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McKinnell, F.H., ed., 1993. Sandalwood in the Pacific region. Proceedings of a symposium held on 2 June 1991 at the XVII Pacific Science Congress, Honolulu, Hawaii. ACIAR Proceedings No. 49, 43 p.

ISBN 1 86320 086 X

Typesetting and layout by Arawang Information Bureau Pty Ltd, Canberra, Australia.

Printed by CPN Publications, Canberra, Australia.

Sandalwood in the Pacific Region

Proceedings of a symposium held on 2 June 1991 at the XVII Pacific Science Congress, Honolulu, Hawaii

Editor: **F.H. McKinnell**

Contents

Preface

SANDALWOOD, produced from the timber of several species of *Santalum*, has considerable cultural importance in many countries in the Asia–Pacific region. For that reason alone, its conservation is an important issue and deserves more attention. Sandalwood also has high economic value, and if suitable methods for cultivation can be developed, it has the potential to make a significant contribution to the rural economies of several countries.

Cultivation of sandalwood is, however, not an easy matter, as all species of *Santalum* are obligate root parasites. This means that natural regeneration or artificial establishment is dependent on the presence of suitable host plants, as well as suitable environmental conditions. In addition, sandalwood is vulnerable to fire and browsing, both common factors of the environment of all species. Nearly all species of *Santalum* have been heavily exploited in the past, to the point where there are grounds for concern for the survival of some species. For these reasons, ACIAR has supported research on sandalwood establishment in Indonesia and has also supported (with the Australian International Development Assistance Bureau, through its International Seminar Support Scheme) attendance of researchers from several countries at the symposium reported here.

The papers reproduced here are edited versions of presentations given at the Symposium on Sandalwood Conservation at the XVII Pacific Science Congress, held in Honolulu, Hawaii, in June 1991. This symposium was a follow-up to a previous symposium on Sandalwood in the Pacific held at the East–West Center, University of Hawaii, April 9-11, 1990. At that time a considerable amount of interest in the conservation of the various species of sandalwood was generated and the 1991 symposium was arranged to give focus to that interest and to gain more information on the conservation status of this important genus.

These papers should be read in conjunction with the proceedings of the 1990 East–West Center Symposium, published by the U.S. Forest Service as General Technical Report PSW-122 (L. Hamilton and C.E. Conrad, technical coordinators). Together, they make a considerable contribution to the published literature on sandalwood.

It will be evident from these two publications that there are still many important gaps in our knowledge of the conservation status and silviculture of several species of *Santalum*. It is hoped that publication of these papers from the Pacific Science Congress will stimulate more interest in sandalwood research and better management of those species which are in a declining state.

I would like to acknowledge the cooperation of the original authors in the process of editing the papers from this symposium. In particular, I would like to thank M. Loic Cremiere from the Centre Technique Forestier Tropical in Noumea, New Caledonia, who accepted the task of sorting out my enquiries on the papers by Jean-Francois Cherrier, following M. Cherrier's unfortunate death in an aircraft crash in Vanuatu.

F.H. McKinnell
Perth, Western Australia
August 1992

The Management and Conservation Status of *Santalum* Species Occurring in Australia

G.B. Applegate* and F.H. McKinnell†

Abstract

The six species of *Santalum* that occur naturally in Australia are *Santalum acuminatum*, *S. album*, *S. lanceolatum*, *S. murrayanum*, *S. obtusifolium* and *S. spicatum*. The paper describes their habitat and areas of natural occurrence, and presents current knowledge of silvicultural requirements and the conservation status of each species.

Only four of the species have commercial value, or the potential for commercial use. *S. spicatum* and *S. lanceolatum* are currently harvested, for their aromatic wood, from natural stands. Exports of over 2000 tonnes per annum of various grades go to countries in Asia. *S. acuminatum*, a species from southern Australia, has reasonably large and edible fruit. This has prompted its use in this region for horticultural production.

S. album, which has a timber with a high aromatic oil content, is limited in its natural occurrence and is not currently harvested for its wood or oil in Australia. It is, however, the focus of a research program aimed at the production of sandalwood in plantations in the tropical regions of northern Australia. As reliable propagation and nursery techniques are developed, research involving this species will be concentrated on tree improvement and plantation silvicultural requirements for quality wood production.

The genus *Santalum* comprises 29 species from Indonesia, Australia, Hawaii, the south Pacific Islands, and the Juan Fernandez islands near South America (Hamilton and Conrad 1990; Hewson and George 1984).

The Australian *Santalum* species

Six species of *Santalum* grow naturally in Australia: *Santalum acuminatum*, *S. album*, *S. lanceolatum*, *S. murrayanum*, *S. obtusifolium* and *S. spicatum*. Five of the species are endemic to Australia, and one, *S. album*, which is found along the northern Australian coastline, is also found in Timor in Indonesia (Hewson and George 1984) and in India. Only *S. spicatum*, *S. album* and *S. lanceolatum* are known as sandalwood, as they contain aromatic wood.

Each of the species found in Australia, while having distinctive features, also has some characteristics in common with the others. They are all believed to be obligate hemi-parasites, and cannot survive unless attached to the roots of other living shrubs or trees, or, occasionally, grasses. There has been some research into the nature of the attachment to the host plant (e.g. Webb and Dell, unpublished data), but very little is known about the nature of the benefit derived from the host.

The species range in height from 2.6 m for *S. obtusifolium*, to 4 m for *S. murrayanum* and *S. album*, and to over 7 m for *S. spicatum*, *S. lanceolatum* and *S. acuminatum*. *S. lanceolatum* is the largest sandalwood in Australia. Specimens of the latter, in excess of 8 m in height and 32 cm diameter at breast height (dbh), have been recorded in northwestern Queensland.

Their leaves are either opposite or whorled, well developed and penninerved. Flowers are bisexual, occurring in terminal or axillary panicles or racemes. The fruit is a spherical drupe with a succulent, firm woody, mesocarp and a rugose endocarp (Hewson and George 1984).

While the host requirements for both pot and plantation-grown *S. album* are known (Barrett 1987a,b;

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McKinnell 1990), few details are known about native hosts, or whether sandalwood grows faster or produce better quality wood with different hosts.

S. lanceolatum is found in association with, but not surrounded by, thickets of *Melaleuca* sp and *Excoecaria* sp. It is often found at the boundary between these thickets (or 'scrubs') and the more open woodland communities which have a grass-dominated ground layer (Applegate et al. 1990). In other regions it is associated with nearly pure stands of gidgee (*Acacia cambagei*).

S. spicatum is often found associated with another wattle, mulga (*Acacia aneura*), on the boundary with eucalypt woodlands. Like *S. lanceolatum*, it is found often at the edge of different vegetation types, and not within them.

S. acuminatum grows as a small tree to 6 m. It is also associated with *Acacia* communities, in both its natural state as well as in remnant native vegetation on farms and along roadsides.

There is little published material available on vegetation types associated with *S. murrayanum* and *S. obtusifolium*. The latter species can be found in the Hawkesbury River basin near Sydney and is observed in association with eucalypt communities.

Area of occurrence

The genus *Santalum* is represented over much of the arid and semi-arid regions of Australia. *S. lanceolatum* is the most widespread; it stretches in discontinuous patches from the northern part of Australia (which experiences a humid and subhumid tropical climate with a distinct wet season in the summer months), to the southern temperate regions of Australia which experience a predominantly winter rainfall. Figure 1(a) shows the distribution of *S. lanceolatum* in Australia. The species is generally found between sea level and 700 m above sea level, in a rainfall belt which receives between 300 and 1300 mm of rain annually. The better developed stands are found in the northern part of its range, occurring on texture contrast (duplex), sandy clay soils; these have a high calcium carbonate content and a pH between 7.4 and 8.0. In other areas in the north, it has shown remarkable development amongst boulders on slopes and in gullies on old tertiary basalt flows (Applegate et al. 1990).

The commercially most valuable species in Australia is *S. spicatum*. It grows between sea level and 300 m above sea level, in a rainfall zone which receives between 200 and 600 mm of rain annually.

It is located on 42 million hectares of the arid and semi-arid zone of southwestern Australia (Fig. 1(d)). Here it grows on rocky outcrops and on loam-textured soils (McKinnell 1990). It formerly occurred over a large area of South Australia, but has largely disappeared from that State due to agricultural and pastoral activities.

In the southern arid zone of Australia, *S. acuminatum* occurs sparsely distributed over an estimated area of 300 million hectares (Wilson 1991). It is found between sea level and 500 m above sea level, in two discontinuous areas separated by the Nullarbor Plain (Fig. 1(f)). This species grows in areas receiving between 300 and 900 mm of rain per annum, occurring on poor soils and coastal dunes, on gravelly plains, granite outcrops and on creek banks.

S. murrayanum, one of the lesser known Australian species, is found in similar locations to *S. acuminatum*, but is not as widespread (see Fig. 1(e)). It grows between sea level and 500 m above sea level on dune sands, and on gravelly and sandy loam soils.

The sandalwood with the most restricted distribution in Australia is *S. album*. It is located on islands between Melville Island and Elcho Island, near Darwin in northern Australia, as shown in Fig. 1(b). Here it grows in coastal areas, in sandy soils behind the mangrove communities, and near small coastal waterholes (billabongs).

The species which has attracted least interest is *S. obtusifolium*. It is restricted to the east coast of Australia between southern Queensland and eastern Victoria (Fig. 1(c)). In the region near Sydney, it is found growing on Hawkesbury sandstones, in sandy soils on the banks of creeks, and in gravelly clay soils in other locations.

Past and Current Utilisation

Australian involvement with sandalwood began in 1803, when Sydney merchants were looking for products to be traded for Chinese tea. The trade was initiated from Sydney, using sandalwood obtained from Fiji and other Pacific Islands (Statham 1990). By the 1860s, this sandalwood trade had almost collapsed; competition from traders in other nations, and the depletion of the Pacific island resource (caused by overexploitation) are likely causes.

From 1844 a sandalwood industry was developed in Western Australia and later South Australia, based on harvesting natural stands of *S. spicatum*. The Queensland industry began in 1886 (Applegate et al. 1990;

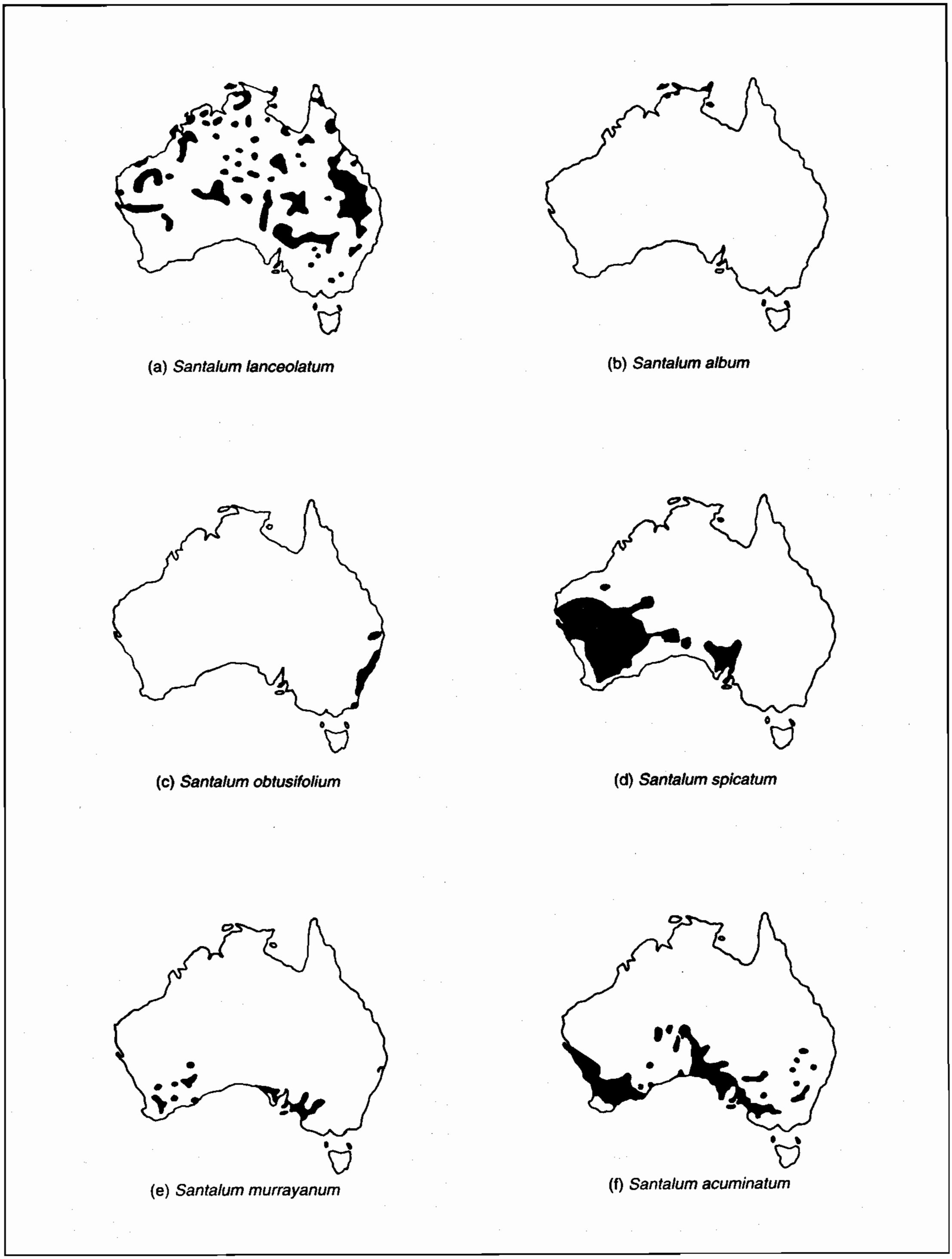

Fig. 1. Distribution of *Santalum* species in Australia (modified from Hewson and George 1984).

McKinnell 1990) and was based on *S. lanceolatum*. Although most of the sandalwood was exported as logs or billets, there was some extraction of the oil of both species, which was mixed to achieve certain pharmaceutical specifications. Distillation for the oil ceased in Australia in 1965.

The boom period of the Australian sandalwood industry, which was associated with unregulated marketing procedures (and few, if any, harvesting controls), lasted until 1929. In 1929, the Western Australian *Sandalwood Control Act* legalised a regulated export agreement, and provided the legal framework for annual harvesting quotas; regulations were attached to the Act to enable the management of the industry. Subsequent events led to the establishment of the Australian Sandalwood Company as a government-approved single marketing organisation.

During the mid 1930s, harvesting and marketing of sandalwood in Queensland was carried out under the *Sandalwood Act of Queensland 1934*. This Act enabled control of harvesting of all Queensland sandalwood to be carried out by the Queensland Forest Service; the produce was then sold to the Australian Sandalwood Company in accordance with the terms of an agreement with that company.

The sandalwood industry ceased in Queensland in 1940, but was revived again in 1982 when the 1934 Sandalwood Act was revoked. The repealing of this Act resulted in the Crown losing management controls over sandalwood growing on private land. Subsequently, the management of sandalwood in Queensland has been plagued with a range of problems, basically due to the inability to determine the source of harvested sandalwood—whether from private land or Crown land. In 1989, harvesting of sandalwood from Crown land was suspended and the purchaser's licence cancelled as a result of breaches of the contract.

The sandalwood industry in Western Australia is still based on *S. spicatum*. For the last 50 years there have been tight controls on all aspects of harvesting and marketing. All operators are licensed, and the sandalwood can be sold only through the Australian Sandalwood Company. A Sandalwood Export Committee, with representatives from the Company and the State Government, determines marketing strategies and annual cutting quotas.

The area harvested and the management of the field operation is carried out by the Western Australian Department of Conservation and Land Management (CALM). Only live trees with a girth greater than 40 cm at 15 cm above the ground can be removed, while any dead material can be collected. All material, down to 2 cm in diameter, is utilised and there is a range of quality grades which are marketed at varying prices.

The system that has evolved in Western Australia for harvesting and exporting sandalwood is proven to be viable. It can provide the framework for Australian and overseas organisations that have not devised a manageable and profitable system for the harvesting and export of sandalwood.

In the 1980s, Sedgley (1982, 1984), undertook research involving various aspects of the native quandong (*S. acuminatum*). Her work provided the basic information for a developing horticultural industry based on quandong. Since then, the industry has expanded, and is predicted to become an important source of income by the year 2000. Quandong farming is now seen as a practical and economic proposition in the arid zone of Australia. The fruit was used by aborigines as a source of food and medicine. Although the fresh fruit has a bitter taste, it takes on the flavour of different fruits when cooked. This makes it a useful dessert flavouring in ice-cream, yogurt and custard. The nut is sold in restaurants and is low-weight dried. The dried fruit has the potential to be packaged and marketed through the tourist industry in central Australia.

The trees, which are spaced at about 270 stems per ha, produce around 3 kg of fruit per year each. Dried quandong fruit is currently selling at around $A50/kg. This price suggests that it has the potential to be a commercial proposition (Wilson 1991).

In the early work (1982) reported by Sedgley, the host plant used was Kikuyu grass (*Pennesitum clandestinum*) and the trees were grown under irrigation with saline bore water. Although Kikuyu grass poses practical difficulties as a host, it indicates that quandong does not have very specialised host requirements.

While the industry is not large, more and more land holders in the arid zones are planting trees. A 2000-tree orchard is being established in mallee sands in northwestern Victoria, while other growers are planning for orchards of more than 2500 trees (Wilson 1991).

The quandong has proved itself to a suitable tree crop for arid, degraded land where the available water is salty. With many of the world's food shortages being experienced by people living in such environments, the quandong has the potential to be cultivated in these regions and to provide another source of food.

More recently, there has been increasing interest in the use of the kernels of *S. spicatum* as a commercial food nut. Current research at Curtin University is examining the variation between trees in flowering and seed yield (Barrett 1987a). There seems every prospect that, with selection of high-yielding strains, and the development of suitable cultural techniques, cultivation of sandalwood nuts in the winter rainfall, semi-arid agricultural region of Western Australia could become a useful rural industry.

Conservation Status

Natural populations of sandalwood (*Santalum*) species are under threat, and in a depleted state, in many countries. That is not the case in Australia, although some species certainly have had their range of occurrence reduced by agricultural activities, and there are few active programs designed to protect sandalwood species from grazing. What has protected the Australian species is that they either occur over huge areas (*S. spicatum*, *S. lanceolatum* and *S. acuminatum*) or in remote locations (*S. album* and *S. murrayanum*) or persist in Crown forests (*S. obtusifolium*).

In Western Australia, CALM has developed a long-term plan, The Sandalwood Conservation and Regeneration Plan (Kealley 1991). This has been designed to conserve and manage *S. spicatum* in Western Australia. Under the plan, areas may be protected from harvesting, or excluded from pastoral leases; both measures are designed to increase the reserve areas in various ecological types. The plan also encourages landholders to plant sandalwood in the wheat and sheep belt, as a means of reestablishing the species in that area.

A range of reserves and national parks exists in Western Australia, as in other States, and contain representative populations of *Santalum* species from the region (see McKinnell 1990). However, the range of reserves containing sandalwood is being expanded progressively by the purchase of pastoral leases.

There is no active program specifically designed to preserve *S. lanceolatum* in any of the states of Australia. This species is very widespread throughout the arid and seasonally arid zone; it is also well represented in National Parks, State Forests and other reserves of reasonably secure tenure. The species is only utilised from a small area in north Australia, which represents a fraction of the area of its total distribution (Fig. 1(a)).

The threat to *S. lanceolatum* comes less from environmental conditions than from existing land use practices. In northern Australia, overgrazing by cattle and the annual burning of the grazing areas damages the sandalwood resource. Sandalwood is palatable to cattle as well as the native fauna, and is very susceptible to fire. Hence, land management patterns involving overgrazing in times of drought, depletion of the native pastures, and burning after a good wet season, cause the destruction of sandalwood in some locations. One of the interesting aspects of this region is that following large floods, which occur on an irregular basis, huge areas of 'wheatfield' sandalwood regeneration can often be seen in the river flood plains. These are often short-lived, but the survivors are in sufficient numbers to ensure viable populations in the region.

While the conservation status of the other four *Santalum* species has not been studied in detail, their distribution is overlapped by a number of reserves in the States and Territories where they occur. Hence, it is reasonable to assume that none of the species is in danger of extinction, and that all are adequately conserved with viable populations.

Although there is little threat to the survival of quandong as a species, since it occurs over such a large area, the gene pool may well have been eroded by grazing with sheep and cattle, through grazing by rabbits, and by the requirements of native fauna populations during times of drought.

Silvicultural Knowledge

Regeneration

Most natural regeneration of *Santalum* species in Australia is by seedling regeneration. However, since most species occur in arid or semi-arid parts of the country, the success in any one year is greatly dependent on rainfall patterns. The more arid the climate the more uncertain the success. In the arid zone of Western Australia, for example, successful natural regeneration of *S. spicatum* requires three successive years of above average rainfall (McKinnell 1990). This condition does not occur very often, and, combined with the browsing of sheep, goats and rabbits, is the major reason why there has been poor regeneration for many years (Kealley 1991).

S. lanceolatum produces a succulent fruit at different times of the year, depending on rainfall. Under natural conditions, the seeds appear to require high humidity and moist soil conditions to germinate and produce seedlings. Few data are available on seed production rates, optimum seed storage conditions, dormancy and actual temperature requirements for seed germination. *S. lanceolatum* is also able to produce coppice shoots from stumps, and produces suckers from the roots of existing trees, particularly those that have been disturbed or wounded. Barlass et al. (1980) regenerated shoots in aseptic culture, and roots following shoot etiolation, in a medium containing indolebutyic acid at pH 4. These results indicate the possibility for clonal propagation of the species.

There is a considerable amount of information available on seed production, viability and suitable handling techniques of *S. spicatum*; (Loneragan 1990; Barrett 1987b). The most successful method of propagation of this species is to grow the sandalwood seedlings in a pot with a suitable host plant, and then to transplant the two, taking particular care not to disturb the plant/host connection. Direct sowing is a practical method of propagation but a 1% seedling establishment rate is not uncommon in suboptimal conditions. Direct seeding regimes require seed less than 2 years old, with seeds sown in spots 5 to 7 cm deep at the drip line of the host's crown. Protection from grazing is then essential (Crossland 1982). *S. spicatum* is a heavy seeder, but does not regenerate from coppice shoots and does not produce shoots from its roots except in a relatively small area near Shark Bay. Research carried out to explore methods of vegetative propagation have been unsuccessful (McKinnell 1990). Cuttings could not be struck, and while plantlets were developed with shoots using tissue culture techniques, roots failed to develop (McKinnell 1990).

S. acuminatum is also a prolific seeder and readily produces seedling regeneration. Results from nursery research suggest that removal of the kernel from fresh fruit produces germination within a couple of months (Grant and Buttrose 1978). Sedgley (1984) obtained comparable results by sowing seeds, in shell, 2 cm below the surface in small pots. Prior to sowing, seeds should be treated with sodium hypochlorite and a fungicide. Pots should be kept moist and maintained at 20°C for optimum germination (Sedgley 1984). The species appears to be quite heterozygous and this led to the development of cultivars; the nursery trade has used these to successfully provide plants suited to an ever-increasing horticultural industry in the arid and semi-arid zone of Australia (Wilson 1991).

Grafting of scion material can commence when the root stock is growing vigorously, and the stem is 2 to 3 cm diameter. A simple splice graft carried out in winter is most successful, with the plant then being kept in the glasshouse at high humidity for 2 to 3 months.

No information is available on regeneration techniques for *S. murrayanum* or *S. obtusifolium*.

Plantation development

While *S. album* is not used commercially in Australia, the Australian Sandalwood Company has decided to obtain the necessary information and expertise to produce this species in plantations, in order to diversify and to ensure its future viability. This decision was taken in light of inventory data suggesting that natural stands of *S. spicatum* in Western Australia will be depleted in 60 years (McKinnell 1990). While there is sufficient information available on the nursery phase (Rai 1990; McKinnell 1990; Fox 1989), and some information available on how to manage sandalwood plantations (Rai 1990; McKinnell 1990), there is a lack of data on plantation silviculture. Some preliminary trials undertaken in northern Australia, designed to investigate secondary host species, have highlighted a few potential hosts (McKinnell 1990).

The next stage in the research process will form part of an aid project in Indonesia funded by the Australian Centre for International Agricultural Research (ACIAR), in collaboration with the Australian Sandalwood Company and CALM. The aim of this work will be to develop suitable silvicultural techniques for the management of sandalwood in Australia.

The selection of superior phenotypes, as well as the testing of a range of different species and their provenances, will be an integral component of this research.

Growth

The only Australian species of sandalwood for which there are good data on growth is *S. spicatum*. Growth studies have been reported by Loneragan (1990). Drawing on the results of field trials established as far back as 1895, Loneragan showed that in a 250 mm rainfall zone near Kalgoorlie, it requires 90 years to grow a sandalwood to merchantable size, whereas in a 400 mm rainfall near Narrogin, in the wheat/sheep agricultural zone, only 50 years were required to grow a tree the same size. There is some indication from field trials that the growth rate is faster with a legume host than with a non-legume, but there are no definitive data to support this observation.

Conclusion and Outlook

Research studies covering the conservation, utilisation and management of sandalwood in Australia have the potential to provide valuable information. This will be needed to maintain the conservation status of, and to provide sustainable economic returns from, sandalwood.

Although the research work on regeneration of *S. spicatum* has been concluded in Western Australia, some exploratory studies into edible fruit production are being undertaken. Success in this area would provide an incentive for wheat and sheep farmers to plant sandalwood for fruit and timber production. These plantings would also assist in the conservation status of the species by supplementing existing reserve networks.

The harvesting of this *S. spicatum* will continue in Western Australia for another 60 years with about 2000 tonnes being produced annually. It is anticipated that during this period, harvesting of plantation-grown *S. album* will have begun; eventually this should lead to a reduction in the rate of harvesting of the native species. In order to develop suitable silvicultural techniques for plantation-grown sandalwood, a research project is being formulated in Australia involving CALM, ACIAR and the Australian Sandalwood Company.

A number of experimental areas have already been established in the irrigation area supplied by the Ord River in the tropical Kimberley region of Western Australia, using seed from India. This year will see the first plantings of clonal material produced by tissue culture, as part of a program to test the practicability and economics of this method of establishment. If successful, the establishment of clonal plantations of high oil-yielding genotypes would be possible. In the near future, then, the area of occurrence of this species in Australia is likely to expand.

It is hoped that links with international collaborating institutions, many of which have a history of sandalwood involvement, will eventually assist in economic diversification in Australia.

The harvesting of *S. lanceolatum* is currently being undertaken only on private land in Queensland. New management procedures are being prepared, to enable the recommencement of sandalwood harvesting on Crown land (i.e. publicly-owned land). It is anticipated that as part of the Queensland Forest Service conservation policy, sandalwood management plans will (1) include environmental protection guidelines, particularly in areas dominated by highly erodible duplex soils; (2) take account of the vast distances over which the resource is spread; and (3) include land use assessments to define sandalwood regeneration and protection practices in the pastoral areas where it is located.

The outlook for both the conservation and commercial aspects of *S. acuminatum* is positive. The results of work being undertaken with this species indicates that it does have a future as a horticultural tree crop in the arid zones of southern Australia, and that it may have potential as a horticultural crop in similar environments in other countries.

Acknowledgment

The approval of the Australian Government Publishing Service for permission to reproduce Figure 1 is gratefully acknowledged.

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Status and Current Interest in Sandalwood in Fiji

L.R. Jiko*

Abstract

Santalum yasi, the only sandalwood species in Fiji, earned F$4.74 million in foreign exchange over the period 1987–90. This recent resurgence in the utilisation of sandalwood has created an interest among landowners in planting and restocking new areas with the species. This paper presents information on early history, traditional uses, growing conditions, silviculture and marketing of yasi, together with some notes on current research directions.

THE small tree, *Santalum yasi*, with aromatic wood grew abundantly along the Bua coast and in grassland areas of Fiji. Although it also occurs in Vanua Levu, northern Lau, Kadavu and Viti Levu, the species is believed to be native to Bua.

Well before the advent of European traders to Fiji, sandalwood was traded between the Fijians and the neighbouring Polynesian island states. Tongan canoes made long voyages to Fiji to barter sandalwood for bark cloth and sting of ray, which the Fijians used for pointing their spears.

Sandalwood was used by Fijians themselves to scent coconut oil and during marriage ceremonies. It was also used as an insect fumigant, and as a medicinal to clear dandruff and head lice.

Following the publication of Captain Bligh's chart of the Fiji Islands in London, navigators and treasure hunters flocked to the Fiji Islands to search for, and trade in, sandalwood, whale products and bêche-de-mer.

High prices for sandalwood in the ports of China at the beginning of the nineteenth century sent adventurers in search of the timber all over the South Pacific. In Fiji, exploitation of yasi began between 1800 and 1805, and lasted only for about 10 years. This boom resulted in the species becoming rare, and commercial exploitation lapsed until recently.

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Growing Conditions

Fiji has a land area of 18300 km^2 on some 300 islands. The largest islands are Viti Levu and Vanua Levu, which comprise 87 per cent of the land area (Fig. 1). The islands lie between 178°E and 179°W longitude and between 16 and 22°S latitude. They are largely volcanic in origin, with reasonably fertile soils and often with steep dissected topography.

The mean annual rainfall varies from 1650 mm in the low leeward coasts of Vanua Levu and Viti levu to over 3800 mm in large parts of the island interiors. Natural hardwood forest areas generally have more than 250 mm per month with only a short dry period. Mean monthly temperatures for the period January to March, during the greatest rainfall, are around 29°C, dropping to 24°C during July to August (Fig. 2(a) and (b)). Cyclones are frequent from December to April, and cause much damage to settlements, crops, plantations and forests.

Distribution

The principal areas of occurrence of yasi are parts of Bua province of Vanua Levu, on the open hills behind Bua Bay and around the southwestern corner of Galoa island. In earlier days, the wood was also obtainable in lesser quantities along the western and northern coast of Vanua Levu as far as Naduri. As a result of heavy

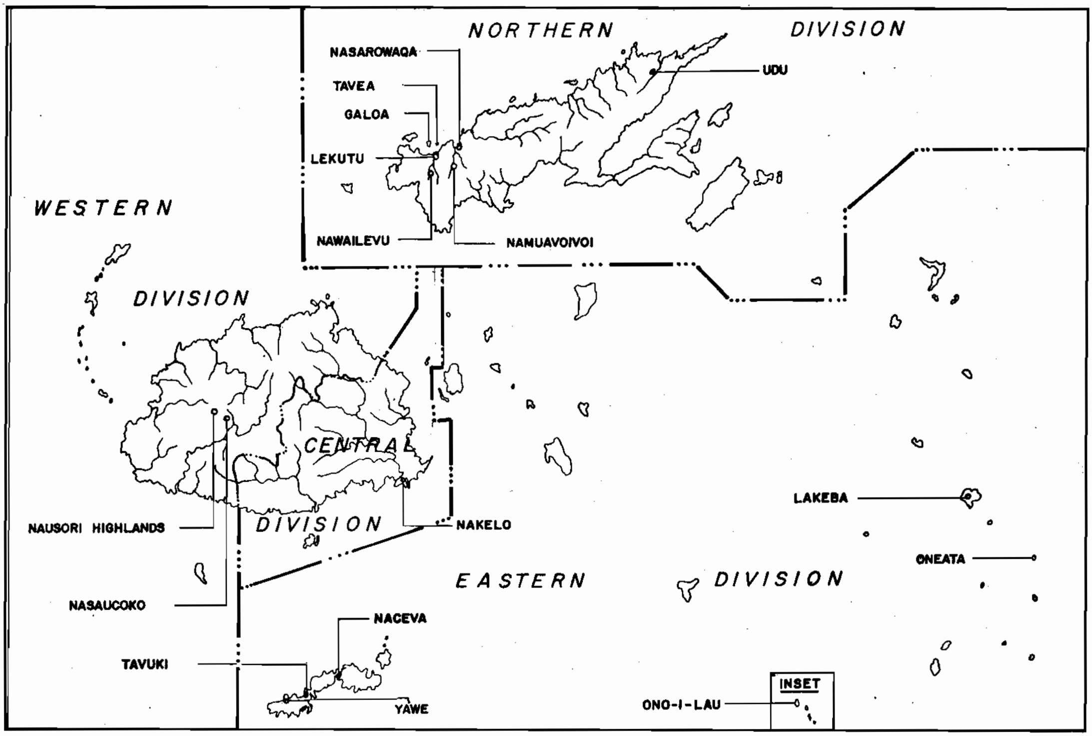

Fig. 1. *Santalum yasi* distribution in the Fiji Islands.

cutting and uncontrolled fire, sandalwood has now disappeared along the Naduri coast.

In Viti Levu, sandalwood was found only on steep banks along the Colo West Range from Tubainasolo to Nasaucoko. During the recent period of harvesting, some supplies were also observed at Nakelo in the Central Division and parts of the Eastern Division including Yawe, Tavuki, Naceva, Lakeba and Ono-i-Lau.

Silviculture

In Fiji, sandalwood grows to a maximum height of 10 m, with a diameter overbark at breast height of up to 40 cm. The bark is grey with brown fissures, and the leaves are opposite, light green and shiny, forming a light crown. The flowers are small and purplish, and the fruit is a small dark purple drupe. The sapwood is white and scentless while the heartwood is yellowish brown, hard, oily and strongly scented.

The sandalwood grows mainly in open forest land with grass and patches of trees. It is usually found on rather stony soil, and under those conditions appears to produce the most scented wood. It has been observed that trees growing in rich soil do not have as much scented wood as trees which are slower growing on stony soils.

In the outlying islands of the Eastern Division, natural regeneration of yasi is found in old gardens and on waste land. It is commonly found on ridge slopes and shallow degraded soils with rock outcrops and also on sandy soil in coastal areas and the edges of swamps.

The following species are usually found serving as hosts for the sandalwood in its natural habitat: *Casuarina equisitifolia*, *C. nudiflora*, *Cocos nucifera*, *Albizzia lebbek*, *Adenanthera pavonica*, *Calophyllum vitiense*, *Acacia richii*, *Fragea gracilipes*, *Alphitonia* spp., *Podocarpus nerifolius*, *Storckiella vitensis*, *Ficus theophrastiodes*, *Hibiscus tiliaceus*, *Litsea* spp., *Inocarpus fagerus*, *Commersonia bartramia*, *Thespia populnea*, *Erythrina* spp., *Citrus reticulata*, *C. sinensis*, *C. lemon*, *Pongamia glabra*, *Dodonea viscosa*, *Zingiber zerumbet*, *Guioa capillacea*, *Antidesma ellassophyllum*, and *Alyxia amoena*.

There has been no attempt to study the sandalwood–

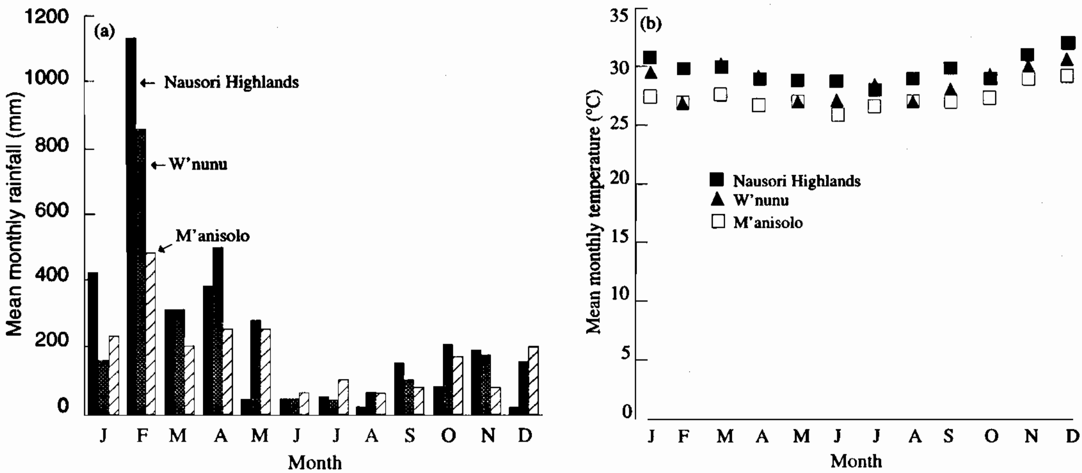

Fig. 2. (a) Mean monthly rainfall, and (b) mean monthly temperature, at typical yasi sites in Fiji.

sandalwood plant may attach itself to the roots of almost any other plant, it seems to grow best in the company of the plants listed above.

In Fiji, the sandalwood tree is a prolific seed bearer and fruiting begins as early as 3–4 years, although the fertility is poor at that age. However, a high percentage of sound seed is available from about 8 years onward, and there is an annual seed crop. Seed collection is carried out from November to March.

Natural regeneration is found mainly under shrubs and not as a rule in the open. This is believed to be partly because birds which have eaten the fruit settle in the shrubs and drop the seeds there, and partly due to better seedling survival in the shelter of the other vegetation.

Sandalwood in Fiji has a tendency to fork early, often when only a few months old. It is not known whether this tendency is inherited, or whether some environmental factor is responsible. An average of two leaders have been observed on seven-month-old seedlings in the nursery, whilst 45 per cent of the 20 saplings sampled at Galoa forked within one metre of the ground, with multiple leaders ranging from two to seven per tree.

Root suckers have been observed on recently felled sandalwood trees.

Harvesting and Marketing

Harvesting of sandalwood began again in 1984 at Bua, and subsequently at all other areas where sandalwood occurs naturally.

A resource survey was carried out at Bua (Usumaki 1981) and on Ono-i-Lau (Tabunakawai and Chang 1984) to determine the quantity available for export.

The standing volume was estimated to be 2623 m^3 in Bua and only 11.5 m^3 in Ono-i-Lau, which is equivalent to about 1000 t of heartwood. The latter was calculated from limited sampling, which indicated the average proportion of heartwood to total volume was 35 per cent (Fig. 3).

The price received for Yasi rose from F$300 to F$1000 per tonne in 1985 to F$16 000 to F$20 000 per tonne in 1990 (F$1 = U$0.71 in May 1991). Unfortunately, no further benefit can be gained from the resource as all marketable trees have been utilised.

The markets for the produce were in Singapore, Hong Kong, Taiwan, Korea and Japan. Despite the exhaustion of the Fijian resource again in 1990, there are still strong enquiries for sandalwood, indicating a strong market and appreciation for the high quality of yasi.

At the beginning of the recent period of exploitation of yasi, the government introduced a regeneration levy in addition to the existing royalty and fees. Of the 17.5 per cent deducted from the price of the sandalwood, 10 per cent was for the regeneration levy, 5 per cent was royalty to the government and 2.55 per cent government fees. The remainder of the income is paid to the land owner.

The regeneration levy is paid to the native Lands Trust Board, an organisation which is the trustee of all Fijian-owned land. The funds so generated are admin-

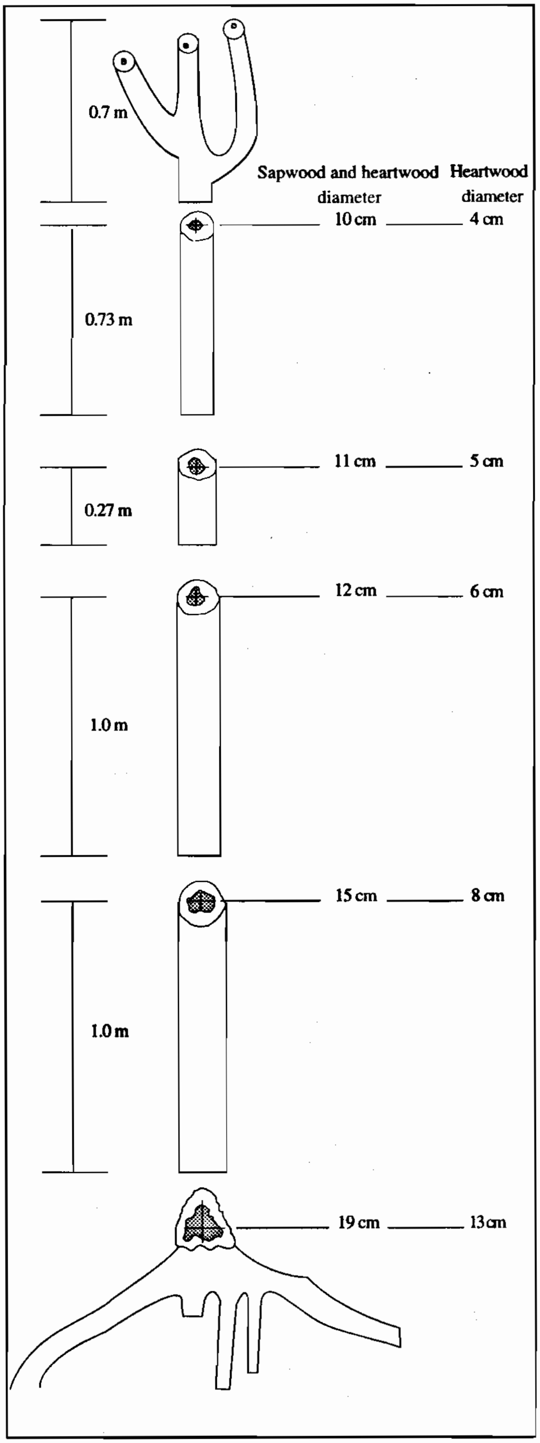

Fig. 3. Heartwood:sapwood proportion in sandalwood (source: Usumaki 1981).

istered jointly by the Trust and the Ministry of Forests. All regeneration work has to be certified in writing as being up to standard before the levy is paid back to forest owners. The amount paid over the four years of harvesting is shown in Figure 4.

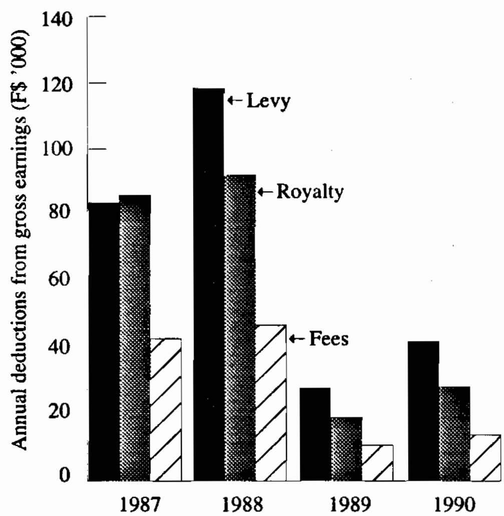

Fig. 4. Annual deductions from gross earnings from sandalwood harvesting and marketing in Fiji.

Current Research

Research on sandalwood in Fiji has been on a casual basis for the last 10 years. It was not until 1989 that an officer was made responsible for this research, and then only part time.

Germination

Obtaining seed for work with *S. yasi* is a major problem, partly because it comes from outer islands where communication is poor, and partly because there are relatively few seed trees available. Indeed, establishment of a secure and reliable source of seed is a priority task. Hurricanes are also a frequent cause of loss of a seed crop.

With fresh seed, germination of sandalwood is rapid. A germination test of 250 seeds pretreated according to the technique of Barrett (1987) showed that germination begins after 14 days and is complete after 31 days (Fig. 5).

Host species

The sandalwood are sown direct into a plant pot into which a host plant has already been planted.

Several hosts have been tested with no species yet being adopted as standard. Currently, *Acacia richii*, *A. mangium*, *Citrus limon* and *Calliandra* spp. are being established for a new field trial. In a previous field trial at Wainunu, the growth and survival of *S. yasi* with no host, and with three different hosts was compared (Fig. 6). There are clearly useful differences in the efficiency of different hosts in respect of sandalwood survival. An experiment on the growth rate of the sandalwood with the different hosts yielded somewhat similar results (Fig. 7).

These data cover only two years and both survival and relative growth rates may change with the passage of time. There is an indication from an earlier trial that there may be subsequent losses of sandalwood (Fig. 8), but that trial used yasi seedlings interplanted among mixed host species, and the results could well reflect variation in success in attaching to a host.

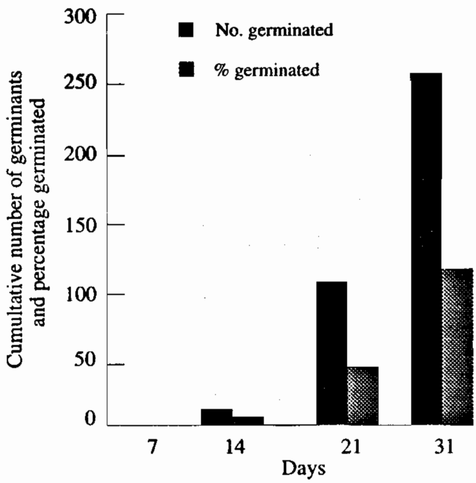

Fig. 5. Germination statistics for a sample of 250 yasi seeds.

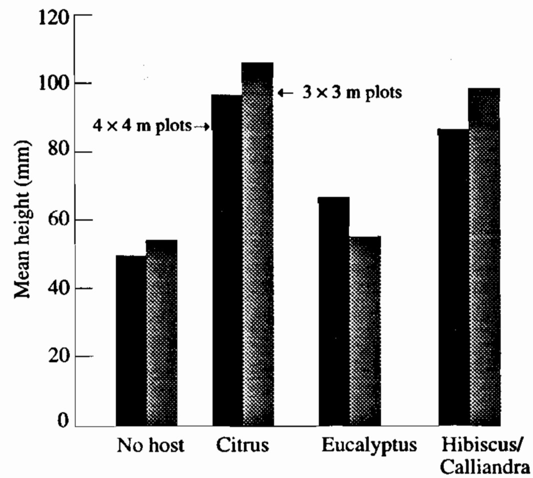

Fig. 7. Growth rate of yasi with different hosts. Mean heights are 2 years after planting.

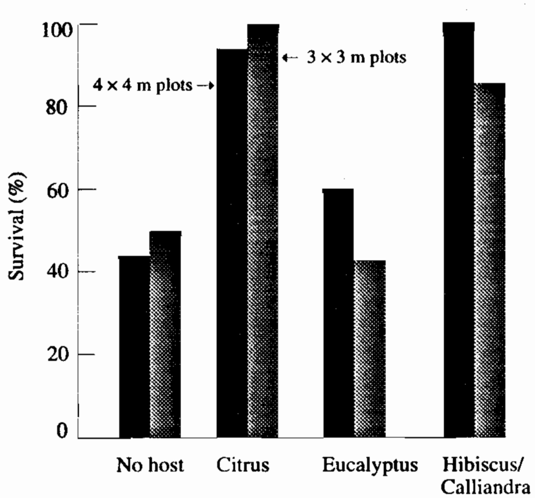

Fig. 6. Percentage survival of yasi with difference hosts at Wainunu site.

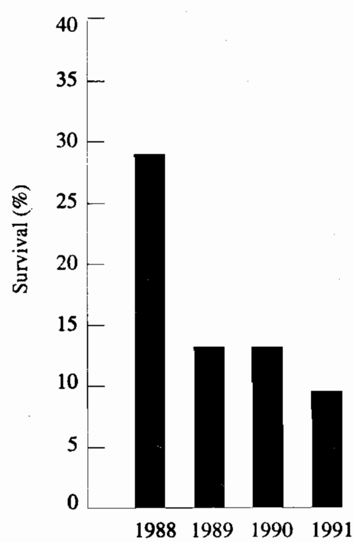

Fig. 8. Survival of yasi with age at Nausori Highlands site. The trees were planted in 1987, at 3 × 3 m spacing, with mixed host species.

Conclusions

The present situation of yasi in Fiji gives some cause for hope. As a result of the financial benefits realised from the recent four-year period of exploitation, landholders in Fiji now have a far greater interest in the cultivation of the species. The challenge for the Forestry Department is now to provide the technical support to keep this impetus going. It is essential that simple and successful establishment techniques are developed and implemented. A great deal of research needs to be done in order to give landholders the sort of information they need. Provided research is continued and the regeneration work is carried out to a good standard, the supplies of yasi should increase in the future.

The main area of concern at the present time is the continuing supply of adequate quantities of good quality seed for the regeneration program. It may be necessary to establish special seed production areas for this purpose.

Acknowledgments

The assistance of Forester T. Raravula, Forest Rangers T. Evo, T. Kubuabola and J. Leitch, and of Dr W. Kunzel and E. Tupua are gratefully acknowledged.

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Sandalwood in New Caledonia

J-F. Cherrier*

Abstract

This paper synthesises the results of research on wood formation in *Santalum austrocaledonicum* in New Caledonia. There is high variability of heartwood content at any tree size. Trees also reach maturity at different heights and diameters, making predictive models of limited value. The best correlation of yield of heart19wood is with sapwood width. The latter is positively correlated with recent growth rate. Sapwood is at a minimum and the proportion of heartwood is highest when the tree matures and growth rate is reduced. It is concluded that the management of sandalwood to maximise heartwood production is complex.

SANDALWOOD, known in antiquity, is mentioned several times in the Old Testament, for example in Psalm 44:8. 'Thy garments are like aloes, myrrh and cassia'. Moldenke and Moldenke (1952) consider that here 'aloes' refers to *Santalum album* of India. The 'Thousand and one nights' furnishes an even more direct reference in the story of Sinbad the sailor. During his seventh and last voyage, Sinbad is wrecked on an island where he makes a raft. '... I picked up many big branches which I later found to be sandalwood of the finest quality.' He became rich afterwards by selling this wood.

The 'tales' date from the time of Harun-al-Rashid, Caliph of Bagdad in the eighth century. Trade in sandalwood has thus been profitable for a long time. Its discovery in the Pacific during the nineteenth century stimulated the trade which for hundreds of years previously had been confined to the East Indies.

New Caledonia has invested heavily in research on its sandalwood (*S. austrocaledonicum*), covering studies on parasitism, nursery techniques (Chauvin 1988), inventory, silviculture and wood properties. This paper synthesises the results of this research.

Growth Rings and Anatomical Studies

Eighteen trees of 40–70-cm circumference at breast height (cbh) and of known age were studied. The results showed that pigmentation of heartwood makes the growth rings hard to count. The edges of the rings are sometimes clear, and sometimes indistinct. The number of apparent rings exceeds the known age by 10–40 per cent.

Quemin (1988) has studied the wood anatomy. His results indicate that the variations in wood structure at the edges of the rings depend on the fibre density, not on vessel diameter which varies very little. It thus seems impossible to detect true annual rings and to judge the age of a tree by its size.

Sapwood is responsible for the transport of the raw sap, while the heartwood (Bamber and Fukazawa 1988) serves as support for the tree and accumulates biochemical residues. Heartwood formation, which has been little studied and is poorly known, is related to tree age and to lowered tree vitality. In sandalwood the two types of tissue are quite distinct, with a slight transition zone. Differentiation into heartwood also does not follow annual rings exactly. For a given individual, sapwood varies little with the direction and level of the measurements. The size of a log and width of sapwood thus define the amount of heartwood.

The top of the 'cone of heartwood' was observed to be level with the branch whose diameter was twice the width of sapwood. These data enable the measurement of heartwood volume of individual trees and stands.

Measurements of heartwood yield in relation to tree size were made on 186 trees during commercial har-

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Table 1. Weight of heartwood obtained from trees of different size

Girth at 20 cm	40	50	60	70	80	90	100	110	120	130
Mean weight (kg)	33	75	134	162	185	271	320	460	470	823
Min weight (kg)	22	30	44	55	67	148	166	185	324	444
Max weight (kg)	54	146	469	321	554	395	555	721	583	1096
No. samples	3	12	33	43	27	11	8	10	4	4

vesting operations (Table 1). The data so obtained were used to derive relationships of tree size with heartwood weight.

It can be seen that the yield of heartwood is very variable within any size class, especially for values between 60 and 90 cm girth at 20 cm above the ground.

Several simple and multiple regression models have been calculated using these data. For all models the residuals show no significant bias except in the lowest classes (up to 60 cm girth). This bias is mainly due to the nature of the sampling. The four models of most interest are:

Model 1

$W = 6.76G - 333.26$, where W is total weight, G is girth at 20 cm above ground, with $N = 155$ and $r = 0.77$.

It may be noted that heartwood first appears at a girth of 50 cm in this model.

Model 2

$W = 6.22G + 11.3H - 365.5$, where H is tree height in m, and $r = 0.78$. Since the girth and height of the tree are well correlated, this is in practice an inefficient regression.

Model 3

$W = 7.2G - 39.2S - 251$, where S is sapwood width in cm. $N = 155$ as before and $r = 0.81$.

Model 4

$W = 6.3G + 19.9H - 47S - 297$, where H is tree height, and $r = 0.84$.

This is the most complete model, in terms of its ability to account for factors affecting timber weight: however, all regressions give only estimates of the weight of recoverable heartwood. The degree of uncertainty increases with diminishing girth. These weight tables may be used as no others exist, but their limitations must be realised.

Effect of Growing Conditions on Wood Properties

The factors that affect sapwood width have been studied as this is the parameter best correlated with yield of heartwood. The following variables have been studied in an attempt to find correlations with sapwood width: soil depth, plant association, tree shape, height of branching, crown exposure, tree dominance, tree health, growth rate, tree age and number of sapwood rings. The influence of each of these variables is set in Tables 2–8.

The difference in sapwood width between deep and superficial soils (Table 2) is statistically significant ($r = 0.212$). The correlation is strong but hard to interpret.

Table 2. Effect of soil depth on sapwood width

	Soil condition		
	Limestone outcrops	Soil depth < 10 cm	Soil depth > 10 cm
Mean sapwood width (cm)	2.72	2.73	3.22
Standard deviation	0.16	0.12	0.18
N	35	33	42

There appears to be no significant correlation between plant association and width of sapwood (Table 3). This factor was studied further by examining the effect of type of host plant and its distance from the sandalwood on growth rate and heartwood colour (as an approximate indication of heartwood quality). In New Caledonia, a wide variety of plants are known to serve as hosts for sandalwood (Appendix 1). No clear trends could be discerned with respect to growth rate, but there was some indication that heartwood colour was affected by the type of host. This is clearly an area where more research is required, although it is very difficult to reach definitive conclusions with natural stands.

Table 3. Influence of plant association on sapwood width

	Plant association				
	Open forest	Abandoned gardens	Shrubs[a]	Coconut plantation	House gardens
Mean width	2.68	3.17	2.76	2.53	3.03
Standard deviation	0.15	0.29	0.20	0.24	0.16
N	32	27	13	4	34

[a] Refers to a shrub association of *Lantana camara*, *Psidium guava*, and *Schinus terebenthifolius*.

No correlation between sapwood width and tree shape was found (Table 4).

The correlation between sapwood width and height of the first large branch (Table 5) is statistically significant (r = 0.283), but is again difficult to interpret.

There was no significant correlation of sapwood width with degree of crown exposure (Table 6).

Table 4. Association of sapwood width with tree shape

	Shape	
	Stem straight, vertical	Stem twisted or prostrate
Mean width	2.89	3.12
Standard deviation	0.10	0.34
N	96	13

Table 5. Effect of height of first large branch or fork on sapwood width

	Height of branch (m)						
	1	2	3	4	5	6	7
Mean width	2.55	2.62	2.73	2.99	3.14	3.49	3.65
Standard deviation	0.21	0.21	0.16	016	0.46	0.31	0.97
N	8	21	30	30	11	9	4

Table 6. Exposure of tree crown and sapwood width

	Crown exposure	
	In open	Shaded
Mean width	2.88	2.99
Standard deviation	0.11	0.20
N	78	32

The correlation between sapwood width and tree dominance (Table 7) was statistically significant (r = 0.217), but hard to interpret.

There was no significant correlation of sapwood width with tree health (Table 8).

Table 7. Effect of tree dominance on sapwood width

	Crown position	
	Under dominant layer	Dominant layer
Mean width	2.73	3.32
Standard deviation	0.10	0.22
N	76	34

Table 8. Effect of tree health on sapwood width

	Health state[a]		
	State 1	State 2	State 3
Mean width	2.88	2.84	3.32
Standard deviation	0.12	0.22	0.29
N	77	21	11

[a] Tree health was coded as follows: State 1 – Good; State 2 – Poor, bush knife wounds; State 3 – Bad, holes at base, fungal attack, severe knife wounds.

Correlations were sought between sapwood width and growth rate as measured directly by periodic girth increment, and between sapwood width and tree age and mean number of apparent sapwood rings, using 68 observations. Only recent growth rate was significantly correlated with sapwood width, with an r value of 0.405.

To summarise, only four of the variables analysed were significantly positively correlated with sapwood width: rate of growth over the last few years, height of branching, soil depth and tree dominance. All of these are reflections of overall tree vigour. Thus we can say that, as a generalisation, heartwood content of a tree is inversely proportional to its vigour. This conclusion has important implications for sandalwood management, as most forest managers would aim for maximum growth rate, which may result in less than optimum heartwood production.

Growth Rates of Sandalwood

The effect of soil depth on tree increment was studied with the same 68 samples used above. Statistically significant differences were found between shallow (less than 10 cm deep) and deeper soils (Table 9).

Growth rate is also affected by the plant association in which the sandalwood is growing. A total of 106 observations were made in a variety of situations in an attempt to define where sandalwood grows best. The data in Table 10 indicate that sandalwood grows more slowly in open forest than in the other situations. However, it is difficult to assess the effects of soil depth and of plant association as the two tend to be strongly linked.

Table 9. Growth rate of sandalwood on different soils

	Soil type		
	Limestone outcrops	Soil depth < 10 cm	Soil depth > 10 cm
Mean girth increment (cm/year)	1.32	1.26	1.49
Standard deviation	0.09	0.09	0.09
N	20	22	26

Table 10. Influence of adjacent vegetation on sandalwood growth

	Plant association			
	Open forest	Abandoned garden	Shrubs	House gardens
Mean girth increment (cm/year)	1.13	1.46	1.47	1.51
Standard deviation	0.04	0.09	0.20	0.11
N	32	27	13	34

The information on sandalwood growth rate in New Caledonia is as follows: on shallow soils and in open forests, the annual girth increment is 1.2–1.3 cm per year; on deep soils and in plant associations affected by human activity the trees grow at about 1.5 cm girth per year.

Management Implications

These studies were carried out in natural sandalwood stands in New Caledonia. One of the conclusions reached, on the basis of the high variability of heartwood content at any tree size, was that trees reach maturity at different heights and diameters. Management of these stands is therefore complex.

If plantations of sandalwood are developed, some of the factors affecting rate of growth and time to maturity may be controlled, by choice of host species and the relative stocking of the parasite and host. However, much remains to be learned about the influence of different hosts on heartwood quality. In the present state of knowledge, *Acacia spirorbis* seems to be the best host plant to use in plantations.

The conclusion that heartwood content is negatively associated with sandalwood growth rate, needs further study, as it has implications for sandalwood plantation management. Because of the high investment in a plantation it is usual to maximise tree growth, but if this results in an overall low production of heartwood, then little will have been achieved. The value of sandalwood is such that further research on this aspect is justified.

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Appendix 1

Host Species Most Frequently Found with Sandalwood

Common name	Species	Family
Cocotier	*Cocos nucifera*	Palmaceae
Bananier	*Musa* sp. f *paradisiaca*	Musaceae
Pomme-canelle	*Annona squamosa*	Annonaceae
Carosol	*Annona muricata*	"
Manguier	*Mangifera indica*	Anacardiaceae
Faux poivrier	*Schinus terebenthifolius*	"
Avocatier	*Persea americana*	Lauraceae
	Acronychia laevis	Rutaceae
	Lantana camara	Verbenaceae
	Aglaia elaegnoides	Meliaceae
	Disoxylum sp.	"
Lilas	*Melia azedarach*	"
	Olea paniculata	Oleaceae
	Cupaniopsis sp.	Sapindaceae
	Podonephelium homei	"
	Celtis paniculata	Ulmaceae
Bois noir	*Albizia lebbek*	Leguminosae
Mimosas	*Leucaena leucocephala*	"
Gaiac	*Acacia spirorbis*	"
Kohu	*Intsia bijuga*	"
Flamboyant	*Delonix regia*	"
	Glochidion sp.	Euphorbiaceae
	Ficus sp.	Moraceae
Arbre à pain	*Artocarpus altilis*	"
Banian	*Ficus prolixa*	"
Ralia	*Schefflera* sp. f *golip*	Araliaceae
Papayer	*Carica papaya*	Caricaceae
Pin colonnaire	*Araucaria columnaris*	Aruacariacaeae
	Plectronia odorata	Rubiaceae
Tairé	*Gardenia taitensis*	"
Caféier	*Coffea arabica*	"
	Ixora collina	"
	Maba buxifolia	Ebenaceae
Pêcher	*Prunus persica*	Rosaceae
Cerisier bleu	*Elaeocarpus augustifolius*	Elaeocarpaceae
Barbarie	*Opuntia ficus indsia*	Cactaceae
	Elaeodendron sp.	Celestraceae

Sandalwood in French Polynesia

J-F. Cherrier*

Abstract

Sandalwood has a place of some importance in the history of French Polynesia. It is still sought after for use in local handicrafts and traditional cosmetics. However, little is known about the extent of the resource remaining and very little is known about its ecological requirements or silviculture. Nevertheless, the species deserves further study with the hope of one day establishing plantations.

SEVERAL varieties of sandalwood (*Santalum* sp.) occur in the Polynesian Islands and those of the French Territories were exploited by traders from the beginning of the nineteenth century. This paper is a brief overview of the range of occurrence and utilisation of the species in this region.

Occurrence

Sandalwood occurs widely in French Polynesia as a shrub or small tree. The classification by Fosberg and Sachet (1986) recognises one species with several varieties:

- *S. insulare* Bertero var. *insulare*, a shrub occurring at an altitude of 600–700 m on Tahiti and Moorea.
- *S. insulare* var. *alticola*, a shrub growing between 400 and 1200 m altitude on Tahiti and Moorea.
- *S. insulare* var. *marchionense*, a small tree from 300–1200 m altitude on Marquesas.
- *S. insulare* var. *deckeri*, a shrub growing between 250 and 900 m altitude on Marquesas.
- *S. insulare* var. *margaretae*, a small tree from Rapa.
- *S. insulare* var. *raivavense*, a small tree growing between 60 and 900 m altitude on Raivavae.

The ecological requirements of these varieties are unknown at present. Based on a few observations, it appears that *S. album* introduced from India is more adaptable and thus better suited for plantations.

The Tahitians distinguish two varieties of wood (Petard 1986): ahi marea, or yellow sandalwood, and ahi uta, or red sandalwood. The latter has harder and more strongly scented wood.

The Marquesans, on the other hand, recognise four types of sandalwood:

- puahi, which has strongly scented red-brown heartwood and white flowers;
- puahi kua, which has red-brown heartwood, but green flowers;
- puahi fiti, which has very hard heartwood (abundant on Tahuatu Island);
- puahi avaava, which is similar to puahi fiti, but more strongly scented.

Natural stands of *S. insulare* var. *marchionense* still exist on the island of Nuku-Hiva at altitudes between 800 and 1000 m on the eastern and western slopes of the Tekao Range. They occur generally on dry ridges, growing with *Metrosideros*, *Weinmannia* and *Gleichenia*, forming shrubberies 3–4 m high, with some individuals reaching 8 m and a diameter at breast height of 35 cm.

Utilisation

Naturally occurring sandalwood has never been exploited in a rational manner in French Polynesia. Uncontrolled and excessive cutting has thus greatly reduced the reserves of the species. Sandalwood timber has always had a very high commercial value.

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In the period 1811–1820, American and European traders exploited sandalwood almost to the point of exhaustion in Polynesia.

In recent years the Territorial Service of Rural Economy, in cooperation with the local government, has permitted controlled fellings for a craftwood market.

Exploitation of all trees (including sandalwood) is regulated by Decision No. 58-13 of 7.2.58 of the Forestry Service of French Polynesia. All tree felling requires a permit from the Forest Service, but unfortunately this regulation has not, in practice, eliminated unauthorised felling of the remaining sandalwood stands, particularly on the island of Nuku-Hiva (Marquesas). The local authorities therefore established the program of permitted cutting (of dead trees only) to supply local craftsmen. In 1987 each applicant cut his own wood, but variable supplies led the Forestry Service in 1989 to carry out the harvesting itself and make a free distribution to the users.

Besides wood carving, sandalwood was traditionally used in French Polynesia to make scented coconut oil (monoi) as a cosmetic. Some prices of sandalwood objects in the market at Taiohae (Nuku-Hiva) are as follows:

- Tiki – 9000 to 12000 CFP depending on the carving
- Bracelets – 1000 to 3000 CFP depending on width
- Ear rings – 1000 CFP a pair
- Garlands – 3000 to 5000 according to composition
- Necklace – 2500 to 3500 CFP depending on the composition
- Bottle of monoi – 3500 to 5000 CFP depending on the content

These prices vary by 100% according to the appearance of the client (U$1 = 90 CFP).

Acknowledgment

Thanks are due to Tuhito Utia for his invaluable information.

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Sandelwud Bilong Vanuatu—a Bright Future?

G. Daruhi*

Abstract

The species of sandalwood occurring in Vanuatu is *Santalum austrocaledonicum*. Following heavy exploitation in the mid nineteenth century, there has been little economic use of the species in Vanuatu since that time. Sandalwood is still widely distributed on the island of Espiritu Santo, and other islands from Efate southwards, although its conservation status is such that the Vanuatu Government has placed a moratorium on harvesting in recent years. Efforts are being made to encourage farmers to plant sandalwood in old garden areas, but without great success so far.

SANDALWOOD in Vanuatu was the reason for much of the early contact between the island people and Europeans. There was a period of intense exploitation during the mid nineteenth century. Following the apparent exhaustion of the resource, virtually nothing was harvested for the next 100 years, and a considerable amount of regrowth occurred. There is now increasing interest by commercial groups in renewed sandalwood harvesting, and by the Vanuatu Government, which sees sandalwood as a potentially useful export for the country.

Most sandalwood in Vanuatu occurs on privately owned land. The Government is concerned that farmers are given incentives to carry out reforestation so that the long-term conservation of the species and the sustainability of the commercial operation are assured. Information on appropriate reforestation techniques needs to be made available to farmers. Information on the extent of resources is required before any planning for exploitation and utilisation can be undertaken. Until the resource information is available from the current Vanuatu forest inventory, there is a moratorium on sandalwood harvesting.

Information on the Species

The sandalwood occurring in Vanuatu is believed to be *S. austrocaledonicum* Veillard (Bule and Daruhi 1990). It is a small tree, 5–8 m high and up to 30 cm in diameter. The stem is greyish green, rough and fissured longitudinally. The leaves are opposite, simple, oval to elliptical in shape, shiny on top and glaucous underneath. The tree usually has a low branching, scraggly form, a short bole and a conical crown shape.

The flowers, which may occur throughout the year, but especially from January to April, are small, greenish white and arranged in a corymb. The mature fruits are an ovoid drupe 5–8 m in diameter, with a small depression near the tip, bluish black ripening from June to November (Neil 1986). Although the tree can flower at an early age, good seed production is obtained only from trees older than 10 years. A mature tree can produce 8000 to 12 000 seeds in a crop. Seed yield in Vanuatu is often adversely affected by the depredations of birds and by damage to the trees by cattle.

On most islands in Vanuatu, local people recognise two types of tree, identified by their leaf size. The small leaf type is said to be the 'male' and bears few, if any, fruit, and also does not have strongly scented heartwood. The broader leaf type, referred to as the 'female' is the prolific seed bearer, has a more strongly scented heartwood and also grows faster than the 'male'.

Interestingly, there is no local name for sandalwood in any of the islands and 100 dialects comprising

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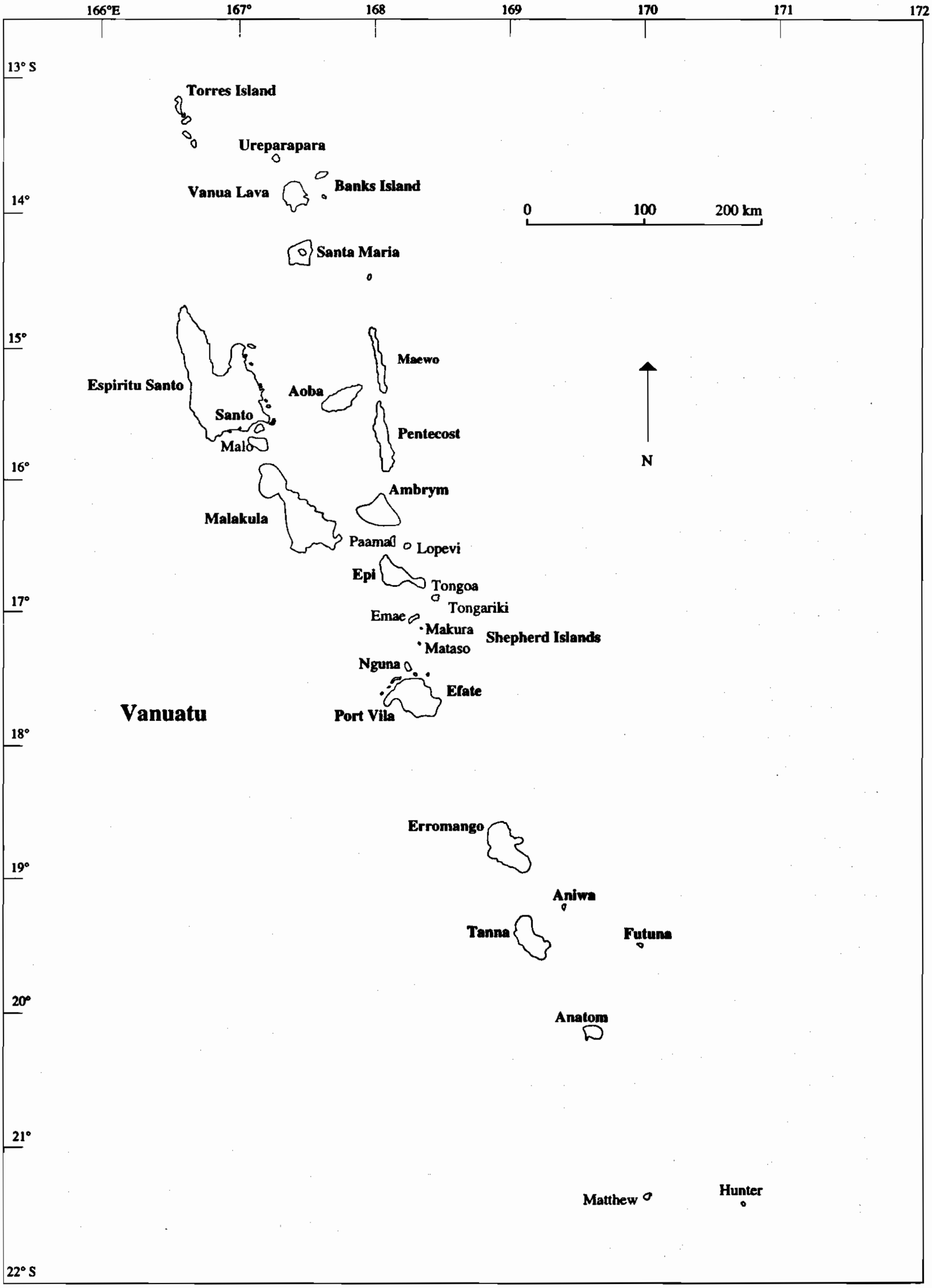

Fig. 1. Map of Vanuatu showing locations of sandalwood-growing areas mentioned in the text.

Vanuatu. It is known only as 'sandelwud' in Bislama, and is being adopted under that name into the local dialects. There is no known traditional use for sandalwood in Vanuatu. Local people use it only for firewood.

The principal occurrence of sandalwood in Vanuatu is around the north-west, west and south-west portions on the island of Erromango and on Espiritu Santo (Fig. 1). The sandalwood occurs in low open forest dominated by *Acacia spirobis*, mixed with low shrubs, mainly of the family Cyperaceae. There, the sandalwood forms 20–50% of the overstorey. Other plants with which it is found are coconut, grasses, *Hibiscus tilliaceus*, *Dracontomelon vitensis*, *Garuga floribunda* and *Pterocarpus indicus*. Sometimes the vegetation is open woodland, but it can be closed forest.

On Erromango, the sandalwood are found growing on both young and old low dissected volcanic plateaux. The rainfall varies from 2300 to 2600 mm, e.g. at Ipota, and is received from November to March. The northwestern part of the island, around Dillons Bay, is much drier, perhaps only 1500 mm. Daytime maximum temperatures average 28°C, with minima around 23°C.

Utilisation

Records of sandalwood utilisation have been kept in Vanuatu only since 1977. There is believed to have been, before that, a considerable amount of trade with overseas buyers, the villagers dealing directly and the timber going mainly to Taiwan and China. After records began to be kept, a total of 726 tonnes of sandalwood was exported between 1977 and 1987 (Vanuatu Statistics Office 1988), with a value of 67 million Vatu (equivalent to US$558 000).

All this harvesting was uncontrolled and there was no official planning to ensure that the resource was used to the best advantage. Villagers simply harvested the stems, roots and limbs of any tree considered of suitable size. It appears that immature trees were also taken.

Conservation Status

Since 1820, an enormous quantity of sandalwood has been harvested from Aneityum, Erromango, Tanna and Espiritu Santo. A major step forward has been the imposition in 1987 of a moratorium on cutting, and a requirement to have a licence for export of sandalwood. The first moratorium expired in December 1990 and was renewed for a further 5 years. This was intended to give time to complete an inventory of Vanuatu forest resources, so that there could be rational planning for sandalwood utilisation.

So far it appears that the species is well represented, although often with only small trees, on most islands were it was known to exist before. Only on Aneityum is there cause for concern about its survival. There are now known to be only about 10 small trees left on that island. While it is possible to procure seed from other islands, there is no doubt that we have already lost some of the genetic variation on this island.

In some areas wild cattle are a destructive agent and either destroy or damage young sandalwood.

As the sandalwood resource occurs on privately owned land the approach of the Forestry Department has been to try to develop suitable establishment methods and pass the information on to villagers. While the research has not been as successful as hoped, the extension work has had some beneficial effect, in that there is certainly more interest among farmers in replanting sandalwood.

Silviculture

The method currently used in Vanuatu is to collect seed in either April–June or October–November. The seedlings are raised in temporary nurseries in the villages, using whatever materials come to hand for plant containers, such as bamboo tubes or old rice bags. Germination is usually good and there is no particular difficulty in raising seedlings about 20 cm high in about 6 months. Currently some problems are being experienced with an unknown insect which kills the plant growing tip, leading to death of small seedlings and forking in older plants.

There is little definitive information on sandalwood growth rate in Vanuatu. The only indication of growth rate is given by a small plot of trees planted in 1989 at Ipota, on Erromango. At 22 months after planting, the mean height of the sandalwood was 1.91 m and the mean basal diameter was 1.04 cm.

No research on plantation management has yet been carried out in Vanuatu, but it is hoped that we can develop a cooperative program with the French CTFT forest research station in New Caledonia, where they have the same species.

Conclusions

It is clear that sandalwood has good commercial prospects in Vanuatu, provided sound management practices are introduced and there is a continuing program of regeneration by landowners. The national forest inventory will give the Forestry Department the information on which to base long-term utilisation plans so that the resource can be used for optimum benefit of the people. The intention is to work towards the development of an industry which is sustainable in the long term, if there is sufficient resource to justify this.

When the moratorium is lifted, the Department will need to set up a marketing unit to ensure that harvesting is kept within the specified limits and sellers receive a fair price for their timber.

With the assistance of CTFT, demonstration plots of sandalwood will be established and the necessary materials to support an extension program will be developed.

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Biogeography and Traditional Use of *Santalum* in the Pacific Region

Peter Brennan and Mark Merlin*

Abstract

Santalum has a disjunct known distribution among the islands of the Pacific Ocean. During the prehistoric period, Melanesian and Polynesian Islanders, who had access to native sandalwood trees and shrubs, utilised the aromatic heartwood for a variety of medicinal and other purposes. Some uses had significant social import, motivating trade of *Santalum* from Fiji to Tonga for status and aesthetic reasons. Pre-contact trade of sandalwood may also have occurred between other South Pacific Islands in Eastern Polynesia. This paper describes the biogeography of *Santalum* spp. and reviews some aspects of the ancient and more recent history of the use of, and human environmental impact on, sandalwood species in the Pacific.

THE story of sandalwood trade between entrepreneurs of European ancestry and Pacific Islanders during the first half of the nineteenth century, has been well told (Shineberg 1965, 1967). The beginnings of this trade can be traced to the introduction of Buddhism into China from India in the first century. With this came the practice of burning sandalwood in temples. As China had no supply of its own, a trade in sandalwood developed with India. Later, when Americans and Australians wanted to trade in Chinese teas, silks, porcelains and other Asian goods, they had to find trade items acceptable to the Chinese. This led to the discovery of sandalwood on many Pacific Islands and an ensuing brief, but intense, exploitation of the wood. The supplies of sandalwood were exhausted on island after island. This trade began in Hawaii sometime shortly after 1790 and was all but over by 1865 with the last shipments from south-west Melanesia (Bradley 1968; Merlin and Van Ravenswaay 1990).

The accounts of this trade generally portray sandalwood as having little value to the natives of the Pacific Islands. Shineberg (1979) claims that 'With very few exceptions, none of them used their sandalwood except as fuel, like any other wood'. This may be true of some islands in Melanesia; for example, a Melanesian chief from the raised coral island of Uvea in the Loyalty Islands told the captain of an Australian ship seeking sandalwood in 1842: 'the Island produced abundance of Sandal Wood that they did not use it for any purpose ...' (Shineberg 1967).

However, a review of the ethnographic literature and the accounts of the first European visitors to the Pacific indicate that sandalwood was used extensively throughout Polynesia and Australia, and some areas of Melanesia, for a wide variety of uses. Indeed, it was highly valued in many areas, especially in parts of Polynesia, and was even an important trade item between some island groups before the arrival of Europeans.

Currently, there is renewed interest in the economic potential of sandalwood in the Pacific and Australia (Hamilton and Conrad 1990). In this paper we review the biogeographical distribution and traditional uses of the genus *Santalum* in the Pacific and Australia.

Distribution of *Santalum*

Native *Santalum* are, or were, distributed widely, possibly from as far west as India, and certainly from eastern Indonesia through much of Australia and many of the Pacific Islands as far east as Juan Fernandez off the coast of South America. All of the known species in the genus are, or were, present in the Pacific region. There are, however, significant gaps in the distribution of the genus throughout the Pacific which make it of particular phytogeographic interest (see Fig. 1).

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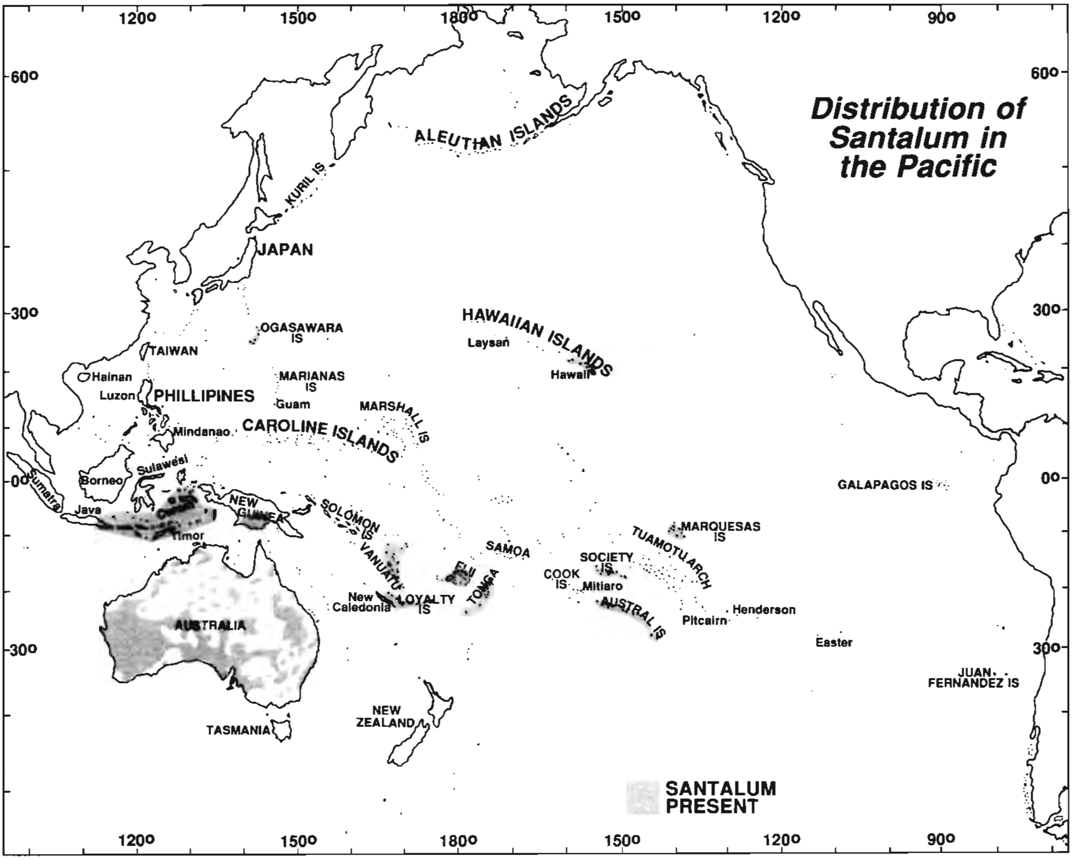

Fig. 1. Distribution of *Santalum* in the Pacific Region.

The genus *Santalum* belongs to Santalaceae, a family in the order Santales. According to Tuyama (1939) there are four sections of *Santalum*: *Eusantalum*, which includes nine species; *Solanantha*, which includes four species; *Hawaiiensia*, which includes four species; and *Polynesica*, which includes three species—a total of 20 species. More recently, Van Balgooy (1966) listed 19 species in the genus and divided them into four sections: *Santalum*, *Solenentha*, *Hawaiiensia* and *Polynesia*. The genus, which includes tree and shrub species, has undergone extensive revisions with reductions in the number of species; and van Balgooy (1966) predicted that this number would be reduced still further (e.g. in Hawaii, see Wagner, Herbst and Sohmer 1990).

A review of the most current literature indicates that there are 16 known species (one of which is assumed to be extinct) and 17 recognised varieties (Hamilton and Conrad 1990: Table 1).

According to van Balgooy (1966), in Australia and the Pacific species within the section *Santalum* occur in Australia, New Guinea, New Caledonia, Loyalties, Vanuatu, Fiji, Tonga and the Ogasawara (Bonin) Islands. Species within the section *Solenentha* and *Hawaiiensia* occur only in the Hawaiian Islands, and those within the section *Polynesia* in the Marquesas, Society, Austral, and Juan Fernandez Islands. In addition, *Santalum* (*S. insulare*, listed in section *Polynesia* by van Balgooy) is also found on Mitiaro (Cook Islands) and Henderson (in the Pitcairn Island Group).

The genus *Santalum* has its northernmost limit in the Ogasawara Islands (26–28° N, 142°E), where there is an endemic species, *S. boninensis*. Because of historic exploitation and habitat loss, this sandalwood species is now an endangered species (Maina et al. 1988)

Santalum is absent, however, from Micronesia, the nearest islands south of the Ogasawara group. In this aspect its distribution is similar to that of *Metrosideros*, a genus of woody species in Myrtaceae commonly found in the forests of many high volcanic Polynesian and Melanesian Islands, but not in similar habitats in Micronesia. This leaves a gap in the distribution of *Santalum* of over 3000 kilometres from the Ogasawara Islands to the nearest sandalwood, *S. macgregorii*, in southeastern New Guinea.

Santalum is absent from the Solomon Islands. This is especially puzzling since suitable habitats for its growth exist within these islands, and native sandalwood species are present in nearby New Guinea to the west and Vanuatu and New Caledonia to the southeast (Whitmore 1969).

Although *S. album* is present in Samoa (Kramer 1903), it was, in all likelihood, introduced into this archipelago after the time of European contact. This economically important species is certainly native to parts of Indonesia and possibly India (cf. Hamilton and Conrad 1990). It is also found in some coastal areas of northern Australia, where pre-European trade with early Indonesian seafarers may explain its distribution in this region of Australia (see below). However, there is no evidence in oral tradition that any sandalwood trees were present in the Samoan Islands before European contact, even though *S. yasi* was a common species in areas of the Fijian Islands to the west and the Tongan Islands to the south (in the latter archipelago its ecological distribution suggests that it may be a naturalised member of the flora, probably introduced prehistorically from Fiji; see below).

In the Cook Islands, *Santalum* has only been found on the small island of Mitiaro (*S. insulare* var. *mitiaro*, see Sykes 1980). This is the same species that is present in the Society Islands (var. *insulare*, var. *alticola* and var. *raiateense*), Australs (var. *Margaretae* and var. *raiavanse*), and Marquesas (var. *deckeri* and var. *marchionense*). In addition, 1500 kilometres to the east of Mitiaro is a variety of *Santalum insulare* (var. *hendersonense*) endemic to Henderson island, and approximately 5000 kilometres to the west of Mitiaro, a species endemic to the Juan Fernandez Islands (*S. fernandezianum*) has apparently become extinct (see below); interestingly *Santalum* is not known from the intervening island of Rapa Nui (Easter Island), nor from the Galapagos islands to the north.

Santalum (*S. fernandezianum* F. Phil.) reportedly disappeared from the Juan Fernandez Islands during the early part of this century (Skottsberg 1956; Munoz 1973). The former presence of *Santalum* on the Juan Fernandez islands is particularly interesting. It is one of only three non-endemic genera in the flora of these islands that are unknown on the American continent only 600 kilometres distant to the east. In all the other American Pacific Islands all the non-endemic genera are also present on the continent (van Balgooy 1971).

The Hawaiian species belong to two sections, according to van Balgooy, possibly reflecting two immigration routes, one from south-eastern Polynesia and the other through the western Pacific. The fact that these original immigrants of such a slow growing plant have had enough time to evolve into different sections in Hawaii, and to radiate into different species and varieties in the respective sections within this archipelago, indicates that their arrival there obviously predates the earliest evidence of human occupation (approximately 1500 B.P.).

The above account shows that the genus has spread great distances, probably from insular Southeast Asia or Australia, to some of the most isolated areas of the Pacific, including the Ogasawara, Hawaiian and Juan Fernandez Islands. However, it is absent from many of the intervening islands between Indonesia and the Juan Fernandez Islands, as well as between the Ogasawara Islands and New Caledonia.

Although *Santalum* is present on many high volcanic islands, it also grows on a number of raised coral islands, including the Loyalty Islands, Henderson and Mitiaro. Another species (*S. insulare*) was found on the coral flats of the small northwest Hawaiian atoll of Laysan. Earlier this century it became extinct on that island owing to the impact of introduced rabbits (Culliney 1988). The presence of *Santalum* on islands with raised coral environments seems to suggest that it is capable of migrating from sinking high islands to the exposed, former fringing reefs and establishing there; or perhaps the reverse has occurred (see next section).

Ecological Aspects

Until recently, the literature contained very little information on the ecology of *Santalum* in the Pacific and Australia. For recent discussions of natural and applied studies of the biology of *Santalum* see Hamilton and Conrad (1990), and other papers in this volume. The relative paucity of ecological information for sandalwood in the Pacific region is no doubt partly due to the fact, because of the extensive sandalwood exploitation during historic times, very little remains of the original stands on many islands. A perplexing question remains: just how common was *Santalum* in the region?

As previously noted, *Santalum* species are slow-growing plants, taking 30 years or more to reach a harvestable stage, and birds are probably the primary agent of dispersal. Propagation is by seed or root shoots. Carlson and Bryan (1959) reported that *Santalum* seeds readily but that inspection of sandalwood areas in Hawaii did not reveal any seedlings though numerous root shoots were seen. This may have been the result of grazing by cattle, sheep and goats or the absence of suitable host plants. Alien rats could also be hindering the seedling growth of *Santalum*; for example, seedling consumption by *Rattus rattus* has apparently affected the reproductive success among the threatened population of *S. haleakalae*, endemic to the sub-alpine zone of Maui Island (Merlin and Van Ravenswaay 1990).

A review of information gleaned mainly from herbarium labels shows that the genus and most individual species grow in a wide variety of habitats. Specimens of *S. insulare* have been collected from coral gravel at sea level on Matu Tehau and at 2000 m in the Societies (Sykes 1980). In Hawaii, on Maui, *S. haleakalae* occurs as high as 3000 m. In Tonga, *S. yasi* has been collected on a limestone terrace at sea level and from a mountain ridge with volcanic soil (Yuncker 1959). In Australia, *Santalum* occupies habitats ranging from coastal sand dunes and the central desert to forests. Most of the species are restricted to the drier areas of the continent with rainfall below 40 cm or to the seasonally dry far-north. *Santalum obtusifolium*, however, is restricted to the moister central and southern east coast (Hewson and George 1984).

Although the genus grows in a variety of habitats, many authors report that the most fragrant wood is believed to come from trees growing in rocky and dry sites and that those from moist sites with good soil are degenerate (Bennett 1832; Seemann 1869; Shineberg 1967).

There is very little information in the literature about the species which occur naturally in association with *Santalum* and those which may act as hosts. Sykes (1980) lists the dominant trees associated with *S. insulare* on Mitiaro in the Cook Islands. They are *Guettarda speciosa* L., *Pandanus tectorius* Parkins., *Pisonia grandis* R. Br., *Planchonella costata* (Endl.) Pierre, *Casuarina litorea* L., and a species of *Celtis*. Unfortunately he was unable to search for haustoria to ascertain which of these were hosts to the *Santalum*. In central Australia, *S. lanceolatum* R. Br. is found on sandhills where grasses of the *Trioda* and *Pleactrachne* genera are dominant with scattered shrubs and low trees of *Eucalyptus* and *Acacia* are present (O'Connell et al. 1983). Carlson and Bryan (1959) reported that, in Hawaii, *S. album* has been planted with ironwood (*Casuarina* spp.) as a host. Unfortunately, no indication is given as to its success. Given the wide range of habitats occupied by *Santalum*, it seems that it must be able to utilise many species as hosts (cf. Hamilton and Conrad (1990), and other papers in this volume).

Impact of Trade and Environmental Change

Santalum is obviously a widespread species in the Pacific region, but again, just how common was it before European contact? Parkinson (1773), a botanical draughtsman on Captain James Cook's first voyage to Tahiti, reported that sandalwood was very scarce there and that they could 'never get sight of the tree, but were told it grew on the mountains'. He also said that it was 'in great request amongst' the inhabitants. Henry (1928) using her grandfather's notes compiled in the early part of the nineteenth century, also indicated that sandalwood was scarce in the Society Islands. In the Marquesas however, the same species was abundant (Brown 1935; Maude and Crocombe 1962) and supported a busy historic trade for several years prior to 1820.

Andrew Cheyne, who conducted the first sandalwood trading voyage to the Isle of Pines off New Caledonia in 1841, noted in his log that 'the trees are very scattered' (Shineberg 1971). Shineberg (1965) quoted missionaries who visited Erromanga in Vanuatu in 1825 as noting that sandalwood was abundant close to the shore. Yuncker (1959) indicated that *Santalum* was frequent in thickets throughout Tonga. It is thought that *Santalum* must have been very common in Hawaii prior to the China trade since so much was exported (Stemmerman 1977). Skottsberg (1956) suggested that sandalwood must have been rather abundant in the Juan Fernandez Islands because of the many place-names that refer to it, for example, Quebrada (ravine) Sandalo and Quebrada Sandalito, on the east side of Masafuera (Alejandro Selkirk) Island.

A review of the literature tends to indicate that on some islands it was abundant while on others it was scarce. This difference in abundance may reflect differences in the physical and biological conditions affecting its growth. Conceivably though, it may also reflect different levels of exploitation and conservation in the different islands, both before and after European contact.

The disjunct distribution of the genus raises a number of interesting questions. Is this distribution the result of chance events in sandalwood dispersal or due to its extinction on many islands? In India, *S. album* is mainly spread by birds (Guppy 1906). In Australia, the seeds of several species have been found in the droppings of the large flightless emus (Pate and McComb 1982). Land birds (such as pigeons, fruit dove, starlings, etc.) are indeed the most likely agents of natural dispersal of the genus throughout the Pacific. However, it is improbable that chance dispersal events could explain the absence of the genus from islands such as the Solomons and Samoa which are relatively close to source areas.

The direct and indirect human role in the extinction of *Santalum* from some islands, such as that which occurred on Laysan Island in the Hawaiian archipelago (see above), has been documented for the post-contact period. Another example, the alleged extinction of *Santalum* in the Juan Fernandez Islands may have been just one of many cases of extinction, but one which Europeans caused and later recorded. Sandalwood on these islands was recognised as early as 1624 by Le Hermite, and the commercial exploitation of *S. fernandezianum* could have begun as early as this (Wester 1991). Sprague and Summerhayes (1927) claimed that all the trees of the species died in one year from an epidemic, however they give no source for this statement. Skottsberg (1956) suggested that the species was exterminated through commercial cutting and the general devastation of the forest (see also Munoz 1973). Wester (1991) tells us that thorough harvesting of the sandalwood trees 'occurred between 1835 and 1872' and that the species 'is now believed to be extinct'.

Santalum ellipticum, a Hawaiian species, probably no longer exists on the island of Kahoolawe (Stemmerman 1977). This species was probably extirpated from that island because of habitat loss due to the devastating influence of domestic and feral ungulates introduced during the late nineteenth and early twentieth centuries (Merlin and Van Ravenswaay 1990).

The endemic variety of *S. insulare* on Henderson Island (var. *hendersonense*) was observed in 1934, by St John and Philipson (1962), as being common on the coralline plateau of this raised atoll. It was not sighted by Paulay and Spencer (1989) in their 1987 survey in which they refer to the sandalwood on this island as belonging to an endemic species (*S. hendersonense*); however, they also note that a resident of Pitcairn Island indicated that 'the species occurs only in localised clusters'.

For at least a century, if not much longer, Pitcairn Islanders have visited Henderson Island on a 'fairly regular basis, chiefly to cut miro wood, *Thespesia polpulnea*, from which carvings are made for sale to visitors' (Fosberg et al. 1983). Based on the use of the genus elsewhere in the tropical Pacific, prehistoric collection of sandalwood may have also taken place on this island and had some impact on the relative abundance of the species on Henderson.

In northwestern Melanesia, the often violent sandalwood trade of the nineteenth century had significant impact on the history of the native peoples and the populations of *S. austrocaledonicum*. For example, at the height of the trade in the middle of that century on the small island of Aneityum (Vanuatu) alone, 'an average of forty anchorages a year were made' to collect sandalwood; and by the second half of the nineteenth century, sandalwood appears to have become extinct on that island (Shineberg 1967:179). Elsewhere in Melanesia, Whitmore (1969) has suggested that forest destruction for agriculture may explain the absence of *Santalum* from the Solomon Islands; if so, when did the genus become extinct in this archipelago—before or after European contact? There appears to be no record of sandalwood exploitation during the post-contact period in the Solomons.

Human impact during the prehistoric period may well have had a significant influence on the distribution of *Santalum*, even resulting in the complete disappearance of sandalwood plants from some islands, or more often from some areas of these islands. The hemiparasitic habit of the genus would also make sandalwood plants more susceptible to reduction in numbers and, in some extreme cases, even to extinction because of limiting natural regeneration when appropriate host species were removed by human impact. During the prehistoric period *Santalum* may have been destroyed or seriously affected on these islands by some combination of direct exploitation of the precious heartwood, inter-island trade of this valuable natural product (see below), and the early clearing of lowland vegetation, especially in the drier areas with stony soils, which may have included sandalwood trees or shrubs. Prehistoric human impact on some forest ecosystems of tropical Pacific Islands, especially in the drier environments, where extensive areas of the woody vegetation has been converted to grassland, is reviewed by Kirch (1982, 1983, 1984).

Since sandalwood was used widely throughout Australia and the Pacific it is possible that humans also played a role in the dispersal of *Santalum*, although this is difficult to assess fully, especially for the prehistoric period. In Australia, *S. album* is confined to the northern coastal areas. These areas were known to have been frequently visited, in the centuries immediately prior to European contact, by fishermen from the eastern Indonesian islands where the species is also present. It is probable that in northern Australia *Santalum* was introduced by these early Asian sailors.

Seemann (1869) reported that the Tongans traded with the Fijian Islands for sandalwood and brought *S. yasi* back to Tonga to transplant. Although this species occurs in Tonga and has been reported by Yuncker (1959) to be common throughout this island group, it was found to have little scent and the trade with Fiji continued. In the Southern Lau Islands, Thompson (1940) reports that the women planted seeds of *S. yasi* from Vanua Mbalavu but they did not grow very well and the wood was not very fragrant. Although there is no indication as to whether this practice pre-dated the arrival of Europeans in the region, the Southern Lau Islands had very little direct contact with Europeans at the time of Thompson's study.

In fact, there was a regular long-distance exchange of chiefly spouses and material goods between Tonga and Fiji during the prehistoric period (Kaeppler 1978). High ranking females and assorted male goods, including whale's teeth ('the essence of Fijian wealth', see Kirch 1984), fine mats made in Samoa, ornaments, and barkcloth were sent from Tonga to Fiji in this pre-European trade. In exchange, female prestige goods, including canoes, red feathers, decorated barkcloth, mats, baskets, sails, pottery and sandalwood were imported from Fiji to Tonga (Tippett 1968). The sandalwood was used in the making of scented oil (its use is discussed below).

This prehistoric exchange had important political, as well as utilitarian, consequences (Kaeppler 1978; Kirch 1984). The red feathers, fine mats, and sandalwood brought from Fiji to Tonga during this traditional prehistoric and historic trade were known as *koloa*, valued 'prestige items vital to Tongan marriage alliances' (Kirch 1984). The most significant context in which these Fijian prestige trade items were used in Tonga was 'on ceremonial occasions—and especially weddings, funerals, and various kinds of state and religious celebrations' (Kaeppler 1978). Overall, the trade, monopolisation and use of the prestige exchange goods helped the paramount chiefs of Tonga to solidify their power over the maritime chiefdom political system of the archipelago.

Prehistoric trade of sandalwood products may have had some effect on the use and distribution of the species in other parts of Polynesia such as the Cook, Society, Austral, Marquesan and Hawaiian Islands. For example, on Mangaia, it was reported in the nineteenth century that sandalwood oil was used to perfume native barkcloth and to help waterproof the fragile material [Gill (1892); see also Campbell (1822) for comments on the extreme fragility of the barkcloth when wet]. The reference to the use of sandalwood in Mangaia is intriguing because no *Santalum* is found on this island today. Sandalwood oil, wood or even seeds could have been imported to Mangaia during the historic or prehistoric period from Mitiaro, another small Cook Island about 200 kilometres to the north, where *S. insulare* is found today in small numbers in a restricted area in the interior; or perhaps *Santalum* has been extirpated from Mangaia (and possibly other Cook Islands) due to overexploitation and/or habitat loss during prehistoric and historic times (see Merlin 1991 for a discussion of human impact on the vegetation of Mangaia, and Merlin 1985 for a discussion of human impact on the vegetation of Rarotonga).

Traditional Uses

Santalum had a wide variety of uses throughout the region before European contact, and there are many reports that indicate it was highly prized in many areas.

The most widespread use was as a scent for coconut oil. Its use in this way has been reported in New Caledonia (Bourret 1981), Tonga (Bennett 1832; Seemann 1869; Yuncker 1959), Samoa (Seemann 1869), the Lau Islands (Thompson 1940), Tahiti (Henry 1928; Parkinson 1784), Tubuai in the Austral group (Aitken 1930), the Marquesas (Brown 1935) and in Hawaii (Handy and Handy 1972). In the Marquesas the sandalwood was grated on the skin of a fish (Brown 1935) and in Samoa, Tonga and Fiji on mushroom coral (Seeman 1869) to produce a fine dust which was then mixed with the coconut oil. The scented coconut oil had a wide variety of uses but was mainly used as a skin lotion, body perfume and hair oil.

On Mangaia, in the Cook Islands, as noted above, the oil was used to perfume garments and to help waterproof them (Gill 1892); this waterproofing use of the pleasant smelling sandalwood oil probably occurred in many areas where barkcloth clothing was used, since 'This cloth, from its texture, is, when wetted, extremely apt to get damaged, in which state it tears like moist paper' (Campbell 1822).

Sandalwood was also used widely throughout the Pacific for medicinal purposes. It has been reported that it was used for the treatment of earache in Tubuai (Aitken 1930), the Marquesas (Brown 1935) and Tahiti (Petard 1946). In Tubuai *Santalum* was grated into a powder and mixed with coconut oil and the leaves of a species of *Cordia*. A few drops of the juice from pressing this mixture were then put into the ear several times a day. Steam from chips of the wood placed on hot coals was regarded as a remedy for earache in the Marquesas. In Tahiti, drops of sandalwood oil were mixed with chopped *Cyperus javanicus*, grated *Cordyline fruticosa* and pressed stems of *Dicronopteris linearis*. This mixture was put in a cloth and placed around the inflamed ear. The odour of the mixture was also inhaled. Petard (1946) claimed to have witnessed the effectiveness of this treatment on several occasions.

In Tahiti (Papy and L'Herbier 1957) and New Caledonia (Bourret 1981), *Santalum* is reported to have been used to treat dermatitis. In New Caledonia grated sandalwood was cooked with grated coconut to make an antiseptic paste which was applied to the affected skin. Kramer (1903) reported its use in Samoa to treat elephantiasis, inflammation of the rib lining and bone ache. In the treatment of elephantiasis, grated sandalwood was mixed with the leaves of *Homalanthus populneus*, diluted with water, strained and taken internally. For inflammation of the lining of the ribs, the juice from a mixture of sandalwood and ground parts of *Phaleria acuminata* was taken.

Guillaumin (1948) reported that the sap from the sandalwood tree was taken internally for bladder trouble and bronchitis in New Caledonia. The juice of the leaves or the grated internal bark of sandalwood, mixed with water, was also taken to gain respiratory relief in cases of pulmonary bronchitis (Bourret 1981). In Hawaii, sandalwood leaves were reportedly put into an infusion used as a shampoo for lice and dandruff, and finely ground powder was mixed with parts of other plants in a drink used to treat ailments of the urogenital tract and sores of long duration (Krauss n.d.). Sykes (1980) reported that sandalwood was used in the preparation of unspecified medical ointments and lotion by the people of Mitiaro and other nearby islands in the Cooks.

A number of other uses have been reported in the literature. Brown (1935) claimed that the Polynesians greatly esteemed sandalwood for ceremonial purposes and that, in the Marquesas, smoke from burning sandalwood was believed to drive away evil spirits. Brown (1935) also reported that this oil had a special use in the Marquesas for embalming the dead. Chips of sandalwood tied in bundles were made into leis and were worn around the head at feasts. In New Caledonia it is believed that termites are repelled by the scent of sandalwood and it is therefore used to perfume thatch cabins to prevent termite attack (Bourret 1981). This application in Melanesia can be compared with that reported by Secoy and Smith (1983) of the use of *S. album* in India as an insect repellent.

In Australia the fruit of at least two species, *S. lanceolatum* and *S. acuminatum*, were eaten by the Aborigines of the central and western parts of the continent (Maiden 1889; O'Connell et al. 1983; Seemann 1869). The root bark of *S. murrayanum* was also used as food by the Aborigines (Maiden 1889).

The above account illustrates that *Santalum* had many traditional uses within the very broad region. However Stemmerman (1977) claims that the Hawaiians did not use sandalwood extensively and Shineberg (1979) claims that the natives of Melanesia had no use for it other than for firewood. This gives the impression that even though it may have been used, it was not considered a valuable or important commodity before European contact. Many of the earliest accounts contradict this contention.

Parkinson (1784), who was on Cook's first voyage to Tahiti, said that sandalwood was 'in great request amongst' the inhabitants. In Tahiti only the chiefs could use it. In the Marquesas, Brown (1935) reports that in ancient times it was 'highly prized' and 'esteemed' even though it was abundant. Bennett (1832) reported that in the Tongan Islands 'a piece of the wood was considered a valuable present by the chiefs' and, as noted above, that they procured it occasionally from the Fiji Islands. Seemann (1869) tells us that sandalwood 'had long been famous' in the Fijian Islands. He also tells us that the Tongans paid for their sandalwood with 'bark-cloth, the sting of a fish used for spears, sail-masts, plaits and a rare ornamental shell peculiar to Vavau'. He also mentions that the Tongans passed sandalwood on to the Samoans. Thompson (1940) mentions that the people of the Southern Lau Islands also traded with Vanua Mbalavu for sandalwood. It also appears that there was trade in sandalwood amongst at least some of the southern Cook Islands, since Sykes (1980) mentions that although *Santalum* only grows on the island of Mitiaro, the people of the other islands in the vicinity also esteem it.

During the early historic period commercial exploitation and trade had ecologically and/or sociologically devastating consequences in several islands including those in Vanuatu, Hawaii and the Juan Fernandez Islands. Although some species of *Santalum* are now rare, endangered or extinct in several Pacific Island ecosystems, recent timber activity in Hawaii has generated substantial revenue and resentment among a variety of people in this island group (Merlin and Van Ravenswaay 1990).

Conclusion

This review shows that *Santalum* has a widespread, but presently disjunct, distribution in the Pacific region. It is a genus of plants that had close links with the traditional peoples of the Pacific. The Polynesians, in particular, held sandalwood in high esteem and exploited it for a wide variety of uses. The similarity of traditional names for sandalwood (e.g. *yasi* in Fiji, *eai* in Tahiti, and *'iliahi* in Hawaii) and uses of it, right across Polynesia, indicate that this was a plant closely related to the spread of Polynesian culture through the region. The role of humans in the spread of the genus and its possible extinction in some areas would seem to be a fruitful topic for future research.

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Sandalwood in Nusa Tenggara Timur

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Abstract

Sandalwood (*Santalum album*) is an important forest product of Nusa Tenggara Timur. The current level of harvest is not sustainable due to the lack of regeneration over many years. A research program in West Timor aims to develop reliable nursery and plantation establishment techniques to underpin a reforestation program for the species. Some preliminary results of this research are presented.

THE forestry sector in the Nusa Tenggara Timur (NTT) province of Indonesia is of paramount importance for regional development, particularly for raising living standards and for providing employment. Since only 40% of the land area of the province is arable, and most of the remainder is usable only for tree growing, the development of viable forest or crop tree-based management systems is a primary objective of regional planning.

The natural forests of the region have a limited range of commercial forest products, although there are many so-called minor forest products used by rural people, such as candlenut, tamarind and cinnamon. The main commercial forest product is sandalwood (*Santalum album* L.), which contributes more than 60% of the value of forest-based activities and about half of the province's export income. It therefore has an important economic role in NTT in addition to its important cultural value as the emblem of the region.

Sandalwood (local name cendana) is endemic to NTT, formerly occurring on Timor, Sumba, west Flores, Alor and Roti islands. However, only on Timor is there still a significant population of the species. This paper refers mainly to that population.

There are two forms of sandalwood found in Timor, a small-leaved form and a large-leaved form. Adriyanti (1989), has proposed that they be known as *S. album* L. var. *album* (small leaf) and *S. album* var. *largifolium* Rudjiman et Adrie var. nov. (large leaf). Field observations by staff of the provincial forestry department suggest that the large-leaf form has higher sandalwood oil content, and this tends to be supported by data quoted by Adriyanti. On the basis of three samples of each type, admittedly a small sample, the mean wood oil content of small-leaved trees was 0.30%, while that of large leaved trees 7.2%.

Sandalwood grows in association with a wide variety of host plants, including grasses, shrubs and trees. The tree species with which it is most often naturally associated in Timor are *Eugenia guajava*, *Casuarina junghuhniana*, *Cassia siamea*, *Schleichera oleosa* and *Pterocarpus indicus* but it is known to parasitise a large number of trees and shrubs.

A comprehensive forest inventory in 1976 showed that the population of sandalwood in NTT was 525 681 trees, of which 422 868 were in West Timor and 102 813 were in Sumba. Since that time there has been continuous harvesting with very little regeneration, and the population is rapidly declining. The main reasons for this are shifting cultivation, uncontrolled cattle grazing, uncontrolled fire and lack of a definite sandalwood reforestation program. The natural stands of sandalwood clearly have a very limited future.

There is an urgent need, therefore, to carry out the research required to support a successful plantation program for sandalwood. This knowledge, combined with appropriate investment in staff training and in plantation establishment, will ensure the species will continue to make a valuable contribution to the economic and cultural life of NTT.

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Area of Occurrence

The NTT province contains several islands, with two very different geological histories, which have profound influences on the nature of the soils, and hence vegetation. The Inner Banda Arc of islands (Sumbawa, Flores, Alor, Wetar) are volcanic in origin, while the Outer Banda Arc (Timor, Sumba, Roti and Sabu), with which we are mainly concerned here, are composed of sea floor deposits uplifted by crustal plate collision. The bedrock material of the Outer Banda group consists of clayey material or coral laid down in a marine environment which gives rise to soils which are heavy textured, and often sodic, alkaline (pH 8–9) and saline.

The Outer Banda islands are composed basically of Bobonaro Scaly Clay, overlain with deposits of coral or limestones and marls. Soils are typically heavy in texture and tend to be very stony. The dominant soil types are alfisols, inceptisols, vertisols and entisols. Topography is generally rugged and only a very small proportion of the island is suitable for rice growing.

The area is characterised by a short wet season of two or three months, with the annual rainfall ranging from 900 mm in the lowlands to 2000 mm in the highlands, and averaging 1480 mm. Daily maximum temperatures average 31.6°C in the dry season.

As a consequence of this combination of climate, soils and land use patterns, soil erosion is a major problem in the province.

Sandalwood is believed to occur on all soil types, but as a result of past exploitation is now found mainly on stony soil types. Tree vigour appears to be better on entisols and alfisols than on vertisols (Hamzah 1976). It grows from sea level to as high as 2000 m near Kapan in West Timor.

Utilisation and Conservation

The exploitation of sandalwood is believed to have been carried out more or less continuously for over 1000 years. So far as is known, all this harvesting has been carried out in natural stands of the species and no conscious attempt has been made, until recent times, to cultivate the tree.

The level of recorded harvest has varied greatly in the last 60 years. According to Hamzah (1976), production in 1929 was 52497 kg, 45703 kg in 1931, rising dramatically in postwar years to 1267 t in 1967 and 1581t in 1968. After an inventory of growing stock in 1976, it was apparent that the resource could not sustain this level of cut and there has since been a marked reduction in the level of harvest (Fig. 1). The cut is still greatly in excess of overall growth, and there is little recent regeneration, so a sustainable harvest is not possible at the present time.

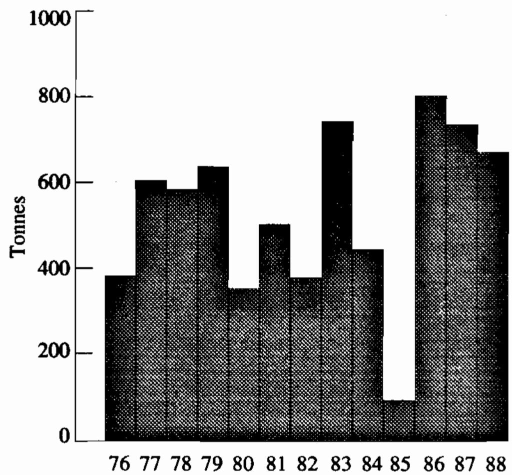

Fig. 1. Sandalwood production in Nusa Tenggara Timur, 1976–88.

The current harvest is controlled by the Indonesian Government. Exploitation is confined to trees which have a heartwood diameter of at least 10 cm and a sapwood depth of less than 2.5 cm. This is intended to ensure that juvenile trees are not harvested, but some illegal cutting still occurs. The annual cut is prescribed on the basis of utilising the resource over as long a period as possible, while retaining a viable local oil distillation industry.

The current main uses for sandalwood in NTT are for oil distillation, sandalwood carving and joss stick production. Virtually all production is exported and is an important contributor to regional income. Table 1 shows the export value of sandalwood over the last few

Table 1. Export value of sandalwood products from NTT 1969–89

Sandalwood product	Export value (US$)			
	1969–74	1974–79	1979–84	1984–89
Logs	3 174 526	740 000	–	–
Oil	–	1 630 245	1 555 093	2 448 200
Sapwood	–	177 828	198 093	166 121
Residue	–	–	108 603	395 685
Carvings	–	–	62 101	234 789

years. The regional significance of the sandalwood industry is indicated by the fact that in 1990, for example, sandalwood exports accounted for some 60% of the value of all exports from NTT province.

Some sandalwood is exported as logs for carving elsewhere, and some is distilled in Timor to produce sandalwood oil for perfume production overseas. The sapwood removed during processing for these two higher value products is also marketed and is used elsewhere for joss stick production. The residue from oil distillation, known as 'multiple joss' is also sold for joss production overseas. Some carving of sandalwood also takes place in NTT.

Due to the importance of the industry, the provincial government has assumed control of sandalwood management in NTT. All naturally growing trees are the property of the Government, whether they occur on privately or publicly owned land. Trees may be owned by others only if they have been planted on private land. Although the purpose of this ownership arrangement is to promote conservation of the remaining stocks of sandalwood, it is very difficult to control the harvest of sandalwood on private land, and this is a very important part of the resource in some districts. Figure 2 shows the distribution of sandalwood by land ownership in several Kabupaten (local government areas) in NTT.

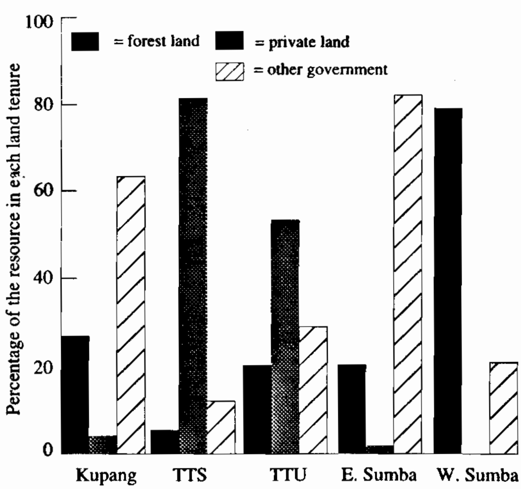

Fig. 2. Location of sandalwood by local government area in Nusa Tenggara Timur.

Attempts have been made since 1924 (Hamzah 1976) to develop sandalwood plantations in NTT, but without consistent success. Under the Indonesian Government's national development plans Repelita I–IV, about 505 hectares have been planted with sandalwood, but only 3.42%of the trees have survived.

The main reasons for the lack of success with sandalwood plantings have been:

- the relatively rapid expansion of extensive shifting cultivation, accompanied by heavy grazing pressure and uncontrolled burning of grasslands;
- the lack of appropriate silvicultural techniques for sandalwood regeneration; and
- the lack of professionally trained forestry staff with the facilities to manage and protect the sandalwood plantations adequately.

Clearly, there can be no possibility of an improvement in sandalwood stocks unless there are significant changes in land use in NTT. Population pressure and concern about current land degradation are expected to result in such changes over the next 10 years. In the meantime, research is taking place to develop a reliable regeneration technique for sandalwood. At the same time, staff training is being improved, although more slowly than required. However, there remains a critical deficiency in facilities and equipment to enable proper management of a plantation estate.

Silvicultural Knowledge

Research on sandalwood silviculture in Indonesia is concentrated at the Forest Research Institute in Kupang. There is also a cooperative sandalwood research project funded by the Australian Centre for International Agricultural Research (ACIAR). The research program has several parts:

(a) Seed collection

Flowering and fruiting of sandalwood in NTT is very variable. Most trees flower twice a year, in April–May and in September–October. However, some trees flower only once a year or only every second year.

Germination of sandalwood seed generally begins 20 days after sowing and about 60–70% of seeds actually germinate under laboratory conditions.

Due to the decline in stocks of sandalwood referred to earlier, seed supply is becoming more and more difficult in NTT. Seed production areas are urgently required, but if they are to be established it is necessary to ensure that only planting stock of high quality is used. To this end, Fox (1990) in the ACIAR project has commenced a program of locating plus trees, based on the heartwood content as measured by increment cores. Studies by Fox have shown that heartwood content is most strongly correlated with tree diameter, tree volume and bole length (Table 2).

Table 2. Correlations of heartwood volume with various factors

Measurement	Correlation coefficient	Significance
Heartwood weight	0.980	*
Diameter (BH)	0.848	**
Total volume	0.788	**
Bole length	0.784	**
% heartwood basal area	0.734	*
Sapwood radius	0.696	*
Tree height	0.636	*

(b) Nursery propagation

Success in establishing seedlings in the field has been shown to be dependent on planting sturdy plants at least 20 cm in height in close proximity to a suitable long-term host plant. Seedling growth is strongly influenced by the soil mix used in the nursery. Experiments in NTT have shown that the best growth of sandalwood seedlings was obtained with a mixture of 37.5 % sand and either of two local soils (lithosol or grumosol) (Kharisma 1988; Surata 1990; Fox 1990). For practical use a mix of 40% sand with soil is recommended.

Germination is also affected by the properties of the germination medium. Surata (1990) found significant differences in germination percentage between sand (81.33%), sawdust (77.33%), cow dung compost (70.66%) and soil (30.67%). It is likely these differences are a reflection of the amount of fungal attack in each medium.

A number of trials have been undertaken to determine the optimum first (nursery) stage host for sandalwood seedlings. Based on initial height growth, the best host species are *Alternanthera* sp., *Crotalaria juncea*, and *Desmanthus virgatus*. However, acceptable early growth is given by *Sesbania grandiflora*, *Cajanus cajan*, *Lycopersicum esculetum*, *Capsicum frutescens*, *Acacia ampliceps* and *Acacia villosa*. Some of the more vigorous of these host species require pruning in the pot stage to reduce competition for the sandalwood seedling.

As nitrogen is generally the most deficient nutrient in Timor soils, an attempt was made to increase early growth of sandalwood seedlings with urea fertiliser. The treatments applied were control (no fertiliser), 2 g, 4 g, and 8 g per seedling. All levels of urea depressed seedling growth, and there was considerable sandalwood mortality at the highest level.

Field observations suggest that there is considerable variation in growth rate of sandalwood with different hosts, so it is likely that the nutrition factor is worthy of further study, perhaps after the sandalwood plants have passed the seedling stage.

(c) Plantation

No reliable plantation establishment technique has yet been developed in NTT. Preliminary field trials have indicated that *Acacia villosa* is a good early host and that *Acacia auriculiformis* is a good long-term host. However we lack any definitive information on variation in growth rate with different host, or any information at all on the desirable stocking of host and sandalwood in a plantation situation. Much research remains to be done in this area.

So far sandalwood plantation research has concentrated on the use of nursery-raised seedlings for establishment. While this is a useful research tool, it is expensive to establish sandalwood in this fashion. Ideally, there should be a direct seeding system developed, which will greatly reduce plantation establishment costs.

Conclusions

We are only at the very beginning of developing a reliable and economical system of establishing sandalwood plantations in NTT. However, continuing research, especially in cooperation with ACIAR, is expected to yield a workable technique in a few years.

In the meantime, it is important to conserve a representative range of sandalwood genetic resources in NTT to enable selection of high yielding genotypes for the future reforestation program. Selection of plus trees and their propagation in a seed orchard is now a high priority. Plus tree selection is an important part of the ACIAR Forestry Project in NTT.

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