, 11.5 t on Lifou, and 7.7 t on Ouvéa). Using a regression model based on the utilization of the circumference at 1.30 m upon soil level (Nasi, 1994), we calculated the production of sandalwood expected in the next 15 years (that is $C_{1.30} \geq 50$ cm). We took into consideration the zones where this exploitation is reputedly sustainable, that is excluding the zones of overexploitation or under-regeneration. In this computation, we decided to conserve 10 % of the largest trees in order to provide seeds and to enforce natural recruitment. Using the same methods of computation, we found that the quota of harvesting calculated by Quemain (1988) had been widely overestimated. Fortunately, there had been no major consequences on the maintenance of the resource because exploitation of sandalwood has been maintained below this level during the last 15 years. The exploitation level is equivalent to the exploitation of 200-250 trees ($C_{1.30} \geq 50$ cm) a year on Maré (257 on Lifou, and 171 on Ouvéa).

This approach using an exhaustive sampling was useful to propose a sustainable management of sandalwood resources following different spatial scales. Using this methodology package, we found in 2003 contrasting situations showing either sustainable management or overexploitation, depending on the scale considered. In accordance with the recommendations of the workshop on sandalwood held in New Caledonia 2002, we confirmed that the exploitation of sandalwood needs to be assessed at different scales: a low level exploitation at a large scale may result in overexploitation on a finer scale. Considering this level of variation and in accordance with data of the previous inventory, we found that (i) the exploitation of sandalwood in Loyalty islands should not exceed 29.2 tonnes a year (instead of 45 tonnes as proposed by Quemain, 1988), (ii) and that the exploitation should not be maintained in more than 60 % of the whole area containing sandalwood.

1.2. Demographic trends of sandalwood populations

Demographic data on girth distribution of sandalwood trees helps to provide recommendations for a sustainable exploitation at local scales. Figure 1 (below) was realized at the global scale of two islands (Lifou, Ouvéa). It does not reveal threatening features, yet although overexploitation evidently does occur on finer scales. For example at Hapetra (Lifou) we can observe a lack of regeneration, and a dearth of trees in all exploitable girth classes, because of recent overexploitation (Fig. 2). On such a site, IAC has recommended a cessation of exploitation.

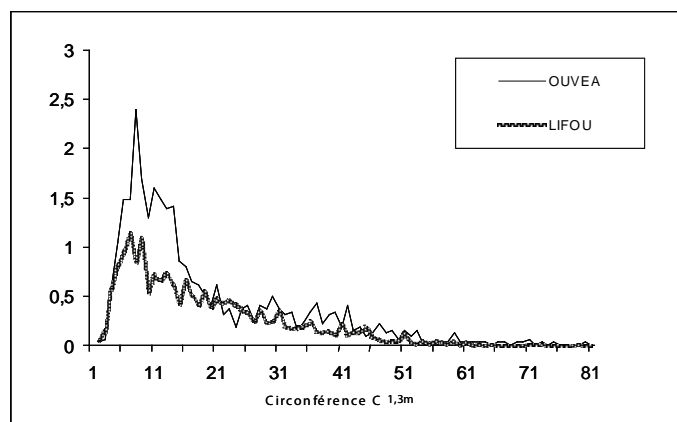


Fig. 1 Distribution of sandalwood girth at 1.30 m from the ground in Lifou and Ouvéa, Loyalty Islands (adapted from Steierer, 2004).

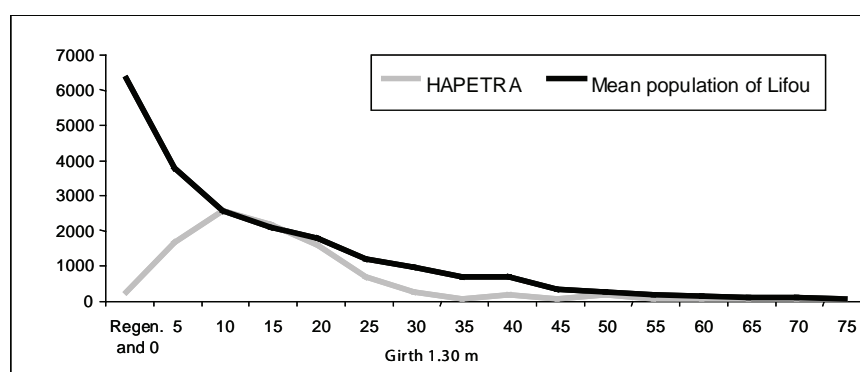


Fig. 2 Distribution of sandalwood girth at 1.30 m from the ground on Hapetra compared to the whole sandalwood population of Lifou, Loyalty Islands (adapted from Steierer, 2004).

2. Trade and Industry

2.1. Historical background

Sandalwood resources of New Caledonia, mainly based in Loyalty Islands and Isle of Pines, were discovered during the first half of the 19th century. The first exploitation is reported to have taken place in 1828. Then, from this date up to 1865, the whole exploitation of sandalwood reached 2000 tonnes of heartwood. Between 1906 and 1923, 980 tonnes were exported to the European market from both New Caledonia and Vanuatu. Overexploitation has driven sandalwood to extinction in several parts of the country. It is now absent from the upward side of Main Island except at one site near Hienghène, the population of which was discovered by IAC staff in 2003. A total of 1985 tonnes of sandalwood were cut in New Caledonia from 1948 to 1990. Two industrial distilleries, associated with ARCO Distical, have produced sandalwood oil in New Caledonia in two periods, from 1978-80 and 1987-90.

At the moment, a co-operative distillery is working on the Island of Maré and uses sandalwood from Loyalty Islands. A private distillery (WE DA SARL) is located on the Isle of Pines. A recently installed distillery on Ouvéa has already ceased to operate.

2.2. General regulations

New Caledonia's forestry regulations are based on décret n°. 405 dated 18th March 1910 and its subsequent amendments and additions from 1926, 1936 and 1968. In 1990, the responsibility to authorize logging was held to by the Provinces, following the approval of the owners (generally the custom chiefs on

native reserves). A permit for the exploitation of sandalwood is lodged with the Provincial authorities, generally by the purchaser. The felling permit lays down the technical and statutory conditions of the exploitation. The exploitation is then administered by the Province Forestry Service which (i) marks the trees to be felled, and (ii) ensures adherence to the specified conditions.

In the Loyalty islands, a new regulatory system is expected to be set up in the next few months in order to re-evaluate the quotas for exploitation taking into account recent inventories and population assessments. Unfortunately, and despite the allocation of quotas at an island scale, the absence of agents in charge of the application of sandalwood regulations represents a major difficulty in ensuring the sustainable exploitation of sandalwood at a more local scale. On Pine Island, the quota is maintained to 40 tonnes per year, in accordance with Quemin's (1988) recommendations.

3. Research and Development

3.1. Research

A state of the art report on sandalwood research in New Caledonia has been provided in 2002 (Tassin, 2005). Research on sandalwood has been conducted since the early 1990's. It had firstly focused on means of production of seedlings in nursery, and sandalwood cultivation. Secondly, an evaluation of genetic resources has been attempted. A progeny trial has been established in Païta in order to test the heritability of interesting characters (height, stem form, quality of heartwood). It will also provide valuable data on growth rates in the field.

From 2002 to 2005, a new program of research has been undertaken in New Caledonia with the help of French Government to obtain a better representation of the dynamics of genetic resources at different scales, and using both the molecular and chemical approaches. The main results of this study are included elsewhere in these proceedings. Some of them have already been published (Bottin *et al.*, 2005ab).

3.2. Artificial regeneration

Since the 1980's, with the efforts of the Territory of New Caledonia and research institutes, a satisfactory technique for the production of sandalwood seedlings has been developed. As a result, thousands of seedlings have been produced by the forest seedlings section at the Port-Laguerre nursery, and in nurseries on Pine Island and Maré. These have given rise to both private plantations and Government plantations. Individual plantations are set up as (i) enhancement plantations (in a natural forest formation after thinning or in a field after bush clearance) or (ii) conventional plantations (on bare lands with the use of host species, e.g. *Acacia spirorbis*). Unfortunately, artificial regeneration progresses slowly and fire remains a huge threat to conventional plantations on Pine Islands. Some important sandalwood regeneration efforts have been realized by provincial authorities. On Pine Island and from 2001 to 2004, 5250 seedlings have been provided to owners by DDR through private nurseries contracting, at a rate of 1200-1400 seedlings a year. On Maré, a nursery has been established by DAE but suffers of a lack of staff.

4. National plan and strategies

The only strategy and action for sandalwood conservation and utilization on New Caledonia is establishment of quotas for sustainable exploitation. Regulation of sandalwood management is dependent on individual Provincial authorities.

5. Extension and awareness

Training and/or awareness activities for sandalwood have yet to be implemented in New Caledonia. Extension sessions on technical processes of production of seedlings were planned by the forest seedlings section of the Port-Laguerre nursery but were never run.

6. Other agencies/programmes in the development sector

Agencies implied in the development sector on sandalwood are strictly restricted to provincial services. These services are also dealing with natural resource conservation, a necessary step in local development. For instance, the inventory of the natural age-old population of sandalwood in Hienghène, realised at the end of 2004, has stressed on the threat due to bush fires. In order to save the population dynamic through natural regeneration, Province Nord tries to include awareness within local Melanesian tribes by providing information on land degradation threats.

7. Four priority national activities to be implemented

During the three past years, there has been considerable improved understanding of two main issues: (i) Knowledge of the sandalwood regeneration dynamics and demography, in order to determine a sustainable level of exploitation and (ii) Knowledge of the variability of the resources.

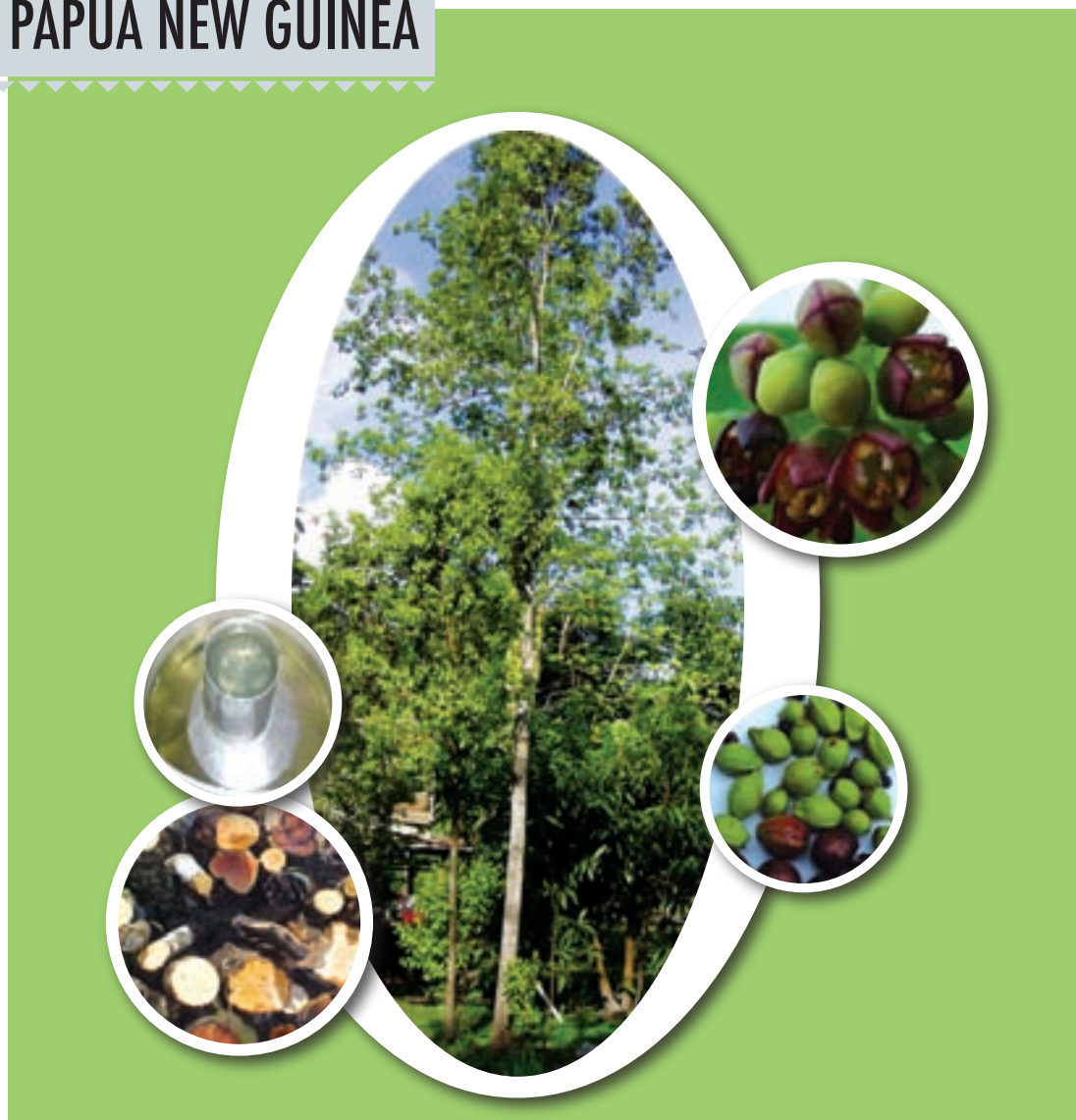
In 2005, the outstanding priority actions for sandalwood in New Caledonia are :

- Enhancement of incentives or measures to promote new plantations in overexploited areas;
- Strong support (and probably recruitment) of officers giving recommendations to individual planters and following sandalwood management in a sustainable way;
- Realisation of a plan for conservation of genetic resources of sandalwood; and
- Development of a certification approach involving distilleries in order to better ensure sustainable exploitation.

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Report of Sandalwood Research, Development and Extension in PNG

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Introduction

In Papua New Guinea interest in sandalwood research, development and extension was rekindled in 1996 but since then progress has been somewhat slow. There has been some success in the attempt to conserve, manage and utilize this scarce but valuable resource. In October, 2002 Papua New Guinea was among the Pacific Island Countries and Territories (PICTs) invited to participate in the second regional sandalwood workshop held in Noumea, New Caledonia. After this workshop, there has been more rapid progress in R&D and extension of sandalwood in PNG.

Sandalwood Resource Base

One of the recommendations put forth by the above workshop was for each country to carry out an assessment of the sandalwood resource available in their respective countries. In Papua New Guinea, despite the endangered status *S. macgregorii* such a survey has not been done due to lack of resources. It can be seen from the sandalwood trade that there is still sandalwood growing across its natural distribution range, mainly in the Central and Gulf Provinces and more recently a small stand of sandalwood has been found in the Western Province.

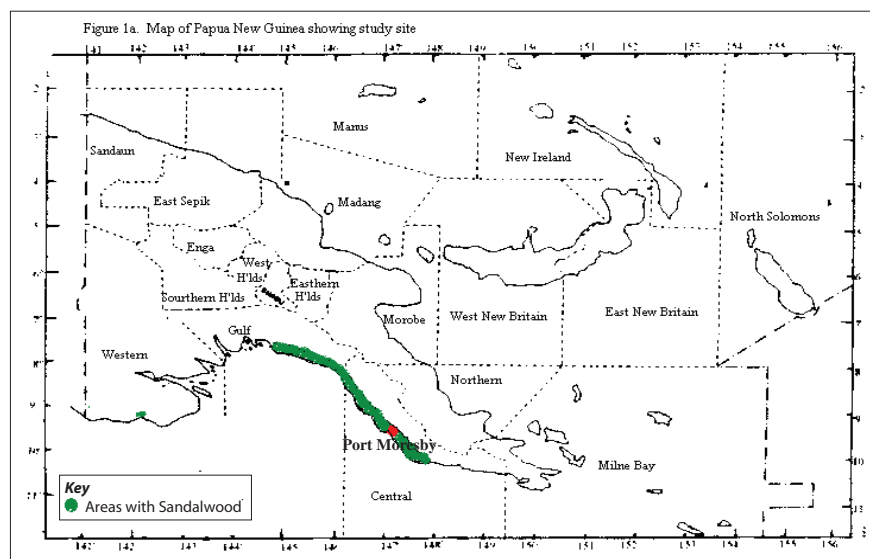


Fig. 1: Distribution of Sandalwood in PNG

Sandalwood Resource Base

One of the recommendations put forth by the above workshop was for each country to carry out an assessment of the sandalwood resource available in their respective countries. In Papua New Guinea, despite the endangered status *S. macgregorii* such a survey has not been done due to lack of resources. It can be seen from the sandalwood trade that there is still sandalwood growing across its natural distribution range, mainly in the Central and Gulf Provinces and more recently a small stand of sandalwood has been found in the Western Province.

Trade and Industry

The trade in sandalwood was thought to have died out in the early 1970s (Paul, 1990), however, since the work on the species started again, it can be seen that the industry has been quietly but steadily growing, an indication that there may be additional unknown sandalwood areas in the three provinces. Currently there are four main buyers and exporters based in Port Moresby (Table 1).

Exporter	Volume (kg)	Value (US\$)	Buyer	Destination
2003				
A & F Forest Products Ltd	8,000	20,000	En Ling Trading Co. Ltd	Taiwan
A & F Forest Products Ltd	9,000	22,500	En Ling Trading Co. Ltd	Taiwan
Hinoki Timbers	7,849	19,620	Lih Chun Rattan Co. Ltd	China
Pomus Resources	5,000	12,500	Uno-Tech Corporation	Taiwan
A & F Forest Products Ltd	13,500	33,750	En Ling Trading Co. Ltd.	Taiwan
A & F Forest Products Ltd	10,000	25,000	International Metropolitan	Taiwan
A & F Forest Products Ltd	6,500	16,250	International Metropolitan	Taiwan
A & F Forest Products Ltd	6,900	17,250	Kawiseraya Corporation	Singapore
Hinoki Timbers	6,638	16,595	Lih Chun Rattan Company	Taiwan
TOTALS	73,387	183,465		
2004				
A & F Forest Products Ltd	10,500	26,250	Kawiseraya Corporation	Singapore
Hinoki Timbers Ltd	7,305	18,262	,Chen Guang Hua Enterprises	Taiwan
Hinoki Timbers Ltd	7,354	18,385	Chen Guang Hua Enterprises	Taiwan
Union Stream Enterprises	8,100	20,250	Tsen Fan Yi Trading	Taiwan
TOTALS	33,259	83,147		
2005				
A & F Forest Products Ltd	10,000	25,000	Tat Seng Agarwood Import and Export	Singapore
TOTALS	10,000	25,000		

Source: Marketing Branch, PNG Forest Authority, Port Moresby; December 2005.

Table 1: Sandalwood Export from PNG

Current domestic price for all grades of sandalwood is K4.50 per kilogram (or US\$2.50) for better grades on the export market. The latter equates to less than K10.00 per kilogram of sandalwood. This price is well below market value as good quality sandalwood usually commands between \$US 30-40 per kilogram on the world export market. There is an urgent need to monitor and regulate the activities of sandalwood buyers in order to standardize an appropriate and higher price sandalwood, thus giving resource owners the incentive to conserve, protect and grow more sandalwood trees.

Research and development

(i) Seed collection

Several seed collection expeditions were made with support from SPRIG prior to the 2002 workshop and seed from these collections has been used for pot host trials, germination techniques and field host trials both here in Papua New Guinea, Australia and under the SPRIG program.

The latest seed and germplasm collection was done in September, 2004 by the PNG Forest Research Institute and CSIRO with funding assistance from the Eco-Forestry Project of the European Union. The seeds, root and stem cuttings collected on this trip are being trialed at FRI in Lae and the results should be available soon.

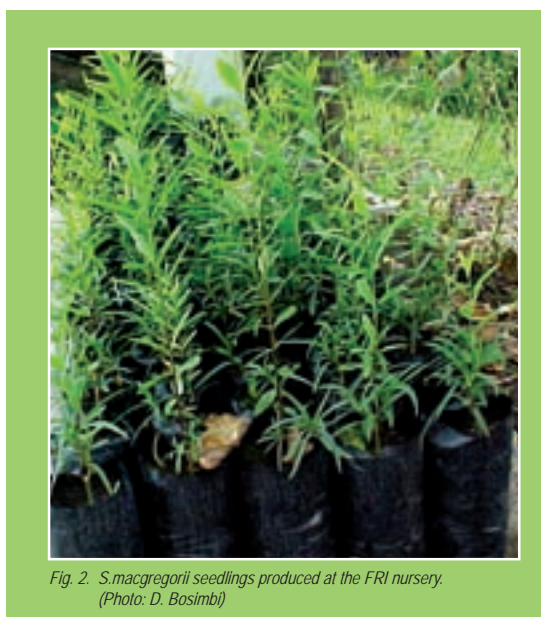


Fig. 2. *S. macgregorii* seedlings produced at the FRI nursery.
(Photo: D. Bosimbi)

(ii) Nursery germination trials

Most of the seed propagation research on sandalwood has centered around germination testing to identify the best pre-treatment techniques and medium for optimum and uniform germination. This work has been concluded and the results internally reported at an FRI seminar in October, 2005. From this work, Tuiwain (2005) reported that the best technique for mass production of *S. macgregorii* is nicking the seed and soaking in water at ambient temperatures overnight and then sowing them in a bed of peat moss and soil, sand or sawdust combination. This resulted in 66-80% in 200 days from sowing to final germination.

National plan and strategies

There are several recommendations to the National Forest Board made under the ACIAR/PNG Species Domestication Project that need to be implemented (Gunn *et al.* 2002). It is suggested that these recommendations be implemented as follows:

- Assess the sandalwood resources in PNG
- Identify villagers in the sandalwood growing areas who are genuinely interested in growing sandalwood and then develop a support program to assist them based on their needs.
- Conduct more tests on the chemical composition and variation in the heartwood oils of *S. macgregorii* from all three provinces to identify sandalwood trees and populations with high levels of Z- α -santalol and Z- β -santalol so these can be propagated and planted in plantations and village woodlots (Doran *et al.* 2005).
- The Papua New Guinea Forest Authority through the Forest Research Institute or the National Tree Seed Centre establish an *ex-situ* seed production orchard to produce and supply seed.
- Papua New Guinea Forest Authority take a lead in sandalwood development by establishing demonstration sandalwood plantations to serve as a model for farmers.

Extension and awareness

During the seed collection trips some training and awareness raising among villagers was conducted on how to conserve and propagate planting material. However, these have been mainly limited to two locations at one village in the Malalaua District of the Gulf province. Such training and awareness activities need to be carried out throughout the entire area where sandalwood is known to grow. One of the main constraining factors is that about 90% of the people in any village do not know about sandalwood and how to identify the tree. Furthermore when FRI identify and mark trees for retention as seed trees for future collection, other villagers usually poach or steal them and sell them to sandalwood buyers. These problems complicate *in-situ* conservation efforts and make seed collection from native stands very difficult.

Other agencies/programs

(i) Other agencies involvement

In addition to the four main buyers of sandalwood listed in the trade and industry section, the main organization interested in sandalwood development in the country has been the Foundation



Fig.3. This 12 year old sandalwood tree at Gomore village, CP is 10m high and 14cm in diameter. Several trees of the same age have been cut and sold. (Photo: D. Bosimbi)

for People and Community Development (FPDC). FPDC has assisted PNGFA and CSIRO officers in carrying out rapid rural appraisals (RRAs) and conducted awareness in sandalwood conservation and sustainable harvesting.

(ii) Collaboration between agencies

Apart from the collaborative work reported above there has been no clear direction or guideline as to where the PNG Forest Authority stands in the overall scheme for sandalwood development in the country. A positive development has been a decision by the Authority, through the Forest Management Division, to establish sandalwood plantations as a strategy to both conserve the species from extinction and as a way to educate and encourage people to start planting sandalwood as a commercial venture.

(iii) Issues and constraints

The main issue here would be that sandalwood is not receiving enough attention (cf. for example eaglewood) because of the vast disparity in the prices paid for the wood per kilogram despite the many advantages sandalwood has over eaglewood.

This is evidenced by the limited response from PNG Forest Authority management to the recommendations made by the team that attended the 2002 Noumea workshop in Noumea, and inaction in implementing the 2003 conservation and management strategy recommended developed under the ACIAR PNG Species Domestication Project.

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Summary

Sandalwood is one of the world's oldest traded commodities. Its uses include fragrance for perfumes, woodcarvings and incense sticks for India, Chinese and other cultures throughout the world. Over the past 15 years the average annual price has increased by 15%. The price increase in recent years is due to the ever-increasing demand, and the continuing diminishing amount of sandalwood available globally. In recent times, auction prices for sandalwood reached almost US\$ 40,000 per tonne, making it one of the most expensive hardwoods in the world. Vanuatu (formerly New Hebrides) has been a source of sandalwood for over 200 years and has also witnessed the increasing demand of sandalwood harvest and prices. The Government through the Department of Forests (DoF), with assistance from SPRIG/AusAID and SPC, has been assisting land or resource owners in growing sandalwood from seed collected from other locations for over 12 years and has successfully overcome many technical problems. In Vanuatu, sandalwood has been integrated with nut trees and citrus on some farms. The Australian Government, through ACIAR, is currently funding a 3-year research program to assist Vanuatu obtain the best commercial results from sandalwood plantations. The first phase has identified superior genetic material for propagation. The Government of Vanuatu through the DoF is committed to the development of sandalwood plantations in Vanuatu and is benefiting from the R&D programs together with other plantation estate or owners. The sandalwood industry has become a major and highly significant income earner to some of the remote and poorest areas in Vanuatu. The sandalwood activities became formally regulated under the Forestry Act giving the DoF legislative power to control and administer trade and management of sandalwood.

Sandalwood Resource base

The current natural stand or stocks in Vanuatu is unknown but sandalwood is found growing naturally throughout Tafea Province in the Southern part of Vanuatu, in the Northern, Eastern and Southern parts of Efate Island, in the South-west area in Malekula island and the West Coast of Santo island (Fig. 1).

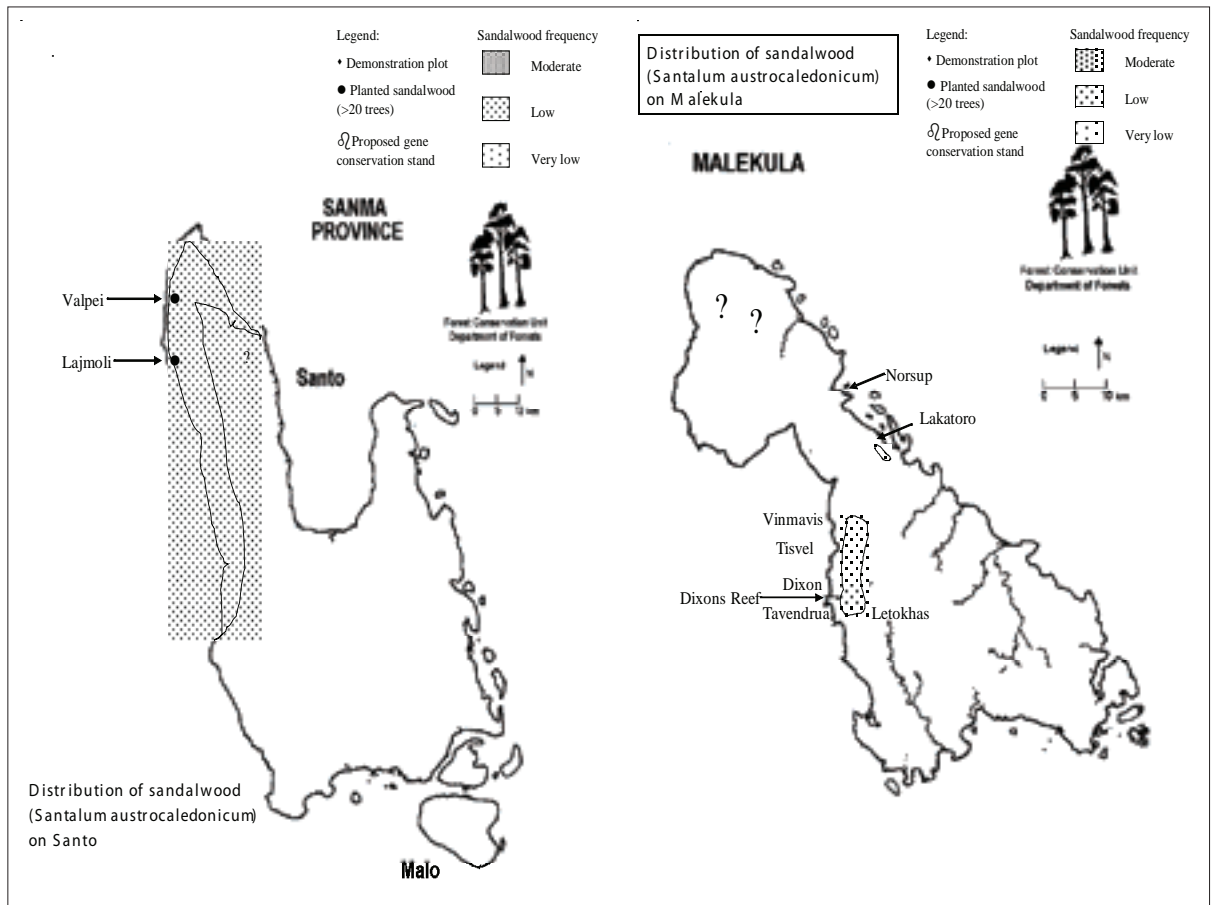


Fig. 1. Distribution of sandalwood in the selected islands of Vanuatu

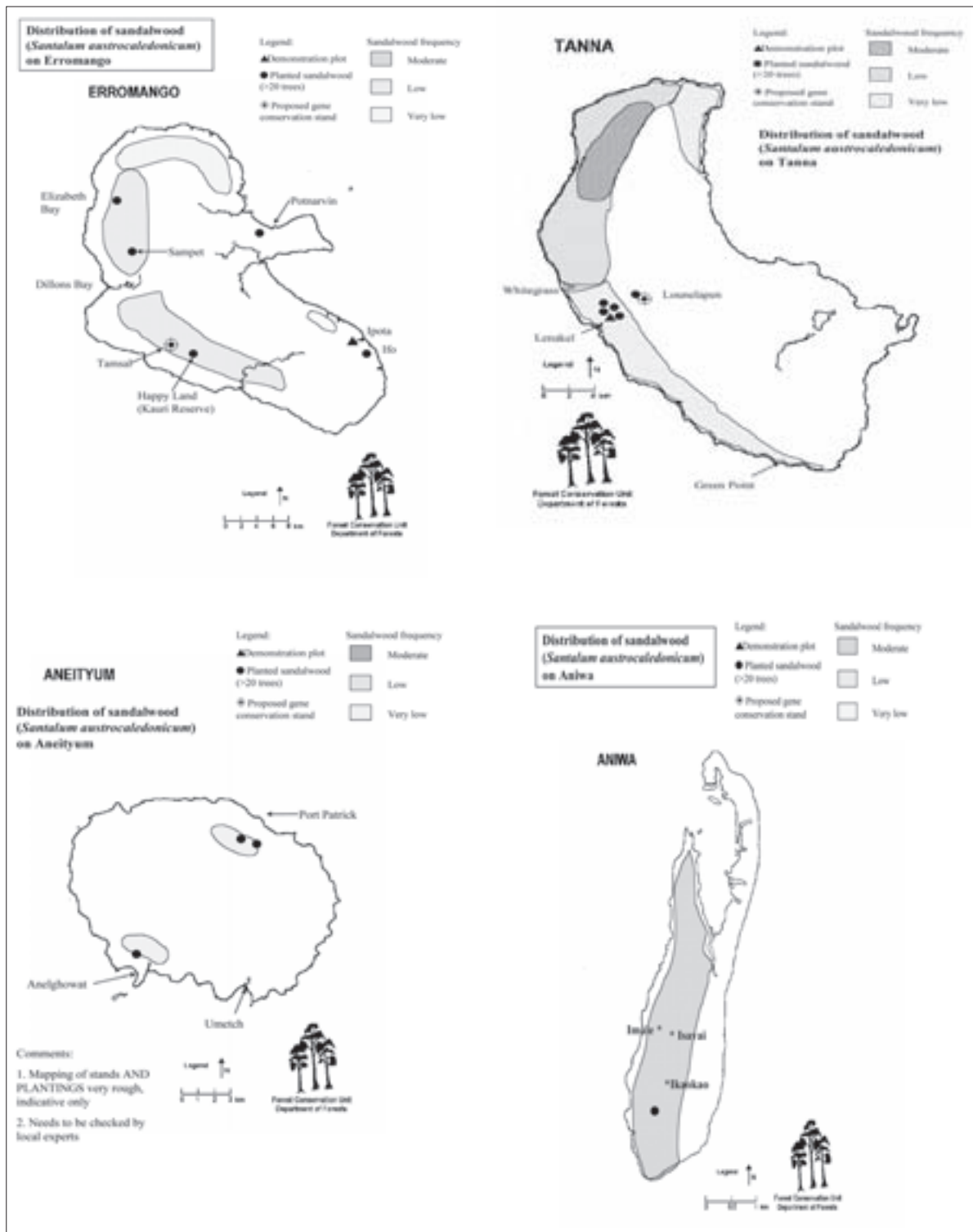


Fig. 1. Distribution of sandalwood in the selected islands of Vanuatu (continued)

Trade and Industry

Santalum austrocaledonicum is the sandalwood species that grows naturally in Vanuatu and has three variants. Everybody involved in the sandalwood trading now appreciates the value of sandalwood although quality (and price paid) may vary with variety. Over the last three years, with sandalwood trading in Vanuatu, there has been an increase in minimum prices from 400 Vatu to 600 Vatu per kilogram of heartwood harvested from the natural forest. This year 2005, sandalwood heartwood were purchased at 800 Vatu per kilogram. There is an emerging market for sapwood, branches and scrapings (residues of sapwood removal) which are normally purchased under the minimum rate and are regarded as low grade products. With the purchasing of the low grade materials, it will mean that more than 50% of the wood is utilised and thereby encourages a more complete utilisation of sandalwood trees. The annual quota under the sandalwood policy is 70 tones but up to 80 tones is allowed to be harvested by the landowners and sold to the two local buyers.

Sandalwood represents a small but vitally important industry for Vanuatu. In 2000, the amount paid to the landowners in royalty for 73 tons of wood was VT. 31,727,850, which was only slightly less than logging royalties which was VT.32,974,910 for 39,860 cubic meters of logs. Over the last three years, sandalwood has been harvested above the quotas and at unsustainable levels (Table 1).

Included in the steady development of the sandalwood industry is the shift in sandalwood products from exporting round logs to sandalwood oil and spent biomass. The current trend with the Department of Forests will see all sandalwood products processed locally into oil, and carved materials.

Year	Qty harvested (kg)	Royalty	FMC	Export raw material (kg) 50%	Export Oil (kg) 50% (35%/ton)	Export value raw material vt990/kg	Export value oil vt38500/kg	Total estimated export (vt) FOB
2001	76,000	27,000,000	2,070,000	63,000		62,370,000		62,370,000
2002	73,386	29,354,400	2,201,595	26,000	2,215	25,740,000	85277500	111,017,500
2003	121,142	48,456,800	3634260	60571	21200	59,965,290	816194225	876,159,515
2004	123,868	60,997,620	3,014,433	30,842	10,794	61,314,561	415,569,00	476,883,561
2005	104,644	69,043,260	3,122,370					

Table 1: Sandalwood Harvesting Summary - 2001 to 2005



Harvesting and Transporting Sandalwood logs to Vila

Sandalwood Processing facilities

2. Research and development

Research into sandalwood in Vanuatu is one of our priority programs to compete in the high value markets. In Vanuatu research into sandalwood began in the late 1980's.

CIRAD-Forêt conducted research into *S. austrocaledonicum* to determine the species variance with regards to oil quality of this species. Research on the socio-economics of the sandalwood in Vanuatu was undertaken by Luca Taconni/University of New South Wales and the DoF in Vanuatu in the years 1993 and 1994. In 1996 DoF carried out research in sandalwood to determine the co-relation between heartwood size and weight.

From 2004 – 2005 the DoF/SPRIG, established two seed */ex situ* gene conservation stands with a total area of 2.3 ha. These stands have the objective of developing a genetically diverse orchard that can provide seed for future plantings, assessment of the growth characteristics of several provenances and to study the effect of host on sandalwood growth and health. The ACIAR Sandalwood Oil Project undertook an oil analysis survey in the Santo, Malekula, Tanna, Erromango, Aneityum and Aniwa to determine the best phenotypes. The two projects then jointly established a grafted clone archive to conserve and provide seeds of superior individual genetic material and also provide scion material for inclusion for further grafted clonal seed orchards.

Sandalwood is an important commercial industry in Vanuatu. Individual farmers or communities do the majority of sandalwood plantings, manage and harvest existing stands. Although, the sandalwood industry has played a large part in the post-European history of Vanuatu, it was only recently that there has been a greater push to start a replanting program. There are several cultural, political and historical factors that have traditionally inhibited any large scale plantings in the islands.

There is increasing interest from local communities in replanting sandalwood, with a number of smallholders planting blocks of sandalwood on the islands of Santo, Erromango, Tanna and Efate. These have been established in association with *Casuarina*, and economic crops such as papaya, citrus, kava, *Barringtonia* and *Canarium*.



The trials are located at Shark Bay Forestry plantation on the eastern side of Spiritus Santo in Vanuatu

The main hindrance in the continued development of sandalwood plantations in Vanuatu is the shortage of supply of good quality seed and seedlings. Nurseries are unable to supply seedlings because currently the only source of seed is from natural stands. This supply is unreliable due to the location of surviving mother trees often remote from villages, low numbers of mature age fruiting trees in wild populations and heavy predation of fruits by birds, bats and rats.

3. National plan and strategies

The national plans and strategies on the future management, conservation and development of sandalwood in Vanuatu include;

- Undertaking an inventory to establish information on sandalwood stock in order to identify and promote appropriate management measures eg. determining the annual harvest quotas as part of a sustainable use strategy,
- Undertaking woodlot assessment to determine the amount of sandalwood planted in plantations or village woodlots,
- Generate and make available seed and silvicultural information on sandalwood through establishment of seed orchards to conserve the gene pools and identify and promote the best sandalwood varieties,
- Increase sandalwood resources through replanting,
- The utilization of sandalwood will be managed through a declared sandalwood cutting and trading season,
- Facilitate sandalwood industries to engage fully in processing locally aiming at value adding (sandalwood oil, powder and carved products), and
- The two main criteria for acquiring and retaining sandalwood licenses are to establish processing facilities and assist in undertaking replanting on a commercial scale.

4. Extension and awareness

An extension and awareness program for sandalwood in Vanuatu is one of the priority areas for the Government and is ongoing throughout the archipelago. The current methods of awareness include distribution of pamphlets and brochures to a wide range of farmers and conducting awareness meetings in the villages by DoF Field Officers. The other main method of awareness is through local radio programs. The main issues and constraints faced are;

- Land disputes between the landowners claiming ownership of areas where the sandalwood are found growing naturally. These disputes have been a continuing issue over the last five years and are normally resolved through mutual agreement. In some recent cases, a few disputed matters have ended up in court in which case the disputed wood is normally locked away pending court decisions,
- Low level of literacy by landowners to fully understand and participate in the extension programs,
- Wild cattle trampling and grazing on young sandalwood trees,
- Shortage of seeds for replanting,
- Lack of resources for implementing some elements of the DoF conservation strategy to maintain the genetic diversity.



Fig.1. Sandalwood seedlings in the nursery



Fig.2. Transporting sandalwood seedlings to local farmers



Fig.3. Farmers sandalwood plot

Other agencies/programmes in the sandalwood development

Apart from the normal Government programs and initiatives impacting on the development of sandalwood in Vanuatu, there are other agencies or projects, which have been very helpful and have contributed significantly to the development of the sandalwood sector. The main projects or programs are;

SPRIG project: focus on genetics improvement through establishment of both in-situ and ex-situ materials. SPRIG has done considerable improvement in identifying locations of remaining stands, best methods and techniques in raising sandalwood in the nurseries, pioneering non-destructive technologies for sampling heartwood, exploring grafting and cuttings for vegetative propagation and development of grafted potted and field seed orchards.

Sandalwood oil analysis survey project: This project helps to identify the best sandalwood variants. The project undertook oil analysis of samples from selected populations to identify superior genetic materials for propagation. Based on these analyses, further work will be carried out on multiplying the plus trees through cloning and grafting. These will be used in establishment of seed orchards and available for tree improvement work. Currently grafted seed orchards are needed as there is a great demand for seeds and of the best varieties.

Summit Estate Limited- a private company which establishes mini sandalwood plantations for various sandalwood products. The mini plantations are established at an area of 0.25 ha of land consisting 798 sandalwood trees (*Santalum austrocaledonicum*). The owners then market the plots of plantations to investors overseas.

Woodlot assessment survey: This is a program undertaken by forestry field officers who visit farms and collected information on planted tree materials. This is to have a better information base on where the planted materials are located and how many trees of different species are being cultivated by farmers. The outcome should indicate the country's progress on sandalwood replanting.

Sandalwood Policy: The sandalwood policy has been developed as a guide towards the better management of the sandalwood resource, and will be periodically updated to reflect the development of the industry within the forestry sector.

Sandalwood Industry: The Department of Forests' management of the trade in sandalwood has benefited the resource owners by getting the highest return for their produce. For the industry, tight control and monitoring has resulted in the establishment of two sandalwood oil distilleries for local processing. The

main products currently marketed from Vanuatu are sandalwood oil, pre-ground chips, carving logs and wood residues (after oil distillation).

5. Four priority national activities to be implemented

The four main national priority activities for development of a sustainable sandalwood industry are:

- Conduct an inventory to establish baseline information on sandalwood stock, and to help identify and promote appropriate management measures,
- Conduct and provide research information on sandalwood, to identify and promote the best sandalwood varieties,
- Facilitate and encourage sandalwood industries to fully engage in local processing and value adding,
- Promote a substantial increase of sandalwood stock through replanting to enhance the industry's long-term sustainability.

The main issues are rural income generation, value added products through local processing and employment opportunities and skill transfer. The main constraints are limited Government budget to implement several important activities or programs, lack of human resources during sandalwood harvesting period to deal with land and sandalwood disputes, and illegal cutting, which may result in lengthy court cases.

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Part B:
Technical and
Development Papers

French Polynesia Technical Paper No. 1

Sandalwood (*Santalum Insulare*) Planting

Efforts in French Polynesia

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This paper is designed as an overview of sandalwood planting efforts in French Polynesia. It only covers the Eastern Polynesian sandalwood (*Santalum insulare*) and does not deal with the propagation, planting and natural regeneration (naturalisation) of *Santalum album* or other more recently introduced species, which, in any case, only cover very small areas.

2. Planting efforts before the Sandalwood Programme

Before 1998 and the beginning of coordinated work on the sandalwood in the Marquesas Islands, individual French Polynesians had already tried to propagate sandalwood in the various island groups. Germination, transplanting, layering and cutting trials were carried out but very few led to successful planting of even one or more trees (Braesco, 1981 and 1982).

Three factors can explain the failure of these attempts:

- Lack of appreciation that sandalwood is a hemiparasitic plant and so the seedling, layers, cuttings or transplanted trees died due to a lack of a host-plant,
- The seeds' sensitivity, particularly the nut, to pathogens during the initial stages of germination (damping-off), and
- The general lack of care for plants raised in nurseries or by private individuals.

Nevertheless, a few trees were established on different islands, either by luck or through persistence. The following sandalwood trees are proof of this:

- A tree planted in about 1990 in the village of Atuona on Hiva Oa, which came from a natural seedling from a stand in Mokoau on Hiva Oa,
- A tree planted in 1990 in Pufau Bay on Raiatea, which came from a natural seedling or controlled germination of sandalwood from Hiva Oa,
- A tree planted in 1991 in Avera rahi Bay on Raiatea, which came from controlled germination of sandalwood from Raivavae,
- A tree planted in 1987 in the small bay north of Faaroa on Raiatea, which came from controlled germination of sandalwood from Nuku Hiva,
- A tree planted in 1986 in the village of Uturoa on Raiatea, which came from controlled germination of sandalwood from the Fetuna stand on Raiatea.

There are probably other trees that the authors are unaware of, particularly on Tahiti. Germination attempts were most successful when pulped seeds were placed in moss taken from the forest and the

emerging seedlings' development was helped along (pieces of the husk removed after the first leaves had emerged).

These trees are all about four meters tall even though their ages differ (from 14 to 20 years old). They were planted along with tree legumes, in particular *Calliandra surinamensis* and *Caesalpinia pulcherrima*. The trees' relative low heights are due, in certain cases, to poor growing conditions (slopes, waterlogged land) or difficulties with surrounding plants and even their host plants, which often attached themselves to their trunks.

With regards to phenology, there are no precise data but they do indicate that flowering can occur less than eight years after planting and fruiting after less than nine years. The only tree observed with fruits is isolated, which indicates possible self-fertilisation.

These few specimens had, then, demonstrated the feasibility of sandalwood propagation and planting and the possible development of seed orchards. Plant production and planting methods still needed to be improved.

3. Plantations established by the Sandalwood Programme

Beginning in 1998, research was conducted over the medium-term so as to develop germination techniques adapted to the Eastern Polynesian sandalwood based on techniques CIRAD was using for the sandalwood in New Caledonia. From 1999 to the present time, this work has led to the production and planting of numerous local sandalwood trees on the various islands of French Polynesia. The results of these planting efforts, all carried out by the Rural Development Service (SDR) on public land, are presented below by island group / island².

On Raiatea, about 50 plants have been produced and planted as both ornamental trees and in public areas. In the Marquesas, no work has been done on Fatu Hiva, while very few seeds were collected on Ua Pou. On Ua Huka, where the natural sandalwood populations seem to have disappeared, 26 sandalwood trees from Nuku Hiva and Tahuata were planted with wide spacing (5x5, 5x7, 5x10 m) in plots of *Tamarindus indica* and *Acacia spirorbis* in 2000.

The planting efforts carried out on Moorea in the Society Islands group and on Hiva Oa/Tahuata and Nuku Hiva in the Marquesas are explained in detail in the following section.

a. Sandalwood plantations on Moorea, Society Islands

Between 2002 and 2004, SDR agents collected several hundred seeds from about 20 fruit-bearing sandalwood trees belonging to a remnant population on Moorea comprised of about 100 specimens. Some of these seeds were placed in germination in January 2003 using the specific protocol described above (germination of unscarred seeds in moss). In early October 2004, some 29 sandalwood plants from this initial attempt at germination were planted on public land in Opunohu on Moorea to enrich a mostly secondary-growth forest. Germination time varied considerably but was typically around three months.

Invasive exotic plant species (*Paraserianthes falcataria*, *Spathodea campanulata*, *Miconia calvescens*, *Lantana camara*) and undesirable species (*Hibiscus tiliaceus*) were eliminated from the area and then paths were opened parallel to the slope. The remaining local vegetation mainly consisted of *Neonauclea forsteri*, *Metrosideros collina*, *Tarennia sambucina*, *Ixora sp.*, *Cyclophyllum barbatum*, *Xylosma suaveolen* and *Angiopteris evecta*. The sandalwood trees were planted six meters apart within and between the rows, within the bushes mentioned above and over an area of about 0.1 ha.

Tree heights were measured on 3 March 2005 and on 30 October 2005. The results are given in Table 1. To date none of the trees have flowered.

²No plantings have been carried out in the Austral Islands group. On Tahiti, seeds have been collected but no germination or planting has been done yet.

Table 1: Heights (m) and growth (m/year) in the Opunohu sandalwood plantation

Date of measurement	3/03/05	30/10/05
Number of trees	29	28
Mean height (m)	1.5	1.89
Standard deviation	0.27	0.29
Maximum	2.1	2.6
Minimum	0.9	1.35
Height Growth (m/year) May 2003 - March 2005 (22 mths)	0.82	-
Height Growth (m/year) March 2005 - October 2005(8 mths)	-	0.59
Mean diameter (cm)	-	1.2
Standard deviation	-	0.18
Maximum	-	1.6
Minimum	-	0.9

Santalum insulare var. *raiateense* trees have reached an average height of about 1.90 m with a diameter of 1.2 cm at 50 cm from the ground, 2.5 years after germination. The recent growth rate was nearly 0.6 m per year whereas the initial mean growth rate had been higher, at exceeding 0.8 m per year. These figures and the maximum heights are comparable to, and even higher than, those for the Hakapehi plantation on Nuku Hiva at the same ages (see b.).

In addition, growth was not optimal since the trees were planted a bit late in terms of their development in the nursery and they had to deal with the growth of invasive vines and bushes, mainly *Mikania micrantha*, *Momordica charantia*, *Lantana camara* and *Spathodea campanulata*.

However, the plantation has been a success with only one of the 29 plants dying (due to smothering by *Mikania micrantha*). The start of growth was not successful, with the nursery plant host (*Alternanthera tenella*) generally being maintained and probable parasitism by the many surrounding species, both invasive and non-invasive. The possibility of planting new plant hosts in those areas where only invasive species are left was also raised. Nono or noni (*Morinda citrifolia*) will probably be chosen for agroforestry purposes (Sandalwood/wood and nono/fruit).

b. Sandalwood plantations on Nuku Hiva, Marquesas Islands

Since 1999, several thousand sandalwood plants from the island of Nuku Hiva have been produced for local plantations on public land (Table 2), but also for a few isolated trees in public areas and at private homes. In fact, since 2002, trees have been sold to the inhabitants of Nuku Hiva. None of the trees have been sold for planting on another island so as not to mix gene pools/provenances.

In addition, following chemical studies (Butaud *et al.*, 2003), two sandalwood provenances have been identified on Nuku Hiva, i.e. high-altitude populations near the Toovii Plateau and low-altitude populations in Terre-Déserte, particularly the fruit-bearing stand in Vaiteheii. These two provenances, which have different chemical and ecological characteristics, are kept separate in all the plantations. The lower chemical quality of the low-altitude provenance is not being spread into the community and a single conservation stand has been established in Terre-Déserte to compare performance with clearly identified trees originating from high altitude.

Table 2: *Santalum insulare* plantations on the island of Nuku Hiva

Date	Site	Provenance	Area	Number
February 2001	Hakapehi	High altitude	0.74 ha	210
February 2001	Terre-Déserte	Low altitude	1.05 ha	192
January 2002	Terre-Déserte	High altitude	0.41 ha	73
2003	Teavanui	High altitude	0.28 ha	107
2004	Teavanui	High altitude	0.39 ha	170

Of these plantations (2.87 ha), those in Hakapehi (0.74 ha) and Terre-Déserte (1.46 ha) have been monitored for height and diameter growth for several years. The results are given below.

Hakapehi plantation

This plantation was created from the seeds of six populations on the Toovii plateau and the high ridges of Terre-Déserte (i.e. high-altitude provenances). Germination began in February 2000 using seeds harvested in 1999 and took place from March to June 2000. The plants were held for eight to ten months in the nursery before being planted. The stand was established on cleared area located at an altitude of less than 100 m: this site had previously been overgrown by invasive plants such as *Leucaena leucocephala* and *Acacia farnesiana*. In mid-February 2001, 210 sandalwood trees and the same number of host plants were planted on an alternating basis every four meters within and between the rows, on an area of 0.74 ha.

The list of host plants is as follows:

Introduced host plants: *Acacia spirorbis*, *Calliandra calothyrsus*, *Acacia ampliceps*, *Tamarindus indica*, *Citrus spp.*, *Agathis robusta*, *Syzygium malaccense*, *Annona muricata*, *Hibiscus rosa-sinensis*.

Local host plants: *Premna serratifolia*, *Dodonaea viscosa*, *Maytenus crenatus*, *Xylosma suaveolens*, *Sapindus saponaria*, *Cyclophyllum barbatum*, *Jossinia reinwardtiana*.

Those introduced host plants that were poorly adapted to the station (*Acacia* and *Calliandra*) were gradually replaced by local species in the stand for demonstration purposes.

Table 3 gives the measurements taken at the plantation over four consecutive years.

Table 3 : Forest mensuration characteristics of the Hakapehi plantation

Date of measurements	27/12/01	7/02/03	4/04/04	28/10/05
Number of trees	210	209	207	209
Mean height (m)	1.03	1.70	2.19	3.01
Standard deviation	0.26	0.39	0.47	0.68
Maximum	1.77	2.8	3.5	4.7
Minimum	0.41	0.55	0.80	0.70
Growth rate (m/year)(20 months)	0.62	x	x	x
Growth rate (m/year) (13.5 months)	x	0.60	x	x
Growth rate (m/year)(14 months)	x	x	0.43	x
Growth rate (m/year) (18 months)	x	x	x	0.55
Diameter (cm) at 50 cm above ground	x	x	2.42	3.41
Standard deviation	x	x	0.85	1.23
Maximum	x	x	5.0	7.2
Minimum	x	x	0.6	0.3
Trees with flowers: Number	0	0	10	21
Trees with flowers: Height	x	x	2.54	3.32
Trees with flowers: Diameter	x	x	3.64	4.72
Trees with fruit: Number	0	0	0	5
Trees with fruit: Height	x	x	x	3.12
Trees with fruit: Diameter	x	x	x	4.46

Although some of the sandalwood trees that died were replaced, mortality was very low (less than 10 %). Watering during the dry periods in the first year certainly played a role in the rapid early growth observed in this plantation.

Nearly 5.5 years after germination, the sandalwood trees had a mean height of > 3 m, with some specimens reaching 4.7 m. Height growth rates appeared to depend substantially on local weather conditions as a gradual downward trend was reversed during the last year and a half, which was wetter. The mean diameter was nearly 3.5 cm at a height of 50 cm from the ground but certain particularly well-developed trees were already more than 7 cm in diameter, only 5.5 years after planting.

The first trees with flowers were observed in June 2003, i.e. 2.3 years after planting and 3 years after germination, whereas the first fruits (7 viable fruits harvested in November and December 2004) appeared in June 2004, i.e. 3.3 years after planting and 4 years after germination. It should be noted that the faster growing trees were the first to flower and bear fruit. Moreover, diameter is a better criterion for indicating early flower production than height.

Terre-Déserte plantations

This stand was created in two stages, first, in February 2001, with sandalwood trees from the low-altitude provenance and then, in January 2002, with high-altitude trees so as to compare provenances. This was a restoration planting of an eroded area with host plants and sandalwood trees planted on an alternating basis every three meters in lines 10 meters apart that had been cut into the secondary vegetation. The introduced host plants were *Acacia spirorbis*, which was well-adapted to the environmental conditions, *Calliandra calothyrsus*, which struggled, and *Acacia ampliceps*, which was not adapted to the site. The existing species were *Terminalia catappa*, *Tectona grandis*, *Psidium guajava*, *Wikstroemia coriacea*, *Xylosma suaveolens* and *Dodonaea viscosa*, kept in the space between the rows.

Table 4 shows the measurements taken at this plantation over two consecutive years.

Table 4: Forest mensuration characteristics of the Hakapehi plantation

Provenances	Low altitude	High altitude	Low altitude	High altitude
Date of measurements	11/02/03	11/02/03	7/04/04	7/04/04
Number of trees	146	57	102	37
Mean height (m)	1.02	0.78	1.56	1.04
Standard deviation	0.36	0.21	0.78	0.35
Maximum	2.4	1.25	3.90	2.05
Minimum	0.4	0.45	0.15	0.50
Growth (m/year) – over 14 months	x	x	0.47	0.23
Diameter (cm) at 50 cm above ground	x	x	1.20	0.86
Standard deviation	x	x	0.78	0.41
Maximum	x	x	3.7	2.1
Minimum	x	x	0.1	0.4
Trees with flowers: Number	0	0	1	0
Trees with flowers: Height	x	x	3.50	x
Trees with flowers: Diameter	x	x	3.6	x

Mortality was very high at 3.2 years after planting, the low-altitude trees had a mortality rate of nearly 45% while the high-altitude trees had a mortality rate of slightly more than 50% at 2.3 years. This was to be expected as the ecological conditions are more difficult at Terre-Déserte and watering during the first year was not as systematic as at the other site. In addition, horses that were allowed to go into the plantation did considerable damage. Finally, the higher mortality rate over a shorter period of time for the high-altitude variety probably indicates that this variety is less able to withstand recurrent dry conditions. In terms of height growth, the high-altitude trees were also a year behind the low-altitude ones. The calculated growth rate between 2003 and 2004 confirmed this impression with only 23 cm as compared to 47 cm for the low-altitude trees.

Nevertheless, only a study over a longer term will allow any reliable comparison since the trees from the two provenances were not planted at the same time and so they may have faced different conditions.

Comparison of the mean heights with those at the Hakapehi plantation showed a delay of slightly more than a year. This difference is partly due to the damage caused by the horses but also from drier conditions at Terre-Déserte. In addition, the maximum heights were practically the same, which shows that even when station conditions are difficult, certain trees are able to grow at satisfactory rates.

The first flowers were observed on a tree from the low-altitude population in March 2004, i.e. 3.2 years after planting and nearly 4 years after germination. Here again, the fertile tree was one of the biggest specimens, with a height exceeding those for the flowering trees at Hakapehi.

Col Teavanui plantations

The two plantations located at Col Teavanui, at an altitude of 600m, were set up on fern flats (*Dicranopteris linearis*). Sandalwood trees from high-altitude populations and local host plants were planted in alternating order within rows or by rows, generally about three meters apart.

c. Producing sandalwood plants from Hiva Oa and Tahuata, Marquesas Islands

Since 1999, sandalwood seeds have been collected periodically on the island of Tahuata (Vaitahu and Hanamiai Bays) and since 2003, fruit-bearing populations have been monitored on Hiva Oa (Hanaavao and Hanauaua).

The first germination attempts were conducted on the island of Hiva Oa in 2000 using seeds from Tahuata. About 30 trees were produced and planted, some in the SDR nursery. About eight months after planting, four sandalwood trees had reached 70 cm tall. Some 15 months after planting and 21 months after germination, they were 1.40 m tall. In February 2005, i.e. 4.5 years after germination, one tree had both flowers and fruit.

In 2004, seeds from sandalwood stands on Tahuata (Vaitahu and Hanamiai) and Hiva Oa (Hanaavao) were germinated in the SDR nursery on Nuku Hiva. The trees (four from Hiva Oa and about 30 from Tahuata) are now several meters tall and were meant to have been returned to their islands of origin for conservation stands on municipal or public lands.

In May 2005, a training session on sandalwood propagation was held on Hiva Oa with a view to germinating seeds from Hiva Oa (Hanauaua) locally. After an attempt at germination in July 2005, 150 plants were produced and are now about 30 cm tall.

Chemical studies have indicated that the same original chemotype as that found on Nuku Hiva exists on Hiva Oa in a single population in Hanaavao. The plants from this population will, then, have to be treated separately from the others, not be distributed to the community and be planted in a real conservation stand, a reasonable distance from the other provenances so as to minimise hybridization.

The next objective is, then, to create a conservation stand of a > 20 sandalwood trees from the Hanauaua population on public land on Hiva Oa.

Conclusion

In 1998, only about 10 isolated sandalwood trees were being grown throughout French Polynesia and on certain islands the inhabitants thought that sandalwood did not grow at the seaside in villages.

Today, several hectares of Eastern Polynesian sandalwood have been planted by the SDR on several islands, at different altitudes and in several different natural environments. The first plantations can all be considered conservation stands, or even seed orchards from which seeds will be harvested to supply nurseries.

Given these different success stories, it appears that *Santalum insulare* grows well in plantations, whether they are on open ground, in lines in mostly secondary vegetation or used for enrichment purposes. In large part, this is possible because sandalwood can benefit or co-exist with a large range of host plants (particularly herbaceous plants and ferns), which allows it to grow fairly easily from the primary host plant in the nursery, i.e., *Alternanthera* spp., to secondary host plants already in the field (in cases of enrichment or forest path plantations) or those planted there (at 3 or 4m, and at the same time) for this purpose. The only precautions that need to be taken are ensuring that the *Alternanthera* plants survive as long as possible and that there are other plants, of almost any type (excluding smothering vines), in the planting area.

In terms of growth, the best specimens were 4.7m tall with a diameter of 7.2cm at 50cm. It is still too early to draw any conclusions about the age at which the heartwood begins to form or the likely suitable rotation length for commercial production of heartwood..

These plantations have also made it possible to monitor Eastern Polynesian sandalwood's development and phenology. The first flowers were observed beginning in the third year after germination and viable fruits began to be produced in the fourth year. This fruiting is an important success as it symbolises the return of the Eastern Polynesian sandalwood, as it completes the cycle since the plants from the first generation plantations (which came from natural sandalwood populations) can be used to repopulate natural forests.

Finally, this work, which has been carried out in a comprehensive manner on the island of Nuku Hiva, needs to be done in each of the *Santalum insulare* provenances identified in French Polynesia (Butaud and Defranoux, 2005). Indeed, there is no thought of introducing one provenance of sandalwood into another as this would result in changes to the existing local, well-adapted and unique gene pools. In terms of the two provenances identified on the island of Nuku Hiva, the plantation Hakapehi is the reference conservation stand for the high-altitude provenance and the Terre-Déserte plantation will be the reference conservation stand for the low-altitude provenance. For that reason, the trees from the high-altitude provenance planted at Terre-Déserte will have to be removed at the end of the comparative study and before any seeds from either provenance are harvested.

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Chemical Variability of Sandalwood Populations in New Caledonia

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This paper reports the main findings from a study on chemical variability of sandalwood heartwood in New Caledonia and French Polynesia, supported by the French Government, Minister of Sustainable Development and Environment, from 2002 to 2005 (Bottin *et al.*, 2005).

1. Introduction

1.1. Mean features about utilization of sandalwood heartwood for perfume industry

Santalum sp. is characterized by its fragrant heartwood, which gave birth to one of the oldest perfumes in the world. Sandalwood is therefore a product of a very high added value. There is considerable variation in heartwood chemistry in different parts of the tree. For example, in *S. album*, a strong variability in oil content is observed among the different parts of the tree, i.e. roots (8.4%), trunk (5.8%), and branches (3.5%) (Jayappa *et al.* 1981). Sandalwood is highly favoured in the perfume industry for its constant characteristic smell, somewhat woody and lightly distinctive, which produced some sandalwood-rushes in Pacific countries during the mid-19th century.

Olfactory qualities of perfume using sandalwood to fix the other fragrant molecules are mainly linked to sequiterpenols which make the most volatile molecules to be exhaled more slowly and make the perfume longer-lasting. Yields vary from 3 to 4% through steam distillation (48-72 h). Cis- α -santalol is responsible for the light woody smell, and Cis- β -santalol is more linked to the stronger woody smell, with a distinctive mark.

Alcohols represent about 90% of the whole composition. The other molecules are mainly hydrocarbons, as α and β santalenes. About 100 compounds have been identified in sandalwood oil resulting from hydrodistillation (Nikiforov *et al.*, 1990).

1.2. Why did we choose to analyse concrete in order to study heartwood chemical variability?

Concrete is a product which results from the extraction of volatile molecules of heartwood. It is obtained by extraction using a solvent (chloroform CHCl_3) instead of using hydro-distillation as it would be realized to obtain essential oil. In concrete, the compounds include those found in the essential oil, as well as other compounds which are not extracted during hydro-distillation (mainly diols). Accordingly, analysis of concrete gives more information than analysis of essential oil, and is more convenient for the analysis of many samples. The use of concretes appeared more appropriate to study the variability of chemical compounds of heartwood of *S. austrocaledonicum*.

1.3. Research questions

To our knowledge, only one chemical study had been realized on the chemical composition of concrete and essential oil of sandalwood (*S. austrocaledonicum*) in New Caledonia (Alpha *et al.*, 1997). This study was conducted on a small number of samples (4 from Maré and 2 from Pine Island). Accordingly given the commercial interest in the species, and variation in heartwood chemistry, there was urgent need to more comprehensively assess its heartwood chemistry.

Considering the possibility of working on a wide range of samples, we aimed to answer the main following research questions: How do the populations of Sandalwood in New Caledonia vary in chemical components of heartwood? More precisely, we stressed the three following questions: Which are the most interesting populations from a heartwood chemistry viewpoint? Do some populations have high specificities? How is it possible to manage and conserve these populations?

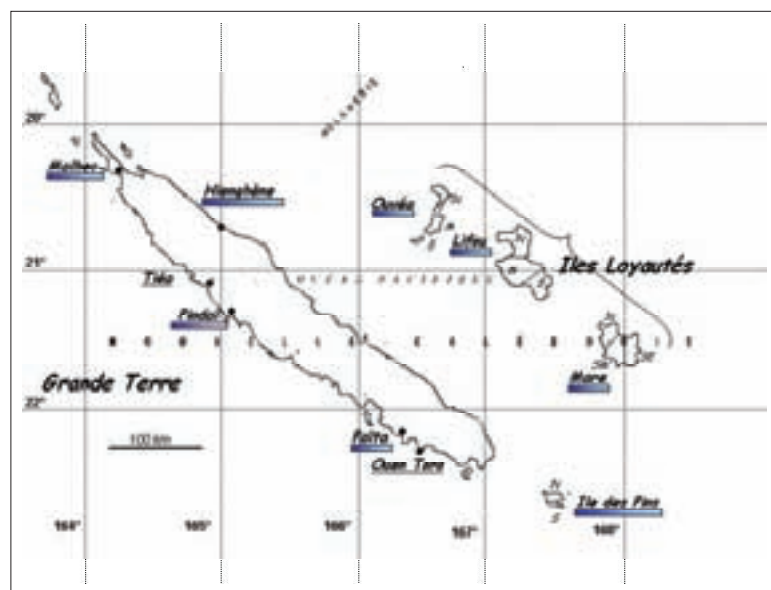
2. METHODS

2.1. Sampling and collecting data

During September 2003, we sampled 8 populations covering 217 individuals (Fig. 1), with a mean of 30 individuals per population (but only 7 samples in the Pindai population).

Individual trees separated by a reasonable distance (at least 30m) were selected in order to prevent sampling of suckered specimens originating from the same individual. Only large trees (diameter > 25 cm) were collected in order to reduce variability due to sampling heartwood of different maturity. Collecting of heartwood material was undertaken at 50 cm above ground level, to prevent the effect of chemical variability due to different position in the tree. Shaving pieces were collected using a driller (5 grams per tree). Additionally, data were collected on stem diameter, tree height and mean rainfall.

Fig. 1. Localization of sampled populations in New Caledonia (from Bottin *et al.*, 2005).



2.2. Chemical analysis procedure

Chemical analyses were undertaken by the laboratory COSMECAL, according to the procedures developed for *S. insulare* by the University of French Polynesia (Phila Raharivelomanana pers. comm.).

The extraction was processed using chloroform (CHCl_3) for 48 h, with addition of a standard solution (octanol) in order to assess the efficiency of the extraction. Analyses were run using a mass chromatograph (about 55 min per analysis).

2.3. Data analysis

The area of peaks was calculated for each chromatogram. Standardization was obtained using the peak of n-octanol (A_e). The whole area of the concrete (A_t) was obtained by summing the different areas.

The percentage of a peak in a chromatogram, named P_p , was defined as following: $P_p = 100 A_p / (A_t - A_e)$. Additionally, the concentration of a peak, named C_p , was calculated as following (M_e is the weight of n-octanol): $C_p = M_e \times A_p / A_e$.

On each chromatogram, peaks (corresponding to one or several molecules) ranged according to a gradient of volatility. A total of 33 peak- areas were calculated, 10 of which having been chemically analysed.

3. Results

3.1. Peak assessment

The same main components were found as in other studies on sandalwood. A high content of (E)-lanceol was observed, in a result consistent with the previous study of Alpha (1997). Alcohols, hydrocarbons and diols represented respectively 89.0%, 3.6% and 3.5% of the concrete. Four compounds had areas over 5% of the total peaks area: (Z)- α -santalol, (Z)- α -transbergamotol, (Z)- β -santalol and (E)-lanceol.

Table 1. Peak area distribution in chemical analysis of concrete of sandalwood in New Caledonia. The four molecules with the widest peak area have been underlined (from Bottin *et al.*, 2005).

Fonction	Pt	Are [%]	Ecartype	CV(kcart - typemoyenne)	Min	Max
Z- α -santalol (5)	0.84	0.43	0.51	0.07	2.84	
7	0.13	0.07	0.57	0.01	0.53	
Ep- β -santalol (10)	0.72	0.32	0.44	0.12	2.04	
Z- β -santalol (11)	0.68	0.40	0.58	0.03	3.04	
groupe 13*	1.07	1.23	1.15	0.03	11.02	
14	0.12	0.27	2.22	0.03	2.75	
15	0.12	0.27	2.33	0.01	2.45	
16	0.10	0.25	2.43	0.03	1.84	
17	0.17	0.33	1.93	0.03	2.17	
24+25	0.63	0.57	0.93	0.10	6.25	
26+28	0.75	0.34	0.46	0.03	2.98	
<u>(+)-(Z)-α-santalol (30)</u>	<u>39.36</u>	<u>11.23</u>	<u>0.28</u>	<u>2.77</u>	<u>53.34</u>	
32	1.32	0.97	0.73	0.16	5.46	
<u>(-)-(Z)-α-trans-</u>						
bergamotol (34)	7.25	2.34	0.31	1.07	11.36	
35	0.19	0.48	2.53	0.01	5.72	
36	0.46	0.22	0.48	0.07	1.62	
ep- β -santalol (37)	2.85	0.85	0.33	0.11	4.35	
38	0.34	0.26	0.77	0.12	2.42	
39	0.47	0.95	2.04	0.01	8.95	
<u>(-)-α-β-santalol (40)</u>	<u>16.42</u>	<u>5.23</u>	<u>0.32</u>	<u>0.45</u>	<u>24.28</u>	
(Z)-nuzibrol (41)	1.47	1.25	0.85	0.15	8.28	
44	0.20	0.13	0.62	0.02	0.89	
45	0.68	0.57	0.83	0.03	4.42	
46	0.52	0.45	0.85	0.10	4.72	
(-)- β -santalol (47)	1.23	0.79	0.85	0.24	6.64	
48+49	0.95	0.96	1.01	0.11	9.29	
(E)-lanceol (50)	13.65	16.61	1.22	0.12	80.83	
51	0.20	0.26	1.28	0.01	2.76	
63	0.42	1.09	2.63	0.02	11.84	
64+69	1.35	1.40	1.05	0.18	11.02	
71	0.37	0.67	2.35	0.03	8.22	
73+77	1.71	1.33	0.76	0.18	10.12	
79+ 80	1.46	0.52	0.35	0.05	3.35	
Moyenne	2.98	1.61	1.08	0.19	9.63	

Principal Component Analysis (PCA) revealed that lanceol and santalol concentrations were negatively correlated. The maximal content of α -santalol and the minimum content of lanceol were found in Hienghène, in the only known remnant population of East Coast, in one of the wettest parts of New Caledonia. Conversely, the minimal content of α -santalol and the maximal content of lanceol were found in Malhec, in the north-western of the Main Island, one of the driest parts of New Caledonia.

3.2. Correlation analysis

No correlation has been observed between diameter and peak areas. That is to say that within our sample, the chemical composition did not vary in a linear way with diameter. Additionally, no correlation was observed between tree height and peak areas.

There was a low but significant correlation between rainfall and hydrocarbons, but also important molecules:

- (+)-(Z)- α -santalol (7.3 % of variability explained by rainfall)
- (-)-(Z)- β -santalol (6.1 % of variability explained by rainfall)
- (-)-(E)- β -santalol (6.8 % of variability explained by rainfall)
- (E)-lanceol (6.8 % of variability explained by rainfall).

These results are consistent with the maxima/minima contents of santalol and lanceol found in the dry Malhec and the wet Hienghène sites.

3.1. Variation between populations

Using PCA on the 157 individuals and the 33 analyzed peaks, we observed that the three main populations (Main Island, Loyalty Islands, Pine Island) were clearly separated by their chemical composition.

Additionally, the main factor of PCA discriminates populations of Main Island from those of other islands.

4. Discussion

The results observed in this study dealing with chemical composition of *S. austrocaledonicum* concrete in New Caledonia are consistent with results observed on other sandalwood species. They are also consistent with previous results found on *S. austrocaledonicum* in Vanuatu (Ehrhart and Raharivelomanana, 1998). They show a domination by santalols and also a high content of lanceol. We can consider that *S. austrocaledonicum* oil from New Caledonia is typically of a good quality, as the content of (+)-(Z)- α -santalol is comprised between 40 and 55% (40.8%) and the content of (-)-(Z)- β -santalol comprised between 17 and 27% (17%).

Chemical composition does not depend on tree size in our sample (for diameters close to and above 25 cm), though it can be proposed that we need to extend the study to a wider range of diameters to confirm this conclusion. No relation is observed with tree height. Conversely, a slight but significant correlation was observed between rainfall and α -santalol.

Our studies were also marked by the observation of high content for different compounds for different Main Island populations, e.g. Malhec - high content of (E)-lanceol, Pindai - high content of one compound belonging to diols, and Hienghène - high content of α -santalol. Oils of the best quality are found in Hienghène and Pine Island. Within the Loyalty Islands, Mare has the lowest oil quality.

It is pertinent to consider that the strongest variability is observed at the intra-population level, which explains 84% of the total variance of peaks. This way, selection of good provenances is difficult, and we must consider that environment (rainfall, but probably also other factors) appear to be of high importance in affecting oil and concrete composition.

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Indian sandalwood (*Santalum album* L.) variation in sesquiterpenoid composition and possible biogenetic pathways

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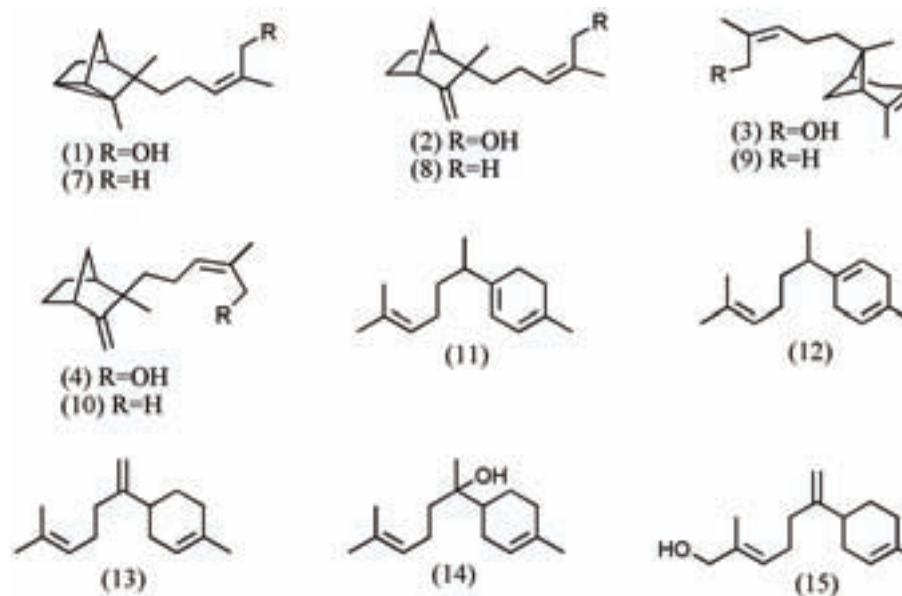
Abstract

A chemotaxonomic approach was used to investigate potential relationships between heartwood sesquiterpenoid components in mature, plantation grown Indian sandalwood, (*Santalum album* L.). Principal component analysis of the population showed no segregation into chemically distinct phenotypes. Strong, linear relationships which bisect the origin exist between the olefinic sesquiterpenes α -santalene, α -trans-bergamotene, epi- β -santalene and β -santalene. Identical relationships were found in wood cores taken from both 30 cm and 100 cm above ground level. Comparison of the equivalent sesquiterpene alcohols did not yield the same linear interactions. These data suggest that the biosynthesis of olefinic hydrocarbons is related to each other, probably via a common bicyclic carbocation intermediate. We report for the first time, significant evidence for the biosynthesis of the santalenes and bergamotene in *S. album* via the same common intermediate.

Introduction

Indian sandalwood, *Santalum album* L. is a hemi-parasitic tree native to India and Indonesia which is highly valued for its fragrant heartwood. The heartwood of mature trees (> 10 years old) contains essential oils, chiefly the sesquiterpene alcohols and their olefinic equivalents (Fig 1) (Adams *et al.* 1975; Christenson *et al.* 1981; Howes *et al.* 2004; Jayappa *et al.* 1981; Verghese *et al.* 1990). Compositional differences have been noted throughout the roots and stem of *S. spicatum* (Piggot *et al.* 1997) and *S. album* (Shankaranarayana *et al.* 1998). It is assumed that the main sesquiterpenes **7-10** are synthesized in the heartwood via cyclase enzymes, and oxidized to the corresponding 12-hydroxyl alcohols (**1-4**).

Fig. 1. Structures of components in *S. album* heartwood oil: 1 α -santalol; 2 β -santalol; 3 α -trans-bergamotol; 4 epi- β -santalol; 7 α -santalene; 8 β -santalene; 9 α -bergamotene; 10 epi- β -santalene; 11 γ -curcumene; 12 β -curcumene; 13 β -bisabolene; 14 α -bisabolol; 15 *cis*-lanceol.



'Chemotaxonomy' usually refers to the profiling of chemical compounds contained within an organism to distinguish phylogenetic relationships. If however, substantial variation in the chemical profile exists within individual plants, care must be taken to ensure that taxonomic delimitations are not merely figments of this variation. Terpenoid variation can be used to explore potential biogenic pathways. A quantitative, mathematical relationship following the general linear form $y = m x + C$ between individual compounds in an oil profile would suggest that the biosynthesis of such chemicals is not only closely related, but may involve the same enzyme system or at least, a common intermediate (Zavarin 1970). Multiple product formation has been noted in various sesquiterpene synthases extracted from plants (Colby *et al.* 1998; Munck and Croteau 1990), and by site-directed mutation of active site residues in functional enzymes (Little and Croteau 2002). *In-vivo* essential oil profiling, with the objective of identifying co-occurrences in these species has not been widely performed.

Quantitative co-occurrence would be most applicable to structural isomers, as functional group changes such as oxidation, reduction and addition of nitrogen invariably require separate enzymes and possibly occurs in a different part of the cell. Correlation between product and functionalised precursor should be apparent however the strength of correlation may be lower than between structural isomers. Such relationships would yield negative linear slopes, where substitution of a precursor compound results in an increase in the proportion of product (Zavarin 1970).

In this study, plantation grown *S. album* was analysed for heartwood oil content and composition. Variation in composition was considered both within individual trees, as well as amongst the population. Relationships between structural isomers and their oxygenated equivalents were studied using percent composition of each compound. The biosynthesis of sesquiterpenes is described with respect to these co-occurrences.

Materials and Methods

Site description

Santalum album trees were growing at the Frank Wise Agricultural Research Station, Kununurra, Western Australia. Flood irrigation was performed monthly for the dry season.

Within-tree essential oil variation (destructive sampling)

Discs (5 cm thick) from ground level were cut from four 10 year-old sandalwood trees in May 2003. Air-dried wood samples were taken from these zones by drilling parallel to the xylem and collecting the shavings. Three replicates of shavings were taken from the sapwood, transition zone (to the inside of the transition line) and central heartwood using a drill equipped with a 9 mm drill bit.

Core sampling of plantation trees (non-destructive)

Core sampling was performed in spring 2004 using a petrol-powered drill with a specialised coring bit. Cores (diameter 12 mm) were extracted from the diameter of the tree at two heights, 30 cm above ground level and 100 cm above ground level. Trees were re-sealed with caulking polymer to prevent infection. Core length and heartwood proportion was measured. In some instances the heartwood was difficult to distinguish from sapwood. Cores were ground to 500 μm and stored.

Solvent extraction of wood material

Sandalwood shavings (4-5 g) were placed into 50 ml volumetric flasks and a 1 ml aliquot of internal standard, (\pm)-camphor, 4.00 g l⁻¹ was added. The flasks were then filled just short of the mark with hexane. Flasks were stored at 21°C for at least 2 days and periodically shaken before being topped up to the mark and analysed by GC.

Gas chromatographic analysis of sandalwood extracts

GC analysis was performed on a Shimadzu GC-17A using an AT-WAX column (30 m, 0.25 mm inside diameter, 0.25 μm film thickness) with FID. Injection port 200°C, detector 250°C. Carrier was helium; flow rate 2.4 ml min⁻¹, split ratio of 20:1. Oven 80°C ramped at 4°C min⁻¹ to 180°C held for 20 min (total run time 45 min). Injection volume was 1 μl . Peak identification was by GC-MS (Agilent HP MSD 5970), authentic standards and comparison to the literature. Integration was performed using Shimadzu GC-Solutions software. Areas were recorded for all detectable peaks, however only peaks represented in all chromatograms were used in comparisons. Principal component analysis was performed using data derived from 30 cm wood cores only. Percent composition was used as a variable over 21 individuals.

Results and Discussion

Total essential oil yield from *S. album* trees varied considerably amongst the sampled population. Presence or absence of sesquiterpene oils was due mostly to the age of the tree, and generally trees under 10 years did not yield fragrant heartwood. Extractable oil yield was compared to the proportion of heartwood in wood cores for both heights. Oil yield was not directly proportional to heartwood content. Several factors may be involved, including xylem vessel frequency and volume, which in turn may be related to growing conditions and genotype.

Essential oil composition varied between heartwood and transition zone, and up the height of the tree. The main sesquiterpenes **7-10** were more common in transition wood, while the alcohols α -santalol and β -santalol were less common in transition wood. A negative linear relationship existed between the proportion of α -santalene and α -santalol **1** ($r = 0.69$), as did β -santalene with β -santalol **2** ($r = 0.64$). This suggested that a product-precursor relationship exists. It appeared that as new heartwood forms in the transition zone and higher up the stem, sesquiterpenes are initially synthesised and later oxidised to the corresponding alcohols.

Highly significant linear correlations existed between the santalenes and bergamotene (Table 1). The quantitative co-occurrence between all four compounds provided evidence that a common intermediate may be involved.

Co-occurrence was also found between γ -curcumene **11** and β -curcumene **12** ($r=0.92$). As neither of these compounds shared a linear relationship with either the santalene series or β -bisabolene, it is hypothesised that the biosynthesis of the curcumenes is a separate process unrelated to the other sesquiterpenes which utilises a different cyclase enzyme.

Table 1. Correlations between sesquiterpenes 7-10. Linear relationships were highly significant and bisected the origin, or very close to it.

Sesquiterpenes compared			Correlation (r)
9	and	10	0.94
7	and	8	0.99
7	and	10	0.97
8	and	10	0.98
7	and	9	0.96
8	and	9	0.94

The percent composition of β -bisabolene **13** was strongly correlated to that of α -bisabolol **14**. Like the santalene series, wood from 100 cm cores tended to contain a greater proportion of **13** and **14** than wood from 30 cm. It is possible that the synthesis of curcumenes **11** and **12** is closely related to that of **13** and **14** as these compounds are structurally similar. No such correlation was seen though, and it is likely that a cyclase enzyme may be specific to the synthesis of **13** and **14**. Structurally, **13** and *cis*-lanceol **15** differ only in the 12-hydroxy group. This similarity was reflected in the quantitative relationship ($r = 0.82$) between **13** and **15**. Furthermore, **14** is closely correlated to **15** ($r = 0.92$). The stronger relationship to the 7-hydroxy compound is interesting, as an elimination reaction would have to take place first, returning to **13** before oxidation of C-12. Also, the positive slope indicates these compounds are being synthesised at the same time, rather than the negative slope expected for product substitution. Further biochemical investigation is required to explain this trend. Again, samples from mature heartwood had lower levels of **13** and **15**, with younger heartwood possessing higher proportions. This was consistent with results from transition zone wood and central heartwood.

The fourth series of sesquiterpenoids in *S. album* heartwood eluted between α -curcumenone and α -bisabolol. Strong linear correlations were present between compounds, while having no correlation with the other three classes of sesquiterpenes. Identification of these compounds is currently underway, but based on their independence from the other sesquiterpenes it is assumed a separate cyclase/synthase enzyme is responsible for their synthesis.

Quantitative co-occurrence was apparent within four separate structural classes of sesquiterpene, but co-occurrence between these classes did not exist. The co-occurrence of these sesquiterpenes was found to prevail in different parts of the stem, evidenced in core samples taken from both 30 cm and 100 cm, and between central heartwood and transition zone wood from destructively sampled discs. A distinct product-precursor relationship existed between α -santalene **7** and α -santalol **1**, along with β -santalene **8** and β -santalol **2**. This was reflected in the location of these compounds within the tree. Despite the variability in oil profiles, no chemically distinct phenotypes could be identified. Major differences in the end-products (**1-4**) or deviations from linearity in co-occurrence patterns would be required to distinguish such chemical phenotypes. Based on these findings, we propose that four separate sesquiterpene synthase enzymes are operating in *S. album* heartwood, and work to isolate these enzymes has commenced.

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Development of the Indian Sandalwood Industry on the Ord River Irrigation Area

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Abstract

Since the early 1980's the authors have been involved in various capacities with trials of *Santalum album* (Indian sandalwood) for commercial production in Western Australia. As far as we are aware this species had not been previously evaluated in Australia in recent decades and perhaps not at all.

This paper describes the evolution of a new forestry industry based *Santalum album* in the tropical area of the east Kimberley of Western Australia. This industry has evolved in a period of only about 20 years from the first trial plantings and government-sponsored research to a commercial enterprise which has attracted corporate investment on a significant scale.

Key Words: *Santalum album*, Kimberley, Western Australia, research, plantation, management, host, hemi-parasitic.

The Ord River Irrigation Area (ORIA)

Situated 2200 km north east of the Perth and 500km south-west of Darwin, the Ord River Irrigation Area is a progressive farming area in the east of the Kimberley Region. Any "white elephant" label it was unfairly burdened with in the mid seventies has been well and truly laid to rest and current annual production from the 13,000 hectares of irrigated farmland varies between about \$40million and \$55 million.

Water for the project is captured from the Ord River in the massive Lake Argyle from which it flows by gravity (via a hydro power station which supplies power to the Argyle Diamond Mine and the towns of Wyndham and Kununurra) to Lake Kununurra, from which it is diverted, again mostly by gravity, to the irrigation areas on the Ivanhoe and Packsaddle Plains.

The main crop on an area basis is sugar, which is processed in the ORIA and of which the crystalline product is usually exported to Korea. Other important crops include a wide range of cucurbits, maize, sorghum, chick pea, sun flower, mango, grapefruit, bananas, beans, snow peas, onions, salad vegetables, pawpaw and some cotton along with a few specialist hybrid seed and vegetable seed crops. Farmers found through bitter experience that reliance on a single crop, for example cotton, was fraught with problems, principally associated with pest control.

Indian sandalwood (*Santalum album*) has become a significant part of the crop mix in the ORIA over the last five years. There are currently (November 2005) nearly 2000 ha of commercial sandalwood plantations in the area, with an annual planting of well over 200 ha. The first commercial harvesting is likely to commence in about 9 years' time.

Sandalwood

Sandalwood harvesting is one of the world's oldest, and still one of its most valuable forestry enterprises. There are 16 species of *Santalum* (not all of which are harvested commercially), containing highly aromatic oil in the heartwood which is prized in India and Asia (Shea *et al.* 1998). Both the Indian sandalwood and the West Australian sandalwood (*S. spicatum*) have very high oil content, making them two of the most commercially valuable species of the genus.

A feature of all sandalwood species is that they are hemi-parasitic, i.e. require a host species to grow successfully. Understanding the host-sandalwood relationship has been one of the most critical aspects in the emergence of the sandalwood plantation industry, especially for Indian sandalwood.

Western Australia's Sandalwood Industry

West Australian sandalwood (*S. spicatum*) was once widespread across the southern half of the state, especially in areas which now comprise the southern agricultural and rangelands zones. In other words it is adapted to a temperate-arid climate. It is a small tree, richly endowed with oil. The normal host species is *Acacia acuminata* (jam wattle).

WA sandalwood has been pulled and the product exported since the earliest days of settlement. It has generated many millions of dollars of export income, and the industry survives to this day. Natural stands have largely disappeared from the agricultural areas, and the industry is concentrated in the rangelands, mostly on areas also used as sheep stations. In these areas, inadequate regeneration is a serious problem because (i) regeneration events are sporadic and (ii) young sandalwood trees are highly palatable to sheep, rabbits and goats.

By the late 1970's it had become clear that West Australian sandalwood could not satisfy the demand for the product. Production from other areas such as India, Indonesia and the Pacific islands had declined rapidly for various reasons (including, over-harvesting, forest clearance for agriculture, disease, unsustainable and illegal logging operations). The WA Forests Department had also at that time introduced a number of measures aimed at making future supply of native sandalwood sustainable. These included strategies such as setting aside of reserves in appropriate areas, protection of regeneration from grazing and feral animals, planting sandalwood in the wild and research into sandalwood plantations. Finally, the department looked at the potential for introducing *Santalum album* as a plantation crop in Australia and specifically in the Ord River Irrigation Area (ORIA) in the state's tropical Kimberley region.

Indian Sandalwood (*Santalum album*) on the ORIA

In 1980 the Forests Department of Western Australia and the Australian Sandalwood Company sent a group to India to look at various aspects of the sandalwood industry there. Forester Peter Richmond represented the Department and was able to arrange for the importation of a small quantity of *S. album* seed to Australia. This seed was distributed to three Forest Department sites in WA and each area obtained about 100 seeds. One of the locations was Kununurra, where the author (C.D.) was stationed at the time. Eventually (with assistance from our colleague Ian Scott) we were able to raise 30 reasonably healthy seedlings. No seedlings were successfully raised at either of the other locations.

In late January 1981 three plots of Indian sandalwood were planted on the Kimberley Research Station (then a CSIRO/WA Agriculture Department establishment some 20 km from Kununurra on the ORIA) and at the Agriculture Department's nearby Research Farm. At the time we knew almost nothing about which host species to plant and when. However, several seedlings were coaxed into surviving for long enough to indicate that, given proper treatment, the species had potential.

Over the next few years we had difficulty obtaining additional seed from India and I (C.D) became aware that there was a collection of five or six *Santalum album* plants in the Northern Territory Herbarium. These came from “naturally” occurring trees at widely separated sites along the NT north coast. The author (C.D.) was able to visit some of the sites and locate one of the original trees at a site near Darwin. No seed was available to be collected at that time. I was unable to locate the other trees, including at the site on Melville Island¹. A vigilant look out for the species at possibly suitable sites along the Kimberley coast has been to no avail.

Some of the original seedlings planted out on the Ord started flowering at about two years of age and seed set was eagerly awaited. Eventually several seed were almost mature on one tree. These were checked regularly but

birds eventually took all seed just prior to full maturation. We are now aware that Great Bower Birds (*Chamydera nuchalis*) which are plentiful in the area, have a great liking for these fruits.

At about this time Forester Peter Kimber became heavily involved in the seed procurement, project planning and research for the, to date almost unfunded and un-resourced Kimberley Indian sandalwood project. In due course the Department was able to procure more seed from India, and despite the fact that it appeared to be of poor physiological quality, we raised more seedlings and in 1986 planted a plot of about 140 Indian sandalwoods in the Forests Department’s Kununurra Arboretum.

In about 1988 an agreement between the Department of Conservation and Land Management (CALM²) and the Department of Agriculture had been reached allowing for long term access to land on the research station for tree trials. The author (PK) designed a series of trials of planting configurations and host species; this work was implemented from 1989. Plots were also planted at about this time by Ian Richmond³ to test various other host relationships. Much of this work was carried out with support from an ACIAR-funded project between Indonesia and Western Australia.

At this time also the Department (CALM) developed a strategy to plant some 20 hectares per annum of Indian Sandalwood as a commercial venture. Seed supply problems and nursery techniques had been solved to a certain extent but inability to control weed regrowth in the former agricultural paddocks prevented this programme becoming established in its first year.

By 1993 some local farmers had expressed an interest in growing Indian sandalwood privately as a commercial crop and during that year the first two private plots were established including one by the senior author (CD).

Advent of a formal research programme

Up until this time research into propagating *S.album* and the technology of plantation establishment on the Ord had been fairly ad hoc. No dedicated scientist or realistic budget and other resources had been allocated to the project, with all the work being done by the authors (CD and PK) largely out of personal interest and having to be fitted in with other work. It had become clear to us, however that the species had considerable potential for commercial establishment on the ORIA.

Major unanswered questions remained:

- (i) How to gain consistent access to good quality seed?;
- (ii) How to raise seedlings in bulk, ensuring optimum recovery from scarce seed supplies?;
- (iii) How to undertake site preparation and weed control?; and
- (iv) What was the correct mix of short and longer term host species which would carry the sandalwood right through a rotation?.

There was also the ongoing worry for all forestry projects in the north of how to protect trees from attack by termites in particular *Mastotermes darwinensis*. Other management problems including irrigation requirements, fire control, pest management and security also had to be addressed.

¹The origin of these NT trees is unknown but it is speculated that they may be descended from either seed or plants distributed by Macassan fishermen who frequented the north coast in large numbers from the late seventeenth century specifically to collect and process trepang but also to trade with Aboriginal people. Perhaps they saw some potential for sandalwood to grow here or conversely, perhaps the introductions, if indeed they were introductions, were accidental. The Macassans left other evidence of their visits including major processi

² CALM had been created in 1985 by an amalgamation of the Forests Department, the wildlife section of the Department of Fisheries and Wildlife and the National Parks Authority.

³ Son of Forester Peter Richmond who arranged for the original seed to be imported. This was privately funded research.

In the early 1990s, funding for research and also for maintenance and development of plantations became available from a Sandalwood Conservation and Regeneration Project (Scarp) established by CALM. This funding was derived from profits from the WA sandalwood (*S. spicatum*) industry.

The first full time research scientist (Andrew Radomiljac) was appointed, with funding support from ACIAR, and located at Kununurra. Mr Radomiljac was quickly able to pick up on the work which had previously been done and he put in a large number of new trials, in particular focusing on host species, nursery technology, site preparation and weed control.

A break-through in producing quality seedlings from the nursery followed the development of a “pot-host” (*Alternanthera sp.*) which ensured that the seedling went into the field already established to a host. Weed control and ground preparation were improved and field establishment was markedly upgraded. Previously identified field hosts were evaluated further with *Sesbania formosa* and *Acacia trachycarpa* being confirmed as important secondary hosts and *Cathormion umbellatum* as a very satisfactory long term host. New host identification trials were implemented and tree improvement work in the form of “family” trials was commenced.

An establishment and management regime was settled upon as a result of the research findings as well as the incorporation of on ground experience. This regime was similar to that detailed below (under “Current Plantation Establishment and Management Prescription”).

Commercialisation of Indian Sandalwood on the ORIA

In the mid 1990s CALM was approached by the promoters of a Managed Investment Scheme who wanted to develop an Indian sandalwood plantation by selling woodlots to investors. CALM agreed to a commercial arrangement in which it provided expertise for the nursery (established by the promoter) and advice on the technical aspects of plantation establishment. Initially a conceptual project of 50 ha was proposed, but this grew rapidly to 150 ha in the first year. The huge jump from small scale trial plantings to large scale commercial plantings proved to be not achievable and this initial venture failed. A number of mistakes were made, including the use of African mahogany (*Khaya senegalensis*) as a host. This species has proven not to be a good host tree and in fact its eventual broad, spreading crown suppresses the sandalwood.

From the point of view of foresters interested in growing sandalwood commercially (if not from point of view of the investors!), this project provided many useful lessons. It was obvious that *Sesbania formosa* was a critical short term host species and also that the quality of nursery stock, time of planting, standard of ground preparation and capacity for follow-up operations in year 1 were all essential ingredients for success.

The advent of other Managed Investment Schemes (MIS) Operations

Despite the problems experienced in the first commercial project, the new industry had developed a momentum of its own. Two new MIS’s emerged and each secured sufficient interest to establish in excess of 100 ha of plantation each in the period 1999/2000.

There have been a number of company name changes and various restructuring but both MIS projects have continued with annual plantings through the early 2000s.

As at November 2005, the total area of sandalwood plantation in the ORIA is now approaching 2000 ha and new plantings exceed 200 ha in most years.

Current plantation establishment and management prescription

The establishment approach has been steadily refined over recent years. Typically today this involves the following broad steps.

- Soil surveys are undertaken to ensure the right soil types are acquired, and the land is either purchased or leased.

- If necessary the paddocks are laser-leveled, and irrigation requirements installed
- It has been found that, almost invariably, the areas need to be deep ripped (to around 750mm) to break up compacted layers caused by previous agricultural practices and the use of very heavy machinery for the laser leveling.
- The ground is prepared into raised beds. A fine tilth is necessary for best results.
- There is a comprehensive program of weed control during the year prior to planting so that by the time of planting, the ground is completely weed-free.
- The ideal planting time is during the cooler months of the dry season, namely mid May till late August.
- Total weed control is aimed for during the first year after planting and this is achieved by a combination of or individual application of 1) very careful use of herbicides and 2) manual hoeing and pulling.
- The hosts (a combination of short, mid and long-term hosts) are planted concurrently with the sandalwood seedlings to nurture the sandalwood throughout the rotation. Short term hosts die within 3 -4 years but the long term hosts must last the full life of the plantation.
- Carefully regulated irrigation schedules. Over watering can induce infection by *Phytophthora spp.* Monitoring the relationship between soil moisture and tree growth is carried out by regular measurements of soil moisture at sample locations and dendrometer readings of some trees.
- The sandalwood trees are lightly form-pruned (more than once if required) in the first two years.
- Weed control continues through the rotation.
- Pest control is carried out as required.
- Fire prevention is catered for by the installation of wide fire breaks surrounding the individual blocks. Suppression of fires is a high priority and the industry is gearing up to enable this.

Some managers are currently experimenting with sowing seed directly into the planting site, so as to avoid the need for nursery operations. This is the approach used with some success in southern WA in plantations of *S.spicatum* (Department of Conservation and Land Management 1990). At this stage it is not a proven technique for the Ord River Irrigation Area plantations.

Issues

• Land availability

The ORIA is of limited extent with only some thirteen thousand hectares currently under irrigation. Whilst a second stage for the scheme has long been proposed⁴ it has never got off the drawing board and land shortages threaten the long term viability of some horticultural crops⁵. However, land for sandalwood plantation development itself has not been limiting as so far it has always been possible to lease or buy sufficient area.

Land in the ORIA is very expensive (currently in the order of \$8,000 - \$10,000 per ha) and it is only possible to pay this such prices for highly profitable crops, such as from the likely projected returns from sandalwood.

• Soil type

Cununurra Clay (a heavy, cracking black clay) is the preferred soil type given its ease of irrigation with the use of the flood irrigation technique. With this type of irrigation Cununurra Clay is not suitable habitat for the potentially devastating termite (*Mastotermes darwiniensis*)⁶. Sufficient soil of this type has been available to service the sandalwood industry to date.

• Risks and Risk Management

○ Insect pests

- ⊙ Cossid moths may attack all species. Larvae of these moths can ring bark small trees.

⁴ Ord Stage Two would increase the irrigable area to more than 60000 hectares about 25% of which would be in the adjacent Northern Territory. Recent (2005) negotiations with local traditional landholders seem to have opened the door for expediting the project.

⁵ For example, the sugar industry is operating at the lower end of the scale in terms of economical mill throughput. Chronically low world sugar prices are reflected locally and farmers sometimes sell the land to sandalwood interests. Additional land dedicated to tree crops (ie tied up for a long period), means less land available for sugar leading to fears that the mill itself will become non viable.

⁶ "Masto" can create havoc in tree crops grown on lighter soil types in the area.

- ⊙ Looper caterpillars, stem borers and occasional white flies can cause damage to sandalwood.
- ⊙ Scale, white fly, red-shouldered leaf eating bugs and the caterpillars of a yellow butterfly can cause problems on several of the host species.
- ⊙ White scale on the sandalwood stems is also being investigated.

Most can be easily controlled chemically but vigilance is required for timely control work to be undertaken. Chemical control is usually only resorted to in extreme situations and efforts to control using more environmentally friendly methods are followed initially.

o *Host species selection and management*

The selection of host species by the plantation manager can be difficult. Some species may be good hosts but their growth may be too vigorous, overtopping and subsequently suppressing the sandalwood. *Albizia lebbek* is an example of this. Other species may not be vigorous enough to ensure adequate contribution to the sandalwood crop. Again others may be good hosts but the sandalwood parasitises them so strongly that they are ultimately killed. This last type of species are used in the ORIA as short term hosts. Most of the best short and long term hosts are leguminous.

Another aspect of “host” selection which was a feature of two of the early commercial ventures was the attempt to use high value timber species as “hosts”, thus producing a multi-value crop. Some leguminous species such as Indian Rosewood (*Dalbergia latifolia*) may in fact have some good properties as hosts but their capacity to prosper when “hosting” sandalwood is an unknown quantity

In our view the use of valuable tropical timbers as “hosts” when their contribution to sandalwood growth is negligible should be avoided. African mahogany (*Khaya senegalensis*) and teak (*Tectona grandis*) are examples of species which have been tried in this way. The silviculture of *S.album* is probably the most complicated of any tree grown under plantation conditions and trying to manage for other valuable timber species in the mix complicates it even further.

The potential sandalwood plantation developer can do no better than to search the literature (mostly Indian) on suitable host species and to use those that are best suited to their particular soil and climate combination.

The more progressive plantation managers in the ORIA tend to segregate sandalwood and their long term hosts into separate rows – so aiding the specialist management requirements of both.

o Fungi

To date the fungal problems which have been associated with the Indian sandalwood plantations have been infection by *Phytophthora* and *Pythium* species. The former is invariably associated with excessive irrigation regimes.

A number of host species have been recorded with infections of the pathogenic fungus *Ganoderma sp.* Species in which mortalities have been recorded to date include some species which may have other qualities making them less than ideal hosts. *Albizia lebek* is one example of this. However, vigilant monitoring is required to check that our favoured host species are not susceptible to *Ganoderma sp.* infection.

o Over optimistic prices

Indian government auctions of sandalwood billets and other sandalwood pieces are held regularly in Tamil Nadu State. The highest quality sandalwood billets may go for \$US60,000 per tonne or more (January 2005). We understand however that for every tonne auctioned legally, 2 or 3 tonnes of high quality stolen sandalwood is sold on the black market for perhaps 50% of the “legal” price.

Conclusions

The evolution of the Indian sandalwood industry in the Ord River Irrigation Area provides an interesting example of the development of a new, high value plantation crop. Early development arose from the enthusiasm of local foresters which led to leader trials and in turn to formal scientific research work. The jump from research to commercialisation was probably made too soon, or was too large a jump because the first plantations were largely a failure. However, the technical aspects of the project have now been more thoroughly researched, and the potential returns promise to be high, leading to ongoing private investment interest and the establishment of a whole new industry.

Questions of management of host species through the rotation, and control of pests (especially water-borne fungal pathogens) persist, but are not regarded as project-threatening.

Research still continues on a limited scale and is carried out by the Western Australian Forest Products Commission⁷ and by commercial interests. The future of this industry is now not so much a question of science and technology, but of commercial aspects, including demand, supply and price. Consumption of sandalwood products is almost entirely overseas (outside Australia), indicating that these commercial aspects will be determined largely by what goes on in the international marketplace.

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⁷This statutory body took over the project from CALM.

Chemical variation in the oils of *Santalum macgregorii* (PNG sandalwood)

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Abstract

Heartwood of *Santalum macgregorii*, PNG sandalwood, has been traded for more than a century but little is published on the chemical composition of its oils. Knowledge of the variation present in oil composition is a prerequisite to designing appropriate sampling strategies for conservation of the species and optimising domestication strategies. In order to provide greater information on this aspect, thirteen wood samples were collected from four locations representing Western, Gulf and Central Provinces during species surveys in 2001, 2002 and 2004. Oils were then extracted from the heartwood by steam distillation and the oil composition analysed by Gas Chromatography/Mass Spectrometry.

The wood oils of *S. macgregorii* were found to be highly variable in composition. Variation in major compounds like *Z*- α -santalol, *Z*- β -santalol, *Z*-lanceol and *Z*-nuciferol appeared to be continuous, rather than forming disjunctions usually associated with chemotypes, although this needs to be confirmed by more intensive sampling. Of note amongst the samples were: two oils from Western Province with *Z*- α -santalol and *Z*- β -santalol at levels compliant with the ISO Standard for *S. album* oil; six oils with substantial proportions (31–75%) of *Z*-lanceol; four oils containing two recently identified compounds, γ -curcumen-12-ol and β -curcumen-12-ol, which were in significant proportions in two of these oils (28–48%); one oil with a substantial proportion (34%) of an unidentified oxygenated sesquiterpene and; five oils containing (E,E)-farnesol, an identified allergen. At least three of these five oils contained (E,E)-farnesol at levels (4% or more of total oil) which may adversely affect their market acceptance for use in perfumes and cosmetics.

The substantial tree-to-tree variation in oil composition in *S. macgregorii* needs to be accounted for in germplasm collections aimed at genetic conservation, where sampling ideally should aim to capture a representative range of oils present in the species, and for plantation development where the focus might be on ensuring production of oils rich in *Z*- α -santalol and *Z*- β -santalol.

Introduction

Santalum macgregorii F. Muell. (PNG sandalwood) varies from a small to medium sized tree, 8 to 20 m tall, often multi-stemmed with short, crooked boles and open crowns. Diameters of larger, single-stemmed specimens reach 25 cm or more at maturity. Trees have rough, moderately tessellated bark with lanceolate to broad lanceolate, light green leaves in opposite pairs that tend to hang pendulously. Bosimbi and Uwamariya (2004) describe the reproductive structures: flowers are small (4–4.5 mm long), yellow-green at the base to red with 4 lobes, 2–2.5 mm long \times 1.5 mm across; fruits are ovoid

drupes about 8–10 mm long, immature fruit is green changing to red then purple through to black when fully ripe.

S. macgregorii exhibits considerable morphological variation and several traditional (folk) varieties are recognised depending on the village (Gunn *et al.* 2002), similar to the practice with other Pacific sandalwoods like *S. yasi* in Fiji and Tonga and *S. austrocaledonicum* in Vanuatu (Thomson 2004). The two folklore varieties of *S. macgregorii* most commonly distinguished are “male” and “female” where the “female” trees flower and fruit more heavily than the “males” and have larger leaves. Both co-occur in the same populations.

Santalum macgregorii is endemic to southern Papua New Guinea where its typical habitat is seasonally dry, evergreen savannah woodlands and grasslands, with occasional occupation of riparian semi-deciduous thickets and, very occasionally, rainforest habitats (Gunn *et al.* 2002). This species prefers well drained sites. Altitudinal range is from near sea level to 160 m, with an isolated occurrence reported at 750 m. Soils vary from almost pure sands to mottled clay loams with calcrete nodules. The natural range of *S. macgregorii* extends from Kwikila in Central Province in the east to Malalaua in Gulf Province (Gunn *et al.* 2002, Bosimbi 2005) with a recently confirmed disjunction of apparent small size near the villages of Buzi and Ber in Western Province (Doran and Lea 2005). Most populations occur within 50 km of the coast. (Fig. 1).

Commercial exploitation of PNG sandalwood commenced in the late 1800s and by 1980 about 9,000 tonnes had been exported requiring the removal of possibly as many as 180,000 trees (Zieck 1970 cited in Bosimbi 2005). The trade is relatively minor today mainly because of the scarcity of the resource. For example, during the five years 1997 to 2002, a total of 220 tonnes of sandalwood were exported to mainly Asian ports of an estimated value of USD 280,000 (Bosimbi 2005).

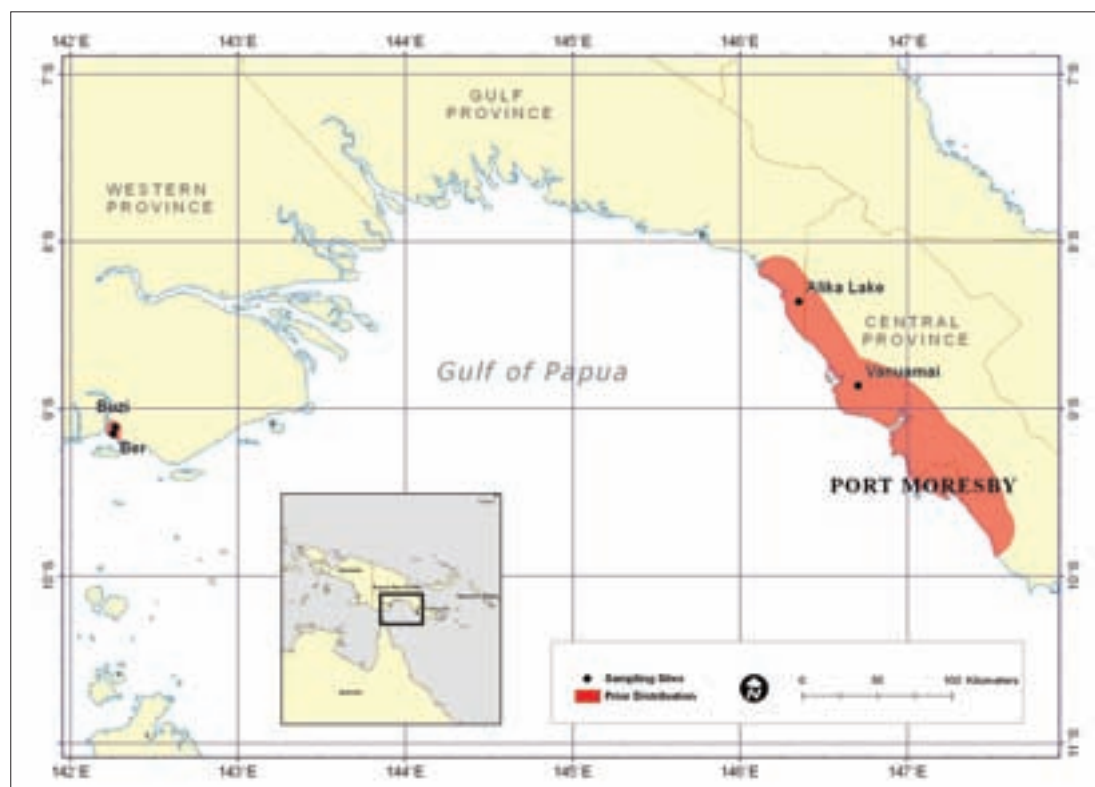
The commercial value of sandalwood depends on its heartwood oil content, oil composition and the quantity of heartwood per tree. The Z- α -santalol and Z- β -santalol contents of some *S. macgregorii* oils compare favourably with those of high quality oils of *S. album* (East Indian sandalwood). *S. album* oils command a premium price in the market place and have an International Standard (International Standards Organisation 2002) with ranges for Z- α -santalol and Z- β -santalol set at 41–55% and 16–24%, respectively. Oil for use in perfumery and cosmetics should be largely free of any one of several allergens, with (E,E)-farnesol being the compound of most concern in sandalwood oils (E. Lassak pers comm. 2005).

Despite a long history of utilisation and the importance of oil composition in determining value of sandalwood oils of commerce, reports in the literature giving information on oil chemistry of *S. macgregorii* are scarce. Doran *et al.* (2005) presented information on the oil chemistry of three *S. macgregorii* wood samples at the 2002 workshop. It was the aim of this paper to report on the variation found in the oils of this species, based on thirteen wood samples, inclusive of the three reported earlier included here for completeness, collected during population surveys over the last few years.

Materials and Methods

Wood samples: Sites where the wood samples were obtained in Western, Gulf and Central Provinces are indicated in Fig. 1 and Table 1. Most samples were taken at the base of the trunk (buttwood) except for one of the Western Province trees which was sampled at breast height because of fire damage to the heartwood lower down. At Vanuamai in Central Province, two trees (JB 5282 and 5283) were sampled in the first visit as representing “male” and “female” folklore varieties but this discrimination was not made in later collections. All samples were wood discs of various thickness. They were air-dried in PNG and transported to Australia where they were stored at room temperature awaiting extraction for periods varying from a few months (e.g. the WP samples) to a few years (e.g. samples JB 5778 to 5783).

Fig. 1 The natural distribution of *Santalum macgregorii* and the location of the four collection sites for this study



Isolation of oils: Before extraction, the sapwood was removed from each sample and the heartwood turned into fine chips by hand using a chisel. The oils were isolated by hydrodistillation with cohobation for up to 24 hours as outlined in Brophy *et al.* (1991). Analyses of the oils were carried out by gas chromatography and combined gas chromatography-mass spectrometry. Oil concentrations per tree (not given here) were low and were deemed by the authors to be unrepresentative of potential commercial concentrations because of the small size (only a few grams of heartwood) of the samples.

Identification of Components: Analytical gas chromatography (GC) was carried out on a Shimadzu GC17 gas chromatograph. A WCOT DB-Wax column [60 m x 0.5 mm, film thickness 1 μm] was used, programmed from 50°-225°C at 3°C/min with helium at 3.5 mL/min as carrier gas. GC integrations were performed on a SMAD electronic integrator without the use of correction factors. GC/MS was performed on both a VG Quattro mass spectrometer operating at 70 eV ionization energy (the column used was DB-Wax [60 m x 0.32 mm, film thickness 0.25 μm] programmed from 35°-220°C at 3°C/min, with helium at 35 cm/sec as carrier gas) and a Shimadzu QP5000 instrument equipped with a DB-5 column [30 m x 0.25 mm, film thickness 0.25 μm]. The latter column was programmed from 35°-250°C at 5°C/min, helium carrier gas flow rate was 30 cm/sec. Compounds were identified by their identical GC retention times to known compounds and by comparison of their mass spectra with either known compounds or published spectra (Adams, R.P. 2001; Heller and Milne 1978, 1980, 1983; Joulain and König 1998; Stenhagen *et al.* 1974; Swigar and Silverstein 1981).

Results

Table 1 lists the main compounds identified in the oils of the thirteen *S. macgregorii* wood samples available for test along with their proportions (% of total oil) in each oil sample.

Table 1 Details of sample location and the major components identified in *Santalum macgregorii* wood oils expressed as a percentage of total oils

Sample No. JB# Folk variety (when known) Location Wood type ⁺ Year collected	Western Province						Gulf Province				Central Province		
	5290	5765	5766	5767	5768	5769	5778	5781	5782	5783	5282	5283	5779
	Buzi	Buzi	Buzi	Ber	Ber	Buzi	near Alika Lakes				female	male	
	-	bw	bw	bw	bw	tw	bw	bw	bw	bw	Vanuamai		
	2001	2004	2004	2004	2004	2004	2002	2002	2002	2002	2002	2002	
Dendrolasin		0.1		0.1		0.1							
E-nerolidol		0.2		0.1		0.1							
α -bisabolol		1.0		1.5		1.0							
Z- α -santalol	46.2	12.7	47.0	24.8	37.8	10.7	30.2	7.3	2.6	3.6	8.8	0.9	
E,E-farnesol								4.3	2.8	5.1		0.8	6.7
Z- α - <i>trans</i> -bergamotol	12.0	1.6	11.5	6.3	10.5	1.7	5.7	1.7	1.7	0.6	1.8	3.6	1.0
epi- β -santalol	3.9	1.1	3.6	1.7	3.0	1.0	3.5	0.3	0.4		0.4		0.3
Z- β -santalol	20.4	7.7	23.6	11.2	17.9	6.8	13.5	2.4	1.9	1.1	0.8		0.7
Z- γ -curcumen-12-ol									1.2		17.5	1.7	10.7
Z- γ -bisabolene-12-ol													
E- β -santalol	1.5	1.6	1.3	1.1	3.4	1.5	4.5						
Z- β -curcumen-12-ol									1.2		30.7	4.1	17.8
Z-lanceol	2.6	70.4	1.7	42.7	4.9	72.3	12.1	64.1	31.3	74.8	4.4	2.2	2.6
Z-nuciferol	2.0	1.7	0.7	5.1	4.0	2.2	2.9	4.4	17.8	5.1	14.2	6.5	25.1
C15 H24 O (1)											4.5		
C15 H24 O (2)	1.7												2.2
C15 Hx O												33.8	

- indicates wood type unknown

+ tw is trunkwood with the wood disc taken at breast height (this tree was felled naturally by fire and the sample was taken above the fire damaged, lower portion of the trunk)

bw is buttwood

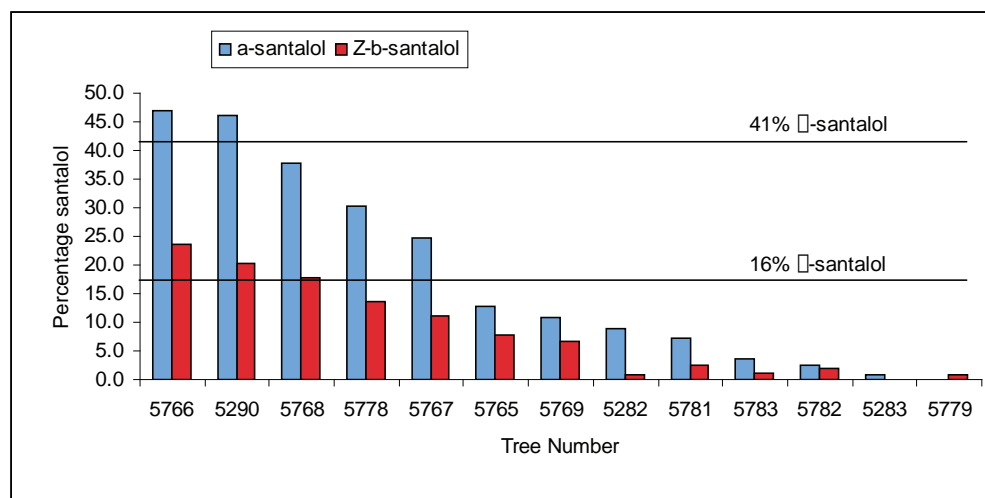
The variation in oil composition was substantial. Four oil samples (5290, 5766, 5768, 5778) contained major amounts of Z- α -santalol (30–47%) and Z- β -santalol (17–24%). Two of these samples (5290, 5766), both from Western Province, gave Z- α -santalol and Z- β -santalol levels consistent with those found in high quality East Indian sandalwood oil (from *S. album*). These were accompanied by lesser amounts of Z- α -*trans*-bergamotol (6–12%), E- β -santalol (1–5%), epi- β -santalol (3–4%), Z-lanceol (2–12%) and Z-nuciferol (1–4%). Quite small amounts of sesquiterpene hydrocarbons were also present in these oils, amounting to less than 5% in total.

Six oil samples (5765, 5767, 5769, 5781 to 5783) contained major amounts of Z-lanceol (31–75%) in similar proportions to that found in many trees of *S. lanceolatum* from northern Queensland (Doran *et al.* 2005). This was accompanied by lesser amounts of Z- α -santalol (3–25%) and Z- β -santalol (1–11%) and varying proportions of the other components mentioned above. Two oil samples ('female' tree 5282, 5779) were rich in up to four oxygenated sesquiterpenes, (E,E)-farnesol, Z- γ -curcumen-12-ol, Z- β -curcumen-12-ol and Z-nuciferol, and the 'male' tree (5283) from Gulf Province produced a different oil again with the principal component being an unidentified oxygenated sesquiterpene (33.8%). The allergen, (E,E)-farnesol, occurred in reasonable high proportions (3–7%) in four of the oils which may adversely affect their market acceptance for use in perfumes and cosmetics.

Proportions of the major constituents appeared to vary continuously (Fig. 2) rather than defining separate chemotypes, although, admittedly, these observations are based on a very limited sample set. Also, because of the small number of samples studied, it was not possible to comment on any association

between oil chemistry and geographic location. Oil concentrations amongst this set of samples varied from 0.5% to 2.5% (w/w% air-dry) but these are almost certainly not representative of commercial yields as they are based on very small wood samples which in some cases were stored for three years before extraction.

Fig. 2 Variation in % santalols of total oils plotted in descending order of % Z- α -santalol from left to right



Discussion

From the small number of samples examined of this species, it would appear to be highly variable with regard to its essential oils. The variation appeared to be continuous for the major compounds such as Z- α -santalol and Z- β -santalol and Z-lanceol. Adding to the extent of variation present in this thirteen sample set were two oils ('female' tree 5282, 5779) from Vanuamai in Central Province which were rich in γ -curcumen-12-ol (18% and 11%, respectively) and β -curcumen-12-ol (31% and 18%, respectively), and sample 5283, a 'male' tree also from Vanuamai, rich (34%) in an unidentified oxygenated sesquiterpene. γ -curcumen-12-ol and β -curcumen-12-ol were first identified in the oil of *S. spicatum* (Western Australian Sandalwood), as recently as 2003 (Valder *et al.* 2003).

Two wood samples (5290, 5766), both from Western Province, gave oils with levels of Z- α -santalol and Z- β -santalol similar to those of high quality East Indian sandalwood oil (from *S. album*). As a consequence, these oils might be expected to command a higher price in the market place than other *S. macgregorii* oils. Western Province populations, although little known and apparently of very limited extent, could be a useful source of genetic material for commercial development of a sandalwood industry based on *S. macgregorii*. The Western Province oils were free of (E,E)-farnesol, which is to be avoided in perfumery and cosmetics because of its listing as an allergen by the European Community requiring special labeling with cut-off levels of 0.01% in 'rinse-off' products and 0.001% in 'leave-on' products (Anon 2003 cited in Lassak 2003).

Genetic resources of *S. macgregorii* throughout its natural distribution in PNG are severely depleted, because of a combination of all too familiar factors relating to sandalwood species including over-cutting exacerbated by uncontrolled burning hindering regeneration. A systematic, range-wide sampling of individual trees of *S. macgregorii* for both germplasm and wood samples (cores), as is being applied to *S. austrocaledonicum* in Vanuatu (Page 2005), is required urgently. Germplasm is needed to allow conservation strategies, as recommended by Gunn *et al.* (2002) as part of ACIARs 'Domestication of Papua New Guinea's Indigenous Forest Species' project, to be effectively implemented. A greater knowledge of variation in heartwood oil characteristics will better ensure that the germplasm collections for conservation purposes capture the extent of chemical variation in the wood oils of this species. It should also identify provenances or regions with a high proportion of individuals with *S. album*-like oil qualities that ideally should be the focus for collections aimed at development of a sandalwood oil industry based on *S. macgregorii*.

Acknowledgements

The authors would like to acknowledge the leaders of the 2002 (Gulf and Central Provinces) and 2004 (Western Province) *S. macgregorii* survey trips, David Spencer and David Lea respectively, for providing the wood samples for analysis. The Australian Centre for International Agricultural Research provided financial support for these surveys through two of its projects with Ensis and Lae FRI. Thanks also to Bob Goldsack who did the oil extractions, Paul Macdonell and Eva Morrow who assisted with the figures and tables and Lex Thomson, Brian Gunn and Erich Lassak for comments on drafts of the paper.

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Sandalwood Phylogeny: Insights for Biogeography, Conservation and Classification

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Objectives

The main objective of this doctoral dissertation research is to reconstruct the evolutionary history of *Santalum*, which includes the commercially and culturally important sandalwoods. The phylogeny will elucidate ancient dispersal patterns and demonstrate patterns of relationship among taxa. Re-circumscription of taxa based on the phylogenetic hypotheses will aid in the recognition and conservation of rare and cryptic lineages. The phylogeny will be published in *Systematic Botany* (in prep.) and any taxonomic revisions will be published in a monograph, both printed and web-based, at the end of the dissertation research (projected Spring 2007).

Introduction

The genus *Santalum* (Santalaceae) includes some of the most widely recognized plants in the fragrance and essential oil industries, sandalwood. It is a fascinating genus for study being naturally distributed widely throughout the Pacific islands, comprising hemi-parasitic trees with a variety of important human uses. Sandalwood oil has been reported to have anti-microbial activity, anti-cancer activity, anti-viral activity, and may even be effective against the AIDS virus and RNA viruses (Jones, *et al.* 1995; Haque *et al.* 2000). In Australia, *S. acuminatum* is an important food for the aborigines, called *quandong* (Ahmed *et al.* 2000), and in the Cook Islands, the grated wood of *S. insulare* has been reportedly used for earaches, toothaches and applied to skin infections (Whistler 1992).

The demand for its valuable oil has led to drastic over-harvesting. It is one of the most heavily exploited groups of plants across its range from Indomalaysia to Hawaii (Brennan *et al.* 1991). In fact, one variety in Hawaii (*S. freycinetianum* var. *lanaiense*) is currently listed on the US Endangered Species List (USFWS 2004), and two other species are considered threatened with extinction, *S. insulare* var. *hendersonense* and *S. boninense* (Walren *et al.* 1995; Maina *et al.* 1988). A species endemic to the Juan Fernandez Islands (*S. fernandezianum*) became extinct in the last century due to human exploitation (Kuijt 1969; Stuessy *et al.* 1992).

The genus includes approximately 15 species and 14 varieties, and 1 extinct species, distributed throughout India, Australia and the Pacific (Applegate *et al.* 1990) (Table 1). Currently, the 16 species within *Santalum* are separated into three sections based on floral morphology (Skottsberg 1930; Sykes 1980; Fosberg 1985; Wagner 1990). The wide distribution of *Santalum* taxa presents the perfect opportunity to study dispersal patterns of organisms across the Pacific and modes of speciation on islands.

A number of regional treatments have been produced within *Santalum* (Roxburgh 1820; Hillebrand 1888; Bailey 1902; Rock 1916; Brown 1935; Skottsberg 1927, 1930a, 1930b 1938; Stemmerman 1980; Sykes 1980; St. John 1984; Fosberg 1985; Hallé 1988) however, no comprehensive monograph of the genus has yet been completed. The taxonomy of the genus is in need of revision (Sprague *et al.* 1927; Egler 1939; McKinnell 1990). Sandalwoods have considerable morphological variation within

a single taxon, which has led to taxonomic confusion (Hamilton *et al.* 1990). The use of cutting-edge phylogenetic methods, using both molecular and morphological data, is essential to properly revise the genus because “sandalwood taxonomy is rather bewildering for the layman and often very different looking trees may belong to the same species” (Pratt 1998).

Over one-quarter of the diversity of named *Santalum* species are endemic to the Hawaiian Islands. A number of hypotheses have been proposed on the number and origination of *Santalum* colonizations to Hawaii. Fosberg (1948) and Wagner *et al.* (1990) both hypothesized that the diversity of *Santalum* in Hawaii is a result of two colonizations, at least one with a South Pacific or Austral origination. On the contrary, Merlin *et al.* (1990) assert that the Hawaiian species are the result of an adaptive radiation from a single ancestor. An adaptive radiation can be defined as a rapid radiation from a single ancestor into diverse habitats, usually as in island archipelagos (Carlquist 1974; Schluter 2002).

Table 1. Sections, species, and localities of *Santalum* taxa.

Section <i>Hawaiiensia</i>	<i>S. ellipticum</i>	Hawaii
	<i>S. paniculatum</i>	Hawaii
Section <i>Polynesica</i>	<i>S. fernandezianum</i>	Juan Fernandez Is. (extinct)
	<i>S. insulare</i>	Society Is., Marquesas, Henderson Is., Austral Is., Cook Is.
Section <i>Santalum</i>	<i>S. acuminatum</i>	Australia
	<i>S. album</i>	India, Indonesia, Australia
	<i>S. austrocaledonicum</i>	New Caledonia, Vanuatu
	<i>S. boninense</i>	Bonin Is.
	<i>S. freycinetianum</i>	Hawaii
	<i>S. haleakalae</i>	Hawaii
	<i>S. lanceolatum</i>	Australia
	<i>S. macgregorii</i>	Papua New Guinea
	<i>S. murrayanum</i>	Australia
	<i>S. obtusifolium</i>	Australia
	<i>S. spicatum</i>	Australia
	<i>S. yasi</i>	Fiji, Tonga

Methods

To reconstruct the phylogeny of the genus *Santalum* across its geographic distribution, and to identify possible cryptic lineages, several specimens of each named taxa will be included in the analysis, if available. Two outgroups, *Osyris alba* and *Colpoon compressum* have been chosen to root the phylogeny, based on the phylogeny of the Santalales by Nickrent *et al.* (2001). Genomic extractions will be taken using a Qiagen extraction kit from silica-dried leaf material when available, otherwise herbarium material will be used. Several gene regions will be directly sequenced using the automated ABI 377 sequencing machine.

There are numerous genes that are commonly used in phylogenetic analyses of plants, both nuclear and chloroplast (Soltis *et al.* 1998). One chloroplast and two nuclear ribosomal gene regions have carefully been chosen to construct the phylogeny of *Santalum*. Both chloroplast and nuclear genes have been chosen in order to detect any possible hybridization (McDade 1995). In combination with the 3' end of the chloroplast intron spacer region *trnK*, the internal transcribed spacer (ITS) and external transcribed spacer (ETS) region of the 18S-26S nuclear ribosomal DNA have been chosen as the most appropriate gene regions for this analysis. The *trnK* introns of the *matK* gene have been shown to be the most rapidly evolving regions in the chloroplast (Johnson *et al.* 1995). ITS and ETS have similar utility, and have proven to be useful sources of phylogenetic characters especially in recently diverged lineages (Baldwin 1995; Baldwin 1998a; Baldwin 1998b).

Sequences will be aligned by eye and series of maximum parsimony analyses will be performed using the computer program PAUP (Swofford *et al.* 1996), which include ITS+ETS, 3' *trnK*, and a

combined analysis of all genes. In all cases, a heuristic search with TBR branch-swapping will be used. All characters are unordered and are given equal weight. Fast-stepwise bootstrap analyses with 100 replicates will be performed to evaluate ambiguity in the data.

The current taxonomy will be re-evaluated using the results of the phylogenetic analysis. The phylogeny will be used to test the monophyly of species (Baum *et al.* 1995). In addition, the phylogeny may indicate lineages that are not yet accounted for in the taxonomy. Identifying cryptic lineages not yet accounted for in the taxonomy will be important in conserving biodiversity (Crozier 1997; Baldwin 2000).

Preliminary results

Although there are slight differences in the topology of the nuclear ribosomal (ITS+ETS) and chloroplast (*3 trnK*) trees, an incongruence length difference test did not show a significant difference in topologies so they were combined. This combined phylogeny is shown in Figure 1 (Harbaugh, in prep). The phylogeny is highly resolved with high bootstrap support for most of the nodes.

There are several important results from this study. The first is that *S. austrocaledonicum* appears to be polyphyletic, with specimens from Vanuatu and New Caledonia having different sister taxa (but further research is need to confirm this unexpected result). Second, *S. lanceolatum* also appears to be polyphyletic, with a specimen from Northern Territory Australia separated from other *S. lanceolatum* specimens and sister to the *Hawaiiensia* clade. These surprising results may indicate either cryptic lineages for which the current taxonomy does not recognize, or incidents of hybrid species formation.

There are a number of biogeographical insights from these results, such as a likely origination of *Santalum* in Australia, because of the basal paraphyletic grade of Australian taxa. Up to seven long-distance dispersal events originating in Australia/Papua New Guinea must account for the current distribution of *Santalum* in India, Juan Fernandez, Fiji/Tonga, Vanuatu, New Caledonia, and Hawaii. Results indicate two separate dispersal events to the Hawaiian Islands. One Hawaiian clade represents the endemic *Hawaiiensia* section, while the other includes *S. boninense* and *S. insulare*, indicating dispersal from Hawaii west to Bonin and south to Polynesia. Interestingly, *S. insulare* is not more closely related to the *Hawaiiensia* section as had previously been hypothesized (Skottsberg 1930b, Wagner *et al.* 1990).

Fig. 1. (Harbaugh, in prep.) Phylogeny of *Santalum* with combined ITS+ETS+3'trnK Strict consensus of 12,929 trees, L=611, 359 parsimony informative characters (332 ITS+ETS, 27 3'trnK) CI=0.764, HI=0.236.



Continued research

With the addition of more *Santalum* specimens, gene regions and morphological characters, the current phylogenetic hypothesis will be strengthened before any taxonomic revisions are made. In particular, at least an additional 10 specimens of *S. austrocaledonicum* from Vanuatu and New Caledonia, and *S. lanceolatum* from Australia, will be analyzed to confirm the polyphyly of these taxa. In addition, the low-copy nuclear gene *Waxy* will be sequenced in order to add resolution and support to the topology, as well as identify the presence and parentage of polyploid or hybrid taxa or individuals.

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Vanuatu Sandalwood – An Industry Perspective from Tropical Rainforest Aromatics Limited

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Introduction

Since 2001, Tropical Rainforest Aromatics Limited (TRA) has been licensed by the Department of Forestry of the Vanuatu Government to buy sandalwood. Because of uncertainties concerning the extent of the resource a total quota of 80 metric tonnes of heartwood (shared between two licensees) was placed on the harvest from 2001 until 2005.

National Forest Policy has been formulated with the following aims:

- to sustainably manage the resource,
- to utilise the harvested material to the maximum extent, and
- to deliver the greatest possible benefits to the indigenous stakeholders.

TRA has demonstrated its commitment to these major planks of National Forest Policy through:

- Staying within its quota of heartwood (averaged over the last five seasons),
- Proposing a **reduction** in quota to 60 tonnes of heartwood annually,
- Searching out new products and markets for fractions of the wood that previously were wasted, with an objective of utilising at least 70% of the tree,
- Developing a set of product specifications understood and accepted by the customers
- Annually increasing the price paid to indigenous resource owners,
- Providing employment for ni-Vanuatu including 48 full-time staff and up to 90 casual staff during the 3-month harvesting period,
- Investing in processing machinery to manufacture value-added products, with a development plan to introduce new machinery that will see an increase in the coming years of value-added products.,
- Installation of new steam distillation equipment in early 2006 that is designed to produce the highest quality oil, and
- Planned introduction of machines to produce powder for incense (for 2007-2008).

TRA has also shown a willingness to divulge to government and the scientific community in open forums detailed information about the quantity and quality of the wood that it has purchased and processed.

This paper presents relevant data that we have accumulated, and that we believe should be available for those concerned with the future of the sandalwood industry in Vanuatu and the region. Some of the data from our large-scale commercial operations is at variance with studies based on small field survey samples processed at a laboratory scale. Resolution of these problems can only be achieved through a continual flow of information between the various stakeholders.

Santalum austrocaledonicum and ISO 3518:2002 International Standard for *S. album*

Sandalwood oil is a complex mixture of hundreds of compounds but it is defined in the first instance by the concentrations of some key components. Oils are commonly assessed for quality in terms of how well they conform to the standards set for *S. album* in ISO 3518 for concentrations of α -santalol and β -santalol. Sandalwood oils derived from *S. austrocaledonicum* in Vanuatu vary widely in composition, depending on a number of factors. Some oils easily meet the standards while others fall short. It should also be noted that the presence or absence of other components in the oil apart from α - and β -santalols has the potential to alter the olfactory “quality” of the oil for better or for worse. Minor components increase the complexity of oil and can improve the aroma. Some components, notably some of the more volatile components that are concentrated in the first fractions from a distillation, are malodorous and can drastically compromise the aroma.

Our experience in laboratory and large-scale commercial distillations pointed to the belief that, while there was a continuum in composition across Vanuatu, sandalwood from the island of Espiritu Santo almost invariably would yield oil that conformed to ISO 3518 and could potentially be a substitute for *S. album*. However most of the oil from southern islands did not conform to ISO 3518 and disappointingly has met with considerable buyer resistance.

The most lucrative market for sandalwood is however not for oil, but for carving logs where the oil quality is of lesser importance than the colour and perfection of the wood itself. Fortunately Vanuatu wood containing oil that is not suitable for carving and does not conform to ISO 3518 can find a ready market in the incense industry. Alternatively there is a little-known market in India as flavouring in chewing tobacco.

The International Standard for *Santalum album* oil specifies that it be obtained from heartwood by steam distillation and gives requirements for physical properties (appearance, colour, odour, relative density, refractive index, optical rotation and miscibility with ethanol). It also defines requirements for chemical composition. Traditionally, the “santalol” content was given as a single value measuring the primary free alcohol content, expressed as if it was all “santalol”. This was determined by an acetylation reaction (described in ISO 3793) and did not distinguish between the many individual alcohols that contribute to the total. ISO 3518 specifies a minimum of 90% “santalol”.

With the advent of modern capillary gas chromatography, it is possible to separate and measure the percentages of individual components. A typical gas chromatogram will reveal the presence of hundreds of components. The standard however only specifies minimum and maximum percentages for *Z*- α -santalol and *Z*- β -santalol (Table 1) in the chromatographic profile.

Table 1. Chromatographic Profile

Component	Minimum	Maximum
<i>Z</i> - α -santalol	41	55
<i>Z</i> - β -santalol	16	24

ISO 3518 also identifies *trans*- α -bergamotol and *epi*- β -santalol in chromatographic profiles but does not specify maximum or minimum percentages.

Industrial-Scale Distillations of *S. austrocaledonicum* Sandalwood

Since we were aware that the bulk of *S. austrocaledonicum* wood from the Vanuatu archipelago would not yield oil that met the International Standard but that sandalwood from Espiritu Santo usually did, we have biased our large-scale distillation program towards using wood from that source and have only performed a few large-scale distillations on wood from southern islands. Our results therefore do not reflect the general composition of *S. austrocaledonicum* oil across the island chain.

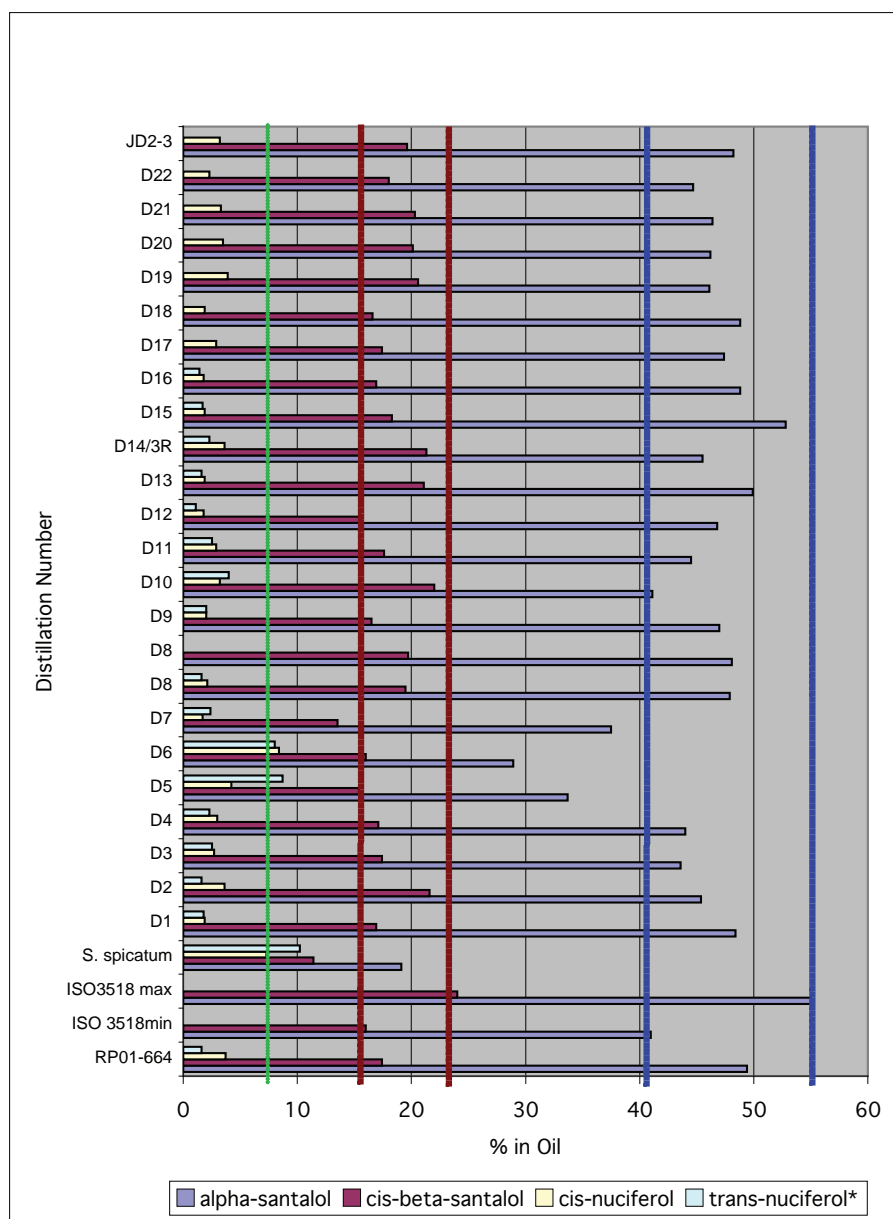
All distillations, apart from that labeled JD2-3, were carried out in an Apolloni steam distillation unit at TRA in Port Vila, Vanuatu. (This still was originally designed for tea tree oil distillation and has proved to have limitations

when used for sandalwood oil.) JD2-3 was performed in Western Australia in a still designed and built by Mr. John Day of The Paperbark Company.

Data for 23 large-scale distillations is presented in Table 2. Analyses were carried out by the Wollongbar Agricultural Institute (NSW Agriculture).

The weight of milled wood that was distilled ranged from 444 kg up to 1126 kg. Initial fractions of approximately 500-1500 ml each (depending on batch size, oil flow rates and oil aroma) were collected and stored separately from the major bulk fraction in each distillation. (See Table 3.) These initial fractions had very unpleasant aromas and contained the highest concentrations of components such as furano-pyrrole, as well as high percentages of hydrocarbons (such as the santalenes and curcumenes). Even with these early fractions removed most batches require further rectification before they lose the unpleasant aromas and take on the smooth, buttery, woody perfume of high quality sandalwood oil. At the time of writing (February 2006) TRA is awaiting the arrival of a new purpose-built still that should deliver better quality sandalwood oil, giving cleaner separations of the malodorous components, and requiring little or no rectification.

Fig. 1. Percentages of Major Components in Large-Scale Distillations of *Santalum austrocaledonicum* oils from Vanuatu



* The GC peak that had been identified as trans-nuciferol in earlier analyses was re-assigned as cis-β-curcumen-12-ol from distillation number D17 onwards.

Table 2. Analyses of Major Fractions from 23 Distillations of *S. austrocaledonicum* Wood

Distillation #	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Analysis Date	14-Jun-02	28/6/02	20/8/02	20/8/02	11/10/02	11/10/02	6/11/02	9/11/02	6/3/03	21/11/02
WAI Code	RP02-227	RP02-236	RP02-318	RP02-323	RP02-360	RP02-364	RP02-385	RP02-390	RP03-011	RP02-395
Island of Origin					Erromango	Erromango	Santo		Santo	Santo
Tree Part	Trunk/Root	Trunk/Root					Trunk	Root	Branch	Branch
Preparation										
α -santalene	0.8	0.4	1.0	1.0	0.8	0.4	3.5	0.4	1.9	0.7
trans- α -bergamotene	0.1	0.1	0.2	0.2	0.1	0.1	0.5	0.1	0.3	0.1
epi- α -santalene	0.6	0.2	0.7	0.7	0.6	0.3	3.5	0.3	1.5	0.5
β -santalene	0.7	0.3	0.8	0.8	0.6	0.3	3.4	0.3	1.6	0.5
γ -curcumene	0.2	0.1	0.3	0.3	0.6	0.4	1.6	0.1	0.6	0.2
ar-curcumene	0.2	0.1	0.3	0.3	0.3	0.2	0.8	0.1	0.3	0.1
β -bisabolene			0.1	0.2	0.2	0.2	0.3		0.1	
β -curcumene	0.3	0.1	0.5	0.4	0.7	0.4	2.5	0.1	0.8	0.2
dendrolasin					0.2	0.2	0.5	tr	0.1	0.1
β -bisabolol	0.8	0.3	0.6	0.6	1.0	1.6	0.9	0.5	0.8	0.3
α-santalol	48.4	45.4	43.6	44.0	33.7	28.9	37.5	47.9	47.0	41.1
α -bisabolol/ β -sinensal	1.3		2.6	2.6	1.3	1.7	1.3	2.0	0.6	1.8
trans- α -bergamotol	7.9	3.6	5.2	5.3	4.8	3.2	5.1	5.8	6.8	5.8
cis-α-santalol	1.2	1.1	1.4	1.4	1.6	2.9	1.4	1.2	1.3	1.5
cedren13-ol-8	1.1	0.3	0.6	0.6	0.6	0.3	1.2	0.6	0.9	0.3
epi-β-santalol	3.1	5.4	3.9	4.0	1.9	2.0	2.6	3.9	3.1	4.0
trans-trans-farnesol		2.3	1.7	1.7	1.0	2.2	0.6	1.2	0.7	1.0
cis-β-santalol	16.9	21.6	17.4	17.1	15.4	16.0	13.5	19.5	16.5	22.0
cis-nuciferol	1.9	3.6	2.7	3.0	4.2	8.4	1.7	2.1	2.0	3.2
trans-β-santalol	0.3	0.8	0.9	0.7	1.3	1.8	0.5	0.7	0.6	1.1
cis- α -bergamotol			1.1	1.1	1.0	2.5		0.7	0.4	
cis-b-curcumen-12-ol										
trans-nuciferol	1.8	1.6	2.5	2.3	8.7	8.0	2.4	1.6	2.0	4.0
cis-lanceol/ α -sinensal	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.3		0.4
α -bisabolol acetate			0.2	0.1						0.3
α -santalol acetate	0.2	0.1	0.2	0.2	0.8	0.6	0.2	0.1	0.3	0.3
trans- α -bergamotol acetate	0.1	0.7	0.3	0.3	0.2	0.4	0.1	0.3	0.2	0.4
β -santalol acetate			0.2	0.2						
Weight of wood distilled	673 kg				1126 kg	935 kg	886 kg*	942 kg	763.5 kg	900 kg
Wt of fraction	6.5 l					20 kg	27.5 l	32 Kg	25 kg	35.5 kg
Fraction % Yield	0.97%									
Total % Yield	2.40%							3.40%	3.27%	3.93%

* RTB = Root/Trunk/Branch

Figure 1 gives a simplified representation of the major fraction of the oil derived from each of the 23 distillations, showing only those components most frequently used in assessing oil quality. The ISO 3518 minima and maxima for α - and β -santalol are also shown and their limits represented by blue and red dotted lines respectively. The analysis labeled as RP01-664 was obtained from a very early, small-scale distillation; it easily conformed to ISO 3518 specifications and was thenceforth used as the benchmark in our distillation program.

All except three distillations fell within the ISO 3518 limits for α - and β -santalol levels. D5, D6 and D7 fell short of the required levels for α -santalol, although D5 and D6 reached the minimum for β -santalol.

It should be noted that for D5 and D6 the nuciferol levels were elevated. An analysis of a typical Western Australian *S. spicatum* oil has been inserted for reference, since they typically have elevated levels of nuciferols. The conclusion is that even the *S. austrocaledonicum* oil that does not reach the ISO 3518 specifications for α - and β -santalols is closer to *S. album* than it is to *S. spicatum* oil.

Even where the oils conform to ISO 3518 limits it is obvious that the composition varies from batch to batch, and if a consistent quality of oil is to be offered commercially then some blending will be necessary. For example, D10 oil that barely reaches the α -santalol specification could have been blended with either D9 or D11 to boost that level. The blending would also have had a beneficial effect on the β -santalol levels in D9 and D11.

TRA proposes that the Vanuatu sandalwood industry should adopt product specifications for two grades of *Santalum austrocaledonicum* oil:

- **Premium grade** – conforms to the gas chromatography analytical profile for *S. album* with respect to α - and β -santalols as defined in ISO 3518. Blending is acceptable to achieve a relatively consistent product.
- **Standard grade** – does not conform to ISO 3518 specifications for α - and β -santalols, but the percentage of α - plus β -santalol must exceed 35%.

Compositional Changes through the Distillation Process

The analyses illustrated above in Table 2 and Figure 1 are representative of the major fraction of oil in each commercial-scale steam distillation. However there are very significant compositional changes in the oil emerging from the still as the distillation proceeds. The first fractions emerging from the still are particularly malodorous.

Table 3 shows the compositional changes of the oil during D1, the first large-scale distillation that TRA carried out in Vanuatu. (Some of the more offensive smelling components, such as furano-pyrrole, were not quantified in these analyses. Even trace amounts can impart an unpleasant odour to the oil.) The analyses show clearly that the more volatile hydrocarbons are concentrated in the early fractions. The concentrations of α -santalol and *trans*- α -bergamotol rise to a maximum in the fourth fraction and start to fall off in the fifth fraction. The concentrations of the less volatile components, *cis*- β -santalol, *cis*-nuciferol and *trans*-nuciferol rise throughout. Judicious choice of fraction cuts, exclusion and blending of fractions can greatly affect the final “quality” of the oil produced in the commercial process and may determine whether the oil meets ISO 3518 standards.

Fraction Number	02060501	02060502	02060503	02060504	02060505
	RP02-228	RP02-229	RP02-230	RP02-227	RP02-232
Analysis Date	17-Jun-02	17-Jun-02	17-Jun-02	14-Jun-02	17-Jun-02
α -santalene	9.2	2.3	1.5	0.80	0.7
<i>trans</i> - α -bergamotene	1.5	0.4	0.2	0.10	0.1
epi- α -santalene	6.7	2.1	1.2	0.60	0.5
β -santalene	7.3	2.2	1.3	0.70	0.5
γ -curcumene	2.2	0.9	0.5	0.20	0.2
ar-curcumene	1.2	0.6	0.3	0.20	0.1
β -bisabolene	0.4	0.2			
β -curcumene	2.9	1.4	0.7	0.30	0.3
β -bisabolol	0.7	1	1	0.80	0.5
α-santalol	32.9	44.5	46.9	48.40	47.4
α -bisabolol/ β -sinensal			0.7	1.30	
<i>trans</i> - α -bergamotol	5.3	7.2	7.5	7.90	7.2
<i>cis</i>-α-santalol	0.7	1	1	1.20	1.3
cedren13-ol-8	0.6	1.2	1.3	1.10	0.7
epi-β-santalol	1.8	2.4	2.7	3.10	3.5
<i>cis</i>-β-santalol	10.5	14.3	15.9	16.90	19.8
<i>cis</i>-nuciferol	1	1.4	1.5	1.90	2.3
<i>trans</i>-β-santalol	0.2	0.4	0.2	0.30	0.6
<i>trans</i>-nuciferol	1.2	1.7	1.8	1.80	2.6
<i>cis</i> -lanceol/ α -sinensal	0.1	0.2	0.2	0.20	0.2
α -santalol acetate	0.2	0.2	0.2	0.20	0.2
<i>trans</i> - α -bergamotol acetate	0.1	0.1	0.1	0.10	0.2
Wt of wood distilled	673 kg				
Volume of oil fraction	1.5 l	0.65 l	1.45 l	6.5 l	6 l
% Yield of oil fraction	0.22%	0.10%	0.22%	0.97%	0.89%
Yield of Oil	2.4% total yield of oil*				

* distillation was stopped prematurely because of plant problems; oil content was probably higher.

Adoption of Specifications for Marketing Wood

As previously discussed, much of the oil from *Santalum austrocaledonicum* in Vanuatu (especially from southern islands) does not meet ISO 3518 specifications. In our experience the standard grade oil has met considerable buyer resistance and dissatisfaction with the “quality”. The wood itself however does not meet these problems when it is destined for incense production in the Asian market.

TRA has been fortunate to form an alliance with Mr. Tim Coakley, President of Wescorp International. His company holds a licence from the Western Australian Government to market all *S. spicatum* harvested from public lands in that State. He brings to our marketing effort therefore over 10 years of experience, not just in selling the sandalwood, but in preparing the product to meet buyer expectations. This has been a critical factor in obtaining good prices. It is important to note that the financial return to TRA (and Vanuatu) has been considerably greater than if this standard grade wood had been converted into oil that did not meet buyer expectations.

Coakley has developed a set of product specifications (Table 4) for Vanuatu sandalwood based on those used at Wescorp with *S. spicatum*. Sandalwood buyers are familiar with and accept these specifications; they can therefore be assured that they will receive what they have paid for in advance.

Having these product specifications has allowed TRA to fulfill one important plank of the National Forest Policy, and that is maximization of the utilization of the resource. Markets have been found for over 70% of the tree, including many parts that previously had to be disposed as waste. It would be to the advantage of the industry in Vanuatu (and indeed throughout the Pacific Islands) if a similar set of specifications were universally adopted.

Table 4. Pacific Sandalwood Product Specifications

Unclean Roots	De-barked solid green roots trimmed to lengths of 30 cm to 1 metre. The diameter of the heartwood to be greater than 2 cm at the smallest end.
Clean Roots	Solid green roots trimmed to lengths of 30 cm to 1 metre. The diameter of the heartwood to be greater than 2 cm at the smallest end. All sapwood must be removed from the roots.
Unclean Butt	De-barked butts separated from roots within 10 cm of Butt junction. Trunk is cut off less than of 25 cm above the ground level.
Clean Butt	Butts separated from roots within 10 cm of junction. Trunk is cut off less than of 25 cm above the ground level. All sapwood is to be removed from the Butt.
Unclean Logs	Solid de-barked green logs trimmed to a length of 30 cm to 1 metre. The diameter of the heartwood to be greater than 10 cm at the smallest end.
Clean Logs	Solid green logs trimmed to a length of 30 cm to 1 metre. The diameter of the heartwood to be greater than 10 cm at the smallest end. All sapwood is to be removed from the logs.
Small Unclean Logs	Solid de-barked green logs trimmed to a length of 30 cm to 1 metre. The diameter of the heartwood to be greater than 3.5 cm at the smallest end.
Small Clean Logs	Solid green logs trimmed along a length of 30-100 cm. The diameter of the heartwood to be greater than 3.5 cm at the small end. All sapwood removed.
Mini Unclean Logs	Solid de-barked green logs trimmed to a length of 30 cm to 1 metre. The diameter of the heartwood to be greater than 1cm at the smallest end.
Second Cut Chips	Product resulting from the de-sapping process from heartwood after the bark has first been removed from the product. Must contain at least 15% heartwood.
Spent Charge	Product after the oil has been extracted from the sandalwood pre-grind
Sap Wood	All sandalwood that does not have any sandalwood heartwood.
Carving Logs	All sapwood removed so there is only good heartwood. No bad cracks or faults with a minimum diameter of 10 cm at the smallest end. Length varies from minimum of 30 cm to maximum of 1.2 metres. Ends will be sealed with clear end sealer coat.

Evaluation of heartwood and oil characters in nine populations of *Santalum austrocaledonicum* from Vanuatu

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Abstract

Morphological variation in *Santalum austrocaledonicum* was evaluated and wood core and leaf samples collected from nine populations on six different islands across Vanuatu. The percentage of heartwood was found to vary independently of stem diameter, and is likely to be influenced by factors such as tree age and environment. Heartwood oil concentration and all major oil constituents exhibited significant tree-to-tree variation, within and between all populations, but mean concentrations were considerably lower than currently reported by industry. Each population had a range of trees with high and low concentrations of α - and β -santalols. The populations from the two northern islands (Santo and Malekula) had a greater proportion of trees with high values for the commercially important oil constituents (santalols) than the populations sampled from the southern islands. The sandalwood populations surveyed in this study provide an important resource for developing superior sandalwood cultivars through a planned programme of domestication.

Introduction

Sandalwood (*S. austrocaledonicum*) in Vanuatu is an economically important tree, which supports both rural and urban employment. In many villages sandalwood harvesting provides the primary means for earning money to pay for children's school fees. This reliance on sandalwood has led to exploitation of natural sources of sandalwood and in most areas the tree has become rare in the wild. The establishment of sandalwood agroforests is a practical method for alleviating the pressure on these wild resources, and is actively being encouraged by the Vanuatu Department of Forests.

Sandalwood-oil is graded and priced according to levels of α - and β -santalols using a standard derived from *Santalum album*, and invariably the market prices reflect the relative species quality. However the likely existence of tree-to-tree variation in oil quality within *S. austrocaledonicum* offers the opportunity to improve oil quality through selection and domestication. The aim of this project is to survey the wild stands of the species and identify a resource that would support a domestication program to increase the availability of planting material with superior oil characteristics. These initiatives can help to ensure that future sandalwood agroforestry plantations in Vanuatu are established from trees that produce high concentrations of superior quality heartwood and sandalwood oil. This will aid in the species's enhanced recognition in the international marketplace.

Materials and Methods

Individual sandalwood (*S. austrocaledonicum*) trees were assessed and wood core samples collected from nine populations on six islands (Santo, Malekula, Moso, Erromango, Tanna and Aniwa) across

Vanuatu. A total of 222 trees were sampled based on a minimum basal trunk diameter of 10 cm to ensure adequate heartwood development and allow sampling of a heartwood core. Cores were consistently sampled at an average of 30 cm above the base, to avoid differences which might arise from sampling of different positions within each tree. Heartwood samples were extracted from living trees using the CSIRO ‘Treecor’ drill. Bark-to-bark samples were taken and the remaining hole was sterilized with 70% ethanol, filled with sterilized doweling (22mm) and each end sealed with bitumen. Heartwood oil was extracted from each core using ethanol and constituents were identified through analytical gas chromatography mass spectrometry.

Eleven quantitative and four qualitative characters (Table 1) were recorded from each tree in order to evaluate within- and between-population variation for the species. Gross morphological characters which were reputed to differentiate trees with good and poor quality heartwood were evaluated using their arithmetic means and Principal Component Analysis (PCA). Type specimens of all sandalwood trees sampled were deposited in the herbarium of the Vanuatu Department of Forests (Port Vila).

Table 1: Characters assessed for each sandalwood sampled

Numerical	Qualitative
Leaf length (mm)	Tree form
Leaf width (mm)	Leaf shape
Trunk diameter at base (cm)	Bark blaze colour
Trunk diameter at 1.3m (cm)	Heartwood colour
Tree height (m)	
Canopy spread (m)	
Heartwood depth (mm)	
Sapwood depth (mm)	
Heartwood oil yield (%)	
Heartwood oil constituents (%)	
Bud, Flower and Fruit numbers	

Results

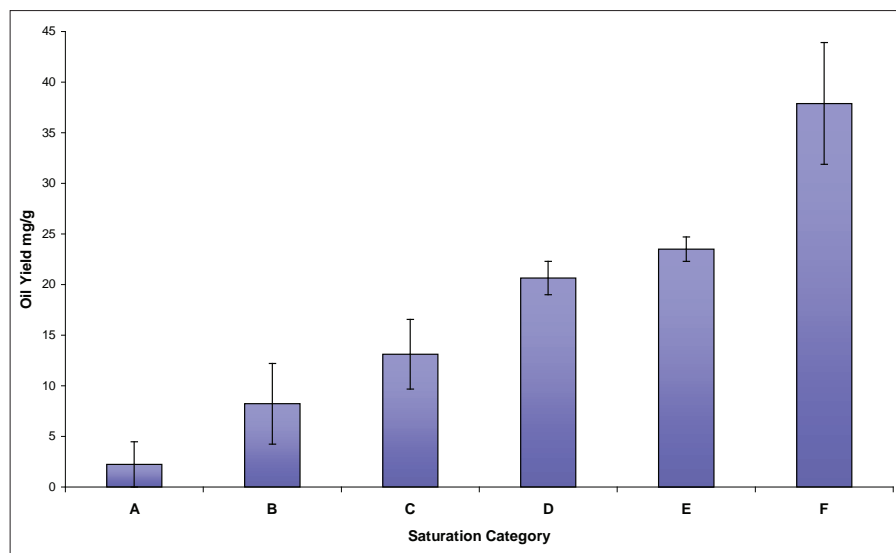
Morphology

Significant variation was found for a range of morphological characters including leaf length and width, percentage heartwood, trunk diameter and tree form/branching habit. Heartwood colour was also extremely variable ranging from ‘topaz’ (5C5) to ‘oxblood red’ (9E7) (Kornerup and Wanscher 1978). The variation in these traits serves as an indication of the high genetic diversity both within and between populations of this species. For leaf dimensions, however, a significant proportion of variation could be attributed to factors other than those associated with the individual tree and thus are likely to be influenced by the localised environment and/or physiological differences between shoots.

It was found that 56% of trees had a single trunk, 40% had a forked trunk, and 4% were multi-stemmed, averaged across all populations. Trees producing a single trunk were located in areas with a dense canopy cover suggesting that the level of shade is a factor determining the form of the sandalwood tree.

Heartwood colour was found to have no predictable effect on the relative levels of the commercially important oil constituents, and therefore is not an indicator of oil quality. Wood colour can have an effect on the colour of extracted oil, but commercial removal of undesirable oil pigments can be achieved through oil purification techniques, and thus is not a useful selection criterion for species improvement. The colour saturation (*i.e.* how dark or light) of the heartwood gave a broad indication of oil yield, but saturation categories used in the current study could only discriminate the very light wood colour with a low oil concentration and the very dark wood with a higher concentration. A total of 80% of the wood colours conformed to intermediate saturations (categories D and E) and the scale could not sufficiently differentiate these according to concentration.

Fig. 1: Heartwood colour saturation vs. heartwood oil yield (mg/g) in *S. austrocaledonicum*.

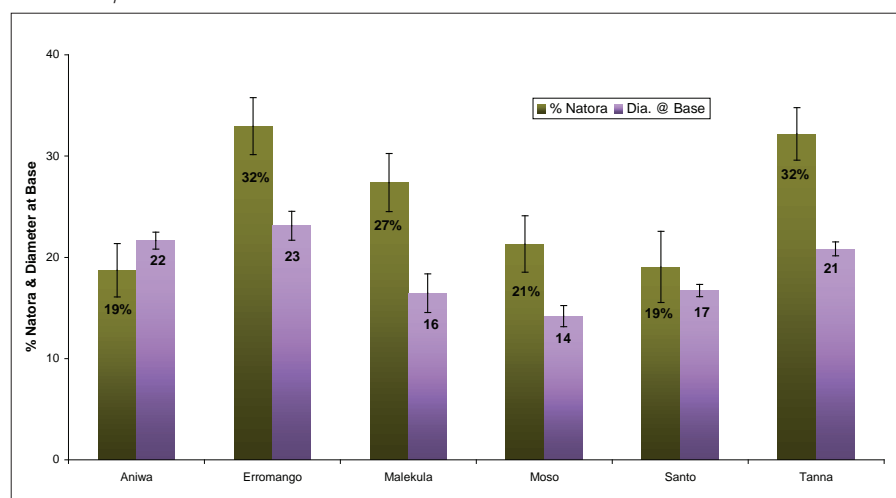


No correlation was found between any of the morphological or ecological characters and the important oil constituents, suggesting that there is no scientific basis for using these leaf or wood characters as a ‘predictor’ of oil quality. In the same way, morphological characters (with the exception of wood colour) were not predictors of oil yield. Therefore this study found no evidence to support reputed differences in oil quality that are ascribed by locals to different folklore varieties in Vanuatu (Doran *et al.* 2002).

Percentage Heartwood

The percentage heartwood varied significantly between different populations, with the trees from Tanna and Erromango found to have the greatest percentage (32%) of heartwood (Fig. 2). Trees on Aniwa had a comparatively large basal diameter (22 cm), but they produced a comparatively small percentage of heartwood (19%). Conversely trees from Malekula had a relatively small basal diameter (16 cm) but high heartwood percentage (27%). Both cases highlight that the size of the tree is not directly indicative of the heartwood percentage, which is confirmed by the lack of correlation between them ($r^2=0.15$). In Timorese populations of *S. album* the age of onset for heartwood formation has been reported to be highly variable ranging from 14 to 46 years (Haffner 1993), while Doran *et al.* (2002) indicates approximately 10 years for plantation grown *S. album* in north-western Australia.

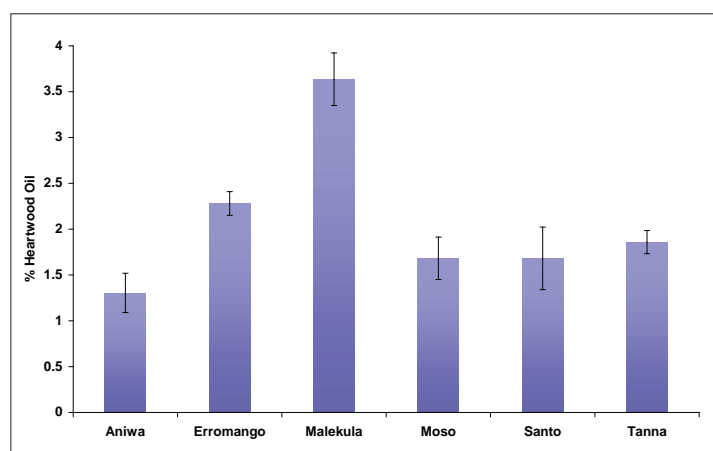
Fig. 2: Variation in percentage heartwood (natora) and stem diameter at base in *S. austrocaledonicum*, across 6 islands of Vanuatu. Vertical bars represent standard errors.



Heartwood-oil concentration

Significant variation was found for heartwood oil concentration within and between populations with a mean of 2.2% across all trees sampled. This mean oil concentration was substantially lower than the 3.0-4.6% yields currently found by the industry in Vanuatu using bulk samples (Peter Murphy, pers. comm. 2005). The difference between steam distillation and ethanol extraction was examined with one sample of *S. lanceolatum* however the concentration differed by only 0.3% indicating the internal standard may be a reasonable estimate of actual concentration. Doran *et al.* (2005), however have reported substantial differences in oil concentration estimates between steam distillation and solvent extractions from sandalwood heartwood. In *S. spicatum* Moretta (2001) found that ethanol extracted samples had a significantly greater yield than water distilled samples. Therefore evaluation of a greater number of samples is required to reconcile any potential error in the estimate used in the current study. Trees from Malekula had significantly greater mean essential oil concentration (3.5%) than the other populations (Fig. 3). Overall, approximately 12% of trees were found to have an oil concentration greater than 4% and this higher oil yielding group included individual trees from all islands, except Tanna. Significant tree-to-tree variation in oil concentration was found within each population ranging from 0.05% to 8% over all trees sampled, indicating that this character may be amenable to improvement through selection.

Fig. 3: Variation in heartwood oil concentration (%) in *S. austrocaledonicum*, across 6 islands of Vanuatu. Vertical bars represent standard errors.

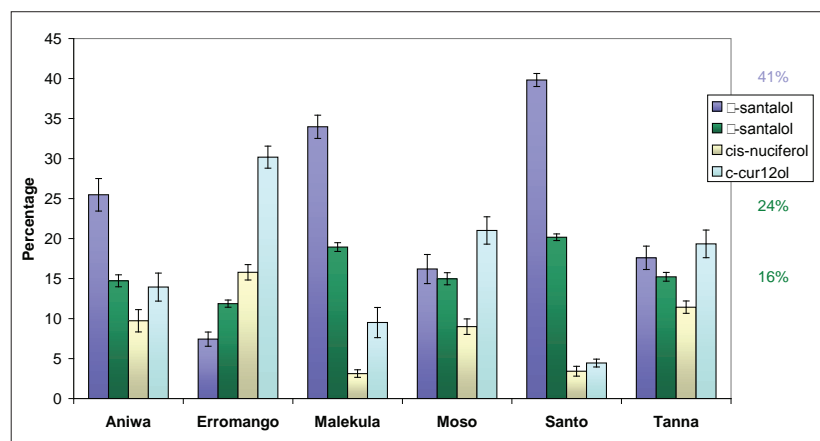


Heartwood oil constituents

In the two northern islands a total of 28% of the trees sampled produced a heartwood oil meeting the international standard (i.e. >41% α -santalol and >16% β -santalol). The selected candidate plus trees from the remaining southern populations had means of 31% α - and 17% β -santalol.

Continuous variation in all the major essential oil constituents was found across the samples collected. The continuous nature of the santalol:non-santalol ratio indicates there is no evidence to support previous claims of different chemotypes in *S. austrocaledonicum* (Ehrhart and Raharivelomanana 1998). Chemotype variation misleadingly appears when examining the relative proportions of major constituents on a site-by-site basis (Fig. 4), and it is suggested that the number of samples in earlier studies were not sufficient to reveal the continuous nature of variation across the species. In a principal component analysis of oil and leaf characters the populations from the islands of Santo and Malekula diverged significantly from the remaining populations indicating possible genetic isolation and local selection.

Fig. 4: Variation in four essential oil components of *S. austrocaledonicum* heartwood, across 6 islands of Vanuatu. Horizontal lines indicate the levels for α - (>41%) and β santalol (16-24%) to meet the international standard (ISO 2002). Vertical bars represent standard errors



The sandalwood populations of the northern islands (Santo and Malekula) had a greater proportion of trees with high values for the commercially important oil constituents (santalols) than the populations sampled from the southern islands. A total of 28% of the trees in each northern island have oil quality that exceeds the International Standard¹ (ISO 2002). The high quality of the *S. austrocaledonicum* from the northern islands indicates that if these populations can be genetically revitalised from their current homozygous state (see results from molecular studies below), the sandalwood industry of Vanuatu could compete on the international market with Indian sandalwood on the basis of high oil quality. This possibility raises the urgency of making seed collections and cross-pollinations, especially as the Forestry Department and the sandalwood industry are now aware that these trees are of high quality.

Vegetation

During the wood core collections, plant species growing within 5 meters of each tree sampled were identified and recorded. This data was examined for any relationships with oil yield and the essential oil constituents of heartwood. Three associated species were found in all populations sampled (*Acacia spirorbis*, *Ervatamia obtusiuscula*, *Murraya paniculata*). Many of the most commonly associated species (Table 2) occurred on all islands. The sandalwood populations of Aniwa, Tanna and Tamsel (south Erromango) were primarily associated with garden species as sandalwood often occurs in current or old garden areas. The other populations (north Erromango, Malekula, Moso and Santo) were relatively distinct in terms of the combinations of different species. Using a mantel-multivariate correlation analysis, the associated vegetation was found to have no effect on the oil characteristics of the sandalwood. To test for any host specificities, the effects of individual associated species on sandalwood oil characteristics was examined by comparing the presence of these species with sandalwood trees in the top 10% for oil quality. Several associated plant species occurred at a high frequency for individuals with high oil yield and quality. The presence of these associated species was inconsistent between populations, suggesting their presence was related to the site and that there was no predictable effect on oil concentration or quality. However, there was a slight suggestion that three species may have some link with trees with a high percentage of α -santalol. *Micromelum minutum* and *Litsea imthurnei* found on Santo and Malekula occurred more frequently with sandalwood having a high percentage of α -santalol in both sites. *Pterocarpus indicus* occurs more frequently with trees of a high percentage α -santalol across most of the sample sites. These three species will be used in a planned host-by-genotype experiment to further evaluate their possible effects on oil quality. *Ixora triflora* appeared to have a possible negative effect on oil quality in the populations it occurred (Malekula, Moso, Punalvaad, Santo). To further test the possible effects these four species have on oil qualities they will be included in the host-by-genotype experiment.

¹International standard for sandalwood oil stipulates a concentration of 41-55% α -santalol and 16-24% β -santalol

Table 2: Species commonly associated with sandalwood in Vanuatu

<i>Acacia spirorbis</i>	<i>Euphorbiaceae</i>	<i>Malaisia scandens</i>	<i>Psychotria forsteriana</i>
<i>Adenantha pavonina</i>	<i>Flacourtiaceae</i>	<i>Mimusops elengi</i>	<i>Rivina humilis</i>
<i>Annona</i> sp.	<i>Gyrocarpus americanus</i>	<i>Morinda citrifolia</i>	<i>Tarenna efatensis</i>
<i>Cupaniopsis</i> sp.	<i>Harpullia arborea</i>	<i>Murraya paniculata</i>	<i>Psychotria forsteriana</i>
<i>Elattostachys falcata</i>	<i>Leucaena leucocephala</i>	<i>Passiflora suberosa</i>	
<i>Ervatamia obtusiuscula</i>	<i>Macaranga dioica</i>	<i>Pouteria costata</i>	

Molecular

Genetic fingerprinting, using microsatellite markers, has so far been undertaken on three of the Vanuatu populations (Santo, Malekula and Erromango) and work on the other populations is in progress. Genetically the populations of Santo and Malekula are quite similar and each clearly genetically distinct from the Erromango population. Erromango exhibits considerable tree-to-tree genetic variation across all 5 loci screened, however a high level of relatedness has been found among the individuals from Santo and Malekula. Consequently, it has become clear from this study that many of the elite individuals with high oil quality in the northern islands are closely related and can be considered to be related, or the result of self-pollination, as there is considerable homozygosity amongst the loci screened. This has important implications for both the conservation of these populations and also the domestication programme. This homozygosity is further evidence of the highly threatened status of the sandalwood from the northern islands. It would seem that introgression between these northern populations (*i.e.* population mixing) is required to generate new genetic variation and avoid deleterious effects of future inbreeding. The highly threatened status of the high quality, northern populations, which are now represented by fewer than 30 trees per site, poses a severe threat to the future viability of the sandalwood oil industry of Vanuatu (and indeed the species of *S. austrocaledonicum*).

Domestication

A domestication strategy based on sexual and asexual approaches to tree improvement has been initiated by the Department of Forests. To enhance genetic diversity and allow cross-breeding replicated grafted seed orchards have been established. These will include the trees identified in this study as having superior oil qualities and the level of heterozygosity. It is envisioned that two separate seed orchards will be established for both the northern and southern regions to maintain genetic variation for future improvement. One centralized seed orchard will also be established that combines the selections from both regions, to help maximise the initial level of genetic diversity in the improvement populations and take advantage of possible hybrid vigour. Replication of the grafted seed orchards in separate locations will provide protection against possible losses in any particular site.

The collection of plant material for the seed orchards will be based on a twin strategy consisting of (i) random collections (seed), and (ii) elite tree selections (scions and seeds). The non-selective seed collections will be exchanged between sites within the northern islands, which have shown very low genetic variation. This will be undertaken to infuse these populations with new genotypes required to generate more heterozygous populations that are more likely to survive over the long term. Exchange of seed between northern and southern populations will not be undertaken in order to maintain the genetic integrity of these very genetically distinct regions.

The asexual component of the domestication strategy will focus on mass propagation of selected elite individuals using leafy stem cuttings. Studies are in progress to develop efficient vegetative propagation techniques for this species.

Conclusion

This survey has revealed that the commercially important oil characters of concentration and quality varies considerably within and between populations of *S. austrocaledonicum*. A domestication programme has been initiated to diversify the genetic base of these populations and through genetic selection to

enhance the yield and quality of *S. austrocaledonicum* heartwood oil. This development should: i) reduce the current pressures on already depleted natural resources and ii) allow local communities to enhance their livelihoods through the planting of superior varieties in agroforestry systems and so to support the sandalwood industry through future access to a consistent supply of trees with high quality oil. This is required for the development of premium-branded sandalwood products.

Acknowledgements

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Evaluation of heartwood and oil characters in seven populations of *Santalum lanceolatum* from Cape York.

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Abstract

Wood core and leaf samples were collected from seven populations of *Santalum lanceolatum* on Cape York Peninsula (Queensland) in order to quantify variation in heartwood oil chemistry and tree morphology. Significant and continuous variation for all major oil constituents was found within and between the populations sampled. One population sampled (Population A) had high levels of the commercially important oil constituents (santalols). Six trees from this population had an oil quality that met the international sandalwood (*Santalum album*) oil standard for α - and β -santalols. The remaining populations were mainly comprised of trees with low levels of both santalols, which is consistent with existing knowledge of oil quality in *S. lanceolatum*. Each population exhibited significant tree-to-tree variation in both oil constituents and oil concentration, which will facilitate the improvement of these commercially important traits through selection. The percentage of heartwood was found to vary independently of tree diameter suggesting that heartwood development is controlled by factors other than trunk size.

Introduction

Sandalwood is a culturally important tree for Aboriginal communities on Cape York, and a species which has the potential to be used for commercial agroforestry. This sandalwood species (*Santalum lanceolatum*) was harvested commercially in many areas on Cape York since the early 1900's, until the natural sources were exhausted. While these natural populations have begun to recover over the past few decades, illegal harvesting remains a problem. Historically *S. lanceolatum* is considered to produce heartwood oil of relatively low quality when compared with Indian and Pacific Islands sandalwoods. In this study, remnant populations of sandalwood were surveyed to determine the range of morphological variation within the species and the potential for developing improved cultivars through domestication. The establishment of commercial agroforestry on Cape York, including improved sandalwood, is a practical method for alleviating the pressure on wild sandalwood resources and providing an income source for indigenous communities (Bristow and Annandale 2003).

Materials and Methods

Seven different populations of *S. lanceolatum* were sampled in different localities on Cape York Peninsula. At the request of the communities, and to protect the sandalwood populations from further illegal harvesting, these sites have been identified as populations A, B, C, D, E, F and G. A total of 177 trees were sampled based on a minimum basal trunk diameter of 10 cm to ensure adequate heartwood development and allow sampling of a heartwood core. Herbarium specimens of all sandalwood plants sampled were collected and these are being held at James Cook University (Cairns). Eleven quantitative and four qualitative characters (Table 3) were recorded for each tree in order to evaluate within- and between-population variation in the species.

Table 3: Characters assessed for each sandalwood plant sampled

Numerical	Qualitative
Leaf length (mm)	Tree form
Leaf width (mm)	Leaf shape
Trunk diameter at base (cm)	Bark blaze colour
Trunk diameter at 1.3m (cm)	Heartwood colour
Tree height (m)	
Canopy spread (m)	
Heartwood depth (mm)	
Sapwood depth (mm)	
Heartwood oil yield (%)	
Heartwood oil constituents (%)	
Bud, Flower and Fruit numbers	

Heartwood samples were extracted from living trees using the CSIRO ‘Trecor’ drill. Bark-to-bark samples were taken and the remaining hole was sterilized with 70% ethanol, filled with sterilized doweling (22mm broomstick) and each end sealed with bitumen.

Results and Discussion

Morphology

Variation in leaf length and width was found within and between populations: plants in population B has significantly shorter and narrower leaves than plants in the remaining populations. While no climatic data are available for these sites it was evident that the trees in population B were growing on a more exposed site on a steep grade with a westerly aspect. Much of the variation in leaf width (31%) and length (40%) was not accounted for either by population or individual tree and indicates that these dimensions are likely to be influenced by physiological and phenological differences between the shoots sampled.

Heartwood colour varied significantly between trees with a similar range as observed in *S. austrocaledonicum* (Page *et al.*, this proceedings) ranging from ‘golden blonde’ to ‘oxblood red’ (Kornerup and Wanscher 1978). Oil concentration and each constituent varied independently of heartwood hue, tone and colour saturation and therefore the colour characteristics of the heartwood, using this scale, are not suitable for selecting trees with superior oil traits.

The primary structure of each tree was assessed whereby 63% had a single trunk, 34% had a forked trunk, and 3% were multi-stemmed. In all populations, except population E, the greater proportion of trees had a single trunk. The density of the canopy cover of associated vegetation had no effect on the incidence of multiple leaders. Bole length is an important character in determining the volume of wood and like all other characters it varied within and between populations. Not surprisingly the mean bole length of trees with a single trunk (209cm) was substantially greater than those with forking trunks (118cm).

Percentage Heartwood

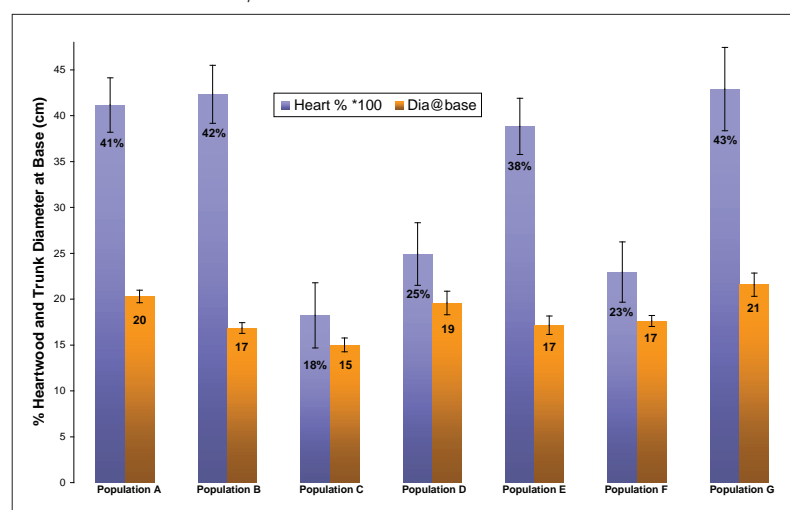
The trees sampled had an average of 34% heartwood, ranging from 18% in population C up to 43% in population G (Fig. 1). Furthermore heartwood percentage varied significantly within populations, with the greatest variation found in population G with a range of 1-93%. Trunk diameter at the base of the tree varied between populations, but 88% of the variation in this character was found within each population which is likely to be a function of different aged trees.

Across all trees sampled the percentage of heartwood was not correlated with basal trunk diameter (Pearson’s coefficient 0.288). There was no correlation between these characters within each population indicating that the initiation and development of heartwood might be influenced by a combination of

factors such as age, environment and genotype rather than trunk diameter. Evaluation in even aged clonal trials over a number of environments is required to determine the relative importance of each factor in the initiation and development of heartwood.

No correlation was found between the length of the bole and the percentage heartwood (Pearson's coefficient 0.16), indicating that a tree with a form considered desirable for maximising timber volume does not necessarily relate to the volume of valuable oil-rich heartwood in sandalwood.

Fig.1. Variation in percentage heartwood and stem diameter at base in *S. lanceolatum*, across 7 populations in Cape York, Queensland. Vertical bars represent standard errors.

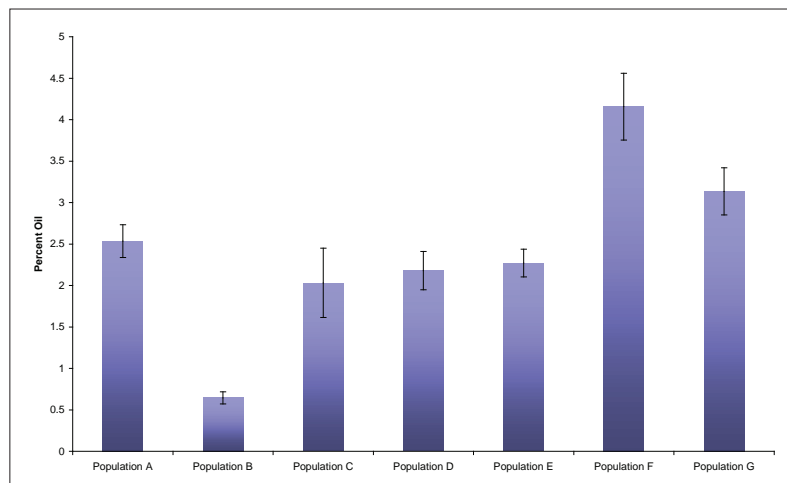


Heartwood-oil concentration

The mean oil yield across the seven populations of *S. lanceolatum* was 2.5%, which is substantially greater than the published accounts of approximately 1%, but lower than reported for other sandalwood species (Radomiljac and Borough 1995). The large variation in oil concentration between trees ranging from 0.1-8.2% means that this character may be improved through selection. There is, however, a need to determine the relative influence of genotype, age and environment on oil concentration before potential gains from wild selection can be estimated. The highest yielding individuals (selection intensity of 10%) had a mean oil yield of 4.1% which is comparable to the oil yields reported for the sandalwood species found in Vanuatu and Fiji (Radomiljac and Borough 1995). The mean α - and β -santalol for these high oil-yielding trees was 13.8 and 8.3% respectively, which is not significantly different from 11.4 and 6.8% across all trees sampled.

The mean oil concentration of population B (0.64%) was significantly lower ($P < 0.01$) than all other populations. Historically the area of population B has been an important resource for the commercial harvesting of this species. It is therefore possible that the current understanding of this species as having yields of 1% and low levels of santalols originates from trees extracted in this area. Population F had a mean oil concentration of 4.1% which was significantly ($P < 0.05$) greater than the remaining sites. However substantial variation was found between the trees in population F ranging from 0.9 to 8.1%. Whilst similar levels of variation were found within the remaining five populations (A, C, D, E and G), their mean yields were not significantly different. The results of this study therefore emphasise that it is not appropriate to characterise a particular sandalwood species as having specific oil properties given the significant variation that may exist within and between natural populations.

Fig. 2. Variation in heartwood oil concentration (%) in *S. lanceolatum*, across 7 populations in Cape York, Queensland. Vertical bars represent standard errors.



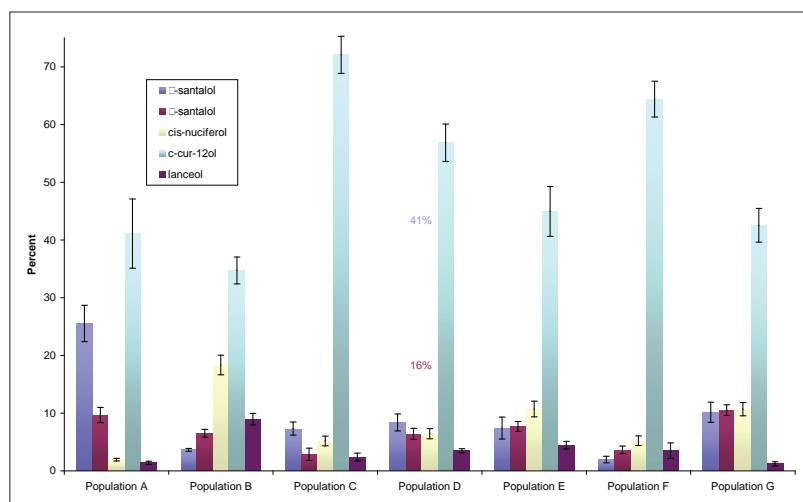
Heartwood-oil constituents

The oil samples of *S. lanceolatum* trees from Cape York generally had higher concentrations of nuciferol and curcumenol than the commercially important α - and β -santalols which across all samples comprised of 9.0 and 7.0% of the total oil, respectively. The relatively low levels for santalols is consistent with perception of *S. lanceolatum* producing lower grade oil when compared with other commercial sandalwood species. However, all oil constituents exhibited significant tree-to-tree variation and trees with elevated levels of α - and β -santalols were found. Population A had the greatest number of such individuals and had an overall population mean of 25.6 and 9.7% for α - and β -santalol, respectively. Of the trees sampled six trees from population A produced a heartwood-oil conforming to the international standard (>41% α -santalol and >16% β -santalol) for Indian sandalwood oil.

The remaining six populations were characterised by trees with low levels of α - and β -santalol and higher levels of *cis*-nuciferol and *cis*- β -curcumen-12-ol. However variation within these sites was found and improvements in this species can be made by individual tree selections from populations D, E and G. These results are encouraging given that only a fraction of the available wild trees for this species has been sampled in this study.

Continuous variation in all the major essential oil constituents was found across the heartwood samples and, as for *S. austrocaledonicum*, there was no evidence of discrete chemotypes within the trees sampled.

Fig.3 Variation in 5 essential oil contents of *S. lanceolatum* heartwood, across 7 populations of Cape York. Horizontal lines indicate the lower levels for α - (41%) and β -santalol (16) to conform to the international standard (ISO 2002).



Vegetation

Species of *Acacia* were clearly identified as being the most common trees associated with *S. lanceolatum* and are likely to be important hosts. The main associated species in each of the populations evaluated were *A. auriculiformis*, *A. polystachya*, *A. cambagei* and *A. farnesiana*, but none of the associated tree, and potential, host species could be identified as having an effect on any of the morphological or oil characters measured. Therefore future selection for oil characteristics may be undertaken independently of any host associations. Nevertheless, relationships between host and sandalwood growth rates are an important consideration for agroforestry production, especially as it has been reported that nitrogen fixing hosts species, such as *Acacia*, can have a positive effect on growth compared with non-nitrogen fixing hosts (Radomiljac and McComb 1998).

Interestingly *Micromelum minutum* which appeared to have a positive effect on the percentage α -santalol in Santo and Malekula populations of *S. austrocaledonicum* was an associated species of population A of *S. lanceolatum*. Co-incidentally this population had trees with a higher percentage α -santalol but there was no evidence that this host species had a positive effect on oil quality in the trees in population A.

Regeneration of sandalwood plants was evident at each site and the percentage of trees with associated young plants/stems ranged from 40% in population B to 90% in population C. The latter population also exhibited the highest number of saplings with an average of 14 per tree. While we didn't categorically resolve whether regeneration was from seedling or suckers at each site it was evident that in population C, most of the saplings were the result of root suckering following a fire.

Domestication

Trees in this study for future domestication and improvement will be selected based on the ratio of (α - and β -santalol) to (nuciferol, curcumenol and lanceol) being greater than one. A total of 24 individual trees from four populations (A, D, E and G) had ratios of greater than 1. These individuals represent a selection intensity of approximately 14% and have a combined mean oil concentration of 2.6% yield, which is comparable to the Cape York mean of 2.5%. The levels of α - and β -santalol in the selected population (34% and 15% respectively) are significantly greater in the selected population than the Cape York mean (9.0 and 7.0% respectively) and offer a considerably improved genetic resource for sandalwood and sandalwood oil during domestication of the species.

The approach taken for the domestication of sandalwood in Cape York involves establishing two improvement plots, a grafted seed orchard and clonal hedges. The grafted seed orchard is intended to produce improved seed from both open- and controlled pollination. The seed orchard is important as seed propagation is technically simple and allows for future improvements through recurrent selection. The grafted seed orchard will be established using sexually mature scion (stem) material and selections will be positioned in the orchard to facilitate cross pollination between unrelated trees.

The establishment of clonal hedges is important in the domestication of sandalwood as it is the most reliable way of supplying improved planting material of a known quality. The commercially valuable heartwood is located in both the roots and the stems of the tree and cutting propagation is a relatively simple method for clonally reproducing both these tissues. The commercial success of these clonal hedges will depend on achieving high rooting and survival rates (at least 75%). The rooting capacity of *S. lanceolatum* stem cuttings is unknown, but given the difficulty of propagating many other *Santalum* species by cuttings it is assumed that further investigations and optimization of more any promising techniques will be required.

Of all the sites sampled the closest geographically were populations A and F which were separated by 120 km. Combined, these populations contributed over 75% of the trees selected for the domestication strategy. It is likely that intensive sampling in other *S. lanceolatum* populations within the region could reveal a greater number of trees with superior oil characteristics. Capturing broad genetically-based variation for *S. lanceolatum* is important to build a breeding population that can sustain genetic improvement over successive generations (Eldridge *et al.* 1993). Therefore further information on the genetic relationships within and between these populations is required to determine the value of such trees to the domestication strategy.

Conclusion

Santalum lanceolatum has been considered to produce a heartwood oil of low quality, which has been reflected in its lower market value compared with other sandalwood species. This has limited the commercial viability of a plantation-based industry in Queensland and led to a reliance on wild harvest. The significant tree-to-tree variation in *S. lanceolatum*, particularly for the level of α - and β -santalols provides a foundation for its domestication. The broad strategy outlined here aims to increase the availability of improved cultivars of *S. lanceolatum* for plantation which can potentially offer an alternative commercial land use option for landowners across the monsoonal dry tropics of Australia. These initiatives can allow greater participation of indigenous communities in the development of a plantation based sandalwood industry and assist in increasing income. Sandalwood agroforestry in Cape York also has the potential to reduce the current pressures on the already depleted natural sandalwood resources in north Queensland. The sandalwood oil industry also stands to benefit through future access to a consistent supply of high quality oil, which is required for developing premium-branded products.

Acknowledgements

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Appendices

WORKSHOP PROGRAMME

SUNDAY 27 NOVEMBER 2005

1500-1700 Meeting of workshop planning and organising committee

MONDAY 28 NOVEMBER 2005

0800-0900 Registration

0900-1000 Opening ceremony

1000-1045 **Group photo and Refreshments**

1045-1100 Election of meeting officials/housekeeping

Session 1 Regional Forestry Programmes and Initiatives

1100-1120 1. SPC Forestry Programme Overview (Sairusi Bulai)

1120-1140 2. SPC/GTZ-PGRFP Overview (Rainer Blank)

1140-1200 3. SPRIG Phase 2 Project Overview (Lex Thomson)

1220-1320 **Lunch Break**

1320-1410 4. Sandalwood – phylogeny of the genus (Danica Harbaugh)

Session 2 Country Presentations

1410-1430 1. Vanuatu (Watson John and Atchinson Smith)

1450-1510 2. Cook Islands (Otheniel Tangianau and Teanuku Koroa)

1510-1530 **Refreshment**

1530-1550 3. French Polynesia (Stephane Defranoux)

1550-1610 4. Indonesia (Anto Rimbawanto)

1610-1630 5. R&D on Santalum in Queensland (Ken Robson and Mark Hunt)

1630-1650 6. PNG (Derek Bosimbi)

1830-2030 Welcoming cocktail

TUESDAY 29 NOVEMBER 2005

0800-0820 7. Fiji (Inoke Wainiqolo and Ponijesi Bulai)

0820-0840 8. Niue (Terry Mokoia)

0840-0900 9. Samoa (Tolusina Pouli) and Solomon Islands (Nixon Denmark)

0900-0920 10. Tonga (Heimuli Likiafu and Sunia Napa'a)

0920-0940 11. R&D on Santalum in PRChina (Daping Xu)

0940-1015 **Refreshment**

Session 3 Technical and Strategy Papers

1015-1045 Phenotypic variation within and between natural populations of sandalwood (*Santalum austrocaledonicum*) in Vanuatu (Tony Page)

1045-1115 Phenotypic variation within and between natural populations of sandalwood (*Santalum lanceolatum*) in Cape York (Tony Page)

1115-1145 *Chemical variation in the oils of Santalum macgregorii* (PNG sandalwood) (John Doran et al.)

1145-1215	Genetic relationships in <i>Santalum insulare</i> (Jean-Francois Butaud, UT)
1215-1245	Wood chemistry of <i>Santalum insulare</i> (Jean-Francois Butaud, UT)
1245-1400	Lunch Break
1400-1430	Indian sandalwood (<i>Santalum album</i> L.); variation in sesquiterpenoid composition and possible biogenetic pathways (Christopher Jones, UWA)
1430-1450	New Caledonia Country Report (Jacques Tassin)
1450-1520	Main results of a genetic and chemical study on <i>Santalum austrocaledonicum</i> in New Caledonia (Jacques Tassin)
1520 – 1540	Refreshment
Session 4	Plantation Development and Private Sector/Industry Perspectives and Activities (program to be confirmed)
1540–1600	The development of the sandalwood industry on the Ord River Irrigation Area of Western Australia (Chris Done and Peter Kimber)
1600-1620	Industry Perspective from India (Navneet Kaur)
1620-1640	Industry Perspective from Vanuatu (Jon Naupa/ Peter Murphy)
1700-1700	Industry Perspective from central/south-western Australia (Tim Coakley)
1700-1730	Sandalwood plantations (<i>Santalum insulare</i>) in French Polynesia
	Evening session – Committee to identify discussion topics and allocate participants to groups

WEDNESDAY 30 NOVEMBER 2005

Session 4

0700- 1800	Field Visit - Sandalwood field research work at Colo-I-Suva and Vunimaqo
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THURSDAY 01 DECEMBER 2005

8.30-8.50	ACIAR presentation (Russell Haines)
8.50-10.30	Group Work 1 - discussions on progress and needs research and development and conservation needs by species (including break for morning tea)
30.30-30.30	Group 1 presentations in plenary
11.30-12.30	Group Work 2 - discussions on selected priority thematic areas
1330-1330	Lunch
30.30-30.30	Group 2 presentations in plenary
14:30-15:00	General Discussion
15:00-15:30	Adoption of workshop recommendations and Closing
1600-1600	Refreshments

WORKING SESSIONS

SPECIES GROUP

Album

Chair: Chris Done
Rapporteur: Anto Ribowanto
Group Members: Huang, Kimber, Pouli, Jones, Daping, Kaur, Hunt, Raboiliku

Austrocaledonicum

Chair: Jacques Tassin
Rapporteur: Tate Hanington
Group Members: John Lui, Kalsakau, Murphy, Smith Marav, Nasak, Page, Harbaugh

Insulare

Chair: Stephane Defranoux
Rapporteur: Jean-Francois Butaud
Group Members: Tangianau, Koroa, Raharivelomanana, Blank, Espigole

Macgregorii

Chair: Israel Bewang
Rapporteur: Ken Robson
Group Members: Bosimbi, Haines, Doran, Stephens, Denmark, Clarke

Yasi

Chair: Inoke Wainiqolo
Rapporteur: Maloni Havea
Group Members: P. Bulai, S. Bulai, Mokoia, Likiafu, Napa'a, Coakley, Simanu, Thomson

THEMATIC GROUPS

Legislation and Certification

Chair: Sairusi Bulai
Rapporteur: Watson Lui
Group Members: Blank, Wainiqolo, Coakley, Hanington, Kaur

Exchange of Germplasm and IP Issues

Chair: Russell Haines
Rapporteur: Tony Page
Group Members: Clarke, Pouli, Daping, Denmark, Bosimbi, Thomson

Replanting, Extension and Awareness

Chair: Nuku Koroa
Rapporteur: To'ufau Kalsakau
Group Members: Bewang, Napa'a, Defranoux, Raboiliku, Nasak, Kimber

Methodologies - Inventory

Chair: Otheniel Tangianau
Rapporteur: Jacques Tassin
Group Members: Smith, Mokoia, Likiifu, P.Bulai, Robson

Methodologies – Heartwood Assessment & Chemistry and Genetic Assessment

Chair: Peter Murphy
Rapporteur: Chris Jones
Group Members: Doran, Done, Raharivelomanana, Hunt, Harbaugh, Butaud, Ribawanto

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Regional Workshop on Sandalwood Research, Development and Extension in the Pacific Islands and Asia. 28 Nov -01 December 2005, Fiji Mocambo Hotel, Nadi, Fiji

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Workshop in Pictures



Workshop opening



Exchange of Germplasm and IP issues
group work session



Students of Natabua Primary School
perform the opening drama as part of the
Opening of the workshop



Heartwood Assessment & Chemistry and
Genetic Assessment group work



Participants at the Sandalwood ColoiSuva
nursery during the Field Day



Insulare group work in progress



Mr Ponijese Bulai explains the sandalwood
population on Vunimaqo to workshop
participants during the Field Day



Another group work in session



Mr Otheniel Tangianau of Cook Islands and
Mr Sairusi Bulai of SPC at the workshop

