United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Research Station**

General Technical Report
PSW-122

Proceedings of the Symposium on
Sandalwood in the Pacific
April 9-11, 1990, Honolulu, Hawaii

Hamilton, Lawrence; Conrad, C. Eugene, technical coordinators. 1990. **Proceedings of the Symposium on Sandalwood in the Pacific; April 9-11,1990; Honolulu, Hawaii.** Gen. Tech. Rep. PSW-122. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 84 p.

Sandalwood (*Santalum* spp.) trees grow in a variety of climates around the world and are culturally and economically important to about 15 countries. Exploitation of the fragrant heartwood for carvings, oil, and incense in the past has led to the need to conserve and manage the genus. The first substantial logging of sandalwood in Hawaii in 150 years generated local controversy in 1988, uncovered misinformation and speculation about the genus, and eventually led to the symposium in 1990. Papers in this proceedings cover history, distribution, status, ecology, management, propagation, and use of sandalwood. A synthesis paper summarizes the state-of-knowledge of the symposium participants. Research is needed to fill gaps in information on various aspects of sandalwood in many of the countries where it grows.

Retrieval Terms: forestry, Pacific, sandalwood, *Santalum,* Australia, Hawaii, India, Indonesia, Papua New Guinea, Vanuatu

Technical Coordinators:

LAWRENCE HAMILTON is a research associate, Environment and Policy Institute, East-West Center, Honolulu, Hawaii. **C. EUGENE CONRAD** is director, Institute of Pacific Islands Forestry, Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Honolulu, Hawaii.

Publisher:

Pacific Southwest Research Station
P. O. Box 245, Berkeley, California 94701
August 1990

Proceedings of the Symposium on

Sandalwood in the Pacific

April 9-11, 1990, Honolulu, Hawaii

Technical Coordinators:

Lawrence Hamilton **C. Eugene Conrad**

CONTENTS

PREFACE

This publication results from the Symposium on Sandalwood in the Pacific held at the East-West Center, Honolulu, Hawai'i, in April 1990. The idea of convening a meeting on the valued and interesting genus *Santalum* came from a meeting of the Hawaii Society of American Foresters in early 1989. This interest in turn was predicated on the local controversy generated by the first substantial logging of sandalwood in 150 years in Hawaii during fall 1988. Speculation and misinformation about sandalwood abounded, and it seemed desirable to pull together what was known about its history, distribution, status, ecology, management, propagation, and use. Inquiries made to other countries where sandalwood was being exploited revealed a similar desire to obtain reliable information on these topics.

Vanuatu had instituted a prohibition on commercial sandalwood harvesting in 1987. High prices possibly were resulting in illegal logging in several other Pacific island countries. Active programs of management and exploitation were producing new knowledge in Queensland and Western Australia. New propagation and establishment research was being carried out in Nepal, Indonesia, and New Caledonia. Long-term work on sandalwood has been carried out in India (especially in Karnataka and Tamil Nadu), but the information was not widely available. Sandalwood was being rustled with loss of human lives in India. Several species or varieties in various countries were in an endangered status; others were extinct; and many planting efforts had met with limited success.

In view of the international nature of the interest and problems, it was deemed appropriate for the Environment and Policy Institute of the Center to adopt, as part of its program effort in Biological Diversity, the convening of a symposium on sandalwood. This was held April 9 and 10, with a working session held on the 11th to produce a synthesis. The National Tropical Botanical Garden joined with the Center and the Hawaii Society of American Foresters in co-sponsoring this event, and indeed the Garden provided half of the funding to bring resource persons from various countries. The publication of the papers presented and a state-of-knowledge report synthesized during the symposium was made possible through the Institute of Pacific Islands Forestry of the Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.

The Nepal-United Kingdom Forestry Research Project, the University of Western Australia, the Western Australian Department of Conservation and Land Management, and the FAO South Pacific Forestry Development Project provided support for the participation of resources persons from each of those organizations. The planning committee was composed of James Chamberlain, Robert Merriam, and Lawrence Hamilton.

Most of the difficult work of preparing the papers for publication was done by technical publications editor Roberta Burzynski and editorial assistant Mark Dougherty of the Pacific Southwest Research Station. They deserve credit for making this publication readable. To all of the scientists and managers who prepared presentations for the symposium and to the symposium participants who so willingly contributed information from their experiences, we express our thanks.

Technical Coordinators:
Lawrence Hamilton, Environment and Policy Institute,
East-West Center
C. Eugene Conrad, Institute of Pacific Islands Forestry
Pacific Southwest Research Station

Opening Remarks[1]

Leonard A. Newell[2]

Good morning and a warm *Aloha nui loa* to all of you from the Hawaii Society of American Foresters. It is a great pleasure and an inspiration to see so many people gathered to exchange information about the wonderful trees of the Genus *Santalum.*

I particularly appreciate the effort that has been made by our international visitors to come here and share your knowledge with us.

The difficulties of growing sandalwood in Hawai'i are well known and have been often cited as reasons for not pursuing the planting of these species more aggressively. Those of us who can see beyond a 40-year time horizon—something which is becoming increasingly difficult to do—have long deplored the lack of progress in restoring sandalwood more conscientiously to its former prominence in our ecosystems and in our economy.

The organizers hope this important meeting will be the beginning of a new era in learning about and managing this fascinating, fragrant, and too-mysterious tree.

When we were discussing the organization of this symposium, I and others expressed a concern that it be kept small, low-key and science-centered. It is difficult to hold any meeting about trees and forestry in Hawai'i without generating intense interest from many people—interest which can become misdirected into political activism and sloganeering before knowledge can be shared or digested.

Our aim has been and remains to concentrate on scientific knowledge about the classification, distribution, propagation, silviculture, physiology, soils, ecology and utilization of the species of the Genus *Santalum.* Once we have learned what it is necessary to know about these things, we can formulate management plans and apply this knowledge to the benefit of the forests of the tropics and the people of the earth.

Your participation in this symposium will lay a foundation that all of us can build upon. This meeting will, I hope, be the beginning of an era of close cooperation among all of us who are interested in sandalwood and in assuring that its fine properties will be available to our great grandchildren, and to theirs. It is a fine task and a difficult one.

Again, thank you for coming and welcome to Hawai'i.

---

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai'i.

[2]Vice-Chairman, Hawaii Society of American Foresters, Honolulu, and Pacific Islands Forester, USDA Forest Service.

Sandalwood in the Pacific: A State-of-Knowledge Synthesis and Summary from the April 1990 Symposium[1]

Abstract: The economic and cultural values of sandalwood (*Santalum* spp.) are attributed to the fragrant oil found mainly in the heartwood. Sandalwoods grow naturally in a variety of climates from warm desert in Australia to subtropical regions with almost uniform rainfall in Hawai'i and New Caledonia. Growth habit varies from large shrubs to tall trees. Species that grow in relatively favorable environments appear to readily regenerate naturally. Guidelines for propagation include these: pretreating seed before sowing, treating the potting medium with fungicide, providing primary and secondary host species, and preparing the site before outplanting. Propagation from cuttings generally is not successful; direct sowing or enrichment planting can be used in some cases. All species are fire-sensitive and palatable to livestock. Spike disease afflicts sandalwood in India and Hawai'i, and a moth attacks *S. album* in Western Australia. Much of the sandalwood harvested is dead wood. Live trees are harvested selectively on the basis of size, which is related to heartwood content. The three major uses for sandalwood are carvings, incense, and oil. About 10 countries produce sandalwood for markets in France, Hong Kong, Nepal, Singapore, and Taiwan. Research is needed to fill gaps in information on various aspects of sandalwood in many of the countries where it grows.

Sandalwood is economically and culturally important to many countries around the Pacific. Some countries that were exploited for their sandalwood in the past are now looking to replant sandalwood forests or to manage natural stands as part of their forestry operations.

The symposium on Sandalwood in the Pacific highlighted the known information on sandalwood in some of the countries where there is an established industry or where sufficient interest exists to establish or revitalize such an industry.

This synthesis paper, produced by a small group of the participants at the April 1990 Symposium on Sandalwood in the Pacific, summarizes the state-of-knowledge on sandalwood. Topics covered are occurrence of sandalwood, ecology, propagation, management, harvesting, marketing, and utilization. In addition, high-priority research needs are outlined.

DISTRIBUTION

The present global distribution of *Santalum* species is listed below, with their approximate rainfall and elevational ranges (Fosberg and Sachet 1985, George 1984, Skottsberg 1930, Smith 1985, Sykes 1980, Tuyama 1939, Yuncker 1971, and Wagner and others 1990). Species reported in the cited references but absent from this list are now considered to be included within the taxa in this list. Additional information is needed to clarify the distribution of this genus.

Taxon and Authority	Rainfall Range (*mm*)	Elevation Range (*m*)	Distribution
Santalum acuminatum (R. Br.) A. DC.	—	0-500	S. Australia
Santalum album L.	300-3000[1]	0-700	India
	800-1500	0-2000	Indonesia: Timor, Sumba, Flores, and now planted in Java, Bali, and elsewhere in Asia and the Pacific
	1400-1800	0-250	Australia
Santalum austrocaledonicum Vieillard			New Caledonia[2]
var. *austrocaledonicum*	—	—	New Caledonia and Isles Loyalty[2]
	1000-1500	0-300	Vanuatu
var. *minutum* Halle	800	100-200	New Caledonia, Northest part of island[2]
var. *pilosulum* Halle	1000-2500	0-800	New Caledonia[2]
Santalum boninense (Nakai) Tuyama	1000	50-100	Ogasawara Island
Santalum ellipticum Gaudichaud	50-1300	0-1390	Hawaiian Islands
Santalum fernandezianum F. Philippi	—	—	Juan Fernandez (extinct)
Santalum freycinetianum Gaudichaud			
var. *freycinetianum*	760-3800	150-980	Moloka'i, O'ahu
var. *lanaiense* Rock	500-1000	90-900	Lana'i, Maui
var. *pyrularium* (Gray) Stemmermarm	900-3800	15-1150	Kaua'i
Santalum haleakalae Hillebrand	850-1900	1800-2590	Maui
Santalum insulare Bertero			
var. *insulare*	—	<1000	Tahiti
var. *alticola* Fosberg & Sachet	—	2000-2066	Tahiti
var. *deckeri* Fosberg & Sachet	—	250-940	Marquesas
var. *hendersonense* (F. Brown) Fosb. & Sachet	—	—	Henderson Island
var. *marchionense* (Skoots.) Skottsberg	—	300-940	Marquesas
var. *Margaretae* (F. Brown) Skottsberg	—	c.250	Austral Islands
var. *mitiaro* Sykes	—	0-10	Cook Islands

[1]Synthesized by Grahame B. Applegate, Queensland Forest Service, Atherton, Australia; James Chamberlain, Nitrogen Fixing Tree Association; Godfrey Daruhi, Department of Forestry, Port Vila, Vanuatu; Joseph L. Feigelson, Exotic Maui Woods, Inc., Haiku, Maui, Hawai'i; Lawrence Hamilton, East-West Center, Honolulu, Hawai'i; Francis H. McKinnell, Department of Conservation and Land Management, Como, West Australia; Peter E. Neil, Nepal-United Kingdom Forestry Research Project, Kathmandu, Nepal; Shobha Nath Rai, Government of Kamataka, Khawad, India; Bo Rodehn, Paia, Hawaii; Pamela C. Statham, University of Western Australia, Nedlands; and Lani Stemmermann, University of Hawai'i at Hilo, Volcano.

Taxon and Authority	Rainfall Range *(mm)*	Elevation Range *(m)*	Distribution
Santalum insulare Bertero var. *raiateense* (J. W. Moore) Fosberg & Sachet	—	200-500 c.60	Society Island (Raiatea)
var. *raiavanse* F. Brown			Austral Islands
Santalum lanceolatum R. Br.[3]	300-1300	0-700	Australia
Santalum macgregorii F. v. Mueller	1000-1500	200-1800	New Guinea
Santalum murrayanum (Mitchell) C. Gardn.	—	0-500	S.W. Australia
Santalum obtusifolium R. Br.	1400-2000	100-700	Australia
Santalum paniculatum A. Gray			
var. paniculatum	380-2550	38-2100	Hawai‘i
var. *pilgeri* (Rock) Stemmermann	760-1350	730-1970	Hawai‘i
Santalum spicatum (R. Br.) A. DC.	200-600	0-300	Australia
Santalum yasi Seeman	—	0-200	Fiji
	—	0-100	Tonga

[1]These ranges are for India. Shobha Nath Rai has suggested that these are extreme values, with most of the cultivated stands occurring between 500 and 2000 mm rainfall, and 300-600 m elevation. While there is some question whether *Santalum is* truly native to India, the conference participants consider it to be. No *Santalum is* native to Nepal, but *S. album* has been planted in Makwanpur (2000 mm rainfall and 450 m elevation) and Gorkha. It is also planted in China and elsewhere.

[2]Dr.J.F. Cherrierof Centre Technique Forestier Tropical in New Caledonia provided information through correspondence to Lawrence Hamilton in May 1990.

[3]This is the most widespread of the Australian species, found from Cape York to W. Australia and S. Australia.

ECOLOGY

Climate

Sandalwoods grow naturally in a variety of climates from warm desert in Australia, through seasonally dry monsoon climate in India, Eastern Indonesia, and Vanuatu, to subtropical climate with almost uniform rainfall in Hawai‘i and New Caledonia.

In Australia, *S. spicatum* grows where rainfall is as low as 200 mm, but is usually found only on water-gaining sites on the lower slopes and drainage lines. In India, *S. album* can be found in rainfall zones from 300 mm to 3000 mm, again generally on the lower slopes. In Vanuatu, *S. austrocaledonicum* is found in areas which have rainfall ranging from 1000 mm to 1500 mm. The Hawaiian species of *Santalum* vary markedly in their occurrence. *S. haleakalae* is found in higher elevations with cool, dry to moist climates and a rainfall of 850-1900 mm. *S.freycinetianum* grows in intermediate elevations and rainfall from 1000-3000 mm, while *S. paniculatum* and *S. ellipticum* are found in generally drier sites at lower elevations. However, these comments are tentative as there seems little definitive information on the Hawaiian species. One interesting feature of *S. paniculatum* var. *pilgeri* is that it appears to have morphological features such as thick leaves which would seem to be an adaption to drier conditions.

We have little information on the conditions under which *S. yasi* grows in Fiji, but it grows in coastal areas on some islands, predominantly in secondary forests and old village gardens.

The range of climatic conditions under which many sandalwood species grow is unknown. A particular species may be very adaptive and can tolerate and grow over a range of site conditions. However, many of these areas may not provide suitable conditions for heartwood development, the most commercially valuable part of the tree.

Soils

In India, sandalwood usually grows on free-draining red loams with a pH range of 6-6.5. Occasionally it is found on sandy textures associated with lateritic soils. It is not found on waterlogged soils. The same species in Timor grows on grey clay and red loam soils formed on coral parent material, often extremely stony, and having a pH of 8-9.

S. spicatum in Western Australia is found growing on red soils which have a high proportion of calcrete nodules where the pH is 7.5 and also on lateritic soils with a pH of 6.0. In Queensland *S. lanceolatum* grows over a wide area on "gilgai" soils, which are sandy clays with a high content of calcium carbonate and where the pH is 7.5-8.0.

In Vanuatu *S. austrocaledonicum* grows on volcanic soils on Tanna, on humic ferralitic red loams on Erromango, and on Efate and the Cumberland Peninsula (on Espiritu Santo) on shallow soils formed on raised coral reef. In New Caledonia, the same species grows on lateritic soils with a high iron content on La Grande Terre. On Isle de Pins and the Loyalty Islands, the soils are said to be derived from coral parent material.

In Hawai‘i, all species of *Santalum* grow on volcanic soils.

It would appear, then, that the genus is quite adaptable as to soil conditions under which it will grow. The only common thread is that all soils are free-draining.

Environmental Factors

Fire

All species are fire-sensitive, which is is a major problem in maintaining the species in some countries, especially Indonesia and India. In Western Australia it is less of a problem for *S. spicatum* because wildfires in the desert are infrequent, depending on a large accumulation of fuel over three or four seasons. Nevertheless, fires have occurred there and killed large areas of the species. In Queensland, fire may be a major factor affecting the local distribution of *S. lanceolatum.* In Vanuatu on the island of Aneityum, fire has played a major role in reducing the natural cover. This and overexploitation may have led to the extinction of *S. austrocaledonicum* on the island.

Grazing

All species seem to be quite palatable to livestock—horses, sheep, rabbits, pigs, goats, and cattle—and grazing is thus another critical factor in successful establishment of sandalwood. Under some circumstances, such as in parts of Queensland, where there is no particular threat to the species, *Santalum* is reported to have been used as livestock fodder on a limited scale in times of drought.

Pests and Diseases

The spike disease, well known and very destructive in India, is also suspected to afflict the Hawaiian species. This disease shortens the internodes, reduces leaf size, kills the haustoria connections, and blocks the vascular bundles in the phloem. It also causes tip dieback, in which leaves fall and give the tree a spiked appearance. In some districts in India, spike disease affects about 2 percent of the population of sandalwood. *S. album* has also been attacked in Western Australia by a moth that girdles the stem to the depth of the cambium.

Growth Habit

Sandalwoods vary from large shrubs or small trees (*S. spicatum*) to tall trees 20 m or more in height (*S. album* in India and *S. paniculatum* in Hawai‘i).

In New Caledonia, trees of *S. austrocaledonicum* on LaGrande Terre can be twisted and deformed on exposed sites, but on more sheltered sites their form is good, with strong apical dominance and a height of about 15 m. On Vanuatu, the same species is commonly forked close to the ground and often has a shrubby habit.

S. lanceolatum in Queensland is generally an erect single-stemmed small tree, but on harsh sites it is reduced to a more shrubby form with crown break at about 1.5 m.

Sandalwoods show marked variations in morphological features such as leaf size, bark appearance and fruit size, and this variation has probably led to the confusion that existed in the taxonomy of the genus in the past and which plagues us even today.

The kernels of most species are edible. In *S. acuminatum,* the fleshy exocarp of the fruit is also edible and has been grown commercially for this purpose to some extent.

Coppicing ability varies widely among species. In Australia, *S. spicatum* does not coppice in the desert zone, but does so readily when close to the sea at Shark Bay, where the climate is much milder. *S. lanceolatum* also coppices freely, as does *S. album* in India but the latter only in the juvenile stage. *S. austrocaledonicum* in Vanuatu does not coppice at all. *S. paniculatum* on the Island of Hawaii also coppices from cut stumps.

Root suckers are found on the Australian species *S. lanceolatum, S. album* in India, and *S. paniculatum* from Hawai‘i. They are not observed in the other species. Presence of root suckers has a bearing on the ease with which one may propagate the species by vegetative means.

Host Species

In India, several species of each of the following genera may act as host species for sandalwood: *Acacia, Paraserianthes, Terminalia,* and *Pterocarpus.* Associated understory species also parasitized are *Carissa, Lantana,* and *Randia.*

In Western Australia, several species of *Acacia, Eucalyptus, Cassia, Casuarina, Eremophila, Dodonea, Mariana, Atriplex,* and *Cratystylis* are recorded as hosts. The last five genera are shrubs.

In north Queensland, *S. lanceolatum,* which is thought to be parasitic, grows in association with *Melaleuca, Eucalyptus, Acacia,* and *Excoecaria parvifolia* (gutta-percha).

An interesting difference occurs in Vanuatu, where grasses may act as hosts, along with *Acacia spirorbis* and *Hibiscus tiliaceus.* In Indonesia, a wide variety of species are recognized as sandalwood hosts, including *Pterocarpus, Acacia, Cassia, Paraserianthes, Casuarina, Sesbania,* and many more.

In New Caledonia, common hosts are *Acacia, Paraserianthes,* and *Casuarina.* Very little seems to be known of host species for the Hawaiian sandalwood species. In Fiji, *S. yasi* is associated with *H. tiliaceus, Cocos nucifera,* and *Alyx amoena.*

The opinion expressed by some, that sandalwood does not need a host at all, is usually based on observations of trees growing alone in the open. This does not necessarily indicate lack of a host. Sandalwood may be parasitizing grasses, as in Vanuatu, or other herbaceous plants. However, it is possible that older sandalwood plants may benefit from the presence of a host but may not require one.

Careful studies on several species— *S. spicatum* in Australia, *S. album* in India, and *S. austrocaledonicum* in New Caledonia—have demonstrated the absolute need for a host during the juvenile stage. It seems unlikely that the other species in the genus would differ in such a fundamental feature.

What is the value of parasitism to the *Santalum*? It can photosynthesize by itself but for some reason has developed special structures on its roots called "haustoria," which penetrate the roots of other plants, even other sandalwood plants. Research on *S. spicatum* has shown that there is direct xylem to xylem union between parasite and host. The parasite can therefore draw moisture from the host if needed. Other research on this species and on *S. album* indicates that N, P, and K may be transferred from the host to the sandalwood.

Plants in the nursery often develop a chlorosis which is cured by the application of iron chelates. In the field this chlorosis is not normally seen so it is likely that the sandalwood can also obtain iron also from its host.

Heartwood and Oil

The main reason for the economic and cultural values of sandalwood is the oil contained in its timber, mainly in the heartwood. Heartwood oil content varies widely between species and, to some degree [in chemical composition], even within species.

S. album has the highest quality oil content, with about 6-7 percent; *S. yasi* from Fiji has about 5 percent; *S. austrocaledonicum* has 3-5 percent, depending on the source; and *S. spicatum,* 2 percent. As far as is known, only *S. album, S. yasi,* and *S. austrocaledonicum* are distilled for their oil. *S. spicatum* is now used only for incense (joss-stick) manufacture, although it has been distilled in the past. No figures are available for the heartwood oil content of *S. lanceolatum* or the Hawaiian species. *S. murrayanum* and *S. acuminatum* from Australia have no or very little oil in their heartwood and have never been exploited for this purpose. Some species such as *S. austrocaledonicum, S. album,* and *S. spicatum* also have low oil content in their sapwood.

Within the commercially used species, a considerable amount of variation in heartwood content exists from tree to tree and from stand to stand. Although much research remains to be done in this area, we can make some generalizations: (a) in relation to rainfall, heartwood contents tend to be higher for a given size tree in lower rainfall conditions (or any other situations where the tree moisture is often under stress); (b) in relation to genetic variation, evidence on *S. album* and *S. spicatum* indicates that oil content varies. There is, in fact, a tree selection program for this feature. There may also be genetic variation in the age at which heartwood development commences; (c) in relation to site quality, generally the faster the growth, the lower the heartwood content of a given size individual is, although it is difficult to separate the effect of growth rate and the indirect effect of other factors. On an individual tree basis, faster growth may well produce a lower proportion of heartwood, but on a per hectare basis faster growth may produce greater total heartwood biomass.

Oil from *S. spicatum* has an optical rotation of -8° to -3°, *S. lanceolatum* from -30° to -40°, and for *S. album* -15° to -21°. The oil of the two Australian species was formerly mixed to simulate *S. album* oil for some medicinal purposes, where the optical rotation of the oil was strongly correlated with the particular medicinal property being sought.

There is no known published information on the oil produced from *S. austrocaledonicum* or *S. yasi* nor from the Hawaiian species.

Flowering and Seeding

S. album starts flowering at age 3 years but does not produce viable seeds until age 5. It has two flowering periods each year, March and September in both India and Indonesia, and seeds mature in April and October. Both seed crops are of similar size. The seed is 6-7 mm in diameter with a thin fleshy exocarp of about 1 mm.

S. spicatum also commences flowering at age 3, with good seed from about 5 years. In the desert, however, flowering is dependent on the right combination of rainfall, so it is extremely irregular in both time and space. In the same year it is possible to find abundant seed in one area but none at all in another, due to chance rainfall events. The seed in the species is 1.3 -1.5 cm in diameter with a leathery brown exocarp which hardens with time and becomes woody.

S. austrocaledonicum flowers twice a year in April and October, with seed maturing in May and November. The November crop is generally heavier; however, any crop can be adversely affected by cyclones, which are frequent in this part of the Pacific. For *S. yasi* there is a similar flowering cycle. Detailed information on S. *lanceolatum* or any of the Hawaiian species was not available when this paper was written.

Birds apparently are the principal method of dispersal of the seed. They are attracted to the fleshy fruit and pass the kernels intact through their alimentary tract. This is certainly so for *S. album* in India and Indonesia, for *S. spicatum* in Australia, and for *S. yasi* in Fiji.

In the natural regeneration of *S. spicatum* in Western Australia, the percentage of seed which actually develops into trees is normally about 1 percent. In a very good season it can be as high as 16 percent.

Growth Rates

Detailed information on growth rates is available for the two most studied species, *S. spicatum* and *S. album.* For *S. spicatum,* the forthcoming Department of Conservation and Land Management publication "An Historical Review of Sandalwood Research in Western Australia" gives details of volume growth rates in two climatic zones—the wheatbelt and desert of Western Australia—and gives estimates of heartwood production from trees of various sizes. In the desert zone where the rainfall is 200-250 mm annually, it generally takes 100 years to grow a tree of merchantable size (127 mm diameter at 150 mm above the ground), while. in the wheatbelt, where the winter rainfall is 300-600 mm, 50 years are required to grow the same sized tree.

For *S. album* in India, under natural conditions, girth increments of 1.0-1.3 cm per year can be expected. This rate can go up to 5 cm per year in the case of cultivated trees. In terms of heartwood the rule of thumb is that after the age of 15 years, on average, every tree adds 1 kg of heartwood to its weight per year. There is a parabolic relationship between tree diameter and rate of increment. Increment is lower in young trees and old trees, while it is comparatively higher in the middle diameter classes.

According to a number trials on Erromango (Vanuatu), *S. austrocaledonicum* had a mean height increment of 1.1 m per year. The buffer rows in these trials were tended and there was no "formally" associated secondary host. Naturally growing stands have a low increment unless they are associated with a good secondary host. In New Caledonia, the same species was found to have a girth increment of 1.2-1.3 cm per year.

PROPAGATION

A reasonable amount of knowledge about the propagation of sandalwood has been accumulated for *S. album,* the Indian sandalwood, *S. spicatum* from Western Australia, and *S. austrocaledonium* from New Caledonia and Vanuatu. In the judgment of those having experience with other sandalwood species, this accumulated information seems generally applicable. What follows is more or less a set of guidelines for propagating sandalwood. These guidelines express in general what is known, though there are still serious gaps in knowledge.

Seed Source

Seed should be obtained only a reputable source of high quality seed, (e.g., genetically selected *S. album* seed from seed production areas in southern India or recognized stands of the various species in other locations such as Hawai'i, Australia, Fiji, Indonesia, Papua New Guinea, Vanuatu.

Seed Collection and Handling

Preferably, all seed should be collected directly from trees, or if this is not possible, from below the trees soon after seed fall. This should be the case for all species of sandalwood. Seed should be depulped immediately by washing in water. Depulped seed should be treated with a disinfectant to reduce fungal and bacterial problems. The leathery exocarp of *S. spicatum* does not encourage the development of fungi, so fungicides are not required for this species. The exocarp must be removed or damaged, however, to enable the seed to germinate. Seed should then be dried under shade and stored in a cool place. Alternately, seed should be dried in an oven to 8 percent moisture content and stored in a refrigerator at about 5°C. If these storage methods are followed, germination percentage should remain good for a number of years. In New Caledonia, the Centre Technique Forestier Tropical (CTFT) specifies that seed of *S. austrocaledonicum* must be picked from the tree when mature, then depulped by rubbing against a steel mesh the same day, washed thoroughly, treated with 1 percent calcium hypochlorite for 1 minute, and dried for storage.

There is a seed domancy period of two months for *S. album* and perhaps one month for *S. austrocaledonicum.* There is no known dormancy period for *S. spicatum.*

Seed longevity appears to vary between species. In *S. album* and *S. austrocaledonicum,* it declines rapidly in the first 6 months and, if stored at ambient temperatures, declines to a very low level by 18 months. Seed life is prolonged by cold storage, although precise data are lacking.

The effect of time on seed viability has been studied in *S. spicatum.* Fresh seed has a germination percentage of 84 percent and this declines steadily to as low as 20 percent after 9 years at ambient temperatures. The optimum storage method for this species is cold storage at 4°C over silica gel. Seed in this environment maintains a germination rate of 52 percent after 9 years.

Nursery Techniques

Germination and Propagation

Seed germination is affected by temperature. At CTFT it has been shown that the optimum temperature for germination of *S. austrocaledonicum* is 25° -27°C. This temperature range was also optimum for *S. album* in research at Curtin University in Perth, Western Australia. Seed of all sandalwood species should be pre-treated before sowing. Germination of most species is slow and erratic, but can be speeded up by presoaking in water or, better still, in 0.05 percent gibberellic acid (GA). Some interesting work in India has indicated that sandalwood leaves themselves have high levels of GA during the flowering cycle, and an infusion of sandalwood leaves contains sufficient GA to have a stimulating effect on seed germination. Another method of enhancing germination is manual scarification with a file or saw to remove the seed coat or to nick it, and then soaking the seed in water at ambient temperature before sowing. This pretreatment should speed up germination rates, increase germination percentage, and ensure that seed germination is more uniform.

Germination generally does not begin for 2 weeks after sowing and may be spread over several months. A very efficient technique has been developed by CTFT which involves pre-soaking with GA, then germinating in vermiculite beds bottom heated to maintain a temperature of 25°C, transferring out the germinated seeds into plastic tubes, to which a primary host is later added. In India and Australia, *S. album* seedlings have been shown to be very susceptible to fungal attack, and regular treatment of seedlings with fungicide is necessary. In India, nematodes are also a problem, and a nematicide must be used in the seed b: d and the potting mix.

The aim is to produce strong and vigorous seedlings of 30-45 cm, which have some lignification of the lower stem. Experience has shown that such stock survives best in the generally harsh environments where they are planted. This should be considered when planning the nursery program so that sufficient time is available to raise seedlings of appropriate size.

The following mediums have been successfully used for germination:

- Beds of a 1:3 sand to soil mixture that have been treated with nematicides and fungicides.
- A mix of sterile peat moss, vermiculite, and fine cinders. However, vermiculite alone or a similar medium might be preferable.

Beds should be kept at an optimum temperature of 28°-30°C. Germinants should be shaded (50 percent) and protected from extremes of temperature, frost, and wind. They should not be over- or under-watered. The sandalwood seedlings should be transferred into large plastic pots (e.g., 13 x 30 cm) at the four-leaf stage. Fertilizer should not be required if a good potting mixture is used.

Chelated iron has sometimes been found to be a useful additive to the potting mix. The mixture also should be treated with fungicides and nematicides. Again, the transplants should be protected from extremes of weather, not over- or under-watered, and kept in partial shade (30-50 percent).

Primary Host Species

When sandalwood seedlings are transplanted into plastic pots, seed or seedlings of a primary host plant should also be transplanted into the pots. Such host plants could include these: *Acacia* spp., *Alternathera* spp., *Amaranthus* spp., *Breynia cerrua, Cajanus cajan,* and *Capsicum* spp. The criterion for selecting a host plant should be that the host should "assist" the sandalwood and not compete with it or physically obstruct it from normal growth. Species that develop a thick, fibrous, and succulent root system with a low growth habit are preferable. These primary host species should be able to take pruning to control competition and be easy to propagate.

Vegetative Propagation

Cuttings generally are not a successful method of propagating sandalwood, but tissue culturing *S. album* has been successful in India and Western Australia. After a considerable amount of research carried out in Western Australia, it was concluded that it is not possible to use tissue culture techniques to propagate *S. spicatum.* Cleft grafting of *S. album* has had up to a 60 percent success rate.

Planting

Site Selection

Seedlings should be outplanted at the start of the rainy season. For *S. album,* the ideal planting site would be at an elevation of 700-1200 mm, with an annual rainfall of 600-1600 mm. Temperatures should be in the range of an annual minimum of 10°C and a maximum of 35°C. For best growth, soils should be fairly moist, fertile iron-rich clays. Plantations have been successfully established on more adverse sites. Waterlogged or saline soils should be avoided. For many other sandalwood species, site requirements still need to be defined.

Site Preparation

General forestry practices involving site cultivation are recommended for plantations of sandalwood. No specific site preparation requirements for *S. album* are apparent to date.

The planting site should be fenced to reduce the possibility of grazing damage. Precautions should be taken against fire.

Regular weeding should be carried out in the first few months following establishment, particularly in areas of vigorous grass competition.

Secondary Host Species and Plantation Layout

Secondary hosts should be established on the plantation site before to planting the sandalwood. In New Caledonia, secondary host species are planted in the year before outplanting *S. austrocalendonicum.* This year allows the roots of the host species to develop sufficiently to allow good host-parasite contact.

The hosts could be of a very wide range of species, with large enough crowns to afford some protection, and preferably would be indigenous. Sandalwood seedlings are occasionally planted very close to their host; otherwise, hosts are planted in alternate or adjacent rows. Hosts should not be further than 2.2 m from the sandalwood, or its growth is significantly reduced.

Desirable features of a secondary host are moderate vigor or tolerance to lopping (e.g., *Paraserianthes falcataria*), a thin canopy, and some other use for local communities (e.g., fuelwood, fodder, or fruit). Sandalwood growth appears to be better with a nitrogen-fixing legume host than with non-legumes. The secondary host should also be reasonably long-lived. In places where grazing animals are a problem, host species with thorns are an advantage. In the desert regions of Western Australia, *Mariana polystyrgia*, a thorny legume which grows to a meter in height, effectively protects *S. spicatum* from sheep grazing. *S. album* is given the same protection by *Acacia nilotica* in India.

Combinations of sandalwood and secondary hosts that have proven successful in the past include these:

- *S. album* with *Casuarina equisetifolia, Melia dubia, Pongamia pinnata*, *Terminalia* spp., and *Wrightia tinctoria*.
- *S. austrocaledonicum* with *Acacia spirorbis* and *Paraserianthes falcataria.*
- *S. yasi* with *Hibiscus tiliaceus* and *Cocos nucifera.*
- *S. spicatum* with *Acacia aneura.*

Spacing and layout in the plantation with respect to sandalwood and its secondary host will be dependent on the growth habit and potential end product of the host species. Fast-growing species with a wide spreading lateral root system can be grown further away from sandalwood than other species whose roots are more confined.

Two different planting spacings have been reported. In India, plantations are established with alternative rows of *S. album* and host trees. *S. album* rows are 5-6 meters apart while the hosts are interplanted at the same spacing. In New Caledonia, a more diagonal planting method is used, where the sandalwood is planted on 4 by 4 meter grid and the host is planted in the center of the square. In other situations, it may be more appropriate to plant the host species and the sandalwood in the same rows.

Direct Sowing

In a number of countries, sandalwood seed is in short supply, either because of past overexploitation or because of climatic factors, such as cyclones which have damaged seed-producing trees. In this situation, direct sowing is unlikely to be a viable method of plantation establishment.

However, in countries with a plentiful supply of seed, the following steps should be followed:

Seed should be dibbled into the ground in areas which already have potential hosts either naturally present or artifically established. Broadcasting of seed is **not** recommended.

In situations where sandalwood is sown directly in existing natural scrub, spacing and layout will depend upon the configuration of the natural species. Some lopping and pruning of the natural vegetation may be necessary before sowing to avoid excess shading.

In situations where artificially planted hosts have been established before direct sowing of sandalwood, layout and spacing should depend on the growth habit and longevity of the host plant, as with out-planted seedlings of sandalwood.

Enrichment Planting

In certain situations, sandalwood seedlings can be directly planted into areas that already have a natural secondary host species present. Examples of these could be the following:

- *Acacia spirorbis* (*S. austrocaledonicum*) in New Caledonia and Vanuatu.
- *Acacia koa* (*S. ellipticum*) in Hawai'i.
- *Acacia catechu, Dalbergia sissoo* and in dry deciduous forest *(S. album)* in India.

Excoecaria parvifolia and *Melaleuca acacioides* (*S. lanceolatum*) in North Queensland, Australia.

Species Selection

Research into the most suitable secondary host for a given sandalwood species and country should be carried out. Only by using the most suitable host will optimum results be obtained. Many of these host species likely will be leguminous and have the ability to fix nitrogen. In countries such as India and Nepal, it would be appropriate to utilize species that could produce fodder or fuelwood to meet local needs. In other countries, the secondary hosts could well be species that produce a valuable product in their own right, e.g., timber, cabinet quality wood, or edible material.

MANAGEMENT

Protection

Fire

Sandalwood is susceptible to fire. Direct or even indirect contact with fire will result in the mortality of even large trees. In *S. spicatum,* coppice from the base of the fire-killed stem has been observed, but it has not survived beyond 2 years. Other species in more favorable climates may well be able to produce viable coppice. A fire that affects only part of the stem may kill part of the cambium and create an entry point for decay of the sapwood.

Grazing

As noted elsewhere, sandalwood foliage is palatable to grazing animals such as rabbits, sheep, goats, cattle, pigs, horses, and camels. In Australia, kangaroos are also occasionally a problem. It is essential to exclude grazing animals from stands containing small trees, as grazing will substantially reduce their growth and can, as in Western Australia, virtually preclude any regeneration.

Exclusion of grazing may well, on drier sites, bring with it a requirement for more weed control to enable the sandalwood seedlings to survive the first dry season. In native stands, wild animal populations may need to be controlled for a period to achieve adequate regeneration.

Illegal Cutting

Due to the high value of sandalwood logs relative to average incomes in most areas where they are found, illegal harvesting is often a severe management problem, to the extent that it can seriously threaten the long-term future of the species. Active management of the remaining stands of sandalwood, wherever they occur, is essential. This implies the enforcement of regulations applying to their conservation and of severe harvesting control procedures. Where such regulations and procedures are lacking, they should be developed urgently in view of the apparent threat to survival of the germ plasm of some provenances. (See section on Conservation of Germ Plasm).

Natural Stands

Harvesting Techniques

Sandalwood growing in natural stands is harvested by taking the whole tree down to quite small branches. In *S. album, S. spicatum,* and *S. austrocaledonicum,* the stump and larger roots are also used, as they contain the best quality wood and highest oil content. Either live or dead trees may be used, as the wood retains its scent for many years after the death of the tree.

Although heartwood is the most valuable portion of the tree, markets do exist for the sapwood of the three species mentioned above, since their sapwood contains some oil.

In most areas where sandalwood harvesting regularly takes place, a well developed product grading system exists. Larger butt logs suitable for carving rate the highest quality, while chipped branches and even sawdust are assigned lower grades.

Trees are selected for harvest on the basis of size, which is related to heartwood content. The ratio of heartwood to sapwood varies considerably between species and even within species (especially the Hawaiian sandalwoods).

In north Queensland, trees of *S. lanceolatum* are considered harvestable if the diameter is greater than 12 cm d.b.h. outside bark and when the sapwood is less than 1/6 the diameter of the tree at 1.3 m above the ground. Measurements are taken by the cutters by chopping into the stem into the heartwood boundary. This avoids unnecessary fellings of trees that cannot be utilized. In Western Australia, there is a simple minimum cutting system: only live trees with a diameter greater than 12.7 cm at 15 cm above the ground can be harvested. This height is a reflection of the frequent multi-stemmed habit of this species. In Queensland, sandalwood branches are utilized down to a heartwood diameter of 3 cm, and down to 1 cm in *S. album* in India and *S. spicatum* in Western Australia.

In both India and Western Australia, dead trees of any size may be taken, and in some parts of both of these areas, dead trees form a major proportion of the harvest.

Natural Regeneration

Species that grow in relatively favorable environments appear to readily regenerate naturally. Regeneration of the Australian species is much more uncertain and is dependent on having a series of good seasons in the arid zones in which they grow.

Birds are an effective dispersal agent for sandalwood seeds as they are attracted to the succulent exocarp. Consequently, regeneration is often found beneath trees is which birds roost. In Western Australia, the large seeds of *S. spicatum* are dispersed by the large, flightless emu.

The ability of a species to coppice or develop root suckers also has implications for management. If coppicing is to be used, either as the main form of regeneration or as a supplement to seedling regeneration, the harvesting techniques should preclude the removal of stumps. If the species does not produce root suckers readily, then it is feasible to utilize the stump. On steep land this may be undesirable because of potential soil erosion problems.

Plantations

Relatively little experience with managing sandalwood plantations has been accumulated, except with *S. album* in India and *S. austrocalodonicum* in New Caledonia. Periodic cutting back of the secondary host is necessary, as is livestock or wildlife exclusion when trees are small.

Little is known about the effect of fertilizers on the growth of sandalwood, apart from research in India that indicates an adverse effect of the application of boron. In Australia, chlorosis of *S. album* seedlings has been remedied by the application of iron chelates.

Conservation of Germ Plasm

Given the generally depleted state of sandalwood populations in most countries (except India and Australia), resource management agencies in countries with sandalwood should do the following to identify and protect the remaining higher quality stands as a future seed source:

(1) Identify and"formalize" seed stands of various species and provenances. These areas should be set aside as protected seed reserves.

(2) Identify "elite" trees with high oil content, high ratio of heartwood to sapwood, and vigor. Investigations will be needed to determine genetic "superiority" versus phenotypic variation due to site-tree interactions. For example, are oil content and heartwood to sap ratio dependent on site alone or are genetic factors involved?

(3) Provide seed to other countries for species and provenance testing. All seed tested should be fully documented for source, latitude, altitude, rainfall and temperature information, date of collection, method of collection, and handling and storage.

(4) In areas where the indigenous sandalwood is threatened by overexploitation or damaging environmental factors, seed should be collected and ex situ seed stands established.

HARVESTING, MARKETING, AND UTILIZATION OF SANDALWOOD AND OIL

Harvesting

Much of the sandalwood harvested today is dead wood, i.e., either standing or fallen trees. Buyers in many ways prefer deadwood because it contains less moisture and thus provides more volume per tonne. Deadwood is also easier to clean than greenwood since sapwood is already decaying. Greenwood is defined as wood taken from standing trees with green leaves. In some cases, a load of deadwood commands higher prices than those currently received for a mix of greenwood and dead wood. However, the mix is sometimes produced since harvesting deadwood is generally more costly than harvesting greenwood because of the labor intensive process required to find dead trees.

To date, sandalwood has not been managed on a sustained yield basis, and over-mature, standing trees show signs of decline with dead branches or rot. The value of these Trees is thus decreasing, although in many cases they will yield sufficient heartwood to be commercially viable.

Harvesting mature trees should be very selective. Tests should be taken to determine the ratio of heartwood to sapwood, and this can be done quite easily by using increment borers or portable drills. Care should be taken to retain at least some of the best mature stems for seed production.

At present, many of these criteria are not understood and therefore not practiced. Hopefully current research and communication will lead to better management of this resource.

While most sandalwood is harvested using simple equipment (often a chain saw and a truck), the high value of good material can make it financially feasible to use a higher level of technology. For remote areas and high value material, helicopters have been used for assembling material.

Marketing and Utilization

Raw sandalwood has three major uses: carving, incense, and oil. Quality specifications, and hence prices for raw sandalwood, vary considerably between species in each of these categories, so it is best to look at each category separately, even though the markets for each use are not strictly differentiated *(Appendix A).*

Carvings

Carvings utilize the best quality sandalwood. Finished products range from large statues of deities to animals, boxes, beads, and other handicrafts. Fans are also made in considerable quantities both by hand and machine. Logs selected for carving usually fall into two major grades. Grade specifications differ for each country (or perhaps between buyers), but in general logs selected for carving must be 1 m (3 ft) in length, defect free (i.e., no cracks, rot, or other blemishes), and have a heartwood diameter of at least 12.5 cm (5 in). Distinctions between grades are made on the basis of heartwood diameter, and examples of grade specifications for three production regions are given in *Appendix B.*

Major buyers of sandalwood logs for carving are from Hong Kong and Taiwan. They in turn distribute to China, Japan, and Singapore. India produces the best sandalwood logs for carving due to the fine grain of the *S. album,* but utilizes it all domestically. Export of *S. album* logs is prohibited. Major exporters of top quality logs are Hawai‘i, Fiji, Indonesia, and Western Australia. Vanuatu, a producer of quality sandalwood, currently has a 5-year moratorium on all cutting and export. Tonga has also been a producer of quality logs, but its prgsent status is unknown. Papua New Guinea also supplies logs, but they are considered lower quality. Many logs for carving are sold clean of sapwood, though buyers prefer Grade A logs with sapwood in order to prevent cracking and splitting. The ends of logs for carving are usually sealed with a compound to prevent cracking and oil loss. Logs should have an oil content of at least 2 percent to facilitate carving.

Incense

The market for incense, an essential component of Hindu and Buddhist religions, is large and increasing. It has also been increasing in the Western world over the last two decades. Singapore and Taiwan are the two major incense (joss-stick) manufacturing sites. Mills reduce the wood into powder, which is either attached to bamboo slivers with wood resin or simply compacted into sticks. The latter are mainly for the Japanese and Saudi Arabian markets.

The incense market absorbs mostly C grade logs, which are either below minimum length or have smaller heartwood diameters. Many buyers prefer to purchase logs and do their own powdering to ensure quality. They also take roots and butts, as well as wood that has been chipped or powdered in the country of origin. Wood sold as chips and powder command prices of around $2,300 U.S. per tonne, and Singapore absorbs most of this product. The roots and butts of *S. spicatum* and *S. album* have a high oil content and are valued for incense, bringing at this writing some $7,000 U.S. per tonne. Prices of logs and pieces for incense vary from $2,000 to $5,000 U.S. per tonne, depending on quality, although prices higher than this may be obtained for *S. album* and *S. spicatum.* Australia supplies most of the world incense market at present. Although India allows some powder and chip export, quantities are limited. Since the sapwood of *S. spicatum* has a thin sap and a low oil content, the logs do not need to be de-sapped before use and the whole log can be chipped and then powdered.

Oil

Sandalwood oil, obtained from the heartwood of the stem and the root of the sandalwood tree, is one of the most valuable oils in the world. It is a colorless or pale yellow liquid with a sweet and persistent woody odor, containing not less than 90 percent free alcohols by weight. The alcohols are principally of the sesquiterpene group and are referred to collectively as santalol. The major odiferous components are a-santalol and b-santalol, while a-santalene, b-santelene and santalyl acetate also contribute in a minor way to the overall odor character of the oil.

Distillation and Extraction—The water distillation method has been carried out in India in small units of production located principally on the West Coast, along the periphery of the Mysore Plateau, and at Kannuj in North India, since ancient times. The heartwood powder is soaked in water in a copper vessel which is then heated on an open fire. The vapors from the still are conducted through a bamboo or copper pipe to receivers kept in cold water. The floating oil in the distillate is mechanically ladled off, and the oil is refined further by filtration and decantation. In this way, yields as high as 4.5 percent are obtained. The oil obtained by this method is claimed to possess a finer odor than the one produced in modern steam stills.

More than 90 percent of the present production of sandal oil in India comes from four government factories employing the modem steam distillation method. The important distilleries are located in Karnataka, Andha Pradesh, Tamil Nadu, and Mahrashtra. These factories each utilize 1.50 tonnes of wood daily, which yield 90 kilograms of oil. The export price of the oil starts at $1,500 U.S. per kilogram and may go beyond this depending upon quality. The final product is a yellow oil, optically clear, possessing the characteristic sandalwood odor, and conforming to pharmacopoeial standards. Average yield of oil ranges between 4.50 and 6.25 percent. Two distillation plants are located on Timor and in New Caledonia.

Production of oil by solvent extraction is possible; however, the product obtained by this method is not preferred by the perfume industry.

Uses—Sandalwood oil is highly prized as a raw material in perfumery, because of its nonvarying composition, fixative properties, and—most importantly—its sweet, warm, spicy, and tenacious fragrance. Sandalwood oils are also used in soaps, face creams, and toilet powder.

Apart from being a supremely satisfying source of the fragrance, sandalwood oil has many medicinal uses. The oil is used as an antiseptic, an antiscabietic, a diuretic, and for the treatment of gonorrhea, bronchitis, and bladder infections. However, its use as a base of fragrance has far outweighed its use in medicine.

Most sandalwood oil is exported to perfumeries in France and New York.

RESEARCH NEEDS

Information is still lacking on many aspects of sandalwood from many of the countries where it grows, and the following research needs should be given a high priority:

(1) Investigating the use of extracts from sandalwood leaves and other substances to improve germination percentages and to speed up the germination process.

(2) Developing techniques to improve the germination of species from Papua New Guinea, Fiji, Hawai‘i, and other Pacific island countries.

(3) For some species, such as those from Hawai‘i and Fiji, for which little is known about potential primary hosts, identifying suitable indigenous host plants and nutritional requirements.

(4) Determining the optimum spacing and layout of sandalwood and secondary hosts depending on the growth habits of the host species and its end use.

(5) Identifying the nature, quality, and quantity of the oils of those sandalwood species for which that information is unavailable.

(6) Developing reliable resource information for existing natural stands to support management for conservation of the species.

(7) Developing yield tables for different sites and species in plantations and natural forests.

(8) Defining the effects of different land use practices on sandalwood stand dynamics, growth, and distribution.

(9) Establish an information network on individuals and institutions that carry out research or management of sandalwood.

APPENDIX A

Distribution and Marketing of Sandalwood Logs 1989-1990

Producing Country	Species	Log Exports tonnes per annum (approx)	Log Import Country
India	*S. album*	Prohibited, except small quantities	Nepal
Indonesia	*S. album*	?	Hong Kong/ Taiwan
Australia	*S. lanceolatum*	500	Taiwan
	S spicatum	1,800+	Taiwan, Singapore, Hong Kong
Hawai'i	*S. ellipticum*	300+	Hong Kong, Taiwan
Fiji	S. *yasi/album*	250	Hong Kong
Tonga	*S. yasi*	40	Hong Kong, Taiwan, Singapore
Vanuatu	*S. austrocaledonicum*	5 yr moratorium since 1987	Hong Kong, Taiwan, Singapore
New Caledonia	*S. austrocaledonicum*	None (only oil)	France
Papua New Guinea	*S. macgregorii*	250+	Hong Kong, Taiwan, Singapore
Marquesas[1]	*S. insulare*		?
	S marchionense		?
Solomon Islands[1]	?		Taiwan+?

[1] Not known if currently producing.

APPENDIX B

Grades and Approximate Prices Per Tonne (Metric) for Three Major Sandalwood Production Areas

India—*S. album*

Average selling price (green and dead), assuming 90 percent cleaned

1987	US$4,590 /tonne	(78,000 rupees)
1990	US$9,410 /tonne	(160,000 rupees)

Wood

A-grade logs 15 cm (6 in.) minimum heartwood, minimum 2 foot length:
Average price: US$ 10,000 tonne

B-grade logs under 15 cm (6 in.) heartwood, butts, and roots:
Average price: US$7,060 /tonne

C-grade defective A and B grade logs & pieces:
Average price: US$4,700 /tonne

Chips and Powder

Average price: US$2,300 /tonne

Oil

Oil content is a crucial determinant of wood quality. Oil content of *S. album* is between 2.8 - 6.5 percent for the quantity of oil, differs between trees, and is difficult to determine beforehand.

Price for oil (government factories) is $1,500/kilo (export price)
$ 470/kilo (internal price)

Australia

Western Australia—*S. spicatum*

Logs, green and dead, sapwood on.

Grade: Single grade, min. length 1 m (3 ft)
Average Price: US$4,260 /tonne ($AUD5,700 /tonne)

Grade: Roots & Butts
Average Price: $5,600 US/tonne ($7,500 AUD/tonne)
(Chips and powder; prices unknown)

Queensland—S. *lanceolatum*

Logs, green and dead, all 90 percent cleaned of sapwood

Grade 1. Min. length 1 m (3 ft), minimum heartwood diameter 7.5 cm (3 in.)
Average price: US$2,000/tonne (AUD$2,500 /tonne)

Grade 2. Under 1 m (3 ft) length, heartwood diameter less than 7.5 cm (3 in.) (billets)
Average price: US$1,600 /tonne (AUD$2000 */tonne)*

Hawai'i

S. ellipticum logs, green and dead, 90 percent cleaned

Grade A: 10 in. heartwood diameter and minimum length 3 ft, defect free
Average price: US$ 10,000 /tonne

Grade B: 5-10 in. heartwood diameter, minimum length 3 ft defect free
Average price: US$4,500 /tonne

Grade C: 2-5 in. heartwood diameter, minimum length 2 ft 5 in.
Average price: US$3,400 US/tonne

Wood under 2 in. must be solid heart and sap free, and is included in grade C as also are roots and butts.

Note: Grade A buyers prefer sapwood on the logs to prevent cracks and splits, and price per *tonne* is adjusted accordingly.

REFERENCES

Anon. Fragrant harvest. 1979. Landscope 40:(4) 26-30. Western Australia Department of Conservation and Land Management.

Chavvin, J.P. 1990. La production de plants de santal en Nouvelle Caledonie. Bois et Forests des Tropiques N°218, 1-10.

Fosberg, F. R.; Sachet, M.H. 1985. *Santalum* in Eastern Polynesia. Candollea 40(2): 459-470.

George, A. S. 1984. *Santalum.* in Flora of Australia, vol. 22. Bureau of Flora and Fauna. Australian Government Publishing Service. Canberra, Australia.

Maina, S. L; Pray, L. A; Defilipps, R. A. 1988. A historical note on the endangered *Santalum boninensis* (Santalacaea) of the Ogasawara Islands: Early reports by Jahrasi Tuyoma. Atoll Research Bulletin 319: 19-24.

Mathur, N.K. 1979. An annotated bibliography of spike disease of sandal *(Santalum album* Linn.) Forestry Research Institute. Dehra Dun. 74 p.

Neil, P. E. 1986. Sandalwood in Vanuatu. Forest Research Report, 5/86, Vanuatu Forest Service, Port Vila, Vanuatu; 8 p.

Neil, P. E. 1989. Possible techniques for raising and planting sandalwood in Nepal. Banko Janakari 2(3):1-6; 1989.

Parthasarathi, K; Rai, S.N. 1989. Physiology, chemistry and utilization of sandal *(Santalum album* Linn.) My forest 25(2): 181-219.

Ross, M.S. 1985. Annotated bibliography on sandalwood, *Santalum album,* and its uses. Bos-Document 2. Dutch Forestry Development Cooperation, Wageningen, The Netherlands. 135 p.

Shineberg, D. 1967. They come for sandalwood. A study of the sandalwood trade in the south-west Pacific 1830-1865. Melbourne: Melbourne University Press; 216 p.

Skottsberg, C. 1930. Further notes on Pacific sandalwoods. Acta Horti Gothoborg 5: 136-143.

Skottsberg, C. 1930. The geographical distribution of the sandalwoods and its significance. Proc. 4th Pacific Science Congress (Java) 3:435-442.

Smith, A. C. 1985. Flora Vitiensis Nova, vol. 3. Pacific Tropical Botanical Garden. Lawai, Kauai, Hawaii.

Statham, P. 1988. The Australian sandalwood trade, small but significant. Working Paper No. 100. Canberra, Australia. Department of Economic History, The Australian National University. 36 p.

Stemmennann, L. 1980. Observations on the genus *Santalum* (Sontalaceae) in Hawai‘i. Pacific Science 34(1):41-54.

Stemmermann, L. 1980. Vegetative anatomy of the Hawaiian species of *Santalum* (Santalaceae). Pacific Science 34(l):55-75.

Sykes,W.R. 1980. Sandalwood in the Cook Islands. Pacific Science 34(l):77-82.

Tuyama, T. 1939. On *Santalum boninense,* and the distribution of the species of *Santalum.* Jap. J. Bot. 15:697-712.

Yuncker, T. G. 197 1. Plants of Tonga. Bernice P. Bishop Museum Bulletin 220.

Wagner, W. L.; Herbst, D. R.; Sohmer, S. H. 1990. Manual of the flowering plants of Hawaii. University of Hawaii Press and Bishop Museum Press, Honolulu.

Managing Sandalwood for Conservation in North Queensland, Australia[1]

Grahame B. Applegate   Allan G. W. Davis
Peter A. Annable[2]

Abstract: *Santalum lanceolatum,* the commercial species of sandalwood harvested in Queensland, was worth $4.2 million in export earnings in 1988. The ecology of the species in natural forests is summarized, and information on seedling regeneration and coppice and root suckering strategies is provided. Stand characteristics and size class distribution in two different environments in northwest Queensland are provided. It is important to manage the resource for conservation. The harvesting guidelines, pricing criteria, and procedures are discussed along with information on heartwood recovery and moisture content of harvested sandalwood. Future research should be undertaken to monitor stand dynamics, growth rates, and the effects of land use practices on the distribution, growth, and dynamics of sandalwood in natural stands.

> *The trade in this fragrant wood has been going on since the dawn of history and will probably not cease until the connection between santal trees and idolators existing from time immorial, shall have been broken up, by either the one or the other becoming as extinct a race as the Archaepteryx or the Dodo.* (Sawyer 1892)

Long before the southern part of Australia was settled by Europeans, the north may have been invaded by the Malays, primarily in search of sandalwood for use in making joss sticks and to carve idols to decorate temples. The first recording of sandalwood exported from Australia was in the State of Western Australia in 1846, when about 4 tonnes of wood were sent abroad for oil production. Sandalwood then became the State's major export income earner, with between 3000 and 4000 tonnes of sandalwood exported annually to the end of the century (Kealley 1989). Today Western Australia has a robust industry controlled by the Australian Sandalwood Company, which in 1988 exported $A 9.1 million worth of sandalwood (Anon. 1988).

The sandalwood industry commenced in Queensland in Cape York around 1865 *(fig. 1).* Initially, sandalwood cutters and export facilities were concentrated in the northern part of Cape York Peninsula around Cooktown, Coen, Weipa, and Somerset *(fig. 1).* Some cutting was carried out north of Normanton in 1917 and just north of the Mitchell River in 1923 (Wharton 1985).

During the 1920's and early 1930's, the industry developed in Western Queensland and was centered on the basalt wall country near the town of Hughenden (Wharton 1985). During this period, the marketing of sandalwood harvested from both Crown (government-owned) and privately owned land in Queensland was controlled under the *Sandalwood Act of Queensland of 1934*. Under the provisions of the Act, all sandalwood from Queensland was marketed by the Queensland Forest Service (Q.F.S.) and then sold in accordance with the terms of an agreement with the Australian Sandalwood Company of Perth, Western Australia.

The Sandalwood Act prohibited any person from harvesting, getting, pulling, or removing sandalwood without a license issued by the Government. The sandalwood industry declined in Queensland in the late 1930's, and, although it had died out by 1940, it was revived again in 1983.

The Sandalwood Act of 1934 granted a monopoly to the Australian Sandalwood Company that effectively halted production of sandalwood in Queensland. The revoking of the Act in 1982 made way for the revival of the sandalwood industry in north Queensland with annual sales from Crown land initially limited to 500 tonnes. The quota was divided among three buyers who were operating on Crown land in the Gulf region from Normanton to just north of the Mitchell River—an area of about 30,000 km^2.

In February 1987, tenders were invited by the Q.F.S. for the exclusive rights to purchase sandalwood from Crown land over a period of 20 years. Although there was no guarantee of

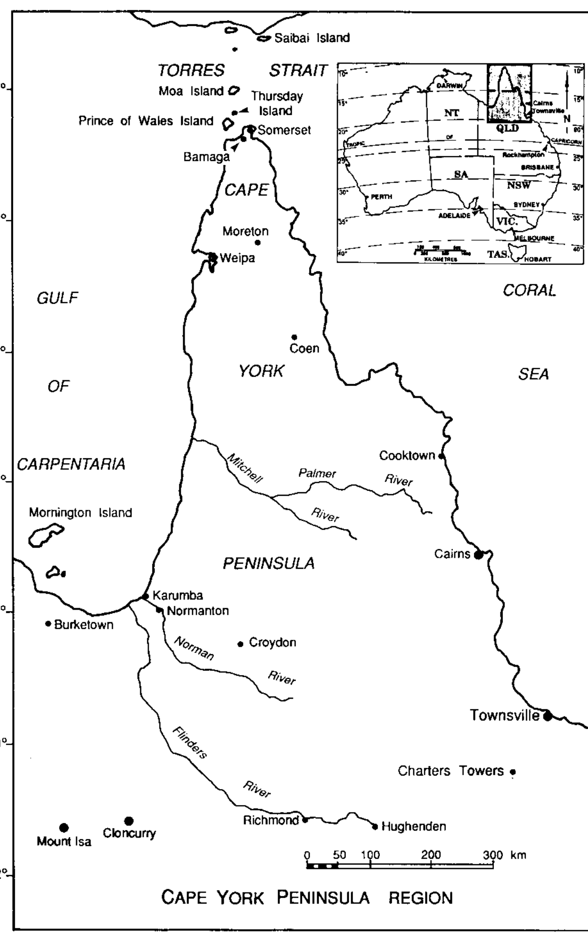


Figure 1—Major sandalwood producing areas in N.W. Queensland.

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawaii.

[2]Officer in Charge, Research Center, Atherton; District Marketing Officer, Atherton; Overseer, Atherton-all with the Queensland Forest Service, Australia.

availability, the sandalwood was offered at the rate of 1000 tonnes (bark-on) per annum. The rights to purchase sandalwood from Crown land in Queensland was awarded to Unex Industries (Australia) Ltd. based in Sydney. The royalty paid for the sandalwood harvested from Crown land was in excess of $1500 per tonne (bark-on).

Until late 1989, Unex had contractors harvest sandalwood from Crown holdings on the basalt wall north of Hughenden and in the Gulf region south of the Mitchell River *(fig. 1).*

SANDALWOOD RESOURCE

Species Description

Santalum lanceolatum R.Br. is the most widespread of all the *Santalum* spp. in Australia. It is found in tropical Australia (10°s) extending down into the south of Queensland, New South Wales, Victoria (30°s) and across to Western Australia.

It grows as a tall shrub up to 7 m, with a crown that is deep and usually drooping. There appears to be a good deal of variation in leaf form, size, and color. The species has a wide, but variable (1.5 to 3 cm) pale yellow sapwood band and a brown heartwood. It also appears to have growth rings, which are thought to be annual. The heartwood is quite heavy when freshly cut but dries out quickly when stacked in the open. It has an air dry density between 930 and 950 kg/m^3, which makes it a moderately heavy timber.

Habitat of the Species

Macrosite

The general area of northwest Queensland has a sub-humid tropical climate with a distinct wet and dry season. The strongly seasonal rainfall comes from the northwest, with most of the rain falling between December and March. The annual rainfall is between 870 and 1250 mm, with the northern area receiving slightly more rain than the south. Temperatures are high throughout the year, with temperatures of around 22 °C occurring in June and July and exceeding 40 °C in December and January.

The sandalwood found in the Mitchell Plains and Delta Country at the southern end of the Gulf of Carpentaria is concentrated in specific areas on old alluvium and colluvium soils. Some of these areas contain texture-contrast (duplex) soils that are solodised-solonetz formed under high levels of exchangeable sodium or magnesium. They are highly erodible, especially when the subsoil is exposed. Sandalwood is rarely seen in the open woodlands but tends to be more common on the outer edge of the scrubs of *Melaleuca acacioides* and gutta percha *(Excoecaria parvifolia)*, adjacent to gilgai areas and around drainage lines. These areas are sometimes adjacent to the woodlands where the topsoil has been disturbed as the subsoil disappears, forming "breakaway" areas. The ecotone in the immediate vicinity of the sandalwood, i.e., at the interface of the melaleuca scrubs and woodlands, has often only a sparse grass cover, if any, and is unlikely to carry a hot fire. Annual fires throughout the region would probably kill the sandalwood seedlings in the densely grassed open woodland but would seldom extend beyond it into the scrubs. Hence, fire is believed to be a contributing factor to the pattern of sandalwood distribution in the region.

Cattle graze most of the area; consequently, the grasslands are burnt annually after the summer storms to provide fresh grass for fodder. Partly as a result of the fine-textured soils and present land use practices, erosion is evident over much of the area. On most areas near the Gulf where the vegetation has been disturbed or removed for roads or stockroutes, natural erosion is exacerbated and the loss of top soil and gullying of the subsoil is conspicuous.

Another region that contains considerable sandalwood trees is the basalt wall near Hughenden *(fig. 1).* The basalt wall, which rises 60 m above the surrounding countryside, is an old tertiary lava flow which runs in an east-west direction just north of Hughenden. The sandalwood grows amongst the boulders, generally on the slopes and in the gullies. Current studies suggest that the trees on the slopes of the wall do not grow as tall or as upright as those in the river systems in the Gulf region.

The basalt wall region is grazed by sheep and, as the ground is covered with basalt boulders, roads are few and grazing is very poor.

Microsite

Sandalwood commonly grows within clumps of other species or adjacent to other sapling sandalwoods (usually < 10 m away). This feature was reported in 1932 on Mt. Frazer. "Rarely was a tree found in isolation in open woodland" (Brass 1932). When the trees do not grow in crowded conditions, the crowns—as expected—are well developed. Often these trees have lighter, less fissured bark than do trees growing in more gregarious conditions. Trees in clumps often have poorly developed crowns with dark fissured bark on their trunks. Although the trees appear overmature, some are quite small. This small size may be explained as follows: the haustoria need to attach themselves to roots of host plants, so seedlings must be close to their hosts to do this; although seedlings derive photosynthates from their hosts, their growth is suppressed by the overtopping crowns of the host plants. Observations of the wood of these trees (in clumps) indicate that they frequently have a slightly narrower sapwood band than open-grown trees of comparable size.

Regeneration Strategy

Seedling Regeneration

Although sandalwood is a reasonably prolific seed producer with a succulent fruit, seedling regeneration in some areas is not very conspicuous. Seeds are easily germinated under nursery conditions, so it is initially surprising that more seedling regeneration is not evident in the field. In some areas, however, seedlings are found in large numbers, often as "wheat field regeneration" in the drainage lines of river systems after flooding.

Field observations indicate that many of these seedlings do not develop or are not given the opportunity to reach maturity. Some of the reasons why seedling regeneration is not more conspicuous are as follows:

- Seedlings require a reasonable moisture regime to grow, and this is not available for much of the year in the Gulf region or on the basalt wall.
- In the region around Hughenden, annual summer rains are not reliable so conditions there are not conducive to seed germination. These conditions may explain the lack of seedling regeneration in part of this area.
- On the stumps where coppice shoots are observed, all are heavily browsed by animals. The animals grazing the regrowth are either livestock or native fauna.

Vegetative Regeneration

Stump Coppice—The stumps of four different ages showed little coppice development. Although some stumps contained numerous coppice shoots, few—if any—appeared to be of a size that would indicate that they would grow into a tree. It is doubtful (from our observations) whether coppice shoots from stumps would have any effect on the long-term regeneration of the species in many parts of north Queensland.

Root Suckers—Formation of root suckers appears to lead to successful regeneration of *Santalum lanceolatum.* In many of the forest types where sandalwood is found, solitary trees are seldom seen, and where two trees are found close to each other, one is usually smaller than the other. Roots from these larger parent trees were excavated and followed to a distance of 7 m from the stem, where a root sucker had produced the other stem. Other suckers were present on other roots coming from the same parent tree.

Regeneration at least to 5 cm d.b.h. resulting from root suckers from the roots of a parent tree is common. Although fire and browsing animals may invade these areas, the presence of prolific and vigorous sucker regeneration would suggest that these suckers have the capacity to survive and grow even when conditions are not conducive for them to do so. No data is available on what triggers root suckering in this species of sandalwood. In other genera, e.g., *Schima* and *Daphne* spp. whose roots often grow close to the surface and sometimes protrude above it, injury to the exposed root causes a shoot to develop near the point of injury. The injury could result from a number of causal agents including fire, trampling by livestock, damage by falling limbs or trees, and the erosion of soil from around the roots—the latter of which is a common phenomenon in and around drainage lines in the Gulf region.

As root suckers are often observed on the roots of unlogged parent trees, removal of stumps during logging would sever the roots, disturb any suckers and might cause them to die. Stump removal could have a major impact on the potential for the residual sandalwood stand to develop. At this stage it is unknown at what age or level of development the root suckers become independent from the root and can survive from the moisture and nutrients obtained by their own roots. This unknown is one of the reasons why living sandalwood roots are not harvested in north Queensland.

Parasitic Habit

Sandalwood appears to be a partial parasite, i.e., the seed is able to germinate readily on its own, but then the seedling seems to require a host plant from which it can sustain itself. One of the reasons why many young seedlings do not grow could be that their haustoria do not find a host plant soon enough after the seedling growth stage.

This parastic habit could be one reason why many sandalwood trees that appear to be growing well are found among clumps of other species. There is no evidence to suggest that this species of sandalwood kills its host plant.

Stand Structure

The structure of sandalwood stands varies with their environment. Two main sandalwood producing areas are located along the lower part of the Gulf of Carpentaria and on the basalt wall near Hughenden. The sandalwood stands in these areas have different structures and size class distributions. To illustrate these differences, the data from two plots, one at Rocky Creek in the Gulf region north of Normanton and another on the basalt wall near Hughenden, are provided *(fig. 1)*. *Table 1* shows the stand characteristics of sandalwood on Rocky Creek and *table 2* shows the stand characteristics of sandalwood found on the

Table 1— *Stand characteristics of* Santalum lanceolatum *on Rocky Creek north of Normanton*

Parameter	Stems per hectare	Percentage of stand
Total no. of stems >1.3 m ht.	21.0	100
No. of stems >10 cm d.b.h.[1]	13.0	61
No. of stems >12 cm d.b.h.	11.5	54
No. of stems >15 cm d.b.h.	6.5	30

[1] d.b.h. is the diameter at breast height.
Plot mean d.b.h. of all stems >12 cm d.b.h.

Table 2— *Stand characteristics of* Santalum lanceolatum *on the basalt wall near Hughenden*

Parameter	Stems per hectare	Percentage of stand
Total no. of stems >1.3 m ht.	21.2	100.0
No. of stems >10 cm d.b.h.'	6.3	29.3
No. of stems >12 cm d.b.h.	4.9	23.0
No. of stems >15 cm d.b.h.	3.0	13.9

[1] d.b.h. is the diameter at breast height.
Plot mean of all stems > 12 cm d.b.h. is 15.7 cm.

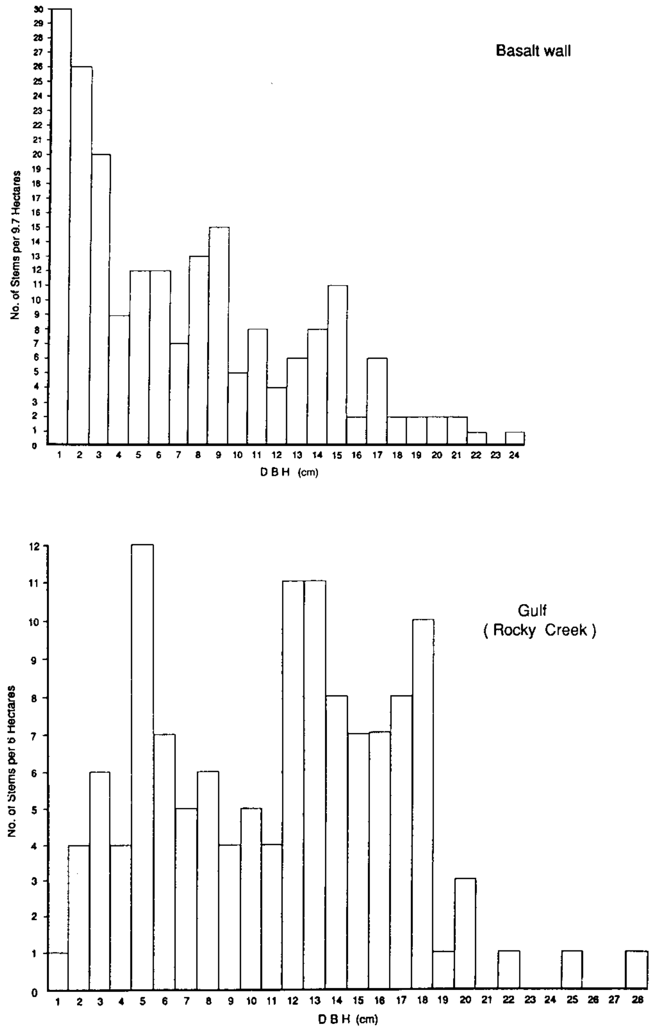


Figure 2—Frequency of sandalwood stands from the Gulf region (Rocky Ck.) and the Basalt Wall.

basalt wall. A frequency distribution diagram for the two sites is given in *figure 2.*

The diagram for the Rocky Creek plot shows a bimodal distribution of sandalwood, indicating the possibility of two populations. This theory corresponds to examples readily observed in many sandalwood areas, where a large parent tree is seen with one or more smaller trees growing off it as root suckers, or in close proximity to seedling regeneration.

The largest tree that was found in the Rocky Creek plot was 28 cm d.b.h., with a small number in the 20 cm to 25 cm d.b.h. range. Most of the parent population range in size between 12 cm and 18 cm d.b.h., with the progeny centered around 5 cm d.b.h.

The frequency distribution for sandalwood on the basalt wall, as shown in *figure 2,* indicates that there may be three populations: A large number of young trees in the 1 to 3 cm d.b.h. range, another population centered around 9 cm, and another at 15 cm d.b.h. Although total stocking levels between the two sites are similar, generally the number of stems on the basalt wall in the larger than 10 cm, 12 cm, and 15 cm class are about half that of comparable size classes on the Rocky Creek site. There is, however, a very large proportion of the stand on the basalt wall site (36 percent) in the 1 cm to 3 cm d.b.h. range as compared with 8.7 percent at Rocky Creek. This difference could be a direct result of land use practices in the region at time of sampling.

MANAGEMENT FOR CONSERVATION

The Industry

Following the successful tender by Unex Industries (Australia) Ltd. in 1987 to secure the sole rights to purchase sandalwood *(Santalum lanceolatum)* from Crown land in Queensland for 20 years, processing plants were established at Richmond and in Brisbane *(fig. 1).* The harvested sandalwood was transported as small logs or branches to Richmond and Brisbane, where the bark and sapwood were removed and the heartwood baled into wool bales for export. Some higher quality logs were not desapped, and instead exported under license as bark-on. In 1988, Unex Industries employed three cutters who operated on Crown land in the Gulf region and on the basalt wall. During this same period, a number of other companies began cutting and processing sandalwood from private land on the basalt wall in the same region. The five companies also obtained licenses to export their product to Asian countries, including Taiwan and Malaysia.

Most of the sandalwood harvested in 1988 came from Crown land. Export licenses were issued for about 600 tonnes exported in desapped form at an average price of $A 5000 per tonne free on board (f.o.b.). A further 550 tonnes in the bark-on form were exported at an average price of $A 2200 per tonne f.o.b. The sandalwood exported had a combined market value of $A 4.2 million (Anon. 1989).

Alleged breaches of contract by Unex Industries were detected during 1989, resulting in the immediate cancellation of the contract by the Q.F.S. Hence, as of January 1990, no sandalwood is harvested from Crown land in Queensland apart from salvage operations during land clearing for pastoral production. A new management document to solicit new expressions of interest in harvesting sandalwood on Crown land in Queensland is being prepared. Sandalwood is still being harvested from freehold land.

Harvesting Guidelines

Before 1988, the lower cutting limit for sandalwood was set at 10 cm d.b.h. Stand table data showed that if this figure was adopted, about 50 percent of the stand would be harvested. This percentage took an actual account of the trees that cutters accidentally bypassed, and therefore remained standing, trees which contained too many defects (often caused by ants, fire, and heartwood rot) or trees with a wide sapwood band.

To ascertain a suitable lower cutting limit, two major aspects had to be considered: (1) whether a viable residual stand remained after harvesting and (2) whether, for economic and conservation reasons, the heartwood constituted the major proportion of the tree that was harvested.

Preliminary investigations showed that the sapwood band could vary considerably between trees of similar diameter. Although in many cases, trees with deeply fissured bark often had a narrower sapwood band than smoother barked trees (the shape and general appearance of these latter trees indicated that they may have been younger), fissured bark was not fully reliable as a means of determining whether a tree had a narrow sapwood band. Sampling was undertaken to assess the width and amount of heartwood likely to be found in a tree of given size. This sampling was carried out to assist in determining the harvesting guidelines with respect to the limits of the sapwood/bark band width for trees of a particular size.

Figure 3 shows a linear regression equation that relates the d.b.h. to the diameter of heartwood estimated from 50 trees sampled from the Gulf region and the basalt wall. Based on the combined equation calculated from data from the two sites, a tree with a 12 cm d.b.h. would have an expected heartwood diameter of 6.2 cm. The heartwood, in this tree as seen in *figure 3*, represents only about 27 percent of the cross sectional area of the bole section of the tree, i.e., a theoretical heartwood recovery of about 30 percent.

The field sampling showed that increasing the lower cutting limit from 10 cm to 12 cm increases the number of trees in the residual stand by 7 percent on the basalt wall and by 10 percent in the stands in the Gulf if all of the stems greater than or equal to 12 cm d.b.h. were harvested.

Before the commencement of the Unex operation in 1988, some cutters wanted to harvest the sandalwood by removing both stump and root, a practice carried out in parts of India. This practice was partly to blame for the decimation of the sandalwood resource in some southern Indian states such as Mysore, since it prevents coppice regeneration from roots and stumps.

In many parts of the Gulf, sandalwood grows on duplex soils which are highly erodible. For this reason, as well as the fact that sandalwood coppices from the root, stump and root harvesting is not practiced in Queensland.

Harvesting Rules and Regulations on Crown Land

Due to the scattered nature of the resource and the huge area over which sandalwood is found, it was not possible to provide resource information to the purchaser. The responsibility for providing such information was given to the purchaser. Once an assessment is made on a Crown holding, logging areas are allocatedby Q.F.S. officers, who then direct harvesting on those areas in accordance with harvesting guidelines.

The purchaser is required to comply with the following guidelines, which are primarily aimed at conserving the resource and minimizing environmental disturbance:

- Trees harvested are not to be smaller than 12 cm d.b.h. unless they are dead, dying, damaged, fungus-infected, or otherwise declining.
- Trees harvested should have a maximum stump height of 10 cm.
- Trees harvested should be utilized to a heartwood top-end diameter of 3 cm. This would include all limbs with at least a 3 cm heartwood diameter.
- Under no conditions are the stumps or roots of trees to be harvested.
- To ensure that trees with a large sapwood to heartwood volume ratio are not harvested, trees are to be blazed to the

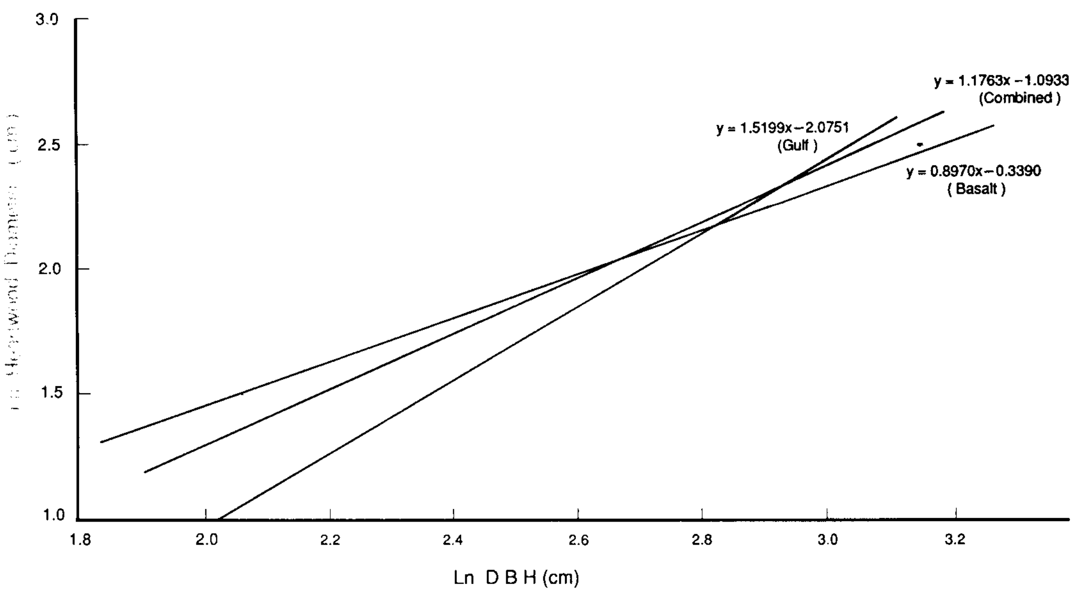


Figure 3—Linear regression equations relating the natural log of the d.b.h. to the natural log of the diameter of heartwood from the Gulf region, the Basalt Wall, and a Combined Equation using data from both sites.

heartwood at 1.3 m above the ground to determine the percentage of sapwood present. Trees should not be harvested if the sapwood plus bark thickness is greater than 1/6 of the d.b.h. outer bark.

- The quantity of timber sold is determined by mass recording over a weighbridge with the documentation of the weights presented for inspection.

Pricing Criteria

Sandalwood growing on Crown land, whether a Crown Holding or State Forest, commands a royalty to be paid by the purchaser. Many timber forest products sold in Queensland by the Q.F.S. are based on volume measurements. There is a tendency to replace this expensive and time consuming form of pricing with weight scaling. Sandalwood is currently sold by weight measurement with the bark on.

The environment in which sandalwood grows becomes very hot in summer, with temperatures often exceeding 40°C for weeks at a time. Consequently when harvested sandalwood is stacked awaiting transportation and subsequent weighing, weight loss occurs. The amount of the loss depends on both the time period between cutting and weighing and the prevailing weather. Hence, if logs are sold by weight, either as bark-on or heartwood only, the royalties payable could be quite variable for a given volume of harvested timber.

To ascertain possible weight losses and subsequent losses in royalty, two studies were undertaken: (1) using bark-on sandalwood and measuring weight loss over a 23-day period, and (2) using heartwood only and recording weight losses over a 6-week period.

1. Bark-on Drying Study: This study involved seven sandalwood stems and 28 branches. The samples were weighed immediately after harvesting in February (hot, dry season) and stacked in the open at Richmond. After 3 1/2 weeks (23 days), the pieces were reweighed. The stems had lost 9.8 percent of their initial weight, while the branches had lost 14.2 percent. The overall loss of weight from the stack was 11.7 percent. Based on these figures, the Crown would sustain a considerable loss in royalty if the purchaser waited a month before passing the stack of sandalwood over the weighbridge.

2. Heartwood Drying Study: A number of stems and branches cut from trees in three locations near Richmond were processed (within 2 days of harvesting) and the heartwood weighed before it was stacked under cover. Although the results were quite variable, the stems had lost 13 percent of their weight after three and a half weeks *(table 3)*. After 6 weeks they had lost 16 percent of their fresh weight. The branches provided similar results to that of the stems with a loss of 12 percent after 3 1/2 weeks and 14 percent after 6 weeks.

Utilization and Recovery

Observations carried out on cut stumps and logs suggest that for a given size tree, the sapwood band can be quite variable. There are a number of theories concerning the relative amounts of sapwood and heartwood in a tree. Three of these theories are as follows:

1. Trees with a relative wide band of sapwood to heartwood are young, relatively fast-growing trees.
2. The amount of sapwood is genetically controlled and is quite variable. It could be independent of age.
3. It could be a combination of 1 and 2, i.e., the sapwood/heartwood ratio is a variable characteristic (like leaf shape and size) and yet is also dependent to some degree on age or rate of growth.

Although the cutting regulations were partly based on achieving a 40 percent recovery of heartwood, variation in the sapwood band from tree to tree and within the same tree necessitated actual field sampling of the processed tree to determine more accurately the heartwood recovery.

To provide such information for the cutting regulations, sample trees were harvested from three sites: two from the basalt wall and one from a tributary of the Flinders River leading to the Gulf of Carpentaria. The stems were weighed before processing and the sapwood was immediately removed using the contractor's desapping machine at Richmond. Not only were trees of commercial size sampled, but also those below 12 cm d.b.h. *(table 4)*.

Table 3—*Weight losses recorded from the trial at Richmond*

Location	Percent Loss in Weight	
	3 1/2 weeks	6 weeks
Kara (Basalt Wall)		
Stems	12.4	14.8
Branches	14.4	16.5
Torquay (Basalt Wall)		
Stems	11.6	15.4
Branches	8.6	10.0
Saxby (Gulf)		
Stems	13.8	16.6
Branches	15.3	17.7
Mean		
Stems	12.8	15.8
Branches	12.3	14.2

Table 4—*Recovery details of the heartwood expressed as a percentage of the bark-on weight of sandalwood harvested from three locations in N.W. Queensland (fig. 1)*[1]

Location	Recovery of Heartwood		
	All Stems	Stems >12 cm	Stems <12 cm
		Percent	
Kara (Basalt wall)	35.4 (29.5-41.3)	41.6 (32.9-50.2)	29.3 (22.7-35.8)
Torquay (Basalt wall)	36.1 (32.9-39.3)	37.0 (34.1-39.9)	33.5 (18.7-48.3)
Saxby (Gulf)	27.0 (22.4-31.6)	29.9 (24.7-35.0)	18.4 (13.1-25.4)

[1]Numbers in parentheses are the 95 percent confidence limits of the

RESEARCH ACTIVITIES

Stand Dynamics

Preliminary data collected to date indicate that stands of sandalwood show a large variation in the number of stems per hectare, size class distribution, both on apparently similar sites and between different sites. Further research should be undertaken in the natural stands monitoring growth rates of existing stems, seedling regeneration, and coppice regeneration and also by looking at the processes that result in the different size class distributions between sites.

Effects of Land Use

Signs are clear that the pattern of sandalwood distribution is influenced by current and past land use practices. It is necessary, therefore, to monitor sandalwood plots in detail to study stand dynamics and the effects that various events and land uses have on the distribution and growth of the tree. These include livestock grazing (light and heavy), floods, fire and browsing by the native fauna.

Marketing

Because of the variable nature of sandalwood, it would greatly benefit both the Crown and the purchasers to investigate alternative methods of selling the product that might take more account of the variability of heartwood recovery and the quantity and type of oils contained in the heartwood and sapwood. Other factors that should also be taken into account include climate and its effect on drying rates, the land tenure from which the sandalwood is harvested, and the isolated and comparatively scattered location of much of the resource.

Plantations

Only some very basic plantings have been undertaken with *S. lanceolatum* as part of Australian Center for International Agricultural Research (A.C.I.A.R.) plantings in the dryland region of north Queensland. Other sandalwood species should be planted in some of the wet tropical regions closer to the east coast of north Queensland.

CONCLUSIONS

Conservation of sandalwood and the long-term viability of the associated industry are economically important to Queensland. The harvesting guidelines devised by the Queensland Forest Service are designed to meet both of these goals. Even though no State Forests exist in areas with commercial stands of sandalwood, National Park reservations in Cape York and the lower Gulf region do cover areas with sandalwood.

It is an essential part of the Queensland Forest Service's conservation philosophy that a sandalwood management plan include (1) harvesting guidelines designed to protect the environment, particularly in areas dominated by highly erodible duplex soils, and (2) harvesting and marketing strategies that take account of the wide range of this resource and results from land use practice studies. This information will help define practices that promote regeneration and development of sandalwood in the predominately pastoral areas in which it is found.

REFERENCES

Anon. 1989. Top 500 exporters. Australian Business Nov.

Anon. 1989. Unpublished report. Dept. of Primary Industry, Canberra.

Brass. 1932. Unpublished records. Queensland Forest Service.

Keally, I.1989. Fragrant harvest. Landscope 4(4):35-39. Conservation and Land Management Department, Western Australia.

Wharton, G. 1985. Antiquarians and sandalwood-getters: the establishment of the Cape York Collection at Weipa. In: Proceedings of the North Australian Mine Rehabilitation Workshop, No 9, Weipa, 1985.

Status of Management and Silviculture Research on Sandalwood in Western Australia and Indonesia[1]

F. H. McKinnell[2]

Abstract: The current status of the conservation and management of *Santalum spicatum* in Western Australia and *S. album* in East Indonesia is outlined. Natural and artificial regeneration techniques for both species in selected areas are discussed. The present Australian Centre for International Agricultural Research program on *S. album* in Nasa Tenggara Timur is described in relation to the management needs of the species in that province. In *S. spicatum,* research on silviculture is essentially complete, and interest is now focused on the marketability of the kernels for human consumption.

This paper is intended to be an overview, albeit incomplete, of current research on silviculture and the management status of the various sandalwood species of Western Australia and Indonesia. It is incomplete because it deals only with those areas with which I have direct experience and is not in any way an exhaustive survey of the whole region.

Trees given the appellation of sandalwood (or various versions such as sandal, santal) occur discontinuously over a huge area extending from India, through Indonesia, New Guinea, Australia, and many Pacific Islands as far east as Juan Fernandez Island. They are primarily tropical species, with the exception of four species occurring in Australia that extend into the warm temperate deserts. All are species of the genus *Santalum* and most (those known as sandalwood) are distinguished by the presence in the mature wood of distinctive oils which have been sought after for centuries for a variety of medicinal, ceremonial, and perfumery purposes.

The taxonomy of the genus is still somewhat untidy, but the following species distribution is a fair approximation of the present occurrence of sandalwood in the Australia-Indonesia-South Pacific region:

Indonesia—*S. album*

Australia—*S. spicatum, S. acuminatum, S. lanceolatum,* and *S. murrayanum*

New Guinea—*S. macgregori*

New Caledonia—*S. austrocaledonicum*

Vanuatu—*S.* a*ustrocaledonicum*

Fiji—*S. yasi*

The species from Indonesia, New Guinea, New Caledonia, Vanuatu, and Fiji are all "merchantable" in that they contain relatively high amounts of heartwood oil, but of the Australian species only *S. spicatum* has had any sustained exploitation. Sporadic use has been made of *S. lanceolatum* in Queensland for timber but little of the other species. *S. acuminatum,* or quandong, is grown to some extent for its fruit and edible kernel.

S. album (cendana) from Indonesia has a very long history of exploitation, going back perhaps more than a thousand years. Some believe that the species is an exotic in India, having been taken there from East Indonesia by traders of the fragrant wood. It would be interesting to carry out chemical studies to try to clear up this point. It occurs naturally now mainly on Timor and to a small extent on Sumba and Flores. The current harvest is about 1000 tonnes per year. Considerable concern has arisen in the government of Indonesia at the continuing failure to mount an effective regeneration program and to protect existing resources.

The original limits of cendana are difficult to define as it has been extensively planted in Java, Bali, and other Indonesian islands. It is also found to a small extent around the northern coast of Australia, and debate exists over whether it is truly endemic to Australia or was imported by fishermen or birds from East Indonesia centuries ago.

Overall, tropical sandalwood resources have been greatly reduced in the last 100 years, and real concerns about their regeneration and long-term management have arisen in *all* tropical countries from India to Tahiti. Still, only in Western Australia is there tight control of the harvesting industry and a long-term management plan that considers both conservation of the species in its various ecological associations and sustainability of the yield.

Significant variations exist in heartwood oil content between the commercially utilized species. *S. album* and *S. yasi* average 5-7 percent, S. *austrocaledonicum* 3-6 percent depending on source (Cremiere pers. comm.), and *S. spicatum* averages only 2 percent. The last is considered too low for distillation under present economic circumstances, and is used only for the incense trade. However, it has been used for distillation in the past. In Indonesia, the wood of S. album is distilled for the oil and the residue is marketed to the incense trade.

The main markets for the oil appear to be New York and Paris, while the centers of the incense trade are Singapore, Taiwan, Hong Kong, and Korea. Every indication is that these markets are relatively stable (although sensitive to resource prices) and that there is little likelihood of the intrusion of artificial substitutes.

MANAGEMENT IN WESTERN AUSTRALIA

The Western Australian sandalwood is a small tree up to about 8 m in height, with a bushy growth habit and a crown diameter of about 2 m. It occurs naturally over a very large area of Western Australia, from the edge of the high forest zone out to the huge desert interior of the state *(fig. 1).* It has virtually disappeared from the 300-600 mm rainfall zone due to widespread conversion of the natural woodland to wheat and sheep farming activities, but is still found over some 42 million ha on the arid zone. Sandalwood is usually found in the mulga *(Acacia aneura)* and eucalypt woodland vegetation types, and particularly at the junction between the two. Sandalwood tends to avoid pure woodlands of one eucalypt species, for example, *Eucalyptus dundasii, E. longicornis, E. salmonophloia,* or the Chenopod

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai'i.

[2]Director, Information Resources, Department of Conservation and Land Management, Western Australia.

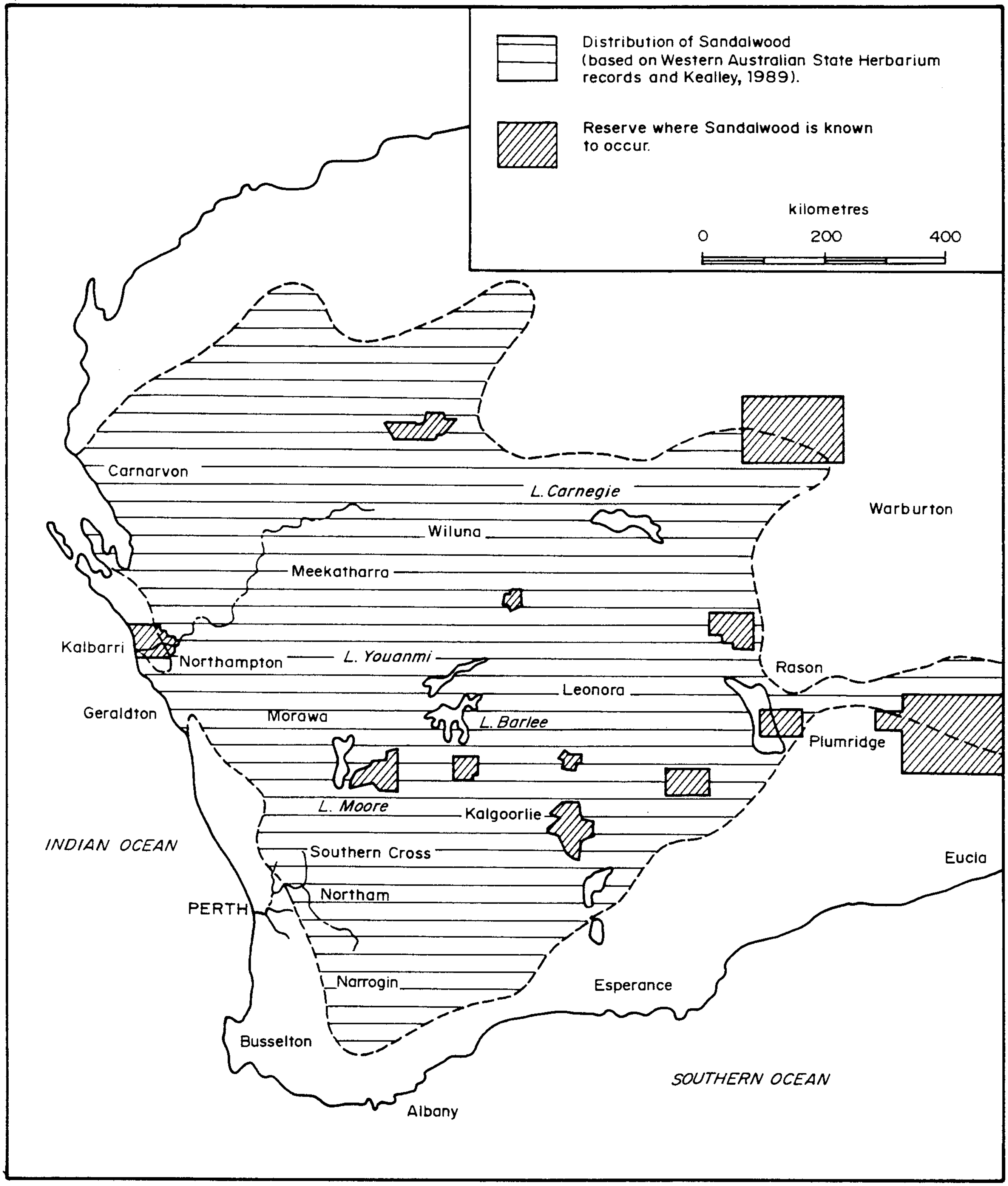


Figure 1—Sandalwood occurs naturally in Western Australia.

communities. Normally, there are only two merchantable stems per hectare of sandalwood in the arid zone, but the huge area involved means that there is still a large resource. Most of this area is under pastoral lease for sheep grazing.

The Western Australia sandalwood industry has been in existence for 150 years (Kealley 1989, Talbot 1983, Statham 1988), the first 100 years or so being quite colorful. For the last 50 years it has been under very tight government control, with all operators in the industry being licensed and all production directed through one company. A Sandalwood Export Committee, which represents both the company and the State Government, is responsible for marketing and setting the level of cut, which at present averages about 1800 tonnes a year. Despite this tight control, concern has arisen about the future of the species in Western Australia because its principal supplies are located in the semi-arid pastoral zone where regeneration is naturally infrequent due to uncertain climate and the prompt destruction of most regrowth by sheep, feral goats, or rabbits. This concern is the reason for the long-standing interest in sandalwood research in Western Australia.

Areas where sandalwood can be harvested are specified by the Department of Conservation and Land Management (CALM) from its inventory data, and licensed "pullers" are allocated an annual quota of so many tonnes of green or dead wood. Since all harvesting activity is closely supervised by CALM and since there is only one timber processor in the state, the industry is under very tight control.

Sandalwood "pullers" are permitted to take only those live trees with a girth greater than 40 cm at 15 cm above the ground. Dead trees of any size are taken. Currently, about half of the sandalwood harvest is of dead wood, a consequence of periodic drought and a series of large wildfires several years ago (Kealley 1987). Sandalwood is very fire sensitive and is killed outright by even a mild fire. There are also restrictions on where the trees may be harvested in relation to homesteads, roads, etc.

Virtually the whole tree is utilized down to about 2 cm diameter on the branches, and the stump is pulled out of the ground (hence the term sandalwood puller rather than cutter). Stems and branches are cut into standard lengths or "pieces" and loaded into pallets. Small branches are chipped and sold at a lower price than the pieces. Formerly the sapwood was removed and wasted, but it is now included in the product.

Most of the present harvest of sandalwood takes place north and east of Kalgoorlie, with some coming from near the west coast at Shark Bay. Harvesting is generally carried out by full-time sandalwood pullers, but licenses for restricted periods are sometimes given to pastoralists undergoing hard times.

A long-term plan (known as the Sandalwood Conservation and Regeneration Plan, or SCARP) for the conservation of the species and the management of the sandalwood industry has been developed and approved by the State Government (Department of Conservation and Land Management, in press). It identifies areas to be set aside from harvesting and prescribes the purchase of additional areas of pastoral lease to widen the representation in secure reserves of the ecological types in which sandalwood grows. Although some very large reserves containing sandalwood exist in the southern part of its range, there are few reserves in the Murchison and Gascoyne areas at present. SCARP also provides for the establishment of a series of sandalwood plantations in the wheatbelt zone to demonstrate plantation management to farmers as part of long term program to return the species to the wheatbelt area.

RESEARCH IN WESTERN AUSTRALIA

Initial research trials on regeneration of sandalwood in Western Australia began in 1895 following the first reservations of land as State forest in the Western Australian Goldfields area. They were not successful and there commenced a long series of trials under the Forests Department extending up to 1982, supplemented after 1978 by research in Curtin and Murdoch Universities in Perth. Following the amalgamation of the Forests Department and other land management agencies in Western Australia in 1985, there has been continuing interest in the regeneration of sandalwood.

Departmental research was initially concerned with natural regeneration of sandalwood in the area where it was considered likely to survive as a species—the pastoral and desert regions of Western Australia. Later, research moved toward the establishment of plantations of the species. The clearing of native vegetation in the agricultural zone was so complete that no future for sandalwood was foreseen for it there. However, this situation has now changed dramatically. There is a great resurgence of tree planting in the agricultural zone, as part of a general trend toward more sustainable farming practices, and prospects for increased planting of sandalwood by farmers are real.

All the department research has been written up by Loneragan and is being published (in press). This report will cover aspects such as phenology, parasitism, adaptation to drought, wood and oil properties, seed production, seed handling and viability, germination, coppicing, fire resistance, growth studies, and regeneration research.

Work on sandalwood was rendered more difficult by the fact that much of it was undertaken in the arid zone. Under natural conditions successful regeneration is dependent on having a run of 3 years of above-average rainfall. This enables the sandalwood to progress through the sequence of flowering, seed set, and establishment of seedlings. Thus, one may have to repeat an experiment for 4-5 years in order to get realistic results.

The research at Curtin concentrated on refining the regeneration technique for plantations on farming land (Crossland 1982, Barrett 1987, Fox and Wijesuriya 1985), while the work at Murdoch focused almost entirely on exploring ways of vegetative reproduction in *S. spicatum* with the ultimate objective of propagating clones with superior oil content. All the University work was funded by the Western Australian Sandalwood Research Institute, a private research organization sponsored by the Australian Sandalwood Company.

The total of all the research on *S. spicatum* has been the development of a reliable establishment technique and good information on its growth under varying conditions, but a complete failure to propagate it vegetatively. Both cuttings and tissue culture have been intensively studied without success (McComb pers. comm.). In tissue culture researchers were able to develop plantlets with shoots but could not, after much work, find a way to promote root formation.

The most reliable establishment technique is to grow the sandalwood seedlings in a large plastic pot, together with a low-growing *Acacia* host, and plant out the two together. This technique is really only a research tool as it is necessary to take extreme care to not damage the host/parasite connection during transport and handling. It is also an expensive system. Suitable low growing species for the wheatbelt zone are *Gastrolobium microcarpum* and *A. pulchella.* The most suitable long-term host is raspberry jam, *A. acuminata.* In the desert zone suitable primary hosts are *Atriplex rhagodioides, Cratystylis subspinescens* and *Mariana polysterygia,* while the usual long-term host is mulga, *Acacia aneura. Mariana* is a particularly useful host as its prickly stems very effectively protect young sandalwood from browsing. With this protection sandalwood can survive even in areas of intense grazing pressure such as sheep holding yards.

For practical establishment, direct sowing can be used, but a tree percent (i.e., the percentage of seeds actually ending up as a free) of only about 1 percent must be expected unless conditions are very favorable. In a good season the tree percent can be as high as 16 percent.

Successful direct seeding requires:

(1) Fresh seed, no more than 2 years old.

(2) Spot sowing 50-70 mm deep into uncultivated spots, four seeds per host plant, at the drip line of the host crown.

(3) Protection from grazing.

There is now little interest in further research on this species in Western Australia, except in the area of development of the kernel as a high priced food nut (cf. macadamia nut). There has been some development of quandong *(S. acuminatum)* for this purpose already. Sandalwood nuts have been consumed by Australian aborigines and by farmers for many years, but in view of suggestions that the kernels of *Santalum* species contain substances similar to those suspected of having carcinogenic properties, further research is required. This concern has also affected the use of quandong for kernel production. If this aspect can be satisfactorily cleared up, there are bright prospects indeed for the promotion of sandalwood nuts as an intermediate product (Barrett and others in press) and the economics of growing the species would be transformed. It could lead to the creation of a large sandalwood resource in the Western Australian wheatbelt, and perhaps in other Australian States.

Sedgley (1982) reported on the results of 7 years experience in the domestication of quandong in South Australia. The trees commenced bearing fruit at 3 years of age, and the best trees at 7 years were producing 10 kg of fruit containing about 6 kg of the flesh. Although the fruits were quite palatable, the kernels were less so, and further work is required to improve that trait. A feature of this work was the high degree of variability in many morphological features, indicating a high potential for selection of desired traits. There is some evidence in *S. spicatum* that this variability extends to the oil content of the timber.

The success in establishing *S. spicatum* has not brought about an extensive regeneration program by CALM, basically because it would be quite uneconomical to do so. As it takes 50 years to grow a merchantable size tree of 10 cm diameter in the agricultural zone, and 100 years in the desert zone (e.g., around Kalgoorlie), normal economic considerations rule it out. For this reason, combined with the general lack of natural regeneration, sandalwood in Western Australia—grown purely for the timber—has been considered to have no long-term future. Interest several years ago turned to *S. album* as a possible future plantation crop for timber production.

INTEREST IN *S. ALBUM* IN WESTERN AUSTRALIA

The Sandalwood Research Institute (SRI) was the first to take an interest in *S. album, as* the Australian Sandalwood Company was keen to ensure its long-term future, even though CALM inventory data indicated there was about a 60 years supply of *S. spicatum* remaining in Western Australia. There was also the possibility that *S. album* would allow the company to diversify its markets. There is adequate land to grow this species in the tropical Kimberley region of Western Australia, and small amounts of the species have been seen growing there and further east in the Northern Territory. A further consideration which has encouraged CALM involvement is a State government policy of actively exploring commercial activities that might diversify the economy of the Kimberley, especially where there is a prospect of value-added processing of the timber for oil production.

Several trial plots were established in the Kimberley from 1986 onward and the next planting season will see the commencement of an operational scale field trial at Kununurra and the first of a series of field trials on different soil types and in different climatic zones.

Early results are very promising: mean heights of 3 m were being achieved in 2 years under irrigation at Kununurra. Survival has been generally good and no real difficulties are foreseen in establishing the species routinely if a suitable nursery procedure can be developed. Early plantings used several Kimberley *Acacia* species as host. There were distinct differences in growth of the sandalwood with different acacias, e.g. there was markedly better growth in the first 2 years with *A. trachycarpa* than with *A. ampliceps.* In the early trials, the sandalwood was grown under supplementary irrigation, as there is ample water available at Kununurra though the annual rainfall is only 500 mm.

All the seedlings in the initial trials were raised in the same pot as the hosts, and some difficulty was encountered in finding a host that did not overcrowd the rather slow-growing sandalwood seedling. Pruning the host was the answer, but that could clearly not be used in anything more than a research trial. A further problem appeared 2 or 3 years after planting out when it was found that the host was too close to the sandalwood and was pushing the sandalwood over. This prompted a move to a two-stage host system: the primary host being a small, low-growing species such as *A. trachycarpa* and the long-term host being a variety of large acacias and other species of tree.

The only real problem so far with sandalwood in the Kimberley has been some damage from a stem girdling moth. Damage is erratic and only noticeable in some seasons, and it is not seen as a real threat at this stage. However, it will have to be watched.

There is also a research program on *S. album* in progress at Murdoch University in Perth. Funded both by the SRI and a Commonwealth Government research grant and with field support from CALM, it has field trials in the Kimberley to determine the best secondary host species and has also been working on vegetative propagation by tissue culture. Secondary host species being tested are these:

Khaya senegalensis, Cordia sebastina, Acacia gracillina, Adenanthera parvoniana, Azaderachta indica, Casuarina equisetifolia, Melaleuca leucodendron, Terminalia pilularis, T. platophylla, Dahlbergia sissoo, Cassia siamea, and *Pterocarpus indicus.*

Vegetative propagation of *S. album* was taken up as it was believed that if a plantation approach to growing this species was to be followed, then it would pay to use only high-yielding strains of sandalwood. This field of research is finally, after some years, meeting with success and has reached the stage of having seedlings growing in pots for field planting in 1990 (Richmond pers. comm.). These trials will give invaluable experience in handling clonal material, and the vegetative propagation technique will be a very useful research tool.

THE ACIAR PROJECT

At about the same time as interest in *S. album* grew in Western Australia, CALM became involved in the management of a research project in West Timor. The project was funded by the Australian Centre for International Agricultural Research (ACIAR), which was partly concerned with the development of reliable techniques for regeneration of *S. album.* This has accelerated the pace of sandalwood research in Western Australia and widened its scope to a considerable degree.

S. album, or cendana, is a tree of great economic and social significance in Timor. It has been intensively harvested for something like 1000 years from the Eastern Indonesian area. For all practical purposes it has gone from Flores and East Timor, is at a low ebb in Sumba, and is becoming in short supply in West Timor. The Government of Indonesia is very concerned at the current lack of regeneration of the species and has established a research station in Kupang partly to work on this problem. The ACIAR project is a cooperative one with the Balai Penelitian Kehutanan (forest research station) in Kupang.

The poor regeneration of the species has been attributed to the effects of uncontrolled fire, grazing, and inappropriate regulatory provisions in a hard-hitting review by Hussain (1983). The writer's observations in West Timor over the last 4 years indicate that little has changed since.

The ACIAR project has several distinct parts:

(1) Determining the effect of tree age and rate of growth on sandalwood oil content;

(2) Identifying high quality stands of *S. album* for reservation as seed production areas;

(3) Developing reliable nursery techniques;

(4) Conducting seed viability studies;

(5) Determining silvicultural requirements of *S. album;*

(6) Conducting direct seeding studies.

Most of this research has been carried out by Dr. John Fox at Curtin University in Perth.

The project so far has concentrated on parts 2, 3, 4, and 5. In view of the steadily declining conservation status of the species in West Timor, it seemed that it was urgent to promote the reservation and protection of any high quality stands that could be identified as desirable sources of seed for any future regeneration program. Dr. Fox has liaised with the Inventory Staff of the regional forest service in Kupang and located a number of suitable areas for reservation, although the necessary action to ensure their preservation is not yet proceeding.

After preparation of a literature view relevant to the project objectives (Bar ett 1988), most of the research has been devoted to the development of a reliable nursery technique for the establishment of the species. Although planting seedlings may not be the technique used by a large-scale regeneration program, it is an essential research tool and at the very least, a fall-back operational establishment procedure, especially if seed resources are limiting.

A two-stage host system has been the approach taken after preliminary trials indicated that use of a single host species sown into the same plant container as the sandalwood resulted in later physical difficulties due to their proximity. The theory is that the primary host may live only 1 or 2 years, be of a nature that permits easy attachment of the sandalwood root haustoria, and be able to provide adequate nutrient supplies to the parasite without competing too strongly with it (or if it does compete strongly, be amenable to pruning). The secondary host(s) must be much longer lived and provide support to the sandalwood for the rest of its useful life.

A number of plants have shown promise as primary hosts. An unidentified species of *Alternathera* from the Kupang area enabled the cendana seedlings to reach a height of 45 cm in 5 months. Similar results have been obtained in trials carried out at the Balai Penelitian Kehutanan (Sutarjo pers. comm.) by *Cajanus cajan, Sesbania grandiflora, Acacia villosa,* and *Amaranthus* spp. Previous experiments on cendana increment under different hosts reported by Kharisma and Sutarjo (1988) indicated that a wide variety of plants could be used as hosts, but that the habit of some of them was not always suitable for operational use. The following data are taken from Kharisma and Sutarjo's paper.

Mean monthly height increment of cendana seedlings over 9 months (cm) were as follows:

Control (no host)	0.36
Phaseolus radiatus	0.38
Glycine max	0.89
Lycopersicum esculentum	1.31
Cassia sophora	2.09
Capsicum frutescens	2.49
Breynia cerrua	2.71
Capsicum annuum	2.74
Calitropis gigantea	3.25

Some of these species, such as the *Calitropis,* do not meet the desirable host criteria outlined above and would cause the same problems encountered in the Kimberley, namely, too much competition with the cendana and later physical obstruction of

The lower-growing species such as *Breynia,* however, would be quite suitable for a silvicultural system that included raising the seedlings in a nursery with a primary host and then transplanting out to an already established plantation of a secondary host such as *Acacia auriculaeformis.* The economics of doing this on any scale might be dubious, depending on the time taken to grow a tree of marketable size, but at least it works.

A persistent problem with growing sandalwood in the nursery has been loss of small seedlings or failure to survive the post-germination phase due to fungal attack. It seems certain, from research by Centre Technique Forestier Tropical (CTFT), that thorough seed cleaning very soon after collection is an important requirement. I suspect that failure to appreciate this point has been responsible for past failures of direct sowing in West Timor. A further problem has been failure to provide adequate control of weeds for the critical first wet season. With adequate weed control and a good host, the cendana seedling can attain a height of 1 meter in its first year. Micro water harvesting structures may also be advantageous.

It is commonly observed that cendana grows naturally in secondary forest or old swidden areas. It is rarely, if ever, found growing in high forest. It is also not often seen growing in the open, so it is of interest to determine if it has a shade requirement in its early growth stages. Field trials at Curtin University indicate better early growth with some shade, but satisfactory growth is obtained from open grown seedlings, so one could conclude that shade is not necessary, although useful in the early stages.

Determination of a minimum rotation length is a crucial point for sandalwood. It is important to know at what age heartwood formation commences and whether the onset of heartwood is influenced by site quality or by cultural practices. Unfortunately there is little experimental material available for such studies and the work would take many years. Perhaps the best way for this aspect to progress is for the work to be coordinated by some international research working group (under the auspices of IUFRO) so that experiences on different sites could be pooled. It is also important to determine to what degree high oil content is a heritable factor, as this could greatly influence the profit-ability and rotation age of a crop. Vegetative propagation will be a key tool in evaluating this aspect, although an isoenzyme analysis technique has been reported as having promise in this respect. The effect of rate of growth on the timing and degree of heartwood development is clearly an important field of study, but suitable material is difficult to find.

It is also of great interest to compare the growth of different species of sandalwood and their adaptation to a range of sites. Some additional funds were obtained from ACIAR in 1988 to support the establishment of an international species and provenance trial to follow up this aspect. It was originally intended to include Australia, Indonesia, New Caledonia, Fiji, and Vanuatu, but could be extended to include other countries if desired. Progress has been slow due to seed losses caused by cyclones and by the withdrawal of Indonesia, but the first plantings should take place this year. I am hopeful that some of the Hawaiian species may now be included.

DISCUSSION

We are now at something of a crossroads in sandalwood research in Western Australia. We have virtually concluded our research on *Santalum spicatum* except for the work on the edibility of the kernel mentioned above. If that is successful, then we can look forward to a continued planting program with this species in the wheat and sheep farming zone of Western Australia as farmers withdraw increasing areas of land from farming for reforestation to control soil salinization and erosion. Such areas are ideal for farmers to develop sandalwood silviculture as a sideline, harvesting the kernels from age 5 to 50, then harvesting the trees at age 50 for the valuable timber.

The conservation status of the species is assured in a number of nature reserves, and the sandalwood industry is managed on a long-term basis through a very effective management structure. It is proposed to progressively extend the area of land growing sandalwood in public ownership by the purchase of selected pastoral leases in Western Australia so that there will eventually be a comprehensive reserve system covering all its ecological associations.

We are pushing ahead with research on *S. album,* with funds generated by the existing sandalwood industry, with the objective of developing it as a plantation crop in the Kimberley. Initially, this will use seedlings raised on the primary host system in a conventional nursery, but when seed supplies are more freely available, direct seeding must be a much cheaper method of establishment. Given the success of this technique with *S. spicatum,* there seems no reason why it should not work in *S. album,* provided sufficient attention is given to good seed handling to avoid fungal problems. We will establish a series of operational scale plantations as a lead up to a full scale plantation establishment program. It is likely that we will be attempting to interest farmers on the Ord River irrigation area to grow sandalwood as a sideline to their other activities. We are hopeful that it will be possible to begin to harvest some of the sandalwood as thinnings from the age of 25 or 30.

The ACIAR project is drawing to the end of its initial phase. It has made some useful progress, but much remains to be done. Perhaps it is unrealistic to expect more rapid progress in a difficult species such as this, and there are practical difficulties in field research in Indonesia due to the critical lack of resources for research there.

As to management of the cendana resource in Indonesia, a crisis point is rapidly approaching. It appears that the present cendana resource has a life, at current harvesting rates, of only 10 years. A rapid decline after that time will have severe adverse economic impacts in West Timor. It will also have a severe social impact among the indigenous people, as cendana is a substance of great cultural significance to them. I believe we will see a marked increase in the effort devoted to its regeneration when the gravity of the situation becomes more widely appreciated. In this context, the ACIAR project is of vital importance in providing the tools for the task of regeneration.

We look forward to stronger international cooperation, especially with our neighbor, Indonesia, in sandalwood research. We also hope that the research in train will also be of value to some of the smaller South Pacific nations that have a need to diversify their economies. In that, sandalwood could well play a significant part.

REFERENCES

Barrett, D.R. 1987. Germination and planting out techniques for the Western Australian sandalwood *(Santalum spicatum)*. Mulga Research Centre Journal, Curtin University, Perth. 9:31-32.

Barrett, D.R. 1988. *Santalum album* (Indian Sandalwood) Literature Survey. Mulga Research Centre, Curtin University, Perth.

Barrett, D.R.; Flanagan, F.; Edmiston, K.; Stein, M. 1990. Sandalwood Nuts as Food. Mulga Research Centre Journal, Curtin University, Perth. (in press).

Crossland, T. 1982. Germination of sandalwood seed. Mulga Research Centre Report, Curtin University, Perth. 5:13-16.

Fox,J.E.D.; Wijesuriya,S.R. 1985. Sandalwood planting with property owners. Mulga Research Centre Journal, Curtin University, Perth. 8:3340.

Hussain, A.M. 1983. Report on the Rehabilitation of Sandalwood and the Trade in Nusa Tenggara Timur Indonesia. PPIPD West Timor.

Kharisma and Sutarjo, S. 1988. Effects of Host Plants on Seedling Growth of Cendana *(Santalum album L.)*. Santalum 2:1-8.

Kealley, I. 1989. Fragrant Harvest. Landscope 4(4):35-39.

Kealley, I. 1987. Management of Inland Arid and Semi-arid Woodland Forest of Western Australia. Proc. Conference of The Institute of Foresters of Australia, Perth, Sept. 28 - Oct. 2, 1987.

Loneragan, O.W.L. An Historical Review of Research on Sandalwood in Western Australia. Department of Conservation and Land Management, Western Australia. (in press)

Sedgley, M. 1982. Preliminary Assessment of an Orchard of Quandong Seedling Trees. J. Aust. Inst. Agr. Sci. 48(l):52-56.

Statham, P. 1988. The Sandalwood Trade: Small But Significant. Working Paper No. 100, Department of Economic History, Australian National University, Canberra.

Talbot, L. 1983. Woodland Gold: Early Days of the Sandalwood Industry. Forest Focus 30:21-31. Forests Department of Western Australia.

The Sandalwood Industry In Australia: A History[1]

Pamela Statham[2]

Abstract: From its inception in 1805, when it contributed to Sydney merchant incomes from whaling ventures, until today, when it earns several million dollars in export revenue, the sandalwood industry has played a small but significant part in Australia's economic development. The history of the industry falls into three major stages: first is the off-shore exploitation of the wood from Sydney, from 1805 to the 1840's and beyond; second is the free exploitation of Australian grown sandalwood from 1844 to 1929; and finally the period of government controlled exploitation from 1929 to the present.

Sandalwood is a highly aromatic wood that has been highly prized for centuries, particularly by the Chinese and Indians. Powdered sandalwood is burnt in joss sticks as incense and forms an integral part of religious ceremonies (see report on details of joss stick manufacture in Forests and Forest Products and Industries of W.A., 1921), while certain species of the wood can be carved into many delicate forms such as fans, inlaid boxes and ornaments, and incense holders. Large carved sandalwood boxes have been especially valued as bride or trouseau boxes, as the wood is said to deter moths and other insects. Sandalwood cones, again of powdered wood, are used today as mosquito deterrents. Sandalwood oil, when distilled from the heartwood, is equally valuable being used as a fixative in making soaps and perfumes, and for medicinal purposes. It is mostly used today in perfumes and up to the Second World War, before penicillin, it was even used to treat venereal disease (Donovan 1975; Underwood 1954, p. 21).

The many uses of sandalwood and its religious significance to vast populations, on one hand, and the relative scarcity of the wood and its very slow growth rate, on the other, have combined to make it an extremely valuable commodity in many parts of the world. Although sandalwood grows in a number of countries, most consume it domestically, and in several nations where the tree does *not* grow, demand is also high (e.g. Singapore and China). Consequently, a large international demand exists for the fragrant wood. Australia, basically a nonuser, has thus become one of the principal suppliers.

Australia has several native species within the broad genus *Santalum,* but only two—*Santalum spicatum* and *Santalum lanceolatum*—have been used for export because of their "true sandalwood" fragrance. These two types can also be ranked in terms of their export potential. *S. spicatum* (also called *S. cygnaum*) has been the major export earner and flourishes mainly in Western Australia. Originally it grew in a broad range from above the Murchison River to Esperence in the South, and inland beyond the Eastern Goldfields through to the foothills of the Darling Ranges (Talbot 1983, p. 25; Irwin 1847; Robertson 1958, p. 4). It also grew on the western borders of the Nullabor in South Australia.

S. lanceolatum, the second major type of sandalwood exported, flourishes in Northern Australia, around Shark Bay and the Kimberleys in Western Australia (Talbot 1983) and in Northern Queensland above Cairns and in the Hughendon-Cloncurry area, a basalt region which also contained a small patch of sandalwood of the *album* variety. Interestingly, 4 tons of this last mentioned wood were apparently used at Ghandi's funeral in 1948 (North Queensland Register 22.9.1979). The northern species of sandalwood were, and still are, highly prized by the aboriginals as the wood and its scent are regarded as fundamental elements in sex-magic (Sansom 1980). It is thus possible that the value they placed on the wood prevented its ready exchange with visiting Macassan fisherman and so delayed world cognizance of its existence until the mid-19th century!

The growth patterns, variance, and problems in propagating and cultivating these native species are discussed in other chapters.

STAGE I: THE OFFSHORE INDUSTRY

Australia's romance with the sandalwood industry began very early. Just 15 years after its foundation in 1788, Sydney merchants were looking for cargoes that could be exchanged for tea from China, for which even the convicts had developed a passion. In this period such trade was difficult not only because the Chinese would accept only limited commodities—including fur and sandalwood—in exchange, but because the British East India Company claimed a monopoly on all British trade in the region. To overcome this monopoly, the Sydney traders soon developed trading links with American whalers in the area and transferred to them the whale oil, seal furs and skins, and the sandalwood they had obtained on their own account, receiving tackle and tea in exchange.

No sandalwood grows naturally on Australia's East Coast. It does grow in northwestern Queensland but not in areas that were readily accessible to the eastern coast in the days of bullock transportion (Boland 1984). All wood collected by the Sydney traders in the early years, therefore, came from stands growing on Pacific Islands, principally Fiji.

Initial exploitation of the wood has been attributed to the increasing activity of Sydney-based sealers and whalers in the Pacific region (Hainsworth 1964-65, p. 2; Shineberg 1967, p. 2) because merchants financing such voyages ordered crews to look for payable cargoes in off-season periods. In this manner merchant Simeon Lord brought the first sandalwood cargo into Sydney in April 1805 (Hainsworth 1964-65, p. 3-5). By 1808 Simeon Lord's London agents were gathering in remittances from Nantucket, which totaled some £30,000 (N.S.W. Archives 1822-26)—a fortune when the Governor's yearly salary was only £500. But the risks of sandalwood voyages for the small colonial vessels and their crews were horrendous. Not only were the Fiji Islands guarded by dangerous reefs, their inhabitants

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai‘i.

[2]Senior Lecturer, University of Western Australia, Nedlands, Perth, Australia.

were cannibal warriors customarily engaged in tribal warfare (Hainsworth 1971, p. 177). Overtime, moreover, the natives became dissatisfied with the beads and nicknacks they had previously accepted in exchange and demanded more valuable goods for the wood they brought to the beaches, hence increasing the costs of each voyage. For all these reasons the sandalwood trade remained small scale, and even during this first boom period total quantities extracted from Fiji did not exceed several hundred tons (Hainsworth 1964-65, p. 18).

Prevailing high prices began to falter in 1809 (mainly due to oversupply) and only sporadic cargoes were collected between then and 1816 when Fijian stands "were to all intents and purposes cut out" (Shineberg 1967, p. 7). Those merchants who had profited had done so, I believe, because the costs of collecting sandalwood had been largely swallowed in the general costs of equipping the whaling and and sealing voyages they were already financing; and because, in the early period at least, the wood was exchanged for scrimshaw—the carved whale's teeth that sailors etched during long periods of inactivity (Hainsworth 1971, p. 164). Carved whale's teeth were known as "Tambua" in Fiji and were worn by chiefs on a string of female pubic hair as a symbol of power. The Tambua are still highly prized and have enormous significance in transactions. Presentation of a Tambua is a matter of great honor, and by law they are not allowed to leave the island. One presented to Prince Charles had to remain in Fiji (oral evidence).

Although isolated incidents of trade in sandalwood by the Sydney traders have been traced to the 1820's and 1830's, low prices in China and political difficulties between China and Britain generally depressed the trade until the 1840's. With the end of the Opium Wars in 1842-43 and the recommencement of open trade with China, however, sandalwood prices began to rise, initiating the second main sandalwood boom which lasted—despite fluctuations—to the 1860's (Shineberg 1967, p. 64-70, 72). The Sydney traders were quick to reenter the trade and extended their collections from Fiji to a wide range of Pacific Islands, especially the Marquesas and the New Hebrides. But the Sydney traders this time had American and English competitors for the wood, and supplies on the small islands were not limitless. To counteract diminishing returns, ships and crews had to venture further and further afield, sometimes into uncharted waters, which increased the risks of shipwreck. Problems with the natives of the islands also escalated with their continuing exposure to Europeans, and natives' demands for more valuable trade items also increased. Profits were thus never as high in this second boom as they had been in the first, and by the mid-1860's the Sydney-based industry collapsed—mainly due to the exhaustion of commercially viable stands in the South Pacific *(table 1).* But by that time the Chinese merchants were being supplied from another Australian source—and this time with native Australian sandalwood.

Table 1—*New South Wales Sandalwood Exports 1842-1862*

Year	Tonnage Carried Total	Total Value[1] Cargos £'s	Imported Exported[2] Tons	Value Exports £'s (est.)	Value Whale & Seal Oil £'s (est.)
1842	1,730	24,205	1,485	19,305	77,012
1843	655	11,665	205	2,665	72,989
18441	622	10,326	302	3,926	57,493
18451	529	7,577	429	5,577	96,804
1846	992	17,677	309	4,017	70,126
1847	1,342	23,606	462	6,006	80,528
1848	1,251	22,396	375	4,875	68,969
1849	811	15,289	133	1,729	45,468
1850	388	7,641	17	221	29,368
1851	352	6,410	90	1,170	25,877
1852	712	11,517	389	5,057	34,562
1853	1,136	11,517	389	5,057	34,562
1854	480	7,395	315	4,095	28,155
1855[3]	555	8,825	325	4,225	20,770
1856	n.a.	n.a	150	1,950	25,355
1857	n.a	n.a	346	4,498	32,306
1858	n.a.	n.a	103	1,339	1,450
1859	n.a	n.a	66	858	532
1860	n.a	n.a	3 1/4	42	136
1861	n.a.	n.a.	152	1,976	—
1862	n.a.	n.a	233	3,029	—

Sources: 1842-55: Shineberg. 1967, Appendix I, p. 219-244. 1855-62:N.S.W. Statistical Register—Oil exports from the 1865 NSW Statistical Register.

[1] Cargos sold in China valued at an estimated average £20/ton, cargos sold in Sydney at an estimated average of £13/ton.
[2] Assuming all wood imported was exported.
[3] End Shineberg, begin Statistical Register Series.

STAGE II. AUSTRALIAN SANDALWOOD, 1844-1929

In the period 1844 to 1929, Western Australia was a dominant exporter of sandalwood, which was purchased mainly by Chinese merchants in Singapore and Shanghai to be powdered for incense. An overview of the volumes of wood exported from Western Australia in this period of free exploitation, however, reveals three separate phases. The first phase, 1844-1880, was the era of discovery and initial exploitation when sandalwood cutting was closely linked with the expansion of the pastoral and wheat industries *(table 2).* The second phase, 1880-1918, was Western Australia's golden era when sandalwood and gold prospecting were closely linked *(table 3).* The third phase, 1918-1929, was marked by a rapid boom, the entry of other states, and by first attempts to regulate and stabilize the industry *(tables 4, 5).*

1844-1880

When the Sydney traders experienced rising prices for sandalwood at the end of the Opium Wars, the news quickly travelled to Swan River, on the other side of Australia, where a cessation of immigration and a critical trade deficit were seriously alarming the government of the 15-year-old colony (Statham 1979). News of a potential new export did not go unheeded!

Indian and Chinese laborers introduced in the late 1830's and early 1840's to work for Swan River pastoralists probably first recognized the commercial potential of the wood, which had been noted by the explorer Ensign Dale in 1832. Sufficient interest was then aroused for the government to agree to send a trial shipment of the wood on the colonial schooner *Champion* to Bombay to "test the market" (Perth Gazette 25.1.1845, Inquirer (editorial) 5.2.1845). Enormous excitement greeted the

Table 2—*Sandalwood exports 1844-1880, compared with wool exports, from Western Australia*

Year	Wool		Sandalwood		
	Quantity (tons)	Value (£'s)	Quantity (tons)	Value (£.'s)	Avg.£ per ton
1844	140,155	7,008	—sample cargo only—		
1845	145,254	7,757	4	40	10.0
1846	291,368	13,363	32	320	10.0
1847	229,297	11,464	370	4,444	12.0
1848	301,965	15,098	1,335	13,353	10.0
1849	276,073	14,374	1,204	10,710	8.8
1850	309,640	15,482	n.a.	1,220	—
1851	359,317	17,883	219	1,593	7.2
1852	356,153	16,768	0	0	—
1853	397,428	19,870	0	0	—
1854	442,881	22,341	0	0	—
1855	493,073	24,723	—	—	—
1856	500,996	25,672	—	—	—
1857	478,486	35,886	280	2,524	9.0
1858	543,504	33,969	745	7,455	10.0
1859	594,665	44,599	1,278	17,259	13.5
1860	656,815	49,261	1,687	16,360	9.7
1861	723,965	54,297	2,558	24,945	9.7
1862	806,006	60,450	2,393	21,541	9.0
1863	1,212,183	84,088	2,807	25,265	9.0
1864	550,598	41,294	2,724	24,520	9.0
1865	1,358,874	101,915	1,686	13,490	8.0
1866	1,234,070	92,555	2,965	23,722	8.0
1867	1,312,016	87,467	2,305	18,442	8.0
1868	1,572,068	98,254	3,256	26,045	7.9
1869	1,880,426	94,021	4,124	32,998	8.0
1870	1,787,812	89,390	6,112	48,890	7.9
1871	1,665,915	111,061	3,366	26,926	7.9
1872	1,839,562	122,637	3,942	31,536	8.0
1873	1,761,323	132,099	6,292	62,916	9.9
1874	2,874,992	215,624	7,057	70,572	10.0
1875	2,428,160	182,112	6,646	66,465	10.0
1876	2,831,174	165,152	6,577	65,772	10.0
1877	3,992,487	199,624	4,247	31,851	7.4
1878	3,019,051	150,953	4,675	35,064	7.5
1879	3,505,688	175,284	4,667	35,001	7.4
1880	4,342,606	271,412	5,197	51,970	10.0

Sources: WA Blue Books 1844-1880 and Battye 1924

Table 3—*Annual sandalwood exports from Western Australia (volume and value) 1880-1918 compared with gold exports*

Year	Sandalwood Export, Vol. (tons)	Sandalwood Export Value £'s	Sandalwood Average Price per Ton (£'s)	Gold Export Qty. (ozs)
1880	5,197	51,970	10.0	—
1881	7,716	77,165	10.0	—
1882	9,605	96,050	10.0	—
1883	7,031	56,250	8.0	—
1884	2,620	20,960	8.0	—
1885	4,527	36,216	8.0	—
1886	3,431	27,450	8.0	302
1887	4,317	34,533	7.9	4,873
1888	4,470	33,525	7.5	3,493
1889	6,385	57,465	9.0	15,493
1890	5,136	51,355	10.0	20,402
1891	3,760	37,600	10.0	30,311
1892	5,713	42,580	7.5	59,548
1893	3,892	32,160	8.2	110,891
1894	2,748	23,430	8.5	207,131
1895	3,851	30,863	8.0	231,513
1896	6,848	65,800	9.6	281,265
1897	5,852	49,480	8.4	674,994
1898	4,349	31,812	7.3	1,050,183
1899	4,084	29,719	7.2	1,434,570
1900	5,095	39,038	7.6	1,414,311
1901	8,864	73,931	8.3	1,703,417
1902	7,995	61,771	7.7	1,871,037
1903	4,406	37,913	8.6	1,871,037
1904	4,510	25,417	5.6	2,064,801
1905	5,521	38,817	7.0	1,955,316
1906	8,848	70,958	8.0	1,794,547
1907	9,212	65,999	7.2	1,697,554
1908	9,564	76,668	8.0	1,647,911
1909	4,805	37,456	7.7	1,595,269
1910	8,228	70,775	8.6	1,470,632
1911	6,907	65,506	9.5	1,370,867
1912	3,154	27,533	8.7	1,282,658
1913	6,260	47,589	7.6	1,314,043
1914	4,702	39,800	8.5	1,232,977
1915	8,375	78,929	9.4	121,112
1916	6,270	61,381	9.7	182,670
1917	7,230	72,699	10.1	—
1918	6,504	81,834	12.6	—

news, on the *Champion's* return early in 1845, that the wood would fetch £ 10 per ton in Bombay or Mauritius and £20-30 per ton if taken directly to Canton (Inquirer [editorial] 5.2.1845; Inquirer 9.7.1845; W.A. Gov. Gazette 9.12.1848). In contrast, exports of heavy timber and whale oil and bone from Swan River were returning no more than £4.10.0-per ton at that time, and were far more costly to exploit than the light, spindly, and fragrant sandalwood. At first, activity was centered in the Avon Valley (inland from Perth), where trees were simply felled with an axe, stacked, and sent by bullock dray down to Fremantle for export.

When the first commercial cargos reached Bombay, an entrepot for the China trade—as were Singapore and Mauritius—the Australian wood was subject to close scrutiny. Buyers concluded that while inferior to the top Timor and Indian wood *(S. album)* and not suitable for carving given its lower oil content, the aromatic quality of the Western Australian wood was excellent. This was a sought-after characteristic for wood to be pulverized for incense—which was good news for Western Australian exporters as there was a major demand for sandalwood from the joss stick and incense makers. Even the butt and roots of the sandalwood tree were valuable for incense, and so trees were later "pulled" out by horse or camel and chains, rather than felled, before they were trimmed of bark, cut into sticks, and stacked (Richmond 1983). About 200 of the 3-foot sticks constituted a ton, and payment was made by the ton on delivery to the merchants at Guildford (the town at the navigable head of the Swan River) or at the Port of Fremantle.

By mid-1847 sandalwood mania had gripped Swan River Colony's population. Feverish competition arose between landowners and laborers as they laid claim to abundant sandalwood areas. Poaching and trespassing increased, and on unallocated Crown lands stand-up fights between teams were not uncommon. In the more settled areas workmen deserted their employers to go cutting sandalwood or charged exorbitant wages to stay

Table 4—*Annual Western Australian sandalwood exports (volume and value) 1916-1929, c/f gold and wool export volumes*

Year	S-W Volume (tons)	S-W Value (£'s)	Annual S-W Price/ton (£'s)	Gold Volume (Fine ozs)	Wool Volume (000's lb's)
1916	6,270	61,381	9.7	182,670	29,103
1917	7,230	72,669	10.0	—	24,405
1918	6,504	81,834	12.6	—	10,632
1919	8,998	117,072	13.0	—	29,645
1920	14,355	240,579	16.7	41,296	59,600
1921	10,839	181,801	16.8	66	43,132
1922	3,990	54,769	13.7	—	58,693
1923	7,623	102,912	13.5	—	41,925
1924	14,081	348,713	24.7	90,523	86,234
1925	6,243	186,775	29.9	36,117	35,015
1926	7,771	238,203	30.6	49,619	49,689
1927	6,821	199,754	29.2	91,080	53,788
1928	4,829	147,426	30.5	14,261	61,240
1929	7,582	225,208	29.7	10.535	57,045

Source: Battye 1924

Table 5—*Total volumes of Australian sandalwood exports by state, 1918-1945 (in tons)*

Year	W.A.	S.A.	Queensland	Total
1918	6,504	—	40	6,910
1919	8,998	—	132	9,130
1920	14,355	—	546	14,901
1921	10,839	—	635	11,474
1922	3,990	—	224	4,214
1923	7,623	—	135	7,758
1924	14,081	—	291	14,372
1925	6,243	347	199	6,789
1926	7,771	1,621	144	9,536
1927	6,821	1,292	96	8,209
1928	4,829	1,543	73	6,531
1929	7,582	2,214	159	9,955
1930	714	895	339	1,948
1931	1,606	543	89	2,238
1932	1,386	1,323	546	3,255
1933	3,068	1,004	446	4,518
1934	2,508	964	463	3,935
1935	2,223	653	310	3,186
1936	1,593	844	169	2,606
1937	2,513	432	169	2,606
1938	747	153	65	956
1940	1,058	354	42	1,454
1941	1,167	102	—	1,269
1942	400	—	—	400
1943	2	—	—	2
1944	—	—	—	—
1945	—	—	—	—

Source: Forests Department Annual Reports

(de Bugh 1981, Irwin 1847). Farmers also complained about the difficulty of procuring transport to bring in supplies and take out their produce, as most of the bullocky teams and horse drays were committed to the sandalwood trade (Erickson 1973, p. 70-71). In fact, the increased road traffic inland put enormous pressure on the colony's few main roads, and the cleared tracks soon deteriorated into deep rutted and pitted nightmares for the wagoners. To rectify the situation, the government decided in mid-1847 to tax those who were causing the problem and to use the revenue for road improvement. An export tax of £ 1 per ton was imposed on sandalwood, but strong opposition led to its replacement in October the same year by a system of licenses to cut in a particular area and a 10-shilling toll (Perth Gazette 11.9.1847, 27.5.1848; Gov. Gazette [W.A.] 1.10.1847, 22.10.1847; Underwood 1954, p. 9-10). Problems frequently arose when both local and central authorities issued licenses to cut the same area of land (Erickson 1973, p. 71).

Some idea of the extent of the boom can be gauged from export figures of the time, which show sandalwood to have risen from virtually zero in 1844 to a position where, in 1848, it challenged whale oil and wool as a leading export earner (W.A. Blue Books, 1844-50). The sandalwood export figures entered for 1 year tended to represent cutting activity in the previous year due to delays in inland and overseas transport. Given this, the feverish activity that occurred in 1847 can be seen in the peak £ 13,353 earned for the export of 1,335 tons in 1848. By mid-1847 the newspapers reported that there were over 1,500 tons of sandalwood cut over the hills waiting transport (Inquirer 4.8.1847). Some of this was lost in winter floods and December bushfires, but the rest was safely carted to Guildford where it accumulated because bad roads and low water prevented its dispatch to the port. In April 1848 it was said that stacked stocks covered more than 1 acre (Inquirer 5.4.1848). By this time, however, most of the sandalwood stands in the Avon Valley had been exhausted, and cutting teams were having to venture further and further inland for payable loads. Transport costs gradually became prohibitive for, as Eliza Brown recorded, it cost eight or nine times more to send a wagon load from Fremantle out 40 km to the Avon Valley than it did to send it from London to Fremantle! (Cowan 1977).

All would have been well if overseas prices of sandalwood had risen to cover the extra transport costs, or if the wood had been easily regrown within a feasible distance from the Port. But neither of these events occurred. Regrowth was prevented by lack of understanding of the parasitic nature of the tree, by widespread land clearance and by the practice of pulling out the tree roots and all, while oversupply of sandalwood on the Chinese market brought prices tumbling in the second half of 1848 (Lefroy 1848; Shineberg 1967, p. 80). By mid-1949 the boom was over (Gov. Gazette 9.12.1848; Underwood 1954, p. 9). At £8.10.0 per ton on overseas markets further exploitation was unprofitable. Cutting all but ceased. Throughout that year cutting teams slowly returned to the towns to seek alternative work, but their return resulted in rising unemployment in Perth and Fremantle—a fact that flew in the face of the labor-scarcity arguments then being forwarded by the pastoralists who were lobbying for the introduction of convicts! (Statham 1981a).

Sandalwood actually had a lot to do with Western Australia's convict decision. It was the scarcity of manpower caused by the 1846-47 sandalwood boom that brought about the pastoralists' first request for convicts. Later it was the deteriorating state of the roads and the lack of other needed public works that finally convinced the townspeople that a limited introduction of first offending convicts would be a good idea. In any event, the colony was hoodwinked by the British Government, which declared Swan River to be a full-fledged penal settlement before informing even the Governor. In the long run, however, this declaration had advantages as it gave colonists the moral power to argue for, and get, considerable concessions, such as a commensurate immigration of free settlers, only male convicts, and full financial support from the British Government! (Statham 1981b).

Somewhat surprisingly, the cheap labor of the convict era, 1850-1868, did not bring about any major resurgence of sandalwood cutting activity. Prices remained low until 1859, when they rose to £13 per ton in Singapore and Bombay, and £20 per ton in China (Underwood 1954, p. 13; Ware 1975, p. 4). Between 1861 and 1865, some 2,300 tons of the wood were exported at an average price of £9.3.0 per ton. Of this, the government took £1.10.0 in tax, which was bitterly resented. Tax and license fee revenue, nevertheless, was used to extend and improve inland roads as initially promised (Colbatch 1929, p. 177). Supplies of the wood in the 1860's came increasingly from further afield. The northern and still uninhabited areas of Western Australia had to be serviced by sea and provided wonderful opportunities for evading the Government tax—in fact, it is said that "Smugglers Cove," above Geraldton was so named because of the illegal sandalwood exports shipped from there! (Donovan 1975, p. 3).

From the end of the convict era in 1868 to the second big Western Australian sandalwood boom of the early 1880's, sandalwood cutting and export continued to provide a useful second income for some farmers and a living for a number of independent teams. This was a period of rapid pastoral extension northwards and southwards onto leased, sandalwood-bearing Crown lands. Sandalwood was cut by shepherds in off-peak periods and stacked until a sufficient quantity had been accumulated to arrange transport. It was discovered in this period that sandalwood foliage provided excellent feed for sheep and cattle, so the two activities were mutually supportive in more ways than one.

Extreme yearly fluctuations in exports could occur in this period through shipping delays (both downriver and overseas), natural h i7ards like bushfires and floods, and supply conditions in overseas markets when sandalwood-laden ships arrived, for prices depended on the season and the frequency of supply vessels. From 1868 to 1880, a total of 58,656 tons were exported, though annual tonnages tended to rise over the period *(table 2).*

During the early 1870's the Mysore sandalwood plantations in India failed to meet domestic demand, and restrictions were placed on export. As a result, Indian import demand increased, and competition was lessened in other markets, allowing the Western Australian industry—marketing mainly in Singapore and Bombay at this stage—to treble in size (Talbot 1983, p. 25-26). The peak of 9,605 tons exported in 1882 was in fact not surpassed for almost 40 years, though annual export tonnages remained high, aided by the construction of railways which significantly lowered the costs of transporting the wood from inland districts to Fremantle.

Figure 1—Sandalwood cutters worked in the Goldfields region of Western Australia around 1930. *Photo:* Neil Mitchell, Battye Library, Western Australia.

1880-1918

Although this period of Western Australia's history was dominated by the discovery of gold, the sandalwood industry also played its part. From the early 1880's, when news of gold finds in the Kimberleys sent many men north, sandalwood began to acquire its reputation as "the Gold-diggers best-friend." When prospectors found Kimberley gold to be elusive (Colbatch 1929, p. 193), they gladly fell back on new stands of sandalwood they came across as a source of finance for provisions and transport—a relationship that was to continue and intensify in future years. (See *table 3* for comparison of sandalwood and gold exports.)

The Kimberley and Pilbara gold finds were soon totally eclipsed by the discovery in the early 1890's of the "Golden Mile," some 300 miles due east of Perth. Conditions in this semi-desert region were appalling, but the lure of gold brought people from far and near. Within 5 years Western Australia's population had increased 46 percent (population 1890—46,290, in 1895—101,1430) and kept on increasing rapidly to the end of the century (Ware 1975).

While alluvial gold was easily obtained there was little incentive to seek out and pull sandalwood, but as surface gold became harder and harder to find after 1895, sandalwood provided a welcome substitute. As eager prospectors moved east, they discovered new, unexploited stands of sandalwood and, when long unlucky stretches exhausted their provisions, they became sandalwood pullers to earn the funds to continue their search *(fig. 1)* (Talbot 1983, p. 27). Sandalwood stands were (and still are), fairly abundant in the Eastern Goldfields Region, and exploitation of this area led to the third main boom from 1896 to 1911, when annual quantities exported reached 8000 and 9000 tons (Ware 1975 and *table 3*).

As sandalwood's value as an export commodity became more widely recognized, fears arose about the industry's long-term survival. The Department of Woods and Forests, created in 1896 (Robertson 1958, p. 8) attempted to conserve and extend sandalwood resources, particularly though reforestation programs. Few of these proved successful, for even when the matter of a suitable host for the seedlings had been determined, germination was not uniform; and pests and grazing animals (especially rabbits) destroyed most seedlings (Western Australia Woods and Forests Dept. 1897).

A story related in a departmental journal clearly indicates the precarious existence of the sandalwood plantations at this time. A small area was fenced and seeded, with hosts, in the eastern Goldfields, and forestry officers were watching it with pride. Unfortunately a local Arab had also noted the new growth and thought it highly suitable for his camels. He therefore applied to the Government for a lease over the land—and got it! Despite immediate objections from the department, the arab and his camels won and another sandalwood plantation failed to mature (Austral. For. J. 15.1.1923).

In November 1908 the old license system was repealed, and a royalty of £5.0 per ton was introduced on all sandalwood pulled, to be collected by the Railways Department together with freight charges (Woods and Forests Dept. Report 1909, p. 15: W.A. Gov. Gazette 27.11.1908). Revenues increased immediately, from £215 in 1908 under the licensing system to £ 1,390 in 1909, the first full year of the royalty system (Woods and Forests Dept. Report 1909, p. 16).

In 1913 another sandalwood venture began in Western Australia when a man named Braddock established a plant at Belmont, just outside Perth, to distill sandalwood oil. By 1917 he was exporting over 3,000 lbs of the oil to England, where there was a ready market (Donovan 1975, p. 7; Underwood 1954, p. 21) due to the British Medical Association's finding that sandal oil, when used in capsule form, helped cure venereal disease (Underwood 1954, p. 22) With the outbreak of World War I the demand for sandal oil for this purpose increased markedly, clearly working to Braddock's advantage. Moreover, the British Pharmacopea announced that tests on the Western Australian oil (all from *S. spicatum*) had an unusual positive refraction, which gave it a unique advantage in medicinal use (Donovan 1975, p. 7). Since the oil was also used in addition as an antiseptic, a fixative in perfumes, and as a base for soaps and creams, demand was high both at home and abroad.

The export of Western Australian Sandalwood also did well throughout the war years and by 1916 commanded four-fifths of the Chinese market (Schorer 1974, Poole 1923). By this time, however, Western Australia had another Australian competitor in the sandalwood trade—albeit a minor one. Queensland had begun exporting small amounts of sandalwood from the Cape York Peninsula in the 1890's (North QueenslandRegister22.9.79, 6.5.83). This wood, of the *lanceolatum* variety, was exported through a Chinese merchant, See Yick, in small quantifies via Thursday Island (Bloodwood 1979). Figures are unobtainable for this period, and annual tonnages were well below 100, but it was a portent of a new era in the history of the Australian sandalwood industry.

1918-1929

Not only was the post-war era characterized by the entry of other Australian states, it was also marked by a boom of unprecedented dimensions and the first Government attempts to control the industry.

Increased post-war activity was stimulated by two factors: first, an increased supply of labor for sandalwood getting, as many men returning from the war saw this as a means of raising the finances to settle on the land; and second, a significant rise in overseas prices. From an overage of £10-£ 13 per ton in China before the war, merchants were receiving an average of £36 by 1920, and even higher prices in the smaller markets of Manila, Singapore, and Bombay (Robertson 1958, p. 16). As a result of these combined forces, Western Australia exported some 14,355 tons of sandalwood in 1919-1920 (Forest Dept. 1920-21), the highest annual export quantity ever recorded *(tables 4, 5).*

During the "frenzied" cutting of sandalwood, some form of Government regulation was necessary. Despite vigorous opposition from the goldfields population (West Australian 11.2.1920, 13.2.1920; Kalgoorlie Miner 11.2.1920), an increase in the royalty payable on sandalwood cut from Crown land from £5.0 to £2 per ton was approved in March 1920 (Forests Dept. Report 1920). The increase in royalty, however, did little to discourage the sandalwood getters, especially as there was a noticeable recession in mining! Overproduction of cut wood in fact led to the accumulation of huge sandalwood stocks on the wharves at Fremantle (Donovan 1975, p. 4; Talbot 1983, p. 30). and to fears that the wood was being overcut. In consequence, strict new regulations were drawn up and introduced in 1923 (W.A. Gov. Gazette 30.10.1923; Underwood 1954, p. 22).

These 1923 regulations were designed to protect the getters, conserve supplies, and ensure that the Crown received due reimbursement for the export of a valuable resource. They called for:

(a) An overall quota on yearly production, to be determined by the Cabinet and not to exceed 6000 tons.

(b) The introduction of export licenses to be held by those accepting the wood.

(c) The increase in royalties to £9 per ton; and

(d) The appointment of forest rangers to check illegal sandalwood cutting, to enforce the minimum size rules, and to assist with programs of reforestation.

It was hoped that by restricting supply the world price of sandalwood would be forced upwards, allowing maximum benefit to be obtained from the large stocks of wood still held in

Figure 2—Immense stacks of sandalwood awaited shipment at the port of Fremantle in Western Australia in the 1920's. *Photo:* Courtesy of Battye Library, Western Australia.

Fremantle *(fig. 2)* and at country rail sidings. To protect the sandalwood getter in the face of this marketing strategy, the government set minimum prices for clean, average quality wood delivered to Fremantle at £16 per ton, free of royalty. Buyers were forced to pay this both by the license system and by the stipulation that without evidence of payment of the minimum price to getters the royalty payable would be £25 per ton.

These curbs on the industry reduced the record profits of the early 20's and spelt the end for some of the contracting companies that had grown up in the good years. Four firms continued: Paterson and Co., Western Australian Sandalwood Co-op; J. Hector and Sons; and Burridge and Warren, but they were only permitted to remove 500 tons between them per month, with the actual allocations being based on the market share each firm had held in past years (Forests Dept. Report 1930, p. 6). One loophole remained, however, for the regulations only applied to sandalwood cut on crown land, and in no way restricted the pulling of sandalwood from private property (Donovan 1975, p. 8; Robertson 1950, p. 21-22). Consequently, the amount of wood delivered to country sidings ostensibly from private property, but in fact from Crown land, increased markedly (Forests Dept. Report 1924, p. 19; 1925, p. 13). However, resulting legal wrangles ate considerably into the profits of the four export companies until the problem was resolved in 1929.

Another major change was introduced in 1925 when responsibility for the allocation of sandalwood orders was transferred from the licensed private trading companies (about whom complaints had arisen over the distribution of orders) to the Forests Department, which set up separate advisory boards to deal with the two distinct types of applications normally received (Robertson 1958, p. 23). Unlike the regular getters, who obtained orders of about 30 tons each per annum, prospectors were usually allotted 10-12 tons to be supplied in two lots, one in May and the next in August-October. Actual orders, however, were fairly evenly distributed between the two groups, with the edge going to the prospector *(table 6)*. These orders, however, were all for sandalwood obtained from Crown land; and throughout this period the problem of additional cutting from private property continued and the amount of stockpiled wood grew.

Opinion was split over the effectiveness of the 1923 and 1925 regulations, but the four licensed companies now had worries on other fronts, for in 1925 South Australia entered the Sandalwood market (Forests Dept. Report 1926, p. 13). Queensland was still producing sandalwood (and rosewood, which was used as a substitute in the incense market), but this did not worry the

Table 6—*Sandalwood orders granted in Western Australia 1925-1929*

	1925-6		1926-7		1927-8		1928-9	
Type	Persons	Tons	Persons	Tons	Persons	Tons	Persons	Tons
Getters	208	4,115	184	4,270	170	3,498	170	5,962
Prosp-ectors	215	2,000	197	2,286	186	2,076	202	

Source: Annual Reports W.A. Forests Dept.
Note: The split-up in the type of orders was discontinued after 1929.

Western Australian merchants as they were dealing in very small quantitites. South Australia, on the other hand, was attempting to break into markets that the Western Australian merchants had considered entirely theirs, and this was a very different matter *(tables 5, 7).*

Trading through a single company, The South Australian Co-operative Sandalwood Co., the South Australians proceeded to undercut the Western Australian companies by offering their wood, which was on average slightly inferior in quality, at lower prices *(table 7).* Also, the South Australians paid no royalty at that time (Robertson 1958, p. 24). In South Australia the wood grew in the west, on the Nullabor Edge, and in the north, and was exploited mainly by marginal wheat farmers settled in those regions on government soldier settlement schemes. Explaining South Australia's late entry into the market, officials stated that the tree had not been recognized until it was drawn to their attention by an ex-West Australian sandalwooder! (oral evidence).

To relieve stress in the industry, representatives of the South and Western Australian governments met in January 1927. They agreed that there should be a measure of joint control of sandalwood pulling, and so total quotas were set for each state—2,600 tons for South Australia and 5400 tons for West Australia—roughly a 1/3-2/3 split (Forests Dept. Report 1927, p. 12). The agreement was successful (neither state reached their quota) and was continued in the next 2 years (table 7). To further reduce the exigencies of open competition, the four licensed sandalwood trading companies in Western Australia formed a Sandalwood Merchants Association in 1928, which then dealt on behalf of the companies with the South Australians and with overseas buyers (West Australian 19.2.1928).

Partly to combat this growth of counterveiling power and protect the getters, and partly to close the private-property sandalwood loophole, the W.A. Government decided to introduce further legislation to effectively control the industry. The strict controls that ensued, combined with a world depression, introduced a new and less active stage for the industry as a whole.

Stage III: 1929 to the Present—Government Control

The period of Government control can also be divided into three phases: first 1929-43, when controls were first implemented (table 5); second, 1945-197 1, when the oil industry was active but sandalwood export languished *(table 8);* and finally, 1971 to the present day, when rising demand overseas has made the Australian industry a multimillion dollar export earner *(table 9).*

Table 7—*West Australian and South Australian sandalwood exports 1925-1931*

	W.A.			S.A.		
Year	Tons	£ Value	Avg. Price per Ton £	Ton	£ Value	Avg. Price per Ton £
1925:	6,243	186,775	29.9	347	10,409	29.9
1926	7,771	238,203	30.6	1,621	46,986	28.9
1927	6,821	199,754	29.2	1,292	35,712	27.6
1928	4,829	147,208	29.7	2,214	55,887	25.2
1930	714	22,228	31.1	895	18,028	20.1
1931	1,606	43,790	27.2	543	9,642	17.7

Source: Sandalwood Export Committee

1929-1943

The Western Australian Sandalwood Control Act of 1929 effectively closed all previous loopholes. It legalized the 1923 regulations and the 1927 Export Agreement with South Australia. But it also went much further. A Government-set quota was to be imposed on all sandalwood pulled in Western Australia in any one year, and of that quota only 10 percent could come from private property. All wood taken from private property, moreover, was to be inspected and branded by forest rangers *before* it was removed, with a fee of £1 per ton levied for the service!

By this time the four private trading companies were in a parlous state. China was tom by civil war and demand for sandalwood had collapsed: only 943 tons were shipped out in 1929-30 after a per annum average of over 5000 tons in the previous 5 years (Robertson 1958, p. 27). Huge stocks accumulated, and by June 1930, 7000 tons were stacked at the port. The four companies could not even pay the pullers for orders given, causing great distress in the goldfields area (West Australian 3.4.1930). To relieve the situation the Government of the day

Table 8—*Western Australian sandalwood exports 1945-71*

	Wood		Sandal Oil	
Year	Tons	Value £'s	Avg. Price £'s	lbs
1945	—	—	—	—
1946	143	7,584	53	28,723
1947	835	100,616	121	—
1948	147	35,571	242	34,726
1949	156	35,635	228	4,200
1950	210	45,546	217	n.a.
1951	429	75,430	176	3,743
1952	468	87,230	186	5,686
1953	558	105,792	190	4,405
1954	438	100,973	230	600
1955	510	101,739	199	5,800
1956	605	119,415	197	7,793
1957	683	140,503	205	6,686
1958	584	113,342	194	10,590
1959	486	112,414	231	4,134
1960	648	140,360	217	6,956
1961	856	198,485	232	13,637
1962	649	183,928	283	10,662
1963	556	159,859	288	6,452
1964	587	179,195	305	5,265
1965	830	237,008	285	4,616
	Tonnes	$	$	
1966	804	314,987	392	4,374
1967	691	476,606	690	3,291
1968	620	453,008	731	3,561
1969	585	409,108	699	8,335
1970	939	549,156	585	3,136
1971	842	535,517	636	

Source: Forests Department Annual Reports to 1951; thereafter G. Hughes, Chairman of Directors and ex-manager W.A. Sandalwood Company, from company files.

Table 9—*Western Australian sandalwood exports 1971-1989*			
Year	Tonnes	Total Value Exports Australian $	Avg. Price Aust. $ per Tonne
1971	842	535,517	636
1972	954	613,549	649
1973	1,429	906,544	633
1974	1,403	918,208	654
1975	1,051	799,917	761
1976	1,206	1,560,854	1,277
1977	1,222	1,195,322	943
1978	1,267	1,480,249	986
1979	1,502	1,849,032	1,188
1980	1,557	2,275,483	1,377
1981	1,644	2,346,452	1,427
1982	1,653	2,434,716	1,488
1983	1,650	2,434,716	1,622
1984	1,746	3,109,464	1,781
1985	1,829	4,366,017	2,202
1986	1,837	4,366,017	2,376
1987	1,810	6,544,541	3,615
1988	1,816	9,068,841	4,993
1989	1,960	11,480,875	5,857

Source: Western Australian Forests Department Reports and records of the Australian Sandalwood Co.

negotiated an agreement with the four companies to buy up all existing stocks—on the condition that they would combine their sandalwooding interests in one new company (Richmond 1985) In effect this agreement meant that the loose association already formed among the Sandalwood Merchants would become a separate entity—the four companies concerned all being to that time general importers and exporters. This Government proposal was agreed to in 1930, and the Australian Sandalwood Company Ltd. came into being (Forests Dept. Report 1930, p. 6), a company that still operates today.

In its first full year of operation, the new company managed to export only 1,606 tons, despite representation in China. In view of the accumulated sandalwood stocks held by the Government, the Forests Department was forced to severely curtail orders issued to pullers, and that year a mere 212 tons of the wood were obtained from Crown lands (Robertson 1958, p. 29). It was recognized that if the industry was to survive, shipments to China would have to be restricted to their actual market requirements. To that end, control would have to be exerted over *all* Australian exports as Australia, holding 80 percent of the market, was by far the major supplier (Forests Dept. Report 1932, p. 9; Talbot 1983, p. 30). With this in mind the Western Australian Government entered into a new export agreement with South Australia in July 1932. Henceforth the management of the export business of the two states, marketing policy and price setting, were to be vested in a Sandalwood Export Committee, consisting of one representative from each government, and one joint representative from the companies (Talbot 1983, p. 30). The agreement also entailed providing a fixed price to sandalwood getters and royalties to each government, which were to be based on a sliding scale according to the selling price of the wood in China. In Western Australia provision was made for 50 percent of its quota (which was two-thirds of the total determined by the Export Committee) to be taken from accumulated stocks, and the remainder from new pulling. This provision, it was hoped, would reduce surplus stocks while maintaining employment in the industry (Talbot 1983, p. 30).

Given the aim to control Australian sandalwood supplies arriving in China, it is perhaps strange that no attempt was made at this stage to involve the Queensland Government in the export agreement. In 1932—the year of the agreement—Queensland wood accounted for some 17 percent of total Australian sandalwood exports, although for the rest of the decade its exports remained well below 10 percent of the total Australian sandalwood supply. When the agreement came up for review in 1934, however, Queensland was included (Robertson 1958, p. 32) although its exports were limited to 500 tons per year—except when total Australian exports exceeded 2,750 tons, when Queensland could increase its production by 10 percent (Queensland Parliamentary Acts 1934). The agreement also stipulated that the Australian Sandalwood Co. of Western Australia would act as the sole agent for the Queensland Government in all overseas sales of sandalwood and substitutes such as rosewood, and that a 5 percent commission would be payable for the service! Activity in Queensland ceased in 1940, mainly due to the War, and, apart from a couple of small consignments (under 5 tons), remained inactive until 1982 (North Queensland Register 6.5.83).

For South and Western Australia the policy of restricted supply embodied in the Export Agreement worked well. Prices rose throughout the 1930's *(table 10),* despite continued disruption in China as a result of civil war, abnormal floods, and a fall in the value of their export commodities (Forests Dept. Report 1933, p. 10). With higher prices, the scaled royalties in Western Australia increased to over £11 per ton by June 1933 (Robertson 1958, p. 31). By that time the accumulated stocks in Western Australia had all but been liquidated and the number of orders issued to getters increased not only for wood for export but also for wood for oil distillation (Forests Dept. Report 1933, p.10). Two hundred eighteen orders were issued for 1,420 tons of new wood for export (the highest for four years), and a further 13 orders for 125 tons of wood for oil distillation.

In 1922 Plaimar Ltd., representing the interests of the Plaistow Confectionary Co. and the chemist-cum-manufacturer J.H. Marr, had taken over Braddocks' sandalwood oil distillery, and so became the only sandalwood oil producer in Australia (Robertson 1958, p. 18-20; Forests Dept. Report 1922-3). Marr revolutionized production methods by introducing a method to replace steam extraction, which had proved inefficient with the low-oil wood from Western Australia, by soaking shavings and sawdust in a solvent and then taking the oil out. Although figures are incomplete *(table 10)*, they indicate that the industry continued to flourish throughout the 1930's until affected (as was wood exports) by a further deterioration of conditions in China and the outbreak of World War II. Wood cut for oil distillation was apparently ordered over and above the quota set. Although quantities cut for this purpose remained very small, they did help smooth out the pattern of total cutting until the war, and thus helped getters affected by the Government's ruling that half the Western Australian quota for export had to come from accumulated stocks. Moreover, the oil company did not have to pay the royalty per ton imposed on the sandalwood company.

No wood or oil was exported from Australia in 1944-45, and neither Queensland nor South Australia reentered the trade on the cessation of hostilities. In Western Australia, however, activity revived quickly to enter a new phase of increasing market dominance.

1945-1971

In anticipation of increased sandalwood activity after the War, the W.A. Government negotiated a new agreement with the Australian Sandalwood Company. On the sliding scale arrangement pertaining between 1938 and 1941, the royalty levied per ton had averaged £12-14 (Robertson 1958, p. 38), while prices paid to getters had averaged £15.10.0 per ton—just under the agreed £ 16 per ton because of the slightly lower prices paid for below-average quality wood (Forests Dept. Report 1930-34). Before World War II there had been no difficulty in filling orders, as alternative employment was still relatively hard to find and the price offered was considered reasonable. After the War, however, many old-timers were unwilling to reenter the industry. They would need to reequip and, in contrast to opportunities available elsewhere in the buoyant economy, the old price per ton offered to getters was not attractive.

To overcome this lack of interest, the W.A. Government negotiated new terms. The royalty was to be dropped to a flat £ 9 per ton; the getters were to be paid an additional 30 shillings per ton (i.e., £17.10.0), and the Government was to receive a share in the profits of the trade, which would be collected by the Forests Department (Robertson 1958, p. 38; Forests Dept. W.A. file 779/49). The actual dimension of the Government's share in the Australian Sandalwood Company's profit was not stated in the 1946 agreement or in the Forests Department annual reports (Forests Dept. 1946-47, 1947-48); it is still not readily divulged today (Hughes, pers. comm.). Records show, however, that between 1946 and 1949, when prices per ton in overseas markets were averaging £200, the government was getting some £140 (Robertson 1958, p. 38) (£131 plus £9 royalty), so the share was apparently about two-thirds. As most sandalwood at that time was coming from Crown land and getters were responsible for transport to Fremantle, the Australian Sandalwood Company could not really complain—especially as exports of wood and oil reached record heights in 1947.

With the hefty increase in prices for sandalwood per ton after the war *(table 8),* and the resultant increase in government revenue from this source, some questioned the feasibility of continuing oil distillation—which had been fostered as an industry of some importance to that time. Royalties on wood delivered for distillation were far lower than that on logwood, as they were based on the yield of oil per ton of wood, and on the market price of sandalwood oil. As noted, the oil yield of Western Australian wood is low, and the price of oil differed according to whether the oil was sold locally or overseas—the domestic price being some 46 percent lower than that prevailing in China. From 1937 to 1941 the Western Australia Forests Department received from £2.16.0 to £7.11.0. a ton in royalty payments from distillers and from £8 to 9 a ton during 1942-1946. Even the increase in Royalty to £19 per ton for wood used to produce domestically sold oil and £41 per ton for wood used to produce oil sold overseas between 1946 and 1949 was far below the revenue that could have been obtained if that wood had been exported as such (Robertson 1958, p. 38). Consequently a review of the oil distillation industry was called for in 1949. As the Export Agreement was also due to expire in October 1949, all aspects of the sandalwood trade were to be closely examined.

At the end of August 1949 the review committee recommended that sandalwood oil distillation should continue, but only as secondary to the log export industry, and that the trading agreement between the government and the Australian Sandalwood Company and with the other State governments should be extended (Robertson 1958, p. 39). After various amendments and extensions the Export Agreement was finally reaffirmed in 1952, and the parties concerned decided that it would remain in

Table 10—*Sandalwood exports, South Australia and Western Australia 1931-1945*

Year	W.A.			S.A.		
	Tons	Value	Avg. £/ton	Tons	Value	Avg. £/ton
1931	1,606	43,790	27.2	543	9,642	17.7
1932	1,386	40,546	29.2	1,323	31,217	23.5
1933	3,068	88,846	28.9	1,004	25,111	25.0
1934	2,508	75,424	30.07	964	24,093	24.9
1935	2,223	66,474	29.9	653	19,572	29.9
1936	1,593	44,916	28.2	844	25,274	29.9
1937	2,513	75,670	30.1	432	12,952	29.9
1938	747	22,884	30.6	153	4,568	29.8
1939	1,106	34,571	31.2	285	9,958	34.9
1940	1,058	41,596	39.3	354	11,116	31.4
1941	1,167	47,613	40.7	102	3,584	35.1
1942	400	17,481	43.7	—	—	—
1943	2	80	40.0	—	—	—
1944	—	—	—	—	—	—
1945	—	—	—	—	—	—

Source: Forests Department Annual Reports force indefinitely (Richmond 1983, p. 1; Forests Dept. 1951-2, p. 8).

Despite problems in attracting getters, exports of sandalwood rose in the early 1950's *(table 8)*. The local price to getters was increased to £26 per ton in 1951 but, even so, the Department reported difficulty in filling orders (Forests Dept. 1951-2, p. 8). In 1954 the trade was threatened by the communist take-over in China, as they banned the burning of joss sticks in religious ceremonies. The resulting increase in numbers of expatriate Chinese in Singapore, Hong Kong, Malaysia, Formosa, and Thailand meant that total demand remained high (Donovan 1975, p. 8). Also in 1954, cutters who were operating more than 100 miles from a railway siding were offered a £4 per ton subsidy from the government (Forests Dept. 1954-55, p. 13), which recognized that isolation and high transport costs were discouraging getters from entering the industry. In 1955 there were only 13 registered sandalwooders in Western Australia, a huge drop from the 200 to 400 employed in the 1920's and 1930's (Donovan 1975, p. 8).

To an extent the drop in numbers employed can be explained by changing technology. By the 1950's trucks had replaced the camels and oxen of the 1920's *(fig. 3)*, and simple stripping machines took over the backbreaking job of adzing off the outer sapwood, which in the 1920's had been carried out either by a partner or by women (often lubras) (Ware 1975, p. 6-7; Talbot 1983, p. 25). Nevertheless, it was reported in 1955-56 that overseas demand continued to exceed supply and that more pullers were needed (Forests Dept. Report 1955-56, p. 12).

Availability of stands was also becoming a problem in the 1950's, for lack of success with reforestation projects in the past meant that the wood had to be brought farther and farther distances to the port. Attention to reforestation had increased after the War, particularly in the mid 1950's, when pullers were encouraged to replace trees with sandalwood nuts (Forests Dept. Report 1955-56, p.12). Overall, however, "the results generally from experimental work have *not* warranted any attempt to grow his species on a large scale" (Forests Dept. Report 1954-55, p. 14).

From the mid 1950's to the end of the 1960's, production and export of sandalwood and oil from Western Australia fluctuated considerably but remained highly profitable. Wood exported varied from a low of 486 tons up to 856 tons in 1961, when a maximum export of 13,637 imperial lbs of sandalwood oil was also reached *(table 8)*. The distillers of oil throughout this period were absorbing some 10-20 percent of the total tonnage of wood pulled in Western Australia, which included *S. lanceolatum* from the north as it was found to blend well with oil from *S. spicatum* and improve its penetrating quality (Forests Dept. 1954-55, p. 14). The gap between the price distillers were prepared to pay for wood ($76) and the price the same wood could command on overseas markets ($731) continued to diverge in 1968. To partly resolve the problem the manager of the

Figure 3—After the war, transport of larger logs over greater distances was made possible by motor vehicles. *Photo:* Neil Mitchell, Battye Library, Western Australia.

Australian Sandalwood Company arranged in 1964-65 to import a higher oil-bearing sandalwood from Indonesia for the Plaimar Oil Company, as it was more profitable to do so than to lose local supplies for the overseas wood market (Hughes, oral evidence). In 1969 the distillery increased its buying price from $78 to $98 per tonne but to little avail, for all distillation of sandalwood oil ceased in 1971 as Plaimar rationalized its undertakings. Plaimar's major profit came from the manufacture of soft drinks, and up to this date the company had been exempt from sales tax because it complied with the 20 percent apple juice requirement which had been imposed to assist the apple industry. When this exemption was removed the company closed its Western Australia operations (oral evidence). There has been no attempt to reactivate this industry since then, perhaps understandably, because the average per tonne price of exported sandalwood increased quite remarkably after 1971 *(table 9).*

As all wood pulled after 1971 was to be exported, there was a slight rise in the quota fixed for export in the years immediately following to ensure continuity of employment. This was felt necessary as the gold industry was in recession and the Export Committee was always sensitive to this industry in determining sandalwood quotas. It should perhaps be noted that Australia went metric in 1966, and sandalwood volumes changed from tons to tonnes (the tonne is .016 larger than the ton), a break which very slightly deflates the post 1966 figures.

1971 to the Present

During the decade 1970-1980, sandalwood production averaged about 1200 tonnes per year, varying some 300 tonnes either way, while prices rose from $636 per tonne to $1,377 per tonne—a 46 percent increase *(table 9)* and Richmond 1983, p. 1). Although the sharp inflation of the period accounts for much of this price rise, it was interesting because the decade saw a significant increase in the amount of dead wood included in the export figures—wood that previously had been discarded (Richmond 1983, p. 1). Called "pieces" in the trade, dead wood when powdered is only marginally less fragrant than average green wood, although considerably less so than the roots and butts of the green tree—where the greatest percentage of oil can be found. Also during the seventies the condition that sapwood had to be removed from sticks before delivery was lifted, and now wood is delivered "undressed"—but cleaned of bark.

The very recent history of the industry has followed the trend set in the 1970's. Rising Chinese populations in nearby Asian markets have significantly increased demand for joss sticks and, as Australia is still the dominant supplier (94 percent of the joss stick sandalwood market in 1988), it is a sellers' market. Prices are negotiated each year by the company's representatives and have continued to escalate.

The profitability of the trade has resulted in renewed export attempts from Queensland, following the repeal of their Sandalwood Act in 1982. Although quantities exported are still small, interest is considerable from both the government and mining companies operating in Northern Queensland in cutting the wood and reforestation. Since the repeal of the Queensland Act the question of control over the industry has become contentious as three domestic traders are presently involved, and the Queensland Government would prefer one. Plans are afoot to let a tender for a single export license, which would bring Queensland into line with Western Australia.

With (1988-89) prices averaging $5757 per ton for green wood and $7573 per ton for roots and butts, sandalwood has truly become a million dollar tree (Hughes, pers. comm., Company records). Prices paid to Western Australian pullers have increased in line with overseas prices, but by far smaller percentages. Pullers were getting an average of $540 per ton for green wood in 1985, which rose to $750 in 1987, and stands at $970 per ton today (Richmond 1983, p. 1; Hughes pers. comm.). A report written for the Western Australian Lands and Forestry Commission in November 1985 stated that there were 28 licensed pullers in the state: 9 full-time, 14 part-time... (most of whom were also prospectors) and 5 pastoralist producers (Richmond 1985, p. 8). Today the number has fallen to 18 regular pullers who employ around 70 workers, most on a part time basis (Richmond 1985, p. 8; Hughes oral evidence; Department of Conservation and Land Management 1985-86). As already mentioned, the Export Committee can adjust quotas and licenses when circumstances change, and just as prospectors have been helped over hard times by a quota increase, so also have pastoralists. In times of drought, especially, pastoralists can and do obtain licenses to pull a maximum of 20 tonnes each in any one year (Richmond 1985, p. 7). The Export Committee considers this to be an appropriate action to help pastoralists in distress through no fault of their own, and to provide goodwill, as in normal times full-time pullers are licensed to take wood from pastoral leases and the cooperation of pastoralists is important. Today also the Board allows 10 percent of the quota from Crown lands to be taken in addition to the quota from private land. As several mining properties are coming onto the market in the Eastern Goldfields after years of inactivity, a lot of good quality wood is currently being cut from this source.

As most of the wood is now brought very long distances from the Eastern Goldfields to Fremantle, the Australian Sandalwood Company has taken over arranging and paying for contract carriers to transport the wood by road to their factory in Spearwood just outside Fremantle, rail transport having being discontinued some time ago when full truck loads (minimum 16 tons) were made compulsory (Richmond 1985, p. 2). Most pullers sent in only 5-8 tons at a time!

The Company itself employs three staff, eight workmen and a foreman, and their wages are linked to comparable positions in the Australian public service. In the factory, pallets of wood are sorted into logs, pieces, roots, and butts, etc. Logs are wrapped in hessian in 62.5 kg lots and sewn to prevent wharfside pilfering. The valuable roots and butts are separately hessian-bagged in 35.7 kg lots, while dead wood (which makes up an increasing proportion of wood exported) is packed in woven plastic bags of 35.7 kg. All small pieces and offcuts are ground into powder and bagged in plastic, again in 35.7 kg lots. Even the sawdust on the floor is periodically collected for sale at reduced prices (Richmond 1985, p. 3).

In addition to royalties, which are set as a given percentage of the free-on-board price negotiated for each shipload, and the profit share that the company has to pay to the W.A. Government, an annual amount is also paid to the W.A. Department of Conservation and Land Management to cover administration expenses. These expenses include field inspections, control by the Regional manager (who issues licenses) and secretarial assistance at head office (Richmond 1985, p.2). Taken together this has meant that in 1988-89, out of a gross income of $11.4 million in export earnings, the government received the following:

	$1,013,217	in royalties
	$76,830	as overheads
	$5,601,337	as profit-share
Total	$6,691,384	for the year

This total was 90 percent of net profit! (figures from Hughes, pers. comm.)

With such a valuable income source available, concern has mounted about the industry's potential life. It was estimated in 1985 that at the existing rate of pulling there were enough commercially viable green stands in Western Australia to last23 years (Richmond 1985). Estimates of the quantity of available commercially viable sandalwood are based on current prices, markets, transport costs, and pulling methods ... any of which can change. The 1985 estimate was based on 36,325 tons of commercially available wood, which "tends to be conservative." It was also noted that a lot more wood could become commercial if conditions change (Richmond 1985, p. 4). Maturation of immature trees and continued collection of dead wood could extend the 1985 estimate by 30 to 40 more years. Moreover, there has been considerable research and activity in experimental planting, financed in Western Australia partly by the government and partly by the Australian Sandalwood Company (Richmond 1983, p. 2), which is opening up the future of the industry.

Experiments have shown that it takes up to 80 years for planted native species to reach maturity, and though suitable areas have been replanted, the long maturation period and the very high risks of failure through stock grazing, insect plagues, bad seasons, etc. have made it a costly exercise. Current research, however, has indicated that the Indian/Timor species, *Santalum album,* can grow in Western Australia and will take only 30 years to reach commercial size (West Australian 16.2.1987; Hughes and Richmond oral evidence). Suitable hosts have still to be determined, but nurseries of the seedlings are already being established and the future of the industry now seems bright.

As demand for sandalwood incense shows no sign of diminishing, with expanding Asian populations and the Western use of the powdered wood for mosquito coils, potpourri, etc., the Australian industry, if carefully managed, should continue to provide a small but significant contribution to future export earnings.

REFERENCES

Australian Forestry Journal. 1923. 15.1.

Battye, J. 1924. History of Western Australia. Oxford: Statistical Appendix. Bloodwood, Bob. 1979. North Queensland Register 22.9.1979.

Boland, D.J. and others. 1984. Forest Trees of Australia. 4th ed., Melbourne: Nelson; 622.

Colbatch, H. 1929. Story of 100 Years. Perth, Australia: Government Printer.

Colonial Secretaries Report. 1848. C.S.R. (Swan River) 313 Suppl

Cowan, P., ed. 1977. A faithful picture: The letters of Eliza and Thomas Brown at York in the Swan River Colony 1841-1852. Fremantle Arts Centre Press; 71.

de Bugh, W.A. 1981. The breakaway's. Perth: St. George's Books; 117.

Department of Conservation and Land Management (old Forests Department). 1985-86. Annual Report. Western Australia.

Donovan, R.J. 1975. A history of sandalwood cutting in Western Australia. Unpublished typescript of interview held by Battye Library, Perth. OH71.

Erickson, R. 1973. Old Toodyay and Newcastle. University of Western Australia Press; 70-71.

Forests Department. 1920. File No. 290/20, Passed 5.3.1920. Western Australia.

Forests Department. 1920-24. Annual Reports. Western Australia.

Forests Department 1926-28. Annual Reports. Western Australia.

Forests Department 1930-34. Annual Reports. Western Australia.

Forests Department. 1946-47, 1947-48. Annual Reports. Western Australia.

Forests Department. 1951-52. Annual Report. Western Australia.

Forests Department. 1954-55, 1955-56. Annual Reports. Western Australia.

Hainsworth, D. R. 1964-65. In search of a staple: The Sydney sandalwood trade 1804-9. Business Archives and History Vol. V.

Hainsworth, D. R. 1971. The Sydney traders. Cassell, Australia.

Hughes, Gerald, Chairman of Directors, Western Australian Sandalwood Company.

Irwin, Colonel F.C. [Acting Governor]; Grey, Earl. 1847 British Parliamentary papers, Colonies General Vol. 4: 356.

Lefroy, Gerald. 1848. Diary. 30.7.1848. Western Australian Archives. 648A.

Maiden, J.H. 1889. The Useful Native Plants of Australia. Sydney.

New South Wales Archives. 1822-26. Claims on Account of Cedar etc. 4/1099; 2.

Poole, Lane. 1923. Report to the Forestry Department. Western Australia.

Queensland Parliamentary Acts. 1934. The Sandalwood Act of 1934. 25 Geo 5, No. 8.

Richmond, P. 1985. Report to the Lands and Forests Commission. File 630/84. Department of Conservation and Land Management, Western Australia; 1.

Richmond, P.C. 1983. The sandalwood industry. Information Sheet 26. Forests Department. Western Australian.

Robertson, J. R. 1958. The government regulation of the sandalwood industry of W.A.: A brief history. File 779/41. Department of Conservation and Land Management, Western Australia.

Sansom, Basil. 1980. The camp at Wallaby Cross. Canberra: Australian Institute of Aboriginal Studies; 199-202.

Schorer, A. 1974. The horses came first. Wandering Shire Council, Western Australia; 25.

Shineberg, D. 1967. They came for sandalwood. Melbourne University Press.

Statham, P. 1979. Swan River Colony 1829-50. In: Stannage, C.T., A New History of Western Australia. University of Western Australia Press; 203. Statham, P.1981 a. Why convicts? I. Studies in Western Australian History. Vol. IV, Dec.; 1-2.

Statham, P. 1981b. Why convicts? II. Studies in Western Australian History. Vol. IV, Dec.; 15-16.

Talbot, L.T. 1983. Forest Focus. No. 30.

Underwood, John. 1954. A history of the sandalwood industry of W.A. File 741 2(02). Unpublished thesis. Department of Conservation and Land Management Library, Western Australia.

Ware, H.G.J. 1975. The sandalwood industry of Western Australia. Typescript in Battye Library, Perth; 4.

Western Australia Blue Books. 1844-1880. Western Australia Statistical Dept.

Woods and Forests Department. 1897. Annual Report. Western Australia.

Woods and Forests Department. 1909. Annual Report. Western Australia; 15.

Sandalwood—the Myth and the Reality[1]

Joseph Felgelson[2]

Abstract: *Santalum paniculatum* trade after more than a century was revived by the author in 1988. Revival of the trade has called attention to this resource, and the focus is now on management of this resource. A discussion about recent sandalwood logging and marketing activities in Hawai'i is presented. The author also points out various anomalies that may be related to habitat and land use variations. The obligatory parasitic nature of this species is questioned and the coppicing tendency is confirmed. Criteria are suggested concerning the harvesting and sales that minimize fragmentation of forest areas. The concept of establishing a sandalwood research center and the cultivation of sandalwood in Hawaii is presented.

I am beginning by quoting "The Holy Scriptures (Masoretic text)" 1 Kings 10:11, 12. This is the part where the Queen of Sheba visits Solomon: "11 And the Navy also of Hiram, that brought gold from Ophir great plenty of Sandal-wood and precious stones. 12 And the King made of the Sandal-wood pillars for the house of the Lord, and for the King's house, harps also and psalteries for the singers; there came no such sandal-wood, nor was seen, unto this day." Later it is mentioned in 2 Chron. 9:10, 11, "10 And the servants also of Hiram, and the servants of Solomon that brought gold from Ophir, brought sandal-wood and precious stones. 11 And the King made of the sandal-wood paths for the house of the Lord, and for the King's house and harps and psalteries for the singers; and there were none such seen before in the land of Judah."

The trained sailors of Solomon's friend King Hiram of Tyre, joined with Solomon's fleet in profitable voyages to Ophir, the exact location is vague. However, we do know that it was easily accessible by sea, on or near the coast; and that the trip to Ophir and back to Ezion-geber, Solomon's harbor at the head of the Gulf of Akabah, took 3 years (1 Kings 9:2,6,10,11,22; 2 Chron. 8:18, 9:10 and that gold, silver, ivory, wood, precious stones, apes and peacocks were found there. Its location is said to be in Africa on the eastern coast and as far north as the Red Sea. This name is often cited as the origin of the name Africa. It was a land famed for the quality of its gold (Isa. 13:12, Ps. 45:10; Job 22:24, 28:16, 1 Chron. 29:4).

The next chronological reference to my knowledge of sandal-wood occurs with Marco Polo in 1292 and his remarks on sandalwood in his travels: "...payment for the hire of ships, that is freight, is reckoned at the rate of ... 40 percent on aloes and sandalwood and all bulky wares." (237) ... all of the forests of this island (Nicobar) are of noble trees of great worth: these are red sandal ... and many other good trees." (258) "The island (Zanzibar) produces scarlet sandal-wood trees as big as the trees in our country. These trees fetch a high price anywhere else; but here they have whole woods of them, as we have other trees." (299) (Latham 1958).

Contrary to popular belief, sandalwood is not the most expen-sive wood in the world. To my knowledge, it is the second most valuable species, first is the aloes, as also mentioned in the Holy Scriptures. Other common names for aloeswood are garu and kabuka. The genus is *Aquilaria*. The resin from this genus is said to be more valuable than gold, ounce for ounce. The price of the high quality wood is based on the gold standard as determined by the London Stock Exchange.

Various references to *Santalum* can be traced through a chro-nological annotated bibliography on sandalwood and its uses (Ross 1985).

Much has been written about sandalwood since the 17th century, but still very little is known about its silviculture and the properties of its products. But rather than present information drawn from others, I will relate to you my personal involvement, observations, and information on sandalwood with an emphasis on utilization, markets, and exploitation.

My interest in hardwoods was aroused the first time I ever polished wood, which happens to be a monkey pod slab on my kitchen counter. The beauty of the grain coupled with a feeling of accomplishment ignited a new passion within me. I was well on my way to becoming an xylophile and a lay dendrologist.

I had delved into the Hawaiian history and had read enough to know that sandalwood was the first commercial wood species from Hawaii, and had read enough to believe the "myth" about sandalwood.

Naturally, I questioned any xylophiles I encountered about their knowledge regarding sandalwood. No knowledge was forthcoming, even from the hardiest of forestry leaders. After 10 years I had received information that a certain individual named George had sandalwood under his house. After contacting him, I learned that he valued his stock at $30,000 and was not willing to part with a sample—he would sell all or nothing! Well I did not even have 10 percent of the purchase price so I rationalized that the wood probably was naio *(Myoporum sandwicensis),* commonly called false or bastard sandalwood.

About 2 years later another xylophile from whom I had purchased a small amount of *Santalum paniculatum* told me that he had heard about George and was going to investigate. I was informed that a deal could be made and to come over from Maui right away.

I was shown a stash of about 45 metric tons that was stored in an old airplane hangar and an old ranch house. Every room was full of logs and branches. This was my first exposure to this type of sandalwood! A deal was struck; 1/2 down, 90 days to remove the wood, and 120 days to pay the balance. I decided to take the risk and borrow the down payment and jump into it. Now what to do next?

Since I was already an exotic wood dealer I called other dealers across the United States. The general response was, "Do you make sandals from this wood?" Much effort convinced me that there was no demand or market in the United States, Canada, or Europe for sandalwood.

Having previously taken a trip around the world looking at the wood market, I had made some contacts in the Orient. I focused on these contacts and made a price list based on 2-inch incre-ments of log diameter.

---

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai'i.

[2]President, Exotic Maui Woods, Inc.

I had a good bite from Taiwan requesting a2-ton sample order. A letter of credit was established that enabled me to move the wood to Maui. A further sample order from Japan requesting 6- to 8-inch diameter logs enabled me to build a shed on my land to store all these logs, roots, and branches. I was informed that the origin of this wood was the Honomalino area of Hawai‘i, which was cleared for the planting of macadamia nuts 38 years ago. George told me that was all he could salvage, but that it was really sad how much sandalwood was bulldozed and burned.

At the end of 1987 a Taiwanese buyer came over and offered close to $200,000 for my acquisition. We celebrated New Year's Eve together, and I was close to ecstatic at my apparent new-found fortune. All I had to do after signing purchase agreements was to wait for the letter of credit, which did not arrive. Chinese New Year was the excuse!

Amazingly, on the first working day of 1988 I received a call from Hong Kong inquiring about the sandalwood. I informed them that a deal was already struck, but that if things did not work out I would get back to them. By this time I had reports back from Taiwan and Japan that there was too much sap on the logs, that the price was too high, and that the quality was not good enough.

When the Hong Kong buyer arrived he carefully measured the heartwood diameters and log diameters. He explained to me that the only usable part of the wood is the fragrant heartwood and that that was all he wanted. Everywhere else in the world that is how the product is bought.

Since all of the other sandalwood-producing countries have cheaper labor than Hawai‘i, it did not appear to make sense to desap the wood in Hawai‘i. Other places would desap in the field. Therefore, his offer to me was less than half of the previous offer. The Hong Kong buyer suggested that buying sandalwood was a highly specialized business. The reason that the previous offer by the Taiwanese buyer was not forthcoming was because it was speculative, opportunistic, not founded on reality, and because he obviously did not know what he was doing. After some calculations the new buyer determined that the quality was about 50 percent heartwood and 20 percent grade A 10-inch heartwood diameter and up.

My final argument to try to up the price was that I could not believe that 50 percent of the volume in dead sapwood could weigh as much as 50 percent volume in heartwood. Well I was surprised! I selected a 36-inch log to clean. Needless to say I picked one with sap that looked more deteriorated than the average. The log was measured and determined mathematically to be 52 percent heartwood (using the formula pi R^2 x L of the log minus pi R^2 x L of the heartwood and divided by the volume of the log x 100 to give percentage of sapwood or, alternatively, heartwood volume divided by log volume x 100 to give heartwood percentage). A quick way to determine the percentage of heartwood would be to eliminate the length and pi factor since they are common to both sides of the equation and to use the simple formula of heartwood diameter^2 divided by log diameter^2 x 100 equals the heartwood percentage. The same causal relationship exists between R^2 x D^2.

It was a new game: guesstimating the heartwood!

After weighing and working for an hour cleaning the aforementioned log, I then reweighed it. To my surprise the log was now 46 percent clean heartwood of original weight, thereby satisfying my impulse that sap should weigh less than heartwood.

Well, I accepted his offer and got to thinking that during the harvest of the sandalwood by the Hawaiians, before 1845, they did not have good shoes, four-wheel drives, roads, and helicopters; and that to eliminate a species of any kind is a formidable task. Maybe it was time to investigate this pandora's box.

By exploring the Honomalino area of Hawai‘i, I was able to identify the specie due to my new familiarity with the trunk and bark. I then realized that this species was abundant on the leeward coast of the Island of Hawai‘i.

To encourage me to seek out more sandalwood the Hong Kong buyer provided me with a contract to procure more sandalwood. The price was based on a 50/50 heartwood/sap ratio, and the contract stated that I provide 20 percent grade A wood. I proposed a contract with one of the ranches on the leeward coast based on this contract with the Hong Kong buyer. The ranch elected not to sign but verbally agreed to go along.

Well, at the end of our 2-week venture we were responsible for the deficit of not supplying the 20 percent grade A. Almost every tree that we cut on the ranch, which were not many, had rot in them *(fig. 1).* The largest tree we cut had a 34-inch log diameter on the butt, but it was rotten throughout.

At this time a second ranch was willing to negotiate a contract. The Hong Kong buyer and I sat down to brainstorm a set of specifications for different price categories. We made a major mistake. Based on the knowledge of our previous dealing, we both assumed that sandalwood in Hawai‘i is naturally 50/50 ratio of sapwood to heartwood. We had written the specifications based on this faulty premise.

By the time this contract came to maturity, naturally all that was recalled was the written word. The buyer was supposed to be present to help us get going because this was our first venture into cutting live sandalwood.

During the course of this contract, the media became involved and articles appeared in the newspaper. The melodramatic ramblings of one of the writers was rather quaint, "...a convoy of trucks coming down the mountain under the shroud of darkness with their precious cargo laden for the Orient."

At this point the deliveries were reaching their destination. There were problems: too much sapwood, and a new phenomenon—wood quality that was not sap and not heartwood. We called this pre-heart or false-heartwood. It was fiber that had not yet become heartwood, and it had no fragrance. The buyers asked us to stop cutting. At the same time the ranch told us to stop cutting. They had received a better offer for the sandalwood due to the media exposure.

It was time to regroup—the buyers and sellers were unhappy and so were some constituents. The legislators called public hearings and the myth was exploded. Most people had been content to believe that sandalwood was virtually extinct. But they had no basis for being upset when we explained that it was plentiful, of commercial value, and that quantities were sufficient to export. It became a non-issue, as the logging was done on private land, and it stopped soon thereafter.

Before the hearings the idea had been to protect the sandalwood; thereafter the emphasis was to manage it.

At that stage the buyers had lost a substantial amount of money due to excessive sapwood. We were liable to return the amount of money overpaid due to their overpayment against the grade A, which was not present.

Due to our limited knowledge at the time, our approach was not streamlined to meet the demands of the buyer. Our approach was to take everything we considered commercially viable rather than to be selective. We had not considered methods of testing the trees and had no knowledge of horizontal increment borers.

Anyway it would be more than a year until our next contract. We had collected seeds from our previous harvest, and we distributed these to various green thumbs.

The germination rate was zero, but this I can attribute to improper handling and storage of the seeds. A fungus had grown all over them.

Our next contract started on October 15, 1989, with one of the larger land holders on the leeward side of the island of Hawai‘i. This contract is valid for 1 year. At this time the principals are involved in legal disputes so I cannot comment any more in that regard. However, this area presents some interesting possibilities.

The ecosystem has more or less been divided into two by a large a‘a flow. Along the northern flank there has been no evidence of cattle intrusion. Moreover the southern area has been cattle-free for at least 6 years. West of this property is sandal habitat still in cattle. Furthermore the property is also crossed by other a‘a and pahoehoe flows, thus creating various pockets referred to as kipukas. These kipukas vary in regard to the age of the trees in them. For example, in a kipuka that probably never had cattle, the habitat has a variety of tree ages, and these trees appear to have less rot and death prior to maturity. All of these areas have the invasive kikuya grass, banana poka, and lantana.

Areas less grazed are definitely better sandalwood habitat. In the habitats that are currently grazed, there is no evidence of regrowth. In the areas that were grazed in the past, there is evidence to suggest high rot occurrence and premature deaths, and regrowth is no older than the time that the cattle have been out of the area. Approximately 2 years ago there was an unauthorized harvest in some of this area, and today there is clear evidence of reproduction by coppicing. Also on the adjoining southern property it has been reported by March Winkler at a Hawaii Forest Industries Association meeting held on February 23, 1990, of coppicing regrowth rates of 3 1/2 feet and the production of seeds after one half a year. A good way to distinguish different areas in the habitat is by using the U.S. Soil Survey maps. According to the soil type it is my observation that rMWD soil type (extremely stony a‘a muck with 6-20 percent slopes) is the preferred type, although it occurs in other types except the pahoehoe flows.

I also feel that it is necessary to provide empiric verification of the supposed parasitic nature of the tree. There is possibly more evidence to suggest that the tree may not be parasitic at all, or possibly the tree is parasitic or maybe symbiotic only at certain times.

I have noticed that older trees have roots that spread out on the soil surface. Many of these roots lead into live or dead mamani, but they then also seem to leave the mamani. After having dug

Figure 1—Heartrot, which is a common problem, can greatly reduce the value of sandalwood.

up the mamani and sandalwood interface it was impossible for me to determine its nature without supportive scientific investigation. Much of the regrowth of the sandalwood regenerates from these roots, especially if some kind of shock such as cutting occurs.

Where one finds singular sandalwood trees without other tree species, only the tree and kikuya grass, or areas where the only tree type is the sandal, one would then ask if the tree is parasitic unto itself or the kikuya grass. Many trees have the kikuya grass growing up the center rot. Maybe the grass parasitizes the tree—at least it appears that way.

Much of the sandalwood habitat was previously logged for the big koa, which in essence means the the understory of sandalwood is now exposed and furthermore that most of the habitat has been subjected to grazing at one time or another. I believe there could be a beneficial relationship between the koa and the sandalwood—certainly the trees would attain straighter and taller trunks—and the possibility for their compatibility as an agro-forestry crop needs to be investigated.

Sandalwood seeds have a very hard shell. Possibly nature meant the seeds to be dispersed by birds, with the acid in their stomachs aiding in germination. In the latter-mentioned ranch area, there is some planting of eucalyptus, and—amazingly—there are young sandalwoods growing under the eucalyptus. I have theorized that turkeys have been feeding on seeds and then roosting in the trees at night, where they drop the seeds.

We should pen some turkeys, feed them seeds, and then germinate the seeds. This may be more effective than scarification or other conventional seed treatments. In general I would say that the sandal wood tree prefers a variety of species for neighbors, the most common being koa *(Acacia koa),* mamani *(Sophora chrysophylla),* ohio *(Metrosideros collina* var. *polymorpha),* kopiko *(Straussia kaduana),* ahakea *(Bobea Mannii),* naio *(Myoporum sandwicensis),* lantana, and kikuya grass.

Ultimately criteria will have to be laid forth concerning harvesting and sales that minimize fragmentation of forest areas, and a sustained-yield concept must be adopted. Separate owner parcels could treat the area as a total ecosystem, adopt sustained yield and sound management principles, and provide access for scientific study.

In January 1989, I made a proposal outlining the concept of establishing a sandalwood research institute, and a proposal regarding the cultivation of sandalwood in Hawai'i. Here are some excerpts:

"Sandalwood has been of historical significance and of economic importance since it was first exported in 1778. As a result of both agricultural development and commercial harvesting, natural stands have become depleted. Interest has therefore developed in replenishing stocks of Sandalwood for marketing, focusing on attempts at re-establishing the species in natural environments.

I have personally been pursuing knowledge about Sandalwood, which I would be willing to share with the State of Hawaii and Resource Management. I have contacted research centers in various countries, including India, Australia and Fiji. Much information concerning studies of the Sandalwood species has come my way, including an invitation to visit various Sandalwood research centers and plantations. Also, an offer from a professor in India with 30 years experience in growing Sandalwood, for us to sponsor a visit to Hawaii where he would like to see our Sandalwood and he would be willing to share his knowledge with us.

Since the rediscovery of Sandalwood in 1988, more than $1,000,000 has come into the State of Hawaii from this export. This would make Sandalwood the largest foreign export commodity for 1988 for the State of Hawaii. Since this genus is cultivated in other countries, it warrants the further studies necessary to determine the best methods and feasibility of cultivating Sandalwood as an agro-forestry crop within the State of Hawaii.

Objective

To establish a Sandalwood Research Institute that would:

A) Determine the geographical areas of Hawaii that have Sandalwood occurrence.

B) Determine the volume of inventory of Sandalwood in these areas.

C) Undertake the study of the germination and establishment of Sandalwood for planting.

D) Sandalwood Research Institute would after studying all published literature concerning all aspects involved for the propagation of Sandalwood undertake recommendations, field experiments establishing the viability of cultivating Sandalwood species. Reports would be published and methods for the successful propagation would be achieved. After the adoption of field tested propagation and planting techniques, Sandalwood can then be grown in large quantities and can be planted on State, Hawaiian Homelands and private lands.

The overall research aims are:

A) To determine the areas that naturally have Sandalwood and to access the inventory.

B) To obtain scientific research of Sandalwood harvesting impacts and to develop a Sandalwood management plan.

C) To establish research plots to determine the best method of germination by seed or coppice to ensure sustainability of the resource."

The technology of satellite mapping can provide 90 percent accuracy for species identification and distribution. This can be a great help to focus more expensive timber cruising and aerial photographic work on smaller targeted areas. The flexibility of digital imagery is proving to be multipurpose, and can be used to assess forest fire danger, and to plan controlled burning strategies based on forest and land cover diversity.

With the help of all my distinguished colleagues attending the Sandalwood Symposium and the Department of Land and Natural Resources, a joint effort to establish a sandalwood research organization would inevitably enhance the ecosystem.

REFERENCES

Latham, R.E., transl. 1958. Marco Polo: The Travels. Penguin Classics.

Ross, M. S. 1985. An annotated bibliography of sandalwood and its uses. University of Oxford. Wageningen, the Netherlands: Foundation for Dutch Forestry Development Co-operation.

Propagation of *Santalum*, Sandalwood Tree[1]

Robert T. Hirano[2]

Abstract: The history of the genus *Santalum* (sandalwood) in Hawaii is reviewed, along with all the early reference regarding its botany and horticulture. This paper gives some seed germination and viability information on *Santalum haleakalae* Hbd. and *S. paniculatum* H. & A. both native to Hawaii and *Santalum album* L. native to Indonesia. Germination was shown to be highly variable: as early as 26 days after sowing for *S. album*, 75 days for *S. paniculatum*, and 155 days for *S. haleakalae*. Seed viability varied from 324 days in *S. album*, 387 days in *S. haleakalae* and 824 days in *S. paniculatum*. Germination percentages ranged from 38 percent to 77 percent.

This study also showed that supplemental chelated iron is essential in the propagation of all the species tested.

The genus *Santalum* (sandalwood) includes several species which are highly prized for their fragrant heartwood and aromatic oils which has been in great demand throughout history especially in the orient. Edwards (1951) dates it as far back as the fifth century B.C. It is also mentioned in passages of the Bible (Modenke and Noldenke 1952). Its value in the orient was well known by the early sea captains and when it was found that sandalwood existed in Hawai‘i, it was soon exploited. Records are inconclusive as to who exported the first shipment of sandalwood from Hawai‘i; however, this product formed the basis for Hawai‘i's first profitable major export which according to Smith (1956) lasted for 52 years, from 1784 to 1836, "when all Hawaii woke to the fact that every tree had been cut." This statement, like those of Mesick (1934) and Kuykendall and Gregory (1926) greatly exaggerated the rarity of this genus and was corrected by St. John (1947) who documented their relative abundance. It is apparent that many of the sandalwood trees were destroyed during the height of this trade and Rock (1974) estimated that over 90 percent of the trees were destroyed.

The genus *Santalum* belongs to the family Santalaceae which includes 29 genera with approximately 400 species, many of which being completely or partially parasitic. St. John (1947) records 19 species of this genus, extending from Java to Juan Fernandez, Hawai‘i and the Bonin Islands. The genus is described by Rock (1916) as being hemiparasitic, obtaining part of its nutrients from roots of other plants by means of a haustoria or suck organ. He also found *Santalum cuneatum* growing all alone with not [sic] trees or other plants within a radius of 1 mile, indicating that this species is not always dependant [sic] on host trees for nutrients.

The first attempt to cultivate native sandalwood is recorded by Hillebrand (1888) who states that "bur trees are probably parasites as is the Indian *S. album;* at least all attempts to cultivate them in my garden have resulted in failure." Rock (1974) also remarked "that any attempt to germinate seeds of the Hawaiian sandalwoods resulted in failure."

Encouraged by Rock's (1916) statement showing that sandalwood was not always dependent on host trees for nutrients, and the fact that he (Judd) also noted a flourishing tree of *Santalum freycinetianum* growing without any apparent host plants within 299 feet of it, Judd (1933) planted seeds of native *Santalum* species. This is the first recorded sowing of native Hawaiian *Santalum* species.

A few years later, Judd (1935,1936) reported that the Forest Service of the Territory of Hawaii was having difficulty growing native sandalwood seedlings because, "the young seedlings ceased to grow after one year, and died in the nurseries after reaching six inches in height." They were, however, successful in developing a system for growing *Santalum* seedlings. It consisted of planting 5-7 month old seedlings in a container with a few seeds of *Casuarina equisetifolia* (ironwood) to act as host plants and subsequently transplanting them together into the field when the sandalwood was about a year old. Using this method, 100 percent survival was reported. It is unclear whether this success was with the native as well as with the introduced species, *Santalum album;* for, Judd (1936) also states that experiments were first started with seeds of native species but later with *S. album* when they could not germinate the native species. Seeds of *S. album* germinated well and seedlings survived with their new system of propagation and planting.

The use of ironwood seedlings is briefly mentioned by Edwards (1951) as being used by Foresters at Volcano National Park, Hawaii. Le Barron (1970) also states, "When the Division of Forestry propagated sandalwood seedlings, a Casuarina or koa seedling was placed in a pot together with each sandalwood to serve as a host." The only other reported unsuccessful attempt at germination of native sandalwood seed is by Obata (1967).

Since studies on the propagation of native sandalwood are lacking these studies (on germination and propagation) were initiated at the Lyon Arboretum. Preliminary results are being reported since substantial success has been obtained in seed germination and seedling growth. Furthermore, this report might stimulate others.

SEED GERMINATION

Seeds of three species, *Santalum haleakalae* Hbd. and *S. paniculatum* H. & A. native to Hawai‘i and *S. album* L. native to Indonesia, were used in these studies. Sources are included in *table 1.*

After the fruit pulp was removed, the seeds were treated with Dithane M-45 (2 tablespoons per gallon of water) for five minutes and sown in seed flats containing horticultural vermiculite (grade 3). The flats were placed on open benches in the greenhouse with a mean temperature of 78 degrees. Germination dates were recorded.

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11,1990, Honolulu, Hawai‘i. Reprinted with permission from Plant Propagator 23(2):11-14, 1977.

[2]Assistant Researcher, Lyon Arboretum, University of Hawai‘i.

Table 1—*Germination data on three species of* Santalum

Species	Source	No. of Seeds	No. germinated	Percent germination	No. of days required for first seed to germinate	Total no. of days between first and last seedling
Santalum album L.	Taiwan Forestry Research Inst., Botanical Garden, Taipei, Taiwan	33	20	67	26	324
S. haleakalae Hbd.	Haleakala, Maui Hawaii	32	12	38	155	387
S. paniculatum H. & A.	Kohala, Hawai'i	136	105	77	75	824

Germination was highly variable *(table 1).* Seeds of *S. album* began germinating 26 days after sowing while those of *S. paniculatum* and *S. haleakalae* required 75 and 155 days respectively. The total number of days (germination period) required for all viable seeds of each species to germinate varied from 324 in *S. album* to 387 in *S. haleakalae* and 824 days in *S. paniculatum* seed lots.

Seedlings appeared normal and growth was normal until cotyledons shriveled and dropped off. The seedlings then began to decline in producing smaller leaves with each new flush of growth; with extremely chlorotic leaves, by reduction in internode length and die-back of short tips. Death occurred shortly thereafter.

SEEDLING GROWTH

Seedlings were potted into media consisting of: 2 parts vermiculite, 2 parts perlite, and 1 part peat plus osmocote (18-6-12) at the rate of 0.25 cup per 5 gallons of mixture. Some seedlings were planted with native Hawaiian host plants, others treated with foliar fertilizer (Nutrileaf 60 20-20-20) and others with chelated iron (Sequestrene 138 Fe).

The first three seedlings of *S. haleakalae* were planted with native *Dodonea* sp. and *Tetraplasandra* sp. seedlings as hosts. These genera were selected since they have been associated with sandalwood populations in native forests. These three plants expired within a year without showing any signs of growth. Subsequently, seedling of *S. paniculatum, S. haleakalae* and *S. album* did not respond to applications of foliar fertilizer (20-20-20). When 0.125 teaspoon chelated iron per 3 inch pot was applied to severely chlorotic seedlings of *S. album,* within 2-5 weeks, most of the chlorotic leaves became green and growth resumed. Likewise, 2 weeks after application of chelated iron on eight chlorotic seedlings of *S. paniculatum,* all the new growth was normal green while those treated with ammonium sulfate only showed no response. Three months after treatment, the remaining chlorotic foliage turned green in those plants treated with iron while those treated only with ammonium sulfate remained chlorotic. The average increase in height over a period of 18 months for the treated plants was 39.0 cm while those untreated averaged only 15.3 cm *(table 2).*

In the experiment using seedlings of *S. paniculatum,* four were treated with 0.125 teaspoon ammonium sulfate per 3 inch pot while another four were treated with 0.125 teaspoon chelated iron plus 0.125 teaspoon ammonium sulfate. Seedling height was measured before and 18 months after treatment *(table 2).*

Table 2—*Growth response of* Santalum paniculatum *to chelated iron and ammonium sulfate at a rate of 1/8 teaspoon each per 3 inch pot*

Treatment	Plant	HEIGHT (CM)			
		Initial	18 months	Net Increase	Average
(Control) Ammonium sulfate	1	5.7	17.4	11.7	
	2	4.9	17.3	12.4	
	3	6.3	23.0	16.7	
	4	6.5	27.0	20.5	15.3
Ammonium Sulfate Plus Chelated Iron	1	5.3	36.8	31.5	
	2	5.1	42.3	37.2	
	3	6.1	48.7	42.6	
	4	6.3	50.9	44.6	39.0

Chlorotic seedlings of *S. haleakalae* were treated with 0.125 teaspoon chelated iron plus 0.25 teaspoon osmocote (18-6-12) per 4-0.75 inch pot. After 3 months these plants were divided into two lots of four plants each. One lot was treated with 0.25 teaspoon osmocote and the second lot with 0.25 teaspoon osmocote plus 0. 125 teaspoon chelated iron. The plants were re-treated after 6 months. Plant height was recorded before and at 6 month intervals up to a year after treatment *(table 3).*

The trial using seedlings of *S. haleakalae* again showed response to chelated iron. The total net increase in height was

Table 3—*Growth response of* Santalum haleakalae *to chelated iron at a rate of 1/8 teaspoon per 4-3/4* inch pot

Treatment	Plant No.	HEIGHT (CM)				
		Initial	6 months	12 months	Increase Net	Average Increase
Control (No Chelated Iron)	1	23.9	35.5	44.5	20.6	
	2	34.5	47.7	58.6	24.1	
	3	24.5	38.3	50.8	26.3	
	4	26.0	39.5	57.6	31.6	25.7
Plus Chelated Iron	1	16.5	27.5	39.4	23.9	
	2	34.0	55.1	72.7	38.7	
	3	15.0	45.2	66.3	42.3	
	4	20.5	14.1	63.1	47.1	38.0

Table 4—*Germination of three seedlots of* Santalum paniculatum						
Santalum paniculatum seed lots	No. of seeds	No. of days from collection to sowing	No. of days (from sowing) required for first seed to germinate	No. of days from collection to emergence of last seedling	No. of days between germination for first and last seedling	Percent germination
1. L-71 .377	27	69.0	866	1759	824	70
2. L-75.148	17	0.5	207	369.5	162	94
3. L-75.186	92	8.0		174		76

greater in those plants treated with iron, averaging 38 cm.; while those untreated, increased in height only 25.7 cm after 12 months. The increase in height of treated vs. untreated was not as great when compared with the *S. paniculatum* trial. It should be noted that all of the plants involved in this trial were treated with chelated iron before the trials began.

DISCUSSION

The germination data seem to indicate some type of dormancy mechanism(s) controlling germination of the *Santalum* ssp. included in these studies. The extreme variation in the number of days 75, 207, and 866, to initial germination for different seed lots of *S. paniculatum,* seems to reflect this *(table 4).* Further evidence is indicated by seed lot number L-71.377 which was not sown until 69 days after collection. This lot required 866 days to germination of first seedling followed by a germination period of over 2 years with 70 percent germination.

The data also show the longevity of the seeds which germinated in a range from a low of 174 days in the case of L-75.186 *S. paniculatum* to a high of 1, 759 days in L-71.377 *S. paniculatum:* indicating seed viability of nearly 5 years *(table 4)* in the latter case. Seeds of this were allowed to dry out for 69 days before being sown and this factor may have contributed to its longevity.

Germination percentages ranged from 38 percent to 77 percent. The data do not show that older seeds tend to be less viable than fresher ones. However, it does show that seeds of *S. haleakalae* have a lower germination percentage when compared with both *S. album* and *S. paniculatum* seed lots. It was shown in the case of L-71.377 where the seeds were held for 69 days before sowing that over 2 years were required before the first germination occurred. It appears that seeds of those species should not be allowed to dessicate in order to hasten germination.

Previous fertilizer practices using both osmocote and foliar fertilizer in scheduled application proved ineffective in promoting growth of the *Santalum* spp. included in this study. The plants gradually declined and their leaves gradually became severely chlorotic, turning a yellowish-white. With each subsequent leaf flush, the leaves became smaller and smaller until the growing tip died. Death followed shortly. With the addition of chelated iron foliage color was restored and growth resumed. Ammonium sulfate applications showed no response and was discontinued after the first trial. It is evident that supplemental chelated iron is essential in the propagation of *S. album, S. haleakalae* and *S. paniculatum* since all of these species responded to the addition of chelated iron as indicated by the data. These studies show that these species can be grown without any host plants. Although the number of plants used in these trials was small, the results are encouraging and further studies are being conducted with larger numbers for statistical analysis.

REFERENCES

Edwards, Webley. 1951. The fragrant wood of Hawaii. Illus. by Jerry Chong. Advertiser Weekly. Honolulu, Sept. 4.

Hillebrand, William. 1888. Flora of the Hawaiian Islands. London: Williams & Norgate; New York: B. Westermann & Co.; Heidelburg: Carl Winter, University-Bookseller, 673 p.

Judd, C.S. 1933. The parasite habit of the sandalwood tree. Thrum, Hawaiian Annual, Honolulu: The Printshop Co. Ltd. 59th Issue; 81-88.

Judd, C.S. 1935. Reviving the sandalwood industry. Paradise of the Pacific. April; 19.

Judd, C.S. 1936. Growing sandalwood in the Territory of Hawaii. Journal of Forestry, Vol. XXXIV (1), reprint.

Kuykendall, Ralph S ; Gregory, H.E. 1926. A History of Hawaii. Illus. New York: Macmillian. 375 p.

Le Barron, Russell K. 1970. Hawaii's sandalwood. Aloha Aina. Department of Land and Natural Resources, State of Hawaii; 6-7.

Mesick, Lillian S. 1934. The Kingdom of Hawaii. Honolulu: Porter, 400 p.

Modenke, Harold N.; Noldenke, A.L. 1952. Plants of the Bible. Waltham, MA: Botanica Company; 328 p.

Obata. John. 1967. Seed germination in native Hawaiian plants. Newsletter of the Hawaiian Botanical Society. Vol. VI (3): 14.

Rock, Joseph F. 1916. The sandalwoods of Hawaii. Botanical Bulletin No. 3. Territory of Hawaii, Board of Ag. and Forestry; 9-43.

Rock, Joseph F. 1974. The indigenous trees of the Hawaiian Islands. Charles E. Tuttle Co., Inc. of Rutland, Vermont and Tokyo, Japan. (Reprint); 548 p.

Smith, Jared G. 1956. Sandalwood and whales. Honolulu Advertiser, May 13, p. A4.

St. John, Harold. 1947. The history, present distribution, and abundance of sandalwood on Oahu, Hawaiian Islands: Hawaiian plant studies 14. Pacific Science Vol. I (1): 5-20.

The History of Human Impact on the Genus *Santalum* in Hawai'i[1]

Mark Merlin **Dan VanRavenswaay**[2]

Abstract: Adaptive radiation of *Santalum* in the Hawaiian archipelago has provided these remote islands with a number of endemic species and varieties. The prehistoric Polynesian inhabitants of Hawai'i utilized the sandalwood trees for many of the same traditional purposes as their South Pacific ancestors who had developed ethnobotanical relationships with *Santalum.* The ancient Hawaiians probably reduced the number and geographical distribution of sandalwood trees significantly through their extensive cutting and burning, especially in the dry forest regions. Nevertheless, vast numbers of the fragrant trees still existed in Hawai'i at the time of Western contact in 1778. Within a century after this contact, the extensive trade in sandalwood produced a massive decline in the Hawaiian species of *Santalum.*. Although cultivation attempts during this cen-tury with both introduced and native sandalwood species have had limited success in Hawai'i, there is renewed interest in developing a sustainable forest industry based on the production of sandalwood for export trade. Biologists in general, however, have cautioned against large-scale harvesting of the remaining *Santalum* trees, suggesting that more research be undertaken first to determine the distribution and vigor of the remaining species.

The Hawaiian Archipelago is one of the most isolated group of islands in the world. Yet, this chain of remote islands has an extraordinarily diverse array of ecological conditions with vast tracts of fertile land. The discovery and colonization of this isolated archipelago was one of the most extraordinary achievements of our species. The people who originally found these islands brought with them plants, animals, and ideas that they utilized to colonize and build a Polynesian society beginning approximately 1,500 years ago (Kirch 1982, 1984). One set of ethnobotanical concepts that the early Polynesian immigrants brought with them involved the practical and ritual use of *Santalum* species. Their ancestors had developed these concepts over thousands of years of human experience in the tropical Pacific Islands of Melanesia and Polynesia. Much later, trade-motivated Westerners brought their ideas about commercial export to Hawai'i and soon identified the presence and marketable value of the native sandalwood trees.

A study of the history of human impact on the sandalwood plants in Hawai'i provides us with an excellent opportunity to examine the multifaceted relationship between *Homo sapiens* and a valuable group of endemic woody *Santalum* species that probably evolved from a single ancestral species through the process of adaptive radiation.

This paper surveys the interaction of social systems, cultural values, and useful plant resources in a variety of natural environments through a review of the exploitation and decline of the genus *Santalum* in Hawai'i. Following a brief overview of the natural history of the genus in the archipelago, we examine the prehistoric use of sandalwood in Hawai'i and the human impact on the distribution of *Santalum* species in these islands. Subsequently, we describe the major economic, political, social, and ecological consequences of the early 19th century sandalwood trade between Hawai'i and China. Finally, we summarize a number of recent events involving a renewed interest and activity in the harvesting, marketing, cultivation, preservation, and scientific study of *Santalum* in the State of Hawai'i.

NATURAL HISTORY OF HAWAIIAN SANDALWOOD SPECIES

Worldwide, the family Santalaceae is represented by roughly 30 genera comprised of about 250 species which are mostly small tropical perennial herbs and shrubs (Press 1989:258). Two genera, *Santalum* and *Exocarpus,* are represented in Hawai'i (Imada and others 1989:78). *Santalum* was first proposed by Linneaus in 1753 in his description of S. *album* (Stemmermann 1977:1). Specimens of the genus were initially collected for taxonomic study in Hawai'i by Gaudichaud during the voyage of the French ship *Uranie* in 1819. When this botanist published his findings in 1830, he described two species, *S. freycinetianum* and *S. ellipticum* (Stemmermann 1977:3).

Since Gaudichaud, a number of taxonomic studies of *Santalum* in Hawai'i have been undertaken. However, significant differences of opinion have arisen regarding interspecific and intraspecific classification. For example, St. John (1947:5) listed 19 species, while more recent revisions tend to group the taxa together into as few as four distinct species (Little and Skolmen 1989:112), with a number of varieties (Stemmermann 1977:114). The most recent classification by Wagner and others (1990) lists the following four species:

S. ellipticum (Coastal sandalwood) *(fig. 1)*;
S. freycinetianum (Freycinet sandalwood) *(fig. 2);*
S. haleakalae (Haleakala sandalwood);
S. paniculatum (Hawai'i sandalwood).

These four endemic species made up the source of the early 19th century sandalwood trade (Little and Skolmen 1989:112; St. John 1947:5,18). More recently an alien *Santalum* species was introduced in Hawai'i. Earlier in this century, the Indian Sandalwood *(S. album),* traditionally the most important source of commercial sandalwood products, was purposefully brought into Hawai'i from India and planted in some areas for possible commercial production and marketing (Fletcher 1968:18).

The Hawaiian "coastal sandalwood" *(S. ellipticum)* generally grows as a shrub or small tree, rarely exceeding more than 18 feet in height (Stemmermann 1977:126). Individuals of this species that grow along or very near the coast are much lower in height; they were formerly classified as a separate variety (var. *littorale).* The other three species of Santalum in Hawai'i grow primarily as trees, with maximum heights of about 65 feet (Daehler 1989:2), though specimens of *S. freycinetianum* have been reported reaching heights over 80 feet (Little and Skolmen 1989:114). Trees of this height would have a diameter of nearly 3 feet (Daehler 1989:2; Little and Skolmen 1989:114).

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11,1990, Honolulu, Hawai'i.

[2]Associate Professor, General Science Department, and Graduate Student, College of Education, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Figure 1—*Santalum ellipticum* Gaud. grows in dry forest at about 1000 ft elevation in the southern Wai‘anae Mountains of O‘ahu.

Figure 2—*Santalum freycinetianum* Gaud. grows in seasonally dry forest at about 2000 ft elevation in the southern Wai‘anae Mountains of O‘ahu.

All members of the family Santalaceae are apparently hemiparasites (Stemmermann 1977:1). While these partially parasitic plants do produce their own photosnythates, they probably obtain some of their nutrition from a host plant(s). The genus *Santalum* utilizes sucker-like organs called haustoria which attach themselves to the roots of one or more host plants *(fig. 3)*. Most haustoria are located within a few inches of the surface of the soil. Judd (1933:88) believed that Hawaiian sandalwoods are facultative, rather than obligate parasites, as evidenced by the occurrence of solitary sandalwood trees (Rock 1917:14). However, recent studies (e.g., Press 1989:258) indicate that many facultative parasites suffer reduced fecundity in the absence of a host. In the past, efforts to culture sandalwood seedlings have had higher success rates when the seedlings were planted alongside seedlings of other tree species (Judd 1936:83; also see other articles in this publication). Hawaiian sandalwoods utilize several species of native and introduced plants as suitable hosts (Judd 1935:19).

The original colonizing ancestor(s) of Hawai‘i's sandalwood probably arrived from Southeast Asia by way of the intervening islands where *Santalum* can still be found today. The relatively large olive-like fruits of *Santalum* are eagerly sought by birds, and the seed(s) was most likely brought to the Hawaiian Islands in the gut of an avian species, as were nearly 40 percent of early colonizing plants in Hawai‘i (Carlquist 1980:4-5). However,

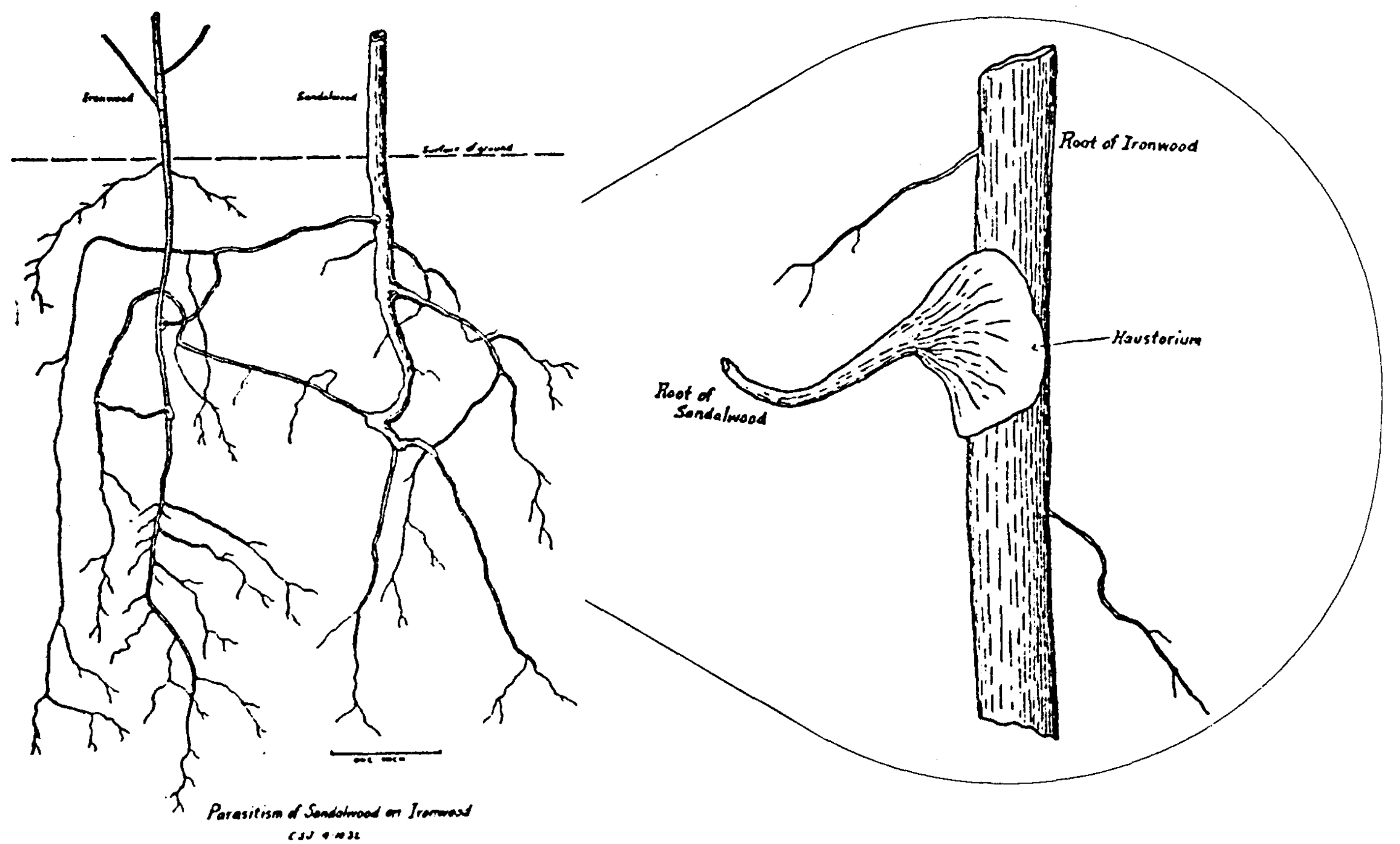


Figure 3—Haustoria of *Santalum* species is shown parasitizing ironwood tree *(Casuarina* sp.). Drawings by C.S. Judd, reproduced from: Cartwright (1935, p. 21).

the ancestral seed(s) carried by the fruit-eating bird may have been smaller than the present forms produced by the genus in Hawai'i. Large seed size is presumed by some to have evolved after arrival and establishment in the islands (Carlquist 1980:97).

The genus *Santalum* was probably introduced to the Hawaiian Islands through the colonization of a single ancestral species. The four (or more) species and their varieties are one of many interesting examples of a process that has commonly occurred in insular environments and is referred to among biologists as adaptive radiation. According to this process, several taxa may evolve from a single ancestor, each adapting to a variety of different environmental conditions. In Hawai'i, Zimmerman (1972:528) suggested that the adaptive radiation was "...given much freedom for operation in a sort of `biological vacuum,"' and noted that in Hawai'i such a "condition resulted in an astonishing proliferation of species, species diversification, adaptive morphology, and habitat utilization."

Santalum established itself throughout the main high volcanic islands. One species, *S. ellipticum,* was even extant on tiny Laysan in the Northwest Hawaiian Islands until it was extirpated by feral rabbits earlier in this century. This species also may have become extinct recently on Kahoolawe due to grazing pressure and soil erosion. Although they are not common in most areas today, some sandalwood plants can still be found in various habitats from sea level to well over 8,000 feet (Stemmermann 1977; Little and Skolmen 1989). Where *Santalum* occurs in the dry forest, it grows as individual trees or in small clumps mixed in with other species (Rock 1916; St. John 1947; for a detailed discussion of the distribution of *Santalum* in Hawai'i, see Stemmermann in these proceedings).

PREHISTORIC ALTERATION OF THE HAWAIIAN ECOSYSTEMS

The original human colonists who settled in Hawai'i arrived by sailing canoes well over a thousand years ago. The early voyagers brought with them a number of species. Most were carried along on purpose, while others were probably introduced accidentally. As many as 25 alien plant species, including more than a dozen crop plants, were brought in consciously, while five or more plant species were unwittingly transported to Hawai'i. Pigs, dogs, and chickens were intentionally introduced, whereas other animals, such as rats, geckos, and skinks were most likely stowaways. The prehistoric Hawaiian immigrants also brought with them concepts about their natural environment and how it should be manipulated. Many of their traditional ideas about nature and resource management had been inherited from their South Pacific ancestors. This "transported landscape" of alien biota and cultural concepts concerning how they should alter the environment included various schemes for changing the land-scape to facilitate the needs of a growing population. For example, the prehistoric Hawaiians cut and burned vegetation to clear the lower forest land for agriculture, and they diverted streams to irrigate artificially constructed pond fields where they cultivated their staple taro crop, *Colocasia esculenta* (Kirch 1982).

Although it is a "difficult task" to ascertain the "shared and practiced" values of the prehistoric Hawaiians, the early inhabitants developed some environmental concepts involving regulated resource use; these ecologically-oriented ideas may have been motivated by an understanding of the significance of conservation (e.g., Burrows 1989). In some cases their values and practices seem to have been developed to sustain resource availability. Such principles of environmental concern or stewardship *(malama)* or resource use regulations *(kapu)* may have functioned primarily for the protection of species that had utilization value at the time.

As the prehistoric Hawaiians extended their influence inland from their early nucleated coastal settlements in windward areas, as well as expanding into drier leeward areas, they had an increasing impact on the areas where sandalwood occurred. Fire was used widely to remove lowland forests, perhaps primarily—but not necessarily only—to produce anthropogenic grassland or savannah where the Hawaiians could cultivate dryland crops such as sweet potatoes *(Ipomoea batatas)* and yams *(Dioscorea* spp.). Well before the first Europeans had arrived in the Hawaiian Islands, large areas of the lower forests were converted into semi-natural grasslands or degraded savannah. According to Kirch (1982), by A.D. 1600, probably 80 percent of all the land below 1,500 feet had been altered by extensive burning. Vancouver (1798, vol. 1:170) described the island of Kauai as having "...a space comprehending at least one half of the island, appeared to produce nothing but a coarse spiny grass [probably pili grass, *Heteropogon contortus]* from an argillaceous soil, which had the appearance of having undergone the action of fire" (quoted in Kirch 1984:142). A number of archaeological studies in Hawai‘i (e.g., on Makaha, O‘ahu; Halawa, Moloka‘i; and Kaho‘olawe Island) have documented the destruction of lowland forest due to conflagrations set off in the prehistoric period (Kirch 1984: 142-143). The use of fire for clearing land was probably the first major impact on the lowland *Santalum* populations, especially those of *S. ellipticum,* which reach down to the littoral fringe, and of *S. freycinetianum,* which can be found as low 800 feet above sea level.

Alteration of these low dry forest habitats also had a severe impact on native bird populations, which in turn may have affected the sexual reproduction of a number of native plants, including the sandalwood species. Fossil records from the Ewa Plain of O‘ahu, coastal areas on Moloka‘i, and elsewhere in Hawai‘i, have revealed numerous species of birds (including geese, perching birds, and crows) that became extinct during the precontact period (Olson and James 1982).

The reduction and, in many cases, the elimination of native bird populations may have affected the sandalwood populations in two ways. First, native birds are important pollinators of native plants in Hawai‘i. A recent survey of *S. haleakalae* estimated a remaining population on Maui of about 400 individuals, but only one seedling could be found. Among the thousands of flowers produced every year by the Haleakala sandalwoods, only a tiny percentage presently form seeds. One reason for this may be the lack of sandalwood pollinators (Kepler 1985:11). Secondly, as noted earlier, birds are important agents of dispersal for sandalwood seeds. A reduction in native seed-eating bird populations (e.g., the extinct finch bill passerines and the extant, but extremely rare, endemic crow) may have resulted in a severe decline in the local populations of their food plants (Fern Duvall, Personal Communication, 1990). Although the population problems associated today with *S. haleakalae* probably involve more recently introduced alien organisms, the pattern of disruption may apply to the earlier demise of lowland sandalwood habitat in the prehistoric period.

Introduced lizards and rodents may have also had an early impact on sandalwood. Geckos and skinks are primarily insectivores. They might have contributed to a reduction in pollinating insects. Rats and mice, including the Pacific rat *(Rattus exulans),* which was an aboriginal introduction, are known to have a great affinity for the sandalwood seeds and will dig up the fleshy hypocotyls of germinating seeds (Judd 1933:85,88; Kepler 1985:11).

Although lowland sandalwood populations were greatly reduced during the prehistoric period, vast numbers of *Santalum* trees remained in the higher forest areas (i.e., above 1,500 feet elevation). Sometimes considered to be an economically self-sufficient unit, the radial land divisions of ancient Hawai‘i, the *ahupua‘a,* were probably developed to take advantage of the ecological diversity of the high volcanic islands. This system of land division usually consisted of an elongated strip of land which extended from beyond the reef to the top of the mountain range, thus acknowledging the "dependence upon the forests for wood and certain other plant materials" (Judd 1926:1). The traditional resource-oriented *ahupua‘a* included native upland forests where a variety of trees, including sandalwood, were harvested. These forests were used as "supply forests" subjected to selective cutting. Judd (1926:2-3) believed that this type of harvesting resulted in limited degradation of the upper forest regions. He reported that native trails were found mainly along the ridgetops, and that large logs (e.g., *koa* canoe logs) were dragged down from the mountains along specified routes. Desirable parts of sandalwood trees were also removed from these forests during the prehistoric period.

TRADITIONAL USE OF SANDALWOOD IN HAWAI‘I

In the Hawaiian language the sandalwood plants themselves are called *‘iliahi,* which refers to the reddish color of new leaves, or the trees in general when they are in full bloom. The latter condition would certainly apply to *S. freycinetianum* and *S. haleakalae* when they produce their profuse blossoms of reddish flowers. The fragrant heartwood of sandalwood is known in Hawaiian as *‘la‘au ‘ala,* literally "sweet wood" or "fragrant wood." Hillebrand (1965:389) suggested that the linguistic "root" for the Hawaiian name of the plant, *‘iliahi,* could be found "...in the Tahitian *Eai* and probably also in the Vitian [Fijian] *Yasi."*

Although it has been suggested that the Hawaiians did not use sandalwood extensively (Stemmermann 1977), products derived from the genus had a number of traditional uses in Hawai‘i, and their source trees may have been highly esteemed. A list of traditional Hawaiian uses of sandalwood is presented below.

A. Medicinal applications (Krauss 1972:199):

1. Curing dandruff (shampoo with infusion of leaf);

2. Eliminating head lice (shampoo with infusion of leaf);

3. Curing diseases of both male and female sex organs (drink made from finely ground powder, mixed with other plants, followed by laxative);

4. Treatment of sores of long duration (infusion of powdered wood, mixed with other plant parts, used as drink, followed by laxative).

B. Perfume (Krauss 1972:199; Kepler 1985:10):

1. The heartwood was pounded into a fine powder, and this, or fine chips, was pounded into new tapa cloth (which had an objectionable smell, especially just after its manufacture).

2. The heartwood powder was also added to coconut oil and used to make a waterproof, perfumed tapa.

C. Firewood (Wagner 1986:150).

D. Musical Instruments (Buck 1964:388):

1. *Iliahi* was sometimes used in the manufacture of the musical bow, or *ukeke,* a Hawaiian type of stringed instrument.

Knowledge of most of the uses listed above was probably brought to the Hawaiian Islands by the migrating Polynesians who arrived from their previous homelands in the South Pacific. The ethnographic record provides ample evidence that the heartwood and oil of *Santalum* were widely used among various other Polynesian and Melanesian Island peoples for a variety of practical, esthetic, and ritualistic purposes (Kirch 1984). For example, elsewhere in Polynesia the use of powdered sandalwood heartwood for scenting tapa, as well as mixing the sweet smelling powder with coconut oil for perfume, has been documented. Kirch (1984) points out that Tongan chiefs traded with Fijians for a number of goods and local sandalwood products, the latter prepared for the valuable exchange that occurred during the prehistoric period.

ARRIVAL OF WESTERN CULTURE AND THE EARLY HISTORIC SANDALWOOD TRADE

During the latter part of the 18th century and early part of the 19th century, a series of events occurred in the Hawaiian Islands that had profound effects on both the natural environment and human social conditions. The third Pacific expedition of Captain James Cook arrived in Hawaiʻi in 1778, ushering in the historic period for the archipelago. Alien species, new materials, and novel ideas entered the remote islands and precipitated significant changes in many realms of activity, including politics and human ecology. Kamehameha the Great rose to power and progressively consolidated his rule over the islands. By 1810 he had successfully unified all the main Hawaiian Islands, a feat never previously accomplished. During this same period the commercial value of Hawaiian sandalwood as an export item became known to various foreign traders and native chiefs.

Following the death of Captain Cook at Kealakekua Bay of the Island of Hawaiʻi in 1779, his expedition continued on to the Pacific Northwest. While there, they purchased sea otter furs to keep themselves warm. Later, when they reached China, they were astonished to find Chinese merchants offering them up to $120 for pelts which they had bought for pennies (Kittelson 1982). Word of this new market spread quickly. In 1785 and 1786, Captain James Hanna led the first two trade voyages whose specific purpose was to purchase sea otter and seal furs in the Pacific Northwest and then resell them in Canton, China, for a large profit. In 1787, American ships began to take part in this trade (Tan 1951). The Hawaiian Islands were a convenient place for these ships to rest and restock supplies of water, firewood, and fresh vegetables.

At least three different sea captains have been credited with the original "discovery" of sandalwood in Hawaiʻi in the late 18th century. According to Tan (1951), this discovery can be attributed either to Captain William Douglass or Captain James Kendrick, while Wagner (1986) argues that it was Captain Simon Metcalf. How the valuable wood was first noticed in Hawaiʻi by foreigners is also uncertain. Possibly a load of firewood taken aboard a ship included logs or sticks of sandalwood. One of the traders, or possibly a Chinese cook, identified the characteristic, fragrant scent when the wood was burned (Daehler 1989; Wagner 1986). Once the presence of sandalwood in Hawaiʻi was identified by outsiders, its potential as a trade item on the Canton market was quickly recognized.

In China, the fragrant heartwood of sandalwood trees has long been used to manufacture ornate cabinets and chests, incense, perfumes, and medicines. It was also used as fuel for funeral pyres in religious observances in the Orient (St. John 1947).

Before the introduction of Hawaiian sandalwood onto the Canton market, most of the wood sold in China was "white sandalwood" *(Santalum album),* which was imported from India and the East Indies. Around the end of the 18th century the supply of this Asian white sandalwood was becoming insufficient to meet market demands in China. This shortage resulted in an increasing market value of acceptable sandalwood from a variety of source areas, including the Hawaiian Islands. As the islands emerged as a major source of raw material the remote archipelago soon became known in China as "Tahn Heung Sahn" or "the Sandalwood Mountains" (Kepler 1983). Sandalwood was sold in China by the "picul," a unit equal to 133 1/3 pounds, the amount that a typical man could carry. The average price per picul in China during the major Hawaiian sandalwood era in the early 19th century was $8 to $10, though the price fell in the late 1820's as a result of poor quality.

Tan (1951) states that the first shipment of marketable sandalwood could not have arrived in China from Hawaiʻi before 1792; however, there is an account of a shipment arriving earlier. Amasa Delano wrote in 1801: "As long ago as the year 1790, I saw more than thirty tons of what was called sandal wood brought from these islands to Canton in one vessel: but it was of an inferior kind, and the Chinese would not give anything for it" (Delano 1818:399). The source of this wood may have been *naio,* the "false sandalwood" *(Myoporum sandwicense),* which is also a native Hawaiian tree found in dry forest environments *(fig. 4)*.

This aborted start apparently did little to deter the efforts of the traders, and the Hawaiian sandalwood trade developed rapidly. In 1791, after leaving Kauaʻi, Captain Kendrick put three men ashore on Niʻihau with instructions to return to Kauaʻi and begin collecting sandalwood (Tan 1951). During Delano's visit to Hawaiʻi in 1801, he also reported that some American traders had recognized the sandalwood trade to be profitable export business during the previous 7 or 8 years (Delano 1818:399). Chinese imports aboard American ships in 1804-1805 was 900 piculs. By 1811-1812 this amount had risen to over 19,000 piculs, and prices rose to the relatively high value of $8 to $10 per picul noted above (Tan 1951).

In the very early years of the sandalwood trade, the American entrepreneurs dealt with the chiefs as well as Kamehameha the Great himself; however, Kamehameha eventually provided himself with an exclusive monopoly over the sandalwood trade. The sudden wealth and availability of many new material goods seem to have overwhelmed the paramount authority of Hawaiʻi in these frenetic years of Hawaiian sandalwood exploitation. Kamehameha accumulated large amounts of luxury goods. The early Russian explorer, Kotzebue (1830:191) tells us that Kamehameha I pledged large amounts of sandalwood in advance for goods and ships, often paying greatly inflated prices for these items (Tan 1951). For example, Kamehameha is said to have paid $800 for a mirror, and $10,000 for a brass cannon (Judd 1926).

Among the ships that Kamehameha purchased with promises of sandalwood payments was a brig which he named the *Kaahumanu,* after his favorite wife. Kamehameha used this vessel in an attempt to enter the China sandalwood trade himself. In February of 1817, under the direction of a foreigner, Captain Alexander Adams, the *Kaahumanu* set sail for Canton. As a result of heavy port charges and brokerage fees in the Chinese harbor, the voyage failed to make a profit. Indeed it incurred a loss of $3,000 (Tan 1951), and returned "...with only a partial cargo of China goods and liquor" (Thrum 1905:5 1). As a result of the voyage, Kamehameha came to recognize the value of charging pilot and port fees, which he then established in Honolulu for his gain. According to Kotzebue (1830:192-3), "When Tameamea [Kamehameha] first sent a ship to Canton with sandalwood, he was obliged to pay a considerable duty for anchorage; whereupon he argued, that what was exacted from himself, he might with a safe conscience demand from others; and every ship is now required to pay forty Spanish dollars for anchorage in the outer, and eighty in the inner harbour of Hanaruro [Honolulu]".

Figure 4—Naio *(Myoporum sandwicense* A. Gray) is called "Bastard" or "False Sandalwood." Source: Krauss ([n.d.] p. 202).

HARVESTING SANDALWOOD IN HISTORIC HAWAIʻI

The great burden of harvesting the sandalwood necessary to pay for the debts Kamehameha I had incurred was principally laid upon the common Hawaiian people. The King "...ordered men to go out in the mountains..to cut sandalwood," and then to transport this heavy harvest "...to the landings" (Kuykendall 1938:8). Judd (1926:3) tells us that because of the lack of roads and vehicles the wood "...was carried down in the form of logs, 3 to 6 feet long, and from 2 to 18 inches in diameter, after the bark and sap[wood] had been chipped off with adzes."

Large numbers of people were involved in the harvesting and handling of the sandalwood *(fig.* 5). In the 1820's, the Reverend

Figure 5—Hawaiians carried out sandalwood from mountain harvesting areas to coastal transport sites during the early 1800's. Drawing by J. Chong, reproduced with permission from: Edwards (1951, p. 1).

William Ellis (1969:397) witnessed a most impressive sight involving the massive transport of harvested sandalwood out of the uplands and far down slope to the South Kohala coast of the Island of Hawaiʻi: "Before daylight on the 22d, we were roused by vast multitudes of people passing through the district from Waimea with sandal-wood, which had been cut in the adjacent mountains for Karaimoke, by the people of Waimea, and which the people of Kohala, as far as the north point, had been ordered to bring down to his storehouse on the beach, for the purpose of its being shipped to Oahʻu. There were between two and tree thousand men, carrying each from one to six pieces of sandal wood, according to their size and weight. It was generally tied on their backs by bands made of ti leaves, passed over the shoulders and under the arms, and fastened across their breast. When they had deposited the wood at the storehouse, they departed to their respective homes." Frequent transport of heavy loads of sandalwood often produced callused areas *(leho)* on the shoulders of male bearers. Men with these marks were called *kua-leho* or "callous backs" (Lydgate 1916:52). According to Thrum (1905), on at least one occasion "About 500 canoes were employed..." in the transfer of sandalwood from shore to a waiting ship!

On the central plain of Oʻahu (and perhaps elsewhere), large areas of grassland and dry forest were burned to make the standing or fallen sandalwood easier to find (St. John 1947:18). This was most likely fatal to seedlings, and may have severely affected any live trees left standing after the fire because of the damage to the haustoria found close to the surface (Judd 1933:88).

In some places in the uplands of the main Hawaiian Islands (e.g., the one next to the road to Waikolu Lookout on Molokaʻi) you can still find large, man-made depressions that were dug to the same dimensions as the hulls of those ships that carried sandalwood from Hawaiʻi to China *(fig. 6)*. These depressions known as *lua moku ʻiliahi* were filled with sandalwood logs, which were later carried down to waiting ships. The amount needed to fill the depressions may have also been the quantity needed to trade for some types of ships (Stemmermann 1977:117,188).

Sandalwood harvesters were often gone for several days, sometimes for weeks, in the mountains collecting sandalwood. Many died of exposure and other misfortunes in the cold, often damp uplands. Kepler (1983:125-126) provides a graphic description of the obligate harvester: "It has been said that every piece of sandalwood cut during those boom years was stained with blood. Some villagers died in harness [carrying the ti leaf bound wood on the backs], crumbling motionless on the trails; others, less fortunate, turned into living skeletons, weak from the corroding effects of exhaustion, disease, malnutrition, and exposure to the chilly mountain winds without adequate clothing. To aggravate matters, much cutting was done at night with the aid of sandalwood torches."

The early historic period in Hawaiʻi brought increasing con-

Figure 6—Sandalwood pits ("Lua Moku Iliahi") such as this one in the Molokaʻi Forest Reserve were used for measuring the amount of logs that could fit in a ship's hold.

tact with foreign people and their debilitating alien illnesses. The combination of exposure to dangerous, often lethal, diseases and very strenuous sandalwood harvesting under harsh environmental conditions was calamitous for the forced laborers. Furthermore, with so many people busy collecting sandalwood for Kamehameha I (and later chiefs and native leaders), crops were neglected. According to the Hawaiian historian, Samuel Kamakau, "Because the chiefs and commoners in large numbers went out cutting and carrying sandalwood, famine was experienced from Hawai'i to Kaua'i.... The people were forced to eat herbs and fern trunks, because there was no food to be had. When Kamehameha saw that the country was in the grip of a severe famine, he ordered the chiefs and commoners not to devote all their time to cutting sandalwood" (quoted by Kuykendall 1938:88-89). Kamehameha I thus allowed the common people to return to their homes and placed a *kapu* (ban) on the cutting of young or small trees in an effort to conserve the resource.

HISTORIC SANDALWOOD TRADE AFTER KAMEHAMEHA THE GREAT

In 1819, Kamehameha I died, leaving the throne to his son Liholiho. Under the young, new ruler, Kamehameha II, the political system in Hawai'i underwent profound changes. The customary reapportionment of the land by the chiefly or royal heir was altered, resulting in the establishment of the principle of hereditary land holdings (Kelly 1970:7). Kamehameha II proceeded with actions that openly abolished the *kapu* system. He was also persuaded to give his chiefs a greater share in the thriving sandalwood trade (Daws 1968:6).

The early 1820's was a very active period in the Hawaiian sandalwood trade *(table 1).* From 1821 to 1823, American ships were selling an average of 21,000 piculs (1,400 tons) of Hawaiian sandalwood per year in Canton at $8 per picul (Tan 1951:9-10). Kamehameha II and the chiefs bought ships and other expensive items from the American merchants on credit with little regard to how much debt they were incurring. The brig *Neo,* which arrived in Honolulu in March 1819, was soon sold for the inflated price of $51,750 to Kalanimoku, the Prime Minister of the Kingdom. "When word of this sale reached Boston, New England mercantile firms scoured shipyards and harbors of the Atlantic Coast anew for ships in good condition or bad. The only requirement was that they were able to reach the Hawaiian Islands" (Gast 1976:25).

Table 1 —*American sandalwood imports at the Port of Canton, China, 1804-1805 to 1832-1833 (Gutz1aff 1834). The data presented below excludes imports of Hawaiian sandalwood from non-American ships. It also includes some sandalwood of non-Hawaiian origin. However, since Hawai'i was the major source of sandalwood imported into China during the early 19th century, the data can be used to gauge the vicissitudes of the sandalwood trade in Hawai'i during this period*

Season	Piculs[1]	Season	Piculs	Season	Piculs
1804-1805	900	1815-1816	2,500	1824-1825	7,438
1805-1806	1,600	1816-1817	7,400	1825-1826	3,097
1806-1807	2,700	1817-1818	15,825	1826-1827	6,680
1807-1808	2,000	1818-1819	14,874	1827-1828	13,265
1808-1809	4,800	1819-1820	10,073	1828-1829	18,206
1809-1810	1,815	1820-1821	6,005	1929-1830	10,807
1810-1811	496	1821-1822	26,822	1830-1831	9,750
1811-1812	11,261	1822-1823	20,653	1831-1832	1,400
1812-1813	19,036	1823-1824	8,404	1832-1833	5,600
1813-1815[2]	1,100				

[1]A picul is a Chinese measurement of weight equaling 133 1/3 lbs.
[2]Total for two seasons combined (1813-1814 and 1814-1815).

Of all the ships purchased by the Hawaiian kings and chiefs, probably none is more famous than Cleopatra's Barge. This 83-foot-long ship was built in Massachusetts in 1816 for $50,000. Four years later the large vessel was purchased by Liholiho and Kalanimoku for $90,000. The purchase price was to be paid for in installments of sandalwood (Alexander 1906:24,29). This "notoriously unseaworthy" ship was wrecked on the coast of Kaua'i by "an incompetent captain" in April 1825 (Bradley 1968:64).

To obtain sandalwood for the China trade, American merchants were willing to extend enormous amounts of credit to Liholiho and the chiefs. In 1821, J.C. Jones, the American Trade Consul, reported that the native debt had risen to $300,000 (Tan 1951:10).

Ward (1972:91-123), in his essay on early trade in the Pacific region, argued that sandalwood in Hawai'i, like the *beche-de-mer* of Fiji, was a locally available resource that had limited value to the islanders before contact with the Western traders. We suggest that the sandalwood in Hawai'i and elsewhere in the tropical Pacific had greater traditional value than may be generally recognized, especially as a powdered perfume to scent native bark cloth and mixed with coconut oil to adorn the human body in life and death. Nevertheless, once the Western traders started purchasing large amounts of sandalwood, the Hawaiian rulers found themselves with a trade item that was exchangeable for foreign goods. "Perhaps it is not to be wondered at that this easy money went to their heads; that it seemed to them an untold wealth with boundless limitations ... in the case of sandalwood there were no expenses absolutely. Nature produced it, the common people collected and delivered it and the king stood by to receive the money" (Lydgate 1916:54). The concept of purchasing goods with a mere promise to deliver sandalwood at some future time (buying on credit) may have been a strange idea, but was widely accepted by the powerful Hawaiian leaders. "King and Chiefs alike were so influenced by the luxuries that sandalwood could purchase and the ease they could obtain these items by merely signing promissory notes dealt disaster to the sandalwood resource as well as to the general welfare of the *maka'ainana* [common people]" (Daehler 1989:5).

In the Hawaiian society the "head of a family was a small farmer, raising just enough for the immediate needs of himself, and those dependent on him. Why should he raise more, since he couldn't sell it, and all he really owned was what he used (Lydgate 1916)."

By 1824, the easily accessible stands of sandalwood had been harvested, and much less wood was being cut. The chiefs were buying considerably fewer goods offered by the opportunistic foreign traders. The commercial trading skills of the Hawaiian rulers did improve somewhat over time as a result of experience and advice they received from the Christian missionaries who began arriving soon after the death of Kamehameha I. The king and the chiefs were also showing little inclination to payoff many of the debts they had incurred (Gast 1976:77).

In 1824, Kamehameha II died of a contagious disease that he contracted in London during a royal visit. In the next 2 years, the reduced amount of sandalwood on the Canton market resulted in a temporary increase in the market price in China. This, in turn, stimulated a renewed effort on the part of American merchants to collect the outstanding sandalwood debts of the Hawaiian chiefs. These events and the earlier (1821) report from the American consul, J.C. Jones, to his government were at least partially responsible for the visit of an American warship to the Hawaiian Islands. The U.S. schooner *Dolphin* arrived in Honolulu in January of 1826 under the command of Lt. Commander John Percival. As a result of Percival's "gunboat diplomacy," Kalanimoku (the prime minister) and his brother Boki (the acting Governor of Oʻahu) signed a note for 5,481 piculs (365 tons) of sandalwood to cover the debts to be paid by the kingdom as soon as possible. Jones, who remained unsatisfied with the situation, sent a letter to Commodore Hull requesting that another American warship be sent to Hawaiʻi. "News of the impending visit of [another armed naval vessel] had preceded it to Honolulu, and for five months traders at that port had looked forward to its arrival with confidence that the presence of an American man-of-war would hasten the collection of the troublesome debts" (Bradley 1968:106). In October, the U.S. sloop *Peacock* arrived under the command of Captain Thomas Catesby Jones. In late December, Kamehameha III and the government of the Hawaiian Kingdom were forced to acknowledge and settle a reported debt of $500,000 owed to the American traders (Tan 1951:10-11); however, the sum of money that the American claimants actually received was probably less than a third of this figure (Bradley 1968:109).

The pressures brought to bear upon the ruling class of Hawaiʻi by the American Naval forces resulted in the passage of the Kingdom's first written law —a sandalwood tax—issued in December 1826 (Gast 1976:82). The law stated that every man was required to deliver one half of a picul of sandalwood to the governor of the district to which he belonged, or to pay in lieu thereof four Spanish dollars, on or before September 1, 1827. Every woman 13 years and older was required to hand over a 12 by 6 foot handmade mat, or a quantity of tapa cloth of equal value. Special places were designated for depositing these payments, and all of the taxes collected were to be applied to the Kingdom's sandalwood debts (Tan 1951:11; Gast 1976:82).

By October of 1827, 20,000 piculs of sandalwood (1,333 tons) had been collected as a result of the tax. The search for, cutting, and transporting of this much sandalwood in less than 10 months caused a great amount of hardship for the common Hawaiian people. Food shortages again plagued the land (Tan 1951:12). The easily accessible sandalwood had already been harvested, making it more difficult to locate trees with adequate heartwood to meet the new tax requirements. "Unjust demands eventually caused the toiling Hawaiians to pull up young sandalwood trees so that their children would not also be compelled to fell and pack sandalwood logs" (Daehler 1989:5). According to Bradley (1968:116), every native person who collected sandalwood for the government in 1827 "...was given the privilege of cutting a half a picul of wood for his own private speculation." Citing a letter written by Captain Jones on November 30, 1927, Bradley indicates that many Hawaiians partook of this offer and "that much of the wood cut during the preceding months was the property of commoners."

Once the pressure of the Kingdom's debt was somewhat relieved, Kamehameha III himself began to purchase ships and other luxury items, and subsequently, in 1828, another American warship arrived in Honolulu in response to the foreign traders' pleas for sufficient, timely debt repayment. Captain Finch, of the U.S. sloop *Vincennes,* held a conference with the King to discuss debts still owed the American merchants. These debts amounted to $50,000. It was agreed that they would be paid off with 4,700 piculs of sandalwood (313 tons) within 9 months; "At the same time the chiefs signed a second note, agreeing to pay 2,165 piculs [144 tons] of wood, which represented the balance due from their purchase of a vessel in February 1828" (Bradley 1968:113). These debt repayments, with the accompanying 12 percent interest, were not completely settled until 15 years later in 1843 (Tan 1951:12; Gast 1976:85).

In 1829, Boki, who was saddled with both his own debts and those of his dead brother Kalanimoku, outfitted two ships for a planned voyage to collect sandalwood in the New Hebrides (Vanuatu). The boats sailed in December of that year. Unfortunately for Bold, the seamen, and their families, the ill-fated expedition was a total failure. Boki and his ship were lost at sea. The remaining vessel suffered from scurvy and a shortage of food. Of the 500 men sailed under Boki's command, only 20 returned alive to Hawaiʻi in August 1830 (Wagner 1986:58).

In the late 1820's the market value of sandalwood on the Canton market dropped steadily, from approximate $13 per picul in 1827 to $10 in early 1828, and then down to between $6 and $8 in 1929; in the next 2 years the price declined drastically, and by the end of 1831 the wood sold for only "a dollar and a half a picul" (Bradley 1968:117). The amount of sandalwood arriving for sale in Canton aboard American vessels in the 1831-1832 season amounted to only 1,400 piculs, less than 15 percent of the quantity arriving the previous year *(table 1).*

The Hawaiian sandalwood trade did rebound somewhat during the first half of the 1830's. In 1836, $26,000 worth of the wood was sold on the Canton market at $7 per picul. However, by 1838, the total season sales in China for sandalwood harvested in Hawaiʻi was down again to only $6,000. In 1839, with nearly all accessible trees gone, the King placed a *kapu* on the remaining sandalwood; permission was required to cut it, and two-thirds of the harvest was reserved for Kamehameha III (Judd 1926:4). By 1840 the Hawaiian sandalwood trade had, for most practical purposes, come to a halt, primarily because of the low quality of the remaining sandalwood in the islands, competition from sandalwood sources in India and the East Indies, and falling sandalwood prices on the Canton market (St. John 1947:9; Tan 1951:13; Bradley 1968:117).

In the 1850's, sandalwood was still being accepted as payment for taxes in Hawaiʻi, but the amount submitted was small and of poor quality. An attempt was made to sell Hawaiian "false sandalwood" *(naio)* in Canton, but it was rejected by the Chinese merchants (Judd 1926:4), as it probably was more than a half a century earlier (see above).

THE IMPACTS OF THE SANDALWOOD TRADE

According to Bradley (1968:119) "The sandalwood trade was a picturesque and passing incident," and aside from the "destruction of the sandalwood forests," it contributed little to the economic gain of the Hawaiian chiefs or common people, and had only minor social consequences. The reported famine and unhealthy work conditions associated with the trade certainly cannot be dismissed so easily. Although the locally accrued profits may not have brought significant general benefits to the Hawaiian people, the commercial sandalwood trade and several other, often interrelated, cultural developments in early historic period (e.g., the arrival and growing influence of the Western missionaries) undoubtedly precipitated important social changes.

For many years it was widely assumed that the sandalwood trees had become extinct due to the exploitative harvesting that had occurred for more than 50 years (e.g., Kuykendall and Gregory 1926; Mesick 1934; Cartwright 1935; Smith 1956). However, it has long been known by some botanists, foresters, and other naturalists—and more recently by the general public—that the sandalwood species can still be found in Hawai'i. Nevertheless, except for some higher mountain areas, such as uplands in the Kona District of Hawai'i Island, the quantity of trees is generally much smaller than it was before the foreign trade.

The ecological impacts of removing the great majority of the sandalwood plants from the Hawaiian forests are not at all clear. According to Judd (1926:3), the "...damage to the forest consequent to the trade...was insignificant in comparison with the damage to the native forest wrought by cattle." As noted above, under natural conditions, the sandalwood species of Hawai'i are found in a mixed association with a number of other species, primarily in the drier forest regions; and, while the selective removal of *Santalum* trees did not remove the forests themselves, the exploitative harvesting processes may very well have opened the way for an unknown number of alien species to become established. Certainly the impacts of human harvesting and the unprecedented grazing and trampling by newly introduced ungulates (e.g., goats and cattle), as well as the possible negative consequences of the introduced seed predators (rats and mice), did not provide ecological conditions conducive to the regeneration of the native vegetation. Cattle grazing still hinders the regeneration of *Santalum* in some upland Kona forests.

SANDALWOOD SINCE THE DECLINE OF THE 19TH CENTURY TRADE

Although Hawaiian sandalwood trees were still extant after the extensive trade, it is believed that in many regions only the most remote trees were left uncut. In the earlier part of this century, the botanist Joseph Rock estimated that as much as 90 percent of the *Santalum* trees were removed during course of the sandalwood trade (Hirano 1977:11). Unfortunately, without complete data on the status of *Santalum* populations after the trade ended, it is very hard to gauge their rates of recovery. A survey of the more recent distribution and status of the genus, however, provides some insight.

In 1926 Kuykendall and Gregory (quoted in St. John 1947:9) referred to the devastating effects of the sandalwood harvest and the status of the trees at that time: "The reckless way in which the trees were cut destroyed the forests. Very little effort was made to preserve the young trees or to replace those which were cut down. In a few years sandalwood almost disappeared from the islands. Even today, a hundred years after the trade was at its height, only a few small groves are to be found."

A little more than 40 years ago, St. John (1947:20) described the distribution of *Santalum* on O'ahu at that time, indicating that sandalwood was still "...common and widespread at its former upper limit, now the lower forest line on the lee side of the Ko'olau Range and on both sides of the Wai'anae Mountains. " St. John also pointed out that some areas of the island had been affected more severely than others. He noted the absence of native sandalwood in the vicinity of Honolulu, which apparently was an area of extremely intense harvesting during the trade era. For example, Nu'uanu Valley may have been totally cleared of sandalwood as early as 1825 (St. John 1947:15).

In 1951, sandalwood trees were found growing on the island of Hawai'i in the Hawai'i Volcanoes National Park below the Chain of Craters Road (Fletcher 1968:18). In 1955, it was reported that a large number of sandalwood trees had been discovered in Kona (Anon. 1955: A1). Although the trees were reported to number in the thousands, they were found on cattle grazing lands; and it was observed that "Seldom do we see a seedling or small tree" (Anon. 1955:3,1).

More recently for the island of Moloka'i, Stemmermann (1980:44-45) reported the location of several populations of *S. freycinetianum* in the mountains between 2,100 and 3,750 feet elevation.

Kaho'olawe, a much smaller island (45 mi^2), probably supported populations of coastal sandalwood, *S. ellipticum,* in the lowland and inland higher regions (Skottsberg 1926; Lamoureux 1970); but the species is now presumed to be extinct on that island (Stemmermann 1977:126; 1980:42).

Maui has populations of at least three species of sandalwood (Stemmermann 1980:42). The Haleakala sandalwood, *S. haleakalae*, is endemic to the higher region of East Maui and one of the most endangered Hawaiian sandalwoods. There are probably only a few hundred individuals of this species left, with very few seedlings to be found (Kepler 1985). This species needs special, immediate protection from alien organisms.

Besides the coastal sandalwood, the island of Lana'i has an endemic variety of the Freycinet sandalwood, *S. freycinetianum* var. *lanaiense,* known as the "Lana'i sandalwood." According to the U.S. Fish & Wildlife Service, only 39 individuals are known to exist, making the Lana'i sandalwood one of Hawai'i's most endangered taxa; only one sapling has recently been observed (U.S. Fish & Wildlife Service 1985:9086-9).

PROPAGATION AND FORESTRY EFFORTS

The earliest recorded attempt to grow Hawaiian sandalwood was undertaken by Dr. William Hillebrand, an avid botanist and horticulturist, sometime between 1851 and 1871 (Hirano 1977). Although numerous species of trees and shrubs which he planted on his Honolulu homestead can still be seen at the site—now known as the Foster Botanic Gardens (part of the Honolulu Botanic Gardens)—Hillebrand was not successful in his efforts with sandalwood; he attributed the problem to the parasitic nature of the species and indicated that "...all attempts to cultivate them in [his] garden have failed" (Hillebrand 1965).

In 1903, the Territorial Division of Forestry was formed. Under the direction of this agency, the first modem forest reserve system was established in the Hawaiian Islands. A major objective was to improve watershed conditions by removing alien ungulates and replanting large areas of uplands that had been degraded by cutting, burning and overgrazing activities, including those associated with the earlier sandalwood trade. The Division of Forestry also began the development of commercial forestry and some native plant propagation and protection (Daehler 1989:7). As a result of fire suppression and the removal of introduced grazing animals, some populations of native sandalwood on these protected lands made small comebacks in the first three decades of this century (Judd 1936b:82).

In the early 1930's, Indian sandalwood was selling for as much as $500 a ton in New York. With this information in mind, Judd (1936a:83) argued that "...pound for pound [sandalwood] is, therefore, the most valuable wood in the world;" Judd also indicated that the Territorial Forest Service was trying "...to determine the best methods of increasing the number of growing trees" of *S. album* in Hawaiʻi. The Forest Service had begun importation of *S. album* seeds from India in 1930 and 1931 (Fletcher 1968:18); however, the trees proved to be difficult to raise. Nevertheless, by 1935, an experimental grove of over 1,500 plants was growing on the ridge 750 feet above sea level on Waʻahila ridge near Honolulu. This early success in cultivation was attributed to the attention paid to sandalwood's need for a host plant, without which the seedling perished before reaching the end of its first year. The Waʻahila grove was planted with two kinds of host plants, *Acacia koa* and *Casuarina equisetifolia,* 6 months before the Indian sandalwood seedlings were placed there. Subsequently it was learned that these hosts could be raised alongside newly sprouted sandalwood plants while they were still in the nursery, and then transplanted together. According to the chief of the Forest Service, C.S. Judd (1936a:83), "Planting by this method has attained 100 per cent success." This early success lead Judd (1936b) to pen an article in the Honolulu Star Bulletin titled "Sandalwood, Once the Gold Mine of Hawaiʻi, is Coming Back." Seeds of the native sandalwood, *S. freycinetianum,* were also tried, but they would not germinate. Judd (1935; 1936b:83) blamed this failure on a fungus which apparently altered the viability of the seeds in fly-damaged fruits.

The economic potential of cultivating sandalwood continued to be a topic of discussion for many years. At least as late as 1949, about 500 Indian sandalwood trees were being planted per year (Anon. 1946:9; Anon. 1949:6).

Unfortunately, the early success of Indian sandalwood propagation did not lead to a new source for the fragrant wood. The trees were found to be very slow growing, not reaching reproductive maturity until they were 40 to 60 years old. Furthermore, nearly all trees died with 10 to 15 years after germination and the few trees that did survive attained trunk diameters of less than 6 inches after 24 years of growth; these survivors would have yielded only a small amount of the valuable heartwood. This planting experiment with the alien *Santalum* did little in Hawaiʻi to encourage further forestry efforts involving cultivation of sandalwood for commercial purposes (Daehler 1989:1,8).

After these early attempts at Indian sandalwood propagation, most of the *Santalum* planting efforts in Hawaiʻi have been mainly the result of interest in Hawaiian history and native plants (Daehler 1989:8). In 1961, the Foster Botanic Gardens participated in an effort to plant native sandalwoods in windward Oʻahu parks (Anon. 1961:A3). In the mid-1970's, the Lyon Arboretum of the University of Hawaiʻi at Manoa undertook research involving the propagation of three species of sandalwood species: the alien *S. album,* and two endemic species, *S. haleakalae* and *S. paniculatum.* This research focused on seedling germination and growth (Hirano 1977).

More recently, the bicentennial celebration of the arrival of the first Chinese immigrants to Hawaiʻi has stimulated renewed interest in planting sandalwoods. Frank Y.F. Lee, president of the Lee Family Association of Hawaiʻi, in cooperation with Herbert Kikukawa of the State Forestry and Wildlife Division, collected sandalwood seeds on Oahu in 1988. These were distributed to horticulturists at Foster Botanic Garden, Lyon Arboretum, and Waimea Arboretum (Taylor 1989:B1). On Kauaʻi, the Kauaʻi County Chinese In Chinese Bicentennial Committee conducted a preplanting project for sandalwood at Iliau Nature Loop in the Puʻu Ka Pele Forest Reserve during January 1989 (Daehler 1989:1).

RECENT SANDALWOOD HARVESTING AND COMMERCIAL TRADE

In fall 1988, native sandalwood made another appearance in the local media. In upland areas of the Kona District standing trees and fallen trunks of *S. paniculatum* were being harvested for shipment to a Hong Kong market. Advocates and detractors of the sandalwood logging and sale soon began debating the impact of this commercial activity. The controversy centered around the Hokukano Ranch (formerly the W.C. Greenwell Ranch) on the slopes of Mauna Loa above Kealakekua on the island of Hawaiʻi. It was reported that since the ranch had changed ownership in July 1987, as many as 1,700 logs of native sandalwood trees may have been harvested; and an estimated 300 tons of the wood was shipped to China at a reported price of $2 per pound (TenBruggencate 1988b:A4). At this price and poundage, the harvest could have grossed over $1,000,000! However, Thomas Pace, the manager of Hokukano Ranch, later claimed that they made only $40,000 from their sandalwood sales (TenBruggencate 1988a:A6).

In a critical response to the recent sandalwood harvesting, environmentalist Deborah Ward (1988:4) of the Sierra Club's Hawai‘i Island Chapter published a "Viewpoint" article in the Hawai‘i Tribune-Herald headlined "The tragic logging of isle sandalwood trees." A number of the statements in her article, such as those describing the relationship between the sandalwood trees and rainfall, length of sandalwood logs, and value of individual harvested trees, were later pointed out to be exaggerations or outright errors. In addition, the land from which the Kona trees were recently harvested is private property, apparently used to graze cattle for many decades (Harada-Stone 1988). This contradicts Ward's allegation that the sandalwood harvesting was taking place in "virgin forests of sandalwood" (Ward 1988). Regardless of the inaccuracies in her article, Ward probably expressed an attitude of serious concern that many residents in the islands have regarding the possible environmental and cultural impact of a renewed, ongoing sandalwood trade.

At a legislative hearing in Kailua, Kona, on September 29, 1988, logger Albert Remmy claimed that young sandalwood plants were growing "all over the place" in the vicinity of the logging operations (Harada-Stone 1988:10). But if the areas referred to are still used as pasture lands, it is unlikely that Remmy was correct. As noted above, however, the manager of Hokukano Ranch has indicated that the cattle and other alien ungulates have been fenced out in the area where the logging took place. In any case, cattle can quickly destroy sandalwood seedlings, either as a result of their grazing or trampling activities.

There are number of potential negative impacts associated with the removal of the large sandalwood trees from upland pasture lands in Kona. The mature, living trees are a needed source of seeds for seedling regeneration of the sandalwood (rather than that which can occur by coppicing or root sucker development). The seeds of *Santalum* are also a food source for native birds and other animals. The remaining, relatively large numbers of standing sandalwoods in the upland ranch lands are unique, but depleted due to many years of cattle grazing. Large numbers of fallen trunks and limbs lie on the ground; many are rotting. Remmy noted from his own logging experience that "...there isn't a good stand of sandalwood anywhere on the island." (Harada-Stone 1988:10). However, even the harvesting of fallen, dead or dying trees could have a negative ecological impact on native organisms, especially insects. For example, they serve as habitat for endemic long-horned beetles. Furthermore, James Juvik, Professor of Geography, has pointed out that forest vegetation provides essential watershed protection necessary for sustainable lowland development (Harada-S tone 1988).

THREATS TO THE SURVIVAL OF THE SANDALWOOD SPECIES

Diverse contemporary dangers threaten the survival of the native sandalwood species in Hawai‘i. Some of these present or potential threats have plagued *Santalum* during both the prehistoric and historic periods. All of the threats described below can be either directly or indirectly associated with human activities.

Harvesting

Harvesting of sandalwood undoubtedly began during the prehistoric human period as early Polynesians cut sandalwood to obtain the fragrant, medicinal, and ritualistic materials the woody plants provided. Although the huge volume of logging that occurred during the early 19th Century sandalwood is evidence of the vast numbers of trees that still existed at the time of western contact, it has been suggested that the prehistoric human impact on *Santalum* was significant and widespread in Hawai‘i, especially in the drier lowland areas. In addition to the rapacious early historic harvesting, we have also referred to the very recent logging on the island of Hawai‘i that has occurred within perhaps the only groves of substantially large and numerous sandalwood trees. Also, along with the actual cutting and removal of the logs, damage results from the movements of vehicles and machinery needed to harvest and transport the wood.

Fire

Selective cutting of sandalwood during the prehistoric human period (lasting approximately 1,500 years) probably had less impact on the distribution and quantities of the *Santalum* species than the use of fire. As noted earlier, prehistoric use of fire converted extensive dry forest areas into anthropogenic grasslands. This process probably resulted in a large loss of sandalwood trees, along with the destruction of numerous other native woody species. Man-made fires have also affected Hawaiian forest areas during the historic period. At least some of the common Hawaiian people reportedly used fire in their obligate search for acceptable sandalwood during the early 19th century (St. John 1947). Increase in the human population intensifies the possibility of intentionally or accidentally set fires which might further reduce the number of sandalwood trees in some areas. A recent fire in the North Kona area near Pu‘uwa‘awa‘a probably resulted in the destruction of some *Santalum.*

Conversion of Forest Lands to Agricultural Areas

Clearing of forest to grow crops has been a major threat to sandalwood at low elevations ever since the first humans arrived in the Hawaiian Islands. Over the past two centuries, the development and expansion of commercial agriculture and ranching has eliminated many areas where sandalwood was part of the former forest. On the island of Lana‘i, for example, approximately 90 percent of the native vegetation has been destroyed by direct and indirect human activities, and the native dry forest has been removed almost entirely—much of it cleared to make way for pineapple cultivation (U.S. Fish & Wildlife Service 1985).

Alien Ungulates

Cattle, goats, and deer all readily eat sandalwood foliage. Cattle also damage the plants by trampling the ground over their shallow root systems (Judd 1933). The impact of cattle and other mammalian herbivores in the remaining sandalwood groves (e.g., the upland Kona forests) must be curtailed if regeneration of *Santalum* is to continue in these important refugia. Recent observations of areas containing *S. paniculatum* in the uplands of Kona by foresters with extensive field experience involving sandalwood ecology are encouraging. Where fencing has been put in place and the alien ungulates have been excluded from areas with sandalwood, regeneration in the form of seedlings, coppicing, and root suckers, proceeds effectively (Grahame Applegate, Research Officer, Queensland Forest Service, personal communication, 1990).

Alien Rodents

Rats and mice are voracious consumers of sandalwood seeds. In the case of both the Lana'i sandalwood *(S. freycinetianum* var. *lanaiense* and the Haleakala sandalwood *(S. haleakalae),* introduced rats and mice have virtually eliminated reproduction of new trees (U.S. Fish & Wildlife Service 1985; Kepler 1985).

Diseases

Sandalwood is apparently plagued by several diseases in Hawaiʻi. Judd (1936a) referred to a fungus affecting the viability of sandalwood seeds; he also called attention to a "spike disease" which did considerable damage to *S. album* in India and may have been introduced to Hawaii. A newspaper account of the Kona harvesting operations in 1988 reported the comments of the Hokukano Ranch manager regarding diseased sandalwood trees on property between 4,500 and 6,500 feet above sea level: "Many trees, standing and down, displayed a severe heart rot from the base into the upper parts of the tree" (TenBruggencate 1988a).

Banana Poka

The alien weed banana poka is a very aggressive passion fruit vine *(Passiflora mollissima)* that climbs over most other plants in the forest areas it invades. Its dense growth eventually covers whole sections of the forest, shutting out sunlight and thus greatly affecting the lives of other species. It already infests approximately 350 acres on Maui, 12,000 acres on Kauaʻi, and 85,000 acres on the island of Hawaiʻi! A recently proposed control measure involves the use of cattle to help remove the weedy vines. This would probably do a considerable amount of further damage to the sandalwood in the affected forests since the bovines are especially fond of *Santalum* seedlings (TenBruggencate 1990).

Poor Germination Rates

Several possible causes for the low viability of sandalwood seeds have been offered, including the loss of native pollinators - both birds and insects (Kepler 1985) and disease (Judd 1936a).

Off-road Vehicles

Use of off-road vehicles have had a negative impact on many of the native Hawaiian coastal plants. For example, until recently Kaʻena Point, Oʻahu, was heavily used by off-road vehicles which severely damaged the native plants there, including the low lying *Santalum ellipticum.*

CURRENT AND PROPOSED CONSERVATION MEASURES

Several suggestions have been offered concerning the conservation and resource management of Hawaiian sandalwood species, including the following:

1. *Moratorium on the Cutting of Sandalwood Trees:* A moratorium was proposed in September 1988 by State Representative Virginia Isbell to provide the State of Hawaiʻi with sufficient time to inventory the quantity of healthy sandalwood trees (Hosek 1988).

2. *Changes in Zoning and Tax Incentives:* A change in the zoning designation of those private lands containing populations of sandalwood from "agriculture" to "conservation" would give the State of Hawaiʻi power to regulate the removal of trees. This could offer a means of protection for the Kona stands of *Santalum.* Tax incentives might motivate ranchers to separate cattle (and other alien ungulates) from the sandalwood plants. Proper fencing and trapping could help natural regeneration of the woody plants.

3. *Private Preserves:* Private preserves could be set up and managed by the land owners themselves, or they could be developed and administered by other organizations such as the Nature Conservancy or other private groups. Motivated by the Kona logging controversy of 1988, the Hokukano Ranch decided to set aside the upper 3,000 acres of the ranch (between 4,500 and 6,500 feet elevation) as a natural area under its own supervision. Probably the most beneficial conservation measure involved in this action is the exclusion of cattle from the area through use of fences. The ranch management has also paid hired help to collect sandalwood seeds. These seeds have been cultivated in "a nursery for eventual planting back in the sandalwood forest;" germination rates are reportedly about 30 percent (TenBruggencate 1988a).

4. *Purchase and/or Management of Natural Areas :* Castle and Cooke recently gave the Nature Conservancy a perpetual conservation easement over a 500-acre site in Kanepuʻu, the last remaining native dry forest area on the island of Lanaʻi. One of the two last stands of Sandalwood *(S. freycinetianum* var. *lanaiense)* is located within the Kanepuʻu area, which has a relatively large number of endemic species.

5. *Use of the Endangered Species Act of 1973:* Official listing of species under the federal Endangered Species Act of 1973 provides protection for species in serious danger of becoming extinct. Presently only one taxon of Hawaiian sandalwood has even been proposed for official listing under the Act. In 1985, the U.S. Fish & Wildlife Service filed to have the Lanaʻi sandalwood listed as an endangered species (see above, U.S. Fish & Wildlife Service 1985). In the future, appropriate taxa of

Hawaiian *Santalum* may be proposed for this special kind of protection.

SUMMARY

For many centuries the heartwood of the Hawaiian sandalwoods has been a valuable natural product. It was used for a variety of purposes in the traditional Hawaiian culture. However, huge numbers of the trees probably perished in the prehistoric period due to cutting and burning. Extensive alteration of some natural ecosystems in Hawaiʻi began long before Western contact in the late 18th century. The sandalwood populations below 1,500 feet elevation must have declined drastically as a result of the wide-ranging development of agricultural systems in both the wet and dry lowland areas. Nevertheless, early written descriptions of Hawaiʻi indicate that vast forests still existed in the uplands of the main islands when the first Europeans arrived. The international trade of the early 19th century was not just "a picturesque and passing incident" in the history of Hawaiʻi as Bradley (1968) has suggested. It was the first major phase in the transformation of the Hawaiian economy from subsistence to commercial orientation. It brought much superficial wealth to the ruling class of native peoples, but inflicted considerable hardship upon the more populous common people.

From an ecological point of view, the sandalwood trade was disastrous, for many native organisms including the *Santalum* species it meant severe declines in actual number or habitat. Although the impact of alien hoofed mammals was almost certainly more harmful to the upland native forests of Hawaiʻi, we should not overlook the environmental changes that were directly produced by human interference associated with the sandalwood trade. Literally thousands of Hawaiian people went into the various forests to search for and destroy sandalwood trees to deliver their quotas of the fragrant heartwood.

The *Santalum* genus in Hawaii did not become extinct as a result of the intense and far reaching harvest of the early 19th century as has been widely believed; but drastic reductions in the sizes of the species populations and significant declines in the quality of the trees most definitely did occur in most areas. Since the cessation of the 19th century, sandalwood trade the species of *Santalum* have recovered to some degree and can be commonly found in a few areas. One species *S. paniculatum* can still be found in relative abundance in some upland areas of Kona on the island of Hawaiʻi. These remaining "groves" have recently become the focus of a renewed and controversial economic activity.

To a large degree, the future of *Santalum* in Hawaiʻi depends upon a combination of factors. These include the vicissitudes of the sandalwood markets (especially abroad), public acceptability of further cutting and export of the native wood, and government decisions concerning conservation of the species for a number of potential economic and non-economic benefits—such as their inherent right to exist and role as habitat and food source for other native species.

The history of human impact on the Hawaiian sandalwoods has not yet come to an end. The native Hawaiian biota is unique and renowned for its remarkable endemism. As one of the greatest "living museums" of evolutionary biology, the Hawaiian native ecosystems and their special flora and fauna are worth our serious consideration. Any further economic development within those Hawaiian environments containing the less common, rare, threatened, or endangered species should be done with great care and the fullest possible understanding of what the ecological consequences will be.

REFERENCES

Alexander, W.D. 1906. The story of Cleopatra's barge. Hawaiian Historical Society Paper. No. 13.25-31.

Anon. 1961. Drive to plant trees in Windward parks. Honolulu Advertiser. March 22. A3, 1.

Anon. 1955. Sandalwood discovery on Big Island told. Honolulu Advertiser. February 18, Al, 3.

Anon. 1949. Sandalwood has failed to make a comeback. Honolulu Advertiser. November 13, 6,

Anon. 1946. New era for sandalwood. Honolulu Star-Bulletin. April 18, 6.

Bradley, H.W. 1968. The American frontier in Hawaii: The Pioneers 1789-1843. Glouster, Mass.: Peter Smith.

Buck, P. 1964. Arts and crafts of Hawaii - Sec. 9: Musical Instruments. Honolulu: Bishop Museum Publication 45.

Burrows, C. 1989. Hawaiian conservation values and practices. In: Stone, C.P. & D.B. Stone (Editors) Conservation biology in Hawaii; 203-213. University of Hawaii Cooperative National Park Resources Studies Unit, University of Hawaii at Manoa, Honolulu, Hawaii.

Carlquist, S. 1980. Hawaii: A natural history. Kauaʻi, Hawaii: Pacific Tropical Botanical Garden.

Cartwright, Bruce. 1935. Extinction of trees soon followed the sandalwood rush—Hawaii's unhappy first export trade. Honolulu: Paradise of the Pacific; 21-23.

Daehler, R.E. 1989. Tahn Heong Sahn - The sandalwood mountains. Forest Management Note, Kauaʻi, No. 89-1. Hawaii DLNR, Division of Forestry and Wildlife.

Daws, G. 1968. Shoal of time: A history of the Hawaiian islands. Honolulu: University of Hawaii Press.

Delano, A. 1818. A narrative of voyages and travels. Boston, Mass.: E.G. House.

Edwards, Webley. 1951 September9. The Fragrant Wood of Hawaii. Honolulu Advertiser, Weekly Magazine Section 7.

Ellis, W. 1969 (orig. 1842). Polynesian researches, Hawaii. Rutland, Vermont: Charles E. Tuttle Co.

Fletcher, W.B. 1968. New hope for the sandalwood. National Parks Magazine. 42(255):16-18.

Gast, R.H. 1976. Contentious consul: A biography of John Coffin Jones. Dawson's Book Shop. Los Angeles.

Gutzlaff, C. 1834. A sketch of Chinese history, ancient and modem. Vol. II. London: Smith, Elder, and Co.

Harada-Stone, D. 1988. Sandalwood logging defended, ripped at special Kona hearing. Hawaii Tribune-Herald, September 30, 1, 10.

Hillebrand, W. F. 1965. (orig. 1888). Flora of the Hawaiian islands. New York: Hafner Publishing Co.

Hirano, R.T. 1977. Propagation of Santalum. Sandalwood Tree Plant Propagator 23(2):11-14.

Hosek, L. 1988. Sandalwood forests mystify scientists. Honolulu Star-Bulletin, September 29, A4.

Imada, C.T.; Wagner, W.L.; Herbst, D.R. 1989. Checklist of Native and Naturalized Flowering Plants of Hawaii. Honolulu: Bishop Museum Occasional Papers. Vol. 29.

Judd, C.A. 1926. The natural resources of the Hawaiian forest regions and their conservation. Territorial Division of Forestry. Unpublished manuscript. 8 p..

Judd, C.A. 1933. The Parasitic Habit of the Sandalwood Tree. Thrum's Hawaiian Annual; 81-88.

Judd, C.S. 1935. Reviving the Sandalwood Industry. Paradise of the Pacific 47(4): 2.
Judd, C.S. 1936a. Growing Sandalwood in the Territory of Hawaii. Journal of Forestry 34(1): 82-83.
Judd, C.S. 1936b. Sandalwood, once the goldmine of Hawaii, is coming back. Honolulu Star-Bulletin, February 8, sec. 3, 1.
Kelly, M. 1970. Some aspects of land alienation in Hawaii. Hawaii Pono Journal 1(1): 6-12.
Kepler, A.K. 1983. Hawaiian Heritage Plants. Honolulu: Oriental Publishing Company.
Kepler, A.K. 1985. Sandalwood: Hawaii's precious ‘iliahi. Mauian. 2(6): 6-11.
Kirch, P.V. 1982. Transported Landscapes. Natural History 91(12): 32-35.
Kirch, P.V. 1984. The evolution of the Polynesian chiefdoms. Cambridge: Cambridge University Press.
Kittelson, D. 1982. Role of Hawaiians in the fur trade. Honolulu Advertiser, January 20, B1.
Kotzebue, O. 1830. New voyage round the world. London: Colburn & Bently Publishers. Vol. 2.
Krauss, Beatrice H. [n.d.]. Ethnobotany of Hawaii. Honolulu: University of Hawaii, Department of Botany; 246 p. Unpublished manuscript.
Kuykendall, R.S. 1938. Hawaiian kingdom, 1778-1854. Honolulu: University of Hawaii Press.
Kuykendall, R.S.; Gregory, H.E. 1926. A history of Hawaii. New York: Macmillan.
Lamoureux, C.H. 1970. Plants recorded from Kahoolawe. Hawaiian Botanical Society Newsletter 9:6-11.
Little, E.L.; Skolmen, R.G. 1989. Common Forest Trees of Hawaii (Native and Introduced). U.S. Dept. of Agriculture& Forest Service, Agri. Handbook No. 679.
Lydgate, J.M. 1916. Sandalwood days. Thrum's Hawaiian Annual.
Mesick, L.S. 1934. The kingdom of Hawaii. Honolulu: Porter
Olson, S.L.; James, H.F. 1982. Fossil birds from the Hawaiian islands: evidence for wholesale extinction by man before Western contact. Science 217:633-635.
Press, M.C. 1989. Autotrophy and heterotrophy in root hemiparasites. Tree 4(9): 258-60.
Rock, J.F. 1916. The sandalwoods of Hawaii. Hawaii Territorial Board of Agriculture and Forestry, Botanical Bulletin 3:9-43.
Skottsberg, C. 1926. Hawaiian vascular plants I. Acta Horti Gothob. 5:135-145.
Smith, J.G. 1956. Sandalwood and whales. Honolulu Advertiser, May 13, A4.
Stemmermann, R.L. 1980. Observations of the Genus Santalum (Santalaceae) in Hawaii. Pacific Science 34(1): 41-54.
Stemmermann, R.L. 1977. Studies of the vegetative anatomy of the Hawaiian representative of Santalum (Santalaceae), and observations of the genus Santalum in Hawaii. Unpublished Master's thesis for Botany Department, University of Hawaii.
St. John, H. 1947. The history, present distribution, and abundance of sandalwood on Oahu, Hawaiian Islands: Hawaiian Plant Studies 14. Pacific Science 1(1): 5-20.
Tan, P. 1951. A historical survey of Sino-Hawaiian trade. Masters Thesis. University of Hawaii.
Taylor, L. 1989. Sandalwood's return timed for Chinese bicentennial. Honolulu Star-Bulletin, January 9, B 1.
TenBruggencate, J. 1990. Wild cattle might be used to stem banana poka. Honolulu Star-Bulletin/Advertiser, February 25, D4.
TenBruggencate, J. 1988a. Salvaging Mauna Loa's historical sandalwood crop. Honolulu Star-Bulletin/Advertiser, October 2, A3, 6.
TenBruggencate, J. 1988b. Private sandalwood logging has state upset. Honolulu Star-Bulletin/Advertiser, September 27, A3.
Thrum, T.G. 1905. The sandalwood trade of early Hawaii as told by pioneer traders, voyagers, and others. Thrum's Hawaiian Annual.
U.S. Fish & Wildlife Service 1985. Endangered and threatened wildlife and plants: proposed endangered status for Santalum freycinetianum Guad. var. lanaiense Rock (Lanai sandalwood or ‘iliahi). Fed. Reg. 50(44): 9086-9089.
Wagner, J.P. 1986. The rape of the fragrant trees. Honolulu Magazine, November, 97 ff.
Wagner and others. 1990. Manual of Flowering Plants of Hawaii, Vol I and II. Honolulu: Bishop Museum Press.
Ward, D. 1988. Viewpoint: The tragic logging of isle sandalwood trees. Hawaii Tribune-Herald. September 25, 4.
Ward, R.G. (Ed). 1972. Man in the Pacific islands: essays on geographical change in the Pacific islands. London: Oxford University Press.
Zimmerman, E.C. 1972. Adaptive radiation in Hawaii with special reference to insects. In Kay, E.A. (ed.) A Natural History of the Hawaiian Islands. Honolulu: University of Hawaii Press, 528-535.

Sandalwood: Current Interest and Activity by the Hawaii Division of Forestry and Wildlife[1]

Mark Scheffel[2]

Abstract: The State of Hawaii Department of Land & Natural Resources (DLNR) protects native species growing on State land, but has no official program funding for growing sandalwood. Part of the DLNR, the Division of Forestry and Wildlife forest and nursery managers maintain exuberant activity in attempting to establish their nursery stock of sandalwood in the field out of personal interest. Nursery and planting techniques are described.

In 1936, when Hawaii was a territory of the United States, Charles S. Judd, the Territorial Forester at the time, made headline news in the Honolulu Star-Bulletin by proclaiming "SANDALWOOD, ONCE THE GOLD MINE OF HAWAII, IS COMING BACK"! Today, sandalwood is found in scattered abundance in Hawaii, but maybe not to the extent that "gold diggers" would prefer.

This symposium came about because of reports in 1988 that the "last remaining" sandalwood forests in Hawai‘i were being cut. This caused a furor locally and put the State's Department of Land & Natural Resources, specifically the Division of Forestry and Wildlife (DOFAW), into the limelight. The Department publicly stated that "there are no statutes, rules or regulations which specifically address the cutting of Sandalwood as a species," and "harvesting that is occurring ... is on private land zoned agriculture. As such, the activity is not within our jurisdiction." (Paty 1988).

DOFAW conducts natural resource inventories of Hawaii about every 10 years, and currently is in the middle of the federally funded Multi Resource Inventory. The islands of Moloka‘i, Kaua‘i, and O‘ahu are finished, and Maui and the Big Island of Hawai‘i are still awaiting survey. Because these inventories are taken at the plot level and because of statistical filters, *Santalum* spp. has rated only a passing mention from the 1960's inventory in (Nelson and Wheeler 1963, p. 32):

Noncommercial tree species: Tree species not now considered suitable for industrial products. The following were tallied on plots: ....*Santalum* spp., ‘ili-ahi (sandalwood)....

DOFAW is made up of managers of the state's natural resources; it does not include research scientists. Without funded programs, any work being done on *Santalum* spp. is at the county or district level and stems from a personal interest by the resource managers. The following is what these district foresters have discovered in trying to germinate *Santalum* spp. seeds in the nursery and plant the seedlings in the wild.

NURSERY ACTIVITIES

On Maui a well drained and loamy/sandy nursery medium works best: 1/4 peat, 1/4 vermiculite, 1/2 cinder (fine cinder from Kula Forest Reserve on the slopes of the dormant volcano Haleakala on Maui).

As host species, nitrogen-fixing leguminous species are best, with koa *(Acacia koa)* being the best of all. Other species used are ironwood *(Casuarina* spp.), mamane *(Sophora chrysophylla)*, mock orange *(Murrayapeliculata)*, ‘a‘ali‘i *(Dodonaea viscosa)*, and wild pea weed *(Macroptilium lathyrodes)*.

Stem's Miracle-Gro, a commercial all-purpose fertilizer, is used.

Germination has been excellent in the nursery for the native Hawaiian species: *Santalum freycinctianum, S. haleakalae, S. ellipticum*, and *S. paniculatum*.

PLANTING ACTIVITIES

In the arboretum next to the DOFAW's Hilo office on the island of Hawaii, the seedlings have been planted with tubes above ground to serve as protection against weed eaters or mowers. Survival has been excellent here.

Santalum haleakalae seedlings have been outplanted on Maui, but none has survived past the seedling stage.

On August 7, 1989, DOFAW and the Outdoor Committee of the Hilo Women's Club planted 50 *Santalum pilgeri* on Pu‘u Huluhulu (a cinder cone just off the Saddle Road on the Island of Hawaii) at about 6000 feet elevation. On November 13, 1989, 34 of the seedlings were alive and healthy. A visit to the site in Spring 1990 revealed that about one third to one half of the original 50 survived.

REFERENCES

Nelson, R.E.; Wheeler, P. R. 1963. Forest Resources of Hawaii—1961. Honolulu: Division of Forestry and Wildlife, Department of Land & Natural Resources.

Paty, W. 1988. [Letter to Honorable Virginia Isbell, State Representative, State of Hawaii]. Located at: Department of Land & Natural Resources, Hawaii.

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai‘i.

[2]Forester, Hawaii Division of Forestry and Wildlife, Honolulu.

Distribution and Status of Sandalwood in Hawai‘i[1]

Lani Stemmermann[2]

Abstract: This paper attempts to summarize what is known of the distribution and status of sandalwoods in Hawai‘i. Four species of sandalwood are recognized as being endemic to the Hawaiian Islands, and one has been introduced. Ecological factors affecting the present and former distribution of Hawaiian sandalwoods are considered.

The sandalwood trade had significant impact on the economy of the Hawaiian Islands during the first century following western contact. No doubt exists that sandalwoods in Hawai‘i today are much more limited in their distribution than they were formerly because of the history of harvest and subsequent land use changes. At present, sandalwood is found on most of the main Hawaiian islands, with a total of four species recognized in the recently published *Manual of Flowering Plants of Hawaii* (Wagner and others 1990) as being endemic to the Hawaiian Islands. That nomenclature is presented here, though it does not agree necessarily with previous more extensive studies of the group (Rock 1916, Skottsberg 1927, Stemmermann 1980a, St. John 1984). The distribution of these species is listed in *table 1* and roughly illustrated in *figure 1.*

Workers in the past have recognized two groups of Hawaiian sandalwoods: Those with red flowers and those with green flowers. There are two recognized species in the red-flowered section, both of which are trees. *Santalum freycinetianum* was described from O‘ahu and is now also recognized from Moloka‘i. Varieties of this species are known from Kaua‘i to Maui. The red-flowered sandalwoods of Kaua‘i and Lana‘i were previously recognized as distinct at the specific rank, but are now recognized as varieties of the type species. These are var. *pyrularium* (Kaua‘i) and var. *lanaiense* (Lana‘i). Variety *lanaiense* is also known from the leeward slopes of Maui. *Santalum haleakalae,* the other red-flowered species, is found at high elevations on Haleakala, Maui, from roughly 6000 ft (1830 m) to treeline. At lower elevations it intergrades with *S. freycinetianum* var. *lanaiense.*

Two species are now recognized in the green-flowered group. Both have very aromatic flowers. One species, *S. ellipticum,* is usually a shrub, and is known from all of the main Hawaiian Islands except Ni‘ihau. It undoubtedly grew there also at one time, and though it was formerly known from both Laysan Island and Kaho‘olawe, it is now extinct on those islands. Plants of this species are sometimes found growing near the coast. Then they are low plants with thick leaves (to 2+ mm). These coastal populations have been recognized as distinct at both the specific and varietal rank in the past but are now included within the species proper. Several other varieties of this species have also been recognized in the past, but not by recent workers.

Table 1—*Distribution of* Santalum *in Hawai‘i*[1]

Species	Island Distribution[2]								
	Ly	N	K	O	Mo	L	Ma	Ka	H
S. freycinetianum									
var. *pyrularium*			X[3]						
var *freycinetianum*				X	X				
var. *lanaiense*						X	X		
S. haleakalae							X		
S. ellipticum	eX		X	X	X	X	X	eX	X
S. paniculatum									
var. *paniculatum*									X
var. *pilgeri*									X

[1]From Stemmermann (1980a), according to the nomenclature in Wagner and others 1990.
[2]Island distribution: Ly-Laysan, N-Ni‘ihau, K-Kaua‘i, O-O‘ahu, Mo-Moloka‘i, L-Lana‘i, Ma-Maui; Ka-Kaho‘olawe, H-Hawai‘i.
[3]X-present, eX-Extinct.

The second species in the green-flowered group is *S. paniculatum,* known only from Hawai‘i. This species includes shrubs and small trees and is widely distributed on the island of Hawai‘i. One variety is recognized, var. *pilgeri,* which has been considered by some taxonomists as a distinct species. It is endemic to the montane forest region of the Kona (western, leeward) coast of Hawai‘i. One of the largest Hawaiian sandalwoods, *S.* p. var. *pilgeri is* presently being commercially harvested.

In addition to these four native species, *S. album* is occasionally cultivated in Hawai‘i. It was planted as a timber crop species in the early 1900's as a means of renewing the sandalwood industry. Though none of the forestry plantations are known to have been successful, a few trees may persist. An interesting sterile hybrid between the endemic Hawaiian *S. freycinetianum* and *S. album* is grown at the University of Hawaii's Lyon Arboretum.

SANDALWOOD SPECIES RELATIONSHIPS

Skottsberg (1927), believed that there were separate natural introductions of red and green-flowered sandalwoods to the Hawaiian Islands, and that they evolved independently to produce the array of sandalwoods now extant. When Skottsberg (1930) considered the genus *Santalum* in its entirety, he recognized the red-flowered Hawaiian sandalwoods (characterized by flowers longer than broad with campanulate-cylindric receptacles, perigynous ovaries, and long styles) as belonging to

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai‘i.
[2]Instructor, University of Hawaii at Hilo, Hawaii Community College, Hilo, Hawaii.

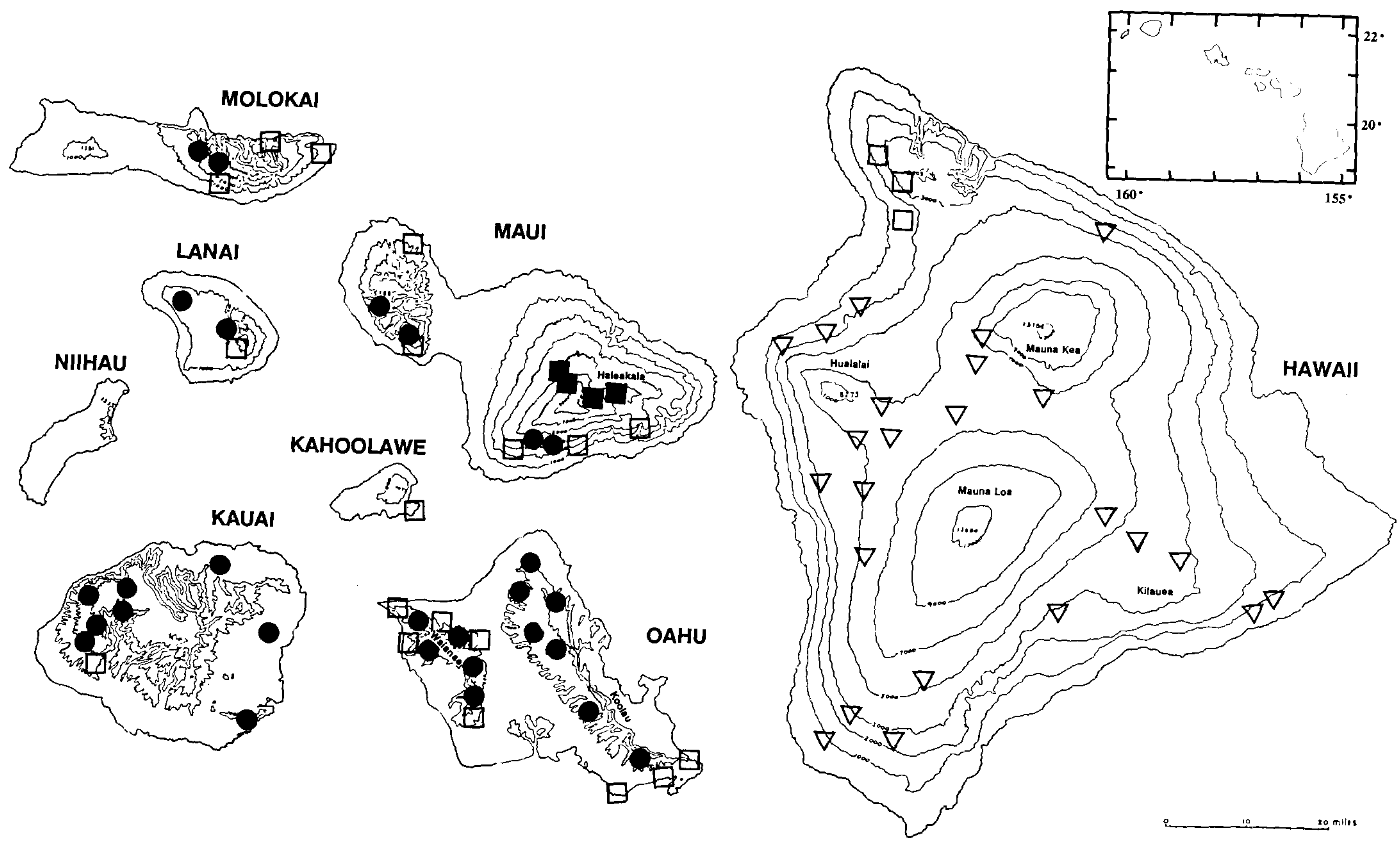


Figure 1—Generalized distribution of Hawaiian sandalwoods.

section *Eusantalum.* In addition to the red-flowered Hawaiian species, several others were included in this group, including *S. album* (Timor to India), *S. macgregorii* (Papua New Guinea), *S. austrocaledonicum* (New Caledonia, Vanuatu, Loyalty Islands, Isle of Pines), *S. yasi* (Fiji), and *S. lanceolatum* (Australia). The sandalwood from the Ogasawara Islands are also included in this group (Tuyama 1939).

Those green-flowered Hawaiian species (characterized by flowers about as broad as long, with obconical receptacles, inferior ovaries, and short styles) were referred to as section *Hawaiiensia* (Skottsberg 1930), which Skottsberg considered to be endemic to the Hawaiian Islands. At the same time that Skottsberg described these two sections with representatives from Hawai‘i, he also recognized a third section of the genus, section *Polynesica,* characterized by whitish to greenish flowers with short conical receptacles, semisuperior ovaries, and short styles. Included in that group are *S. insulare* (various Pacific Islands) and *S. fernandezianum* (Juan Fernandez Islands). Subsequently, Fosberg and Sachet (1985) suggested that there were insufficient differences between the Hawaiian green-flowered sandalwoods and those in south-eastern Polynesia to warrant the recognition of separate sections. They expanded the circumspection of section *Hawaiiensia* to include those species formerly included within the section *Polynesica* and eliminated that section.

Distinct from these two presently recognized sections of sandalwoods are those Australian species that had previously been included in the genus *Eucarya.*

ECOLOGICAL FACTORS AFFECTING DISTRIBUTION

Several ecological factors affect the distribution of the Hawaiian sandalwoods. In general, sandalwoods in Hawai‘i occur in dry to mesic forests. When the green- and red-flowered sandalwoods occur on the same island, the red-flowered taxa are found at higher elevations and in relatively mesic habitats, while the green-flowered *S. ellipticum* is found at lower and drier sites. No Hawaiian sandalwoods are found in areas of very high rainfall—in excess of 150 inches (3800 mm) annually—but some can be found in very dry coastal areas—with annual rainfall less than 20 inches (500 mm) annually—such as Diamond Head, Makapu‘u and Ka‘ena on O‘ahu. Other dry areas likely once supported sandalwood, but these populations have been lost as humans have encroached on those habitats.

Plants in dry areas tend to have smaller leaves than plants from more mesic sites, and sandalwoods are no exception. Within species, those from drier sites are smaller-leaved than those in mesic sites. Populations with the largest leaves, *S. freycinetianum* from O‘ahu and Kaua‘i, and *S. paniculatum* var. *pilgeri* from

Kona, which grow in mesic sites, all exhibit wood and foliar morphological characteristics typical of species from mesic environments (Stemmermann 1980b).

In contrast, *S. ellipticum, S. paniculatum,* and *S. freycinetianum* from Molokaʻi, Lanaʻi, and Maui, and the high elevation *S. haleakalae,* which all grow in relatively dry sites, exhibit wood and foliar morphological traits typical of species found in dry sites. The red-flowered high elevation *S. haleakalae,* which can be found up to 8500 ft (2590 m), exhibits many morphological characteristics typical of plants in high dry sites, including specialized foliar epidermal cells (Stemmermann 1980b). These high elevation plants routinely experience nightly frost.

In addition to tolerance of low rainfall and frost by some species, many Hawaiian sandalwoods are at least somewhat fire-tolerant. Both red- and green-flowered species have been seen to produce root suckers which grow into sizable plants in areas that have burned. In some areas much of the natural reproduction appears to be from suckers rather from seed.

Seed predation has been seen in populations of all species, with both rats and cardinals known to consume large quantities of *Santalum* seed. Neither species is native to Hawaii, but sandalwood seed may have comprised part of the diet for at least two birds once common in the upland Kona forests where *S. paniculatum* var. *pilgeri* is found. These birds, the ʻalala, or Hawaiian crow *(Corvus tropicus),* and the Palila *(Loxioides bailleui),* one of the finch-billed Hawaiian honeycreepers, are now both considered endangered species and are restricted to only a small fraction of their original distribution. Other now extinct Hawaiian bird species similarly may have utilized sandalwood seed.

ESTIMATED PAST DISTRIBUTION

Each of the four species enumerated above are extant in the Hawaiian Islands, though all are likely much less common now than previously. The present distribution of all Hawaiian sandalwoods undoubtedly reflects their past history of exploitive harvest and forest extirpation. While no species of sandalwood in Hawaiʻi has been known to become extinct due to harvesting, most of the harvest in the 1800's occurred before thorough botanical investigation of the Hawaiian Islands. Possibly species that were never documented became extinct. The sandalwood trade began as early as 1790, with the years of heaviest harvest between 1815 and 1825. The first collection of Hawaiian sandalwoods for taxonomic study was made in 1819 by Gaudichaud, who described two species from his collections.

Rock (1916) reasoned that if the amount of sandalwood sold in the early part of the 19th century was accurately recorded, there must have been pure forests that were subsequently decimated. In assessing sandalwood from Oʻahu, St. John (1947) deduced that "there were heavy stands of sandalwood either abundant in, or dominant in, a forest zone from about 300 to about 1,000 feet [90-300 m] altitude, below the koa *[Acacia]* zone, and above the wiliwili *[Erythrina]* zone. Probably the tree occurred on the lower, dry slopes of nearly every secondary ridge leading from the Waianae Mountains and on those leading from the leeward side and the north end of the Koʻolau Range." He further suggests that the present distribution of sandalwood reflects only its former upper range, since it has been almost wholly displaced from its lower range by loss of forests in those areas.

St. John's (1947) conclusions regarding the former distribution of sandalwood on Oʻahu can probably also be applied to other Hawaiian islands. Sandalwoods probably were once common, if not abundant, throughout the Hawaiian lowlands, particularly on the leeward and drier slopes. Records of sandalwood harvests indicate the extent of wood that was shipped from Hawaii, and most of this came from the lowlands. The only taxon officially recognized as endangered is the red-flowered variety from Lanaʻi and Maui, *S. freycinetianum* var. *lanaiense.* Its scarcity can be attributed to forest loss from the slopes of those islands. Elsewhere, too, forest loss has been cited as causing the extinction of *Santalum,* such as *S. fernandezianum* from the Juan Fernandez islands (Skottsberg 1930). In addition to commercial harvest and forest extirpation, heavy grazing of the native vegetation was responsible for the extinction of *S. ellipticum* from Laysan and Kahoʻolawe. This species, however, is still found on many other Hawaiian islands.

MANAGEMENT NEEDS IN HAWAIʻI

In Hawaii, extensive stands of sandalwood are only known from the island of Hawaiʻi. These populations of *S. paniculatum* are now commercially harvested. Hawaii may be the only region in the world where sandalwood is being commercially harvested without regulation. Without a management plan to regulate the industry, preserve some of the remaining old growth, and manage the resource as a renewable resource, the presently harvested species should be considered endangered. Old wood is wood in which the valued resins are deposited, and the present monetary incentive to utilize this wood is considerable. A market for the wood from local woodworkers threatens trees near roads, and foreign markets threaten the extant forests.

What impact will removal of these old growth forests have on other species dependent upon this ecosystem? Because these trees are an important component of these high-elevation mesic forests, their removal will increase the fragmentation of habitat that once supported several species that are now endangered, including the Hawaiian crow, the Akiapolaʻau, and the Palila. It is not known to what degree these bird species use—or used—the sandalwood areas, or to what degree they—or other species—may utilize the old growth associated with these forests. Aside from bird species, numerous arthropods typically are closely associated with individual plant species, and those associated with sandalwood populations should be considered threatened.

Hawaiʻi has the greatest number of candidate endangered species of any state in the United States. While the sandalwood being harvested is not considered endangered, biologists suspect that commercial interests are endangering this species. Monetary incentives need to be reversed so that landowners are duly compensated for their stewardship of these living Hawaiian heirlooms.

REFERENCES

Fosberg, F. R.; Sachet, M. H. 1985. Santalum in Eastern Polynesia. Candollea 40(2): 459-470.

Rock, J. F. 1916. The sandalwoods of Hawaii. Hawaiian Board of Agriculture and Forestry, Botanical Bulletin 3:1-43.

St. John, H. 1947. The history, present distribution and abundance of sandalwood on Oahu, Hawaiian Islands: Hawaiian Plant Studies 14. Pacific Science 1: 5-20.

St. John, H. 1984. Revision of the Hawaiian species of *Santalum* (Santalaceae). Hawaiian Plant Studies 109. Phytologia 55:217-226.

Skottsberg, C. 1927. *Artemisia, Scaevola, Santalum,* and *Vaccinium* of Hawaii. Bulletin 43. Honolulu: Bernice P. Bishop Museum. 89 p. + 8 pl.

Skottsberg, C. 1930. The geographical distribution of the sandalwoods and its significance. Proc. Fourth Pacific Science Congress (Java) 3:435-442.

Stemmermann, L. 1980a. Observations of the genus (Santalaceae) in Hawai‘i. Pacific Science 34:41-54.

Stemmermann, L. 1980b. Vegetative anatomy of the Hawaiian species of (Santalaceae). Pacific Science 34:55-75.

Tuyama, T. 1939. On *Santalum boninense,* and the distribution of the species of *Santalum.* Jap. J. Bot. 15:697-712.

Wagner, W. L.; Herbst, D. R.; Sohmer, S. H. 1990. Manual of the flowering plants of Hawai‘i. Honolulu: University of Hawaii Press and Bishop Museum Press; 1218-1223.

Status and Cultivation of Sandalwood in India[1]

Shobha N. Ral[2]

Abstract: Sandalwood *(Santalum album)* has been part of Indian culture and heritage for thousands of years, and was one of the first items traded with other countries. The heartwood yields fragrant oil, which is used mainly in the perfume industry but also has medicinal properties. The wood is used for carving and manufacturing incense. Generally *S. album* is found in the dry deciduous forests of Deccan Plateau, mostly in the states of Karnataka and Tamil Nadu, The evergreen tree regenerates naturally when conditions are favorable and has been spreading in its distribution. Lack of understanding of the dynamics of hemi-parasitism by sandalwood has caused failure of pure plantations in the past; haustorial connections with its hosts supply sandalwood with nitrogen, phosphorus, and potassium. Plantable seedlings can now be raised in the nursery in 6-8 months with the protection of a nematicide and fungicide. Several techniques for planting seeds directly in the field have also been developed. A tree that is growing well can put on an annual increment of 1 kg per year. The sandalwood resource in India is currently threatened by four factors: fire, browsing by livestock, spike (little leaf) disease, and smuggling.

Sandalwood *(Santalum album)* is a part of Indian culture and heritage. It is the epitome of human excellence, imparting fragrance even to the axe that fells it.

Sandalwood finds description in the oldest of Indian literatures. It finds a mention in the ancient epic Ramayana (around 2000 B.C.). It has been used as an object in ritualistic offerings and also as an ointment for beauty aid. It has nearly 15 different names in the Indian languages, "chandan(a)" being the Hindi name. In Indonesia too it is called "cendana."

In the past, it has been said that *Santalum album* was introduced in India from Timor Island of Indonesia. But sandalwood has such inextricable links with Indian culture, literature, and ethos that it is difficult to support the hypothesis of its introduction.

Sandalwood is growing and regenerating naturally under favorable conditions in India. It is part of the indigenous vegetation and has been spreading in its distribution. However, several factors now threaten the important status of sandalwood.

This paper describes the distribution, ecology, growth habit, and uses of sandalwood in India. Nursery and plantation techniques for growing sandalwood from seeds are given. Current threats to the resource are identified.

DISTRIBUTION

In India sandalwood is mainly distributed on the Deccan Plateau. The total extent of its distribution is around 9000 km^2, of which 8200 km^2 is in the states of Karnataka and Tamil Nadu *(fig. 1)*. In the past, it naturally occurred in peninsular India, but subsequently it has been introduced in other parts too. It generally occurs in the dry deciduous forests of Deccan Plateau at the edge of the Western Ghat Range. A circle with Bangalore city as the center and a radius of 200 km could be said to be the main zone of natural distribution of sandalwood. It thrives best under rainfall conditions of 500-2000 mm and at elevations of 650-1200 m. It can occur beyond these ranges too, but under high rainfall conditions the growth is luxuriant yet the heartwood formation is absent or negligible.

Sandalwood is capable of growing in different kinds of soils like sand, clay, laterite, loam, and black-cotton soil (avoiding water-logged conditions). Even very poor and rocky soils can support sandalwood. It is capable of regenerating profusely in the absence of fire and grazing. If protected, established plants start fruiting and regenerating naturally, and birds may help in propagation.

HABIT AND HABITAT

Sandalwood is an evergreen tree. It can grow to a height of 20 m and attain a girth of over 1.5 m. It flowers and fruits twice a year during March-April and September-October. Trees start flowering from 3 years of age. Seed production generally is good in one of the seasons. Certain trees flower only once a year, and some do not flower regularly. About 6000 seeds make 1 kg. Seeds can be collected directly from the tree. The fruits should be depulped, washed thoroughly in water, dried under shade, and stored in airtight containers.

Sandalwood is a hemi root parasite. It can parasitize over 300 species from grass to another sandal plant. Under gregarious growing conditions, self-parasitism is common. Lack of understanding of the dynamics of parasitism has been the cause of

Figure 1—Distribution of sandalwood in India. Areas in square kilometers are as follows:

Karnataka	5,245	Maharashtra	8
Tamil Nadu	3,040	Kerala	7
Andhra Pradesh	175	Uttar Pradesh	Less than 1
Nadhya Pradesh	33	Private lands	500
Orissa	25		
	Total 9,034		

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai'i.

[2] Conservator of Forests, Karnataka Forest Department, Dharad, India.

Table 1—*Influence of host plants on the growth of sandal seedlings (pot culture studies)*

Species	Sandal				Host				Number Haustorical Connections
	Ht. cm	Biomass grams			Ht. cm	Biomass grams			
		Stems	Roots	Total bio-mass		Stems	Roots	Total bio-mass	
Casuarina equisetifolia	110	48	38	86	152	141	113	254	390
Melia dubia	88	43	33	78	110	48	85	133	107
Acacia nilotica	74	43	30	73	82	22	18	40	124
Wrightia tinctoria	71	40	32	74	70	23	40	63	117
Pongamia pinnata	70	40	30	70	87	31	50	81	175
Terminalia arjuna	70	39	25	64	103	42	60	108	108
Terminalia alata	69	37	26	63	80	44	65	109	140
Dalbergia sisso	68	29	32	61	91	48	85	133	120
Dalbergia latifolia	62	31	29	60	80	30	60	90	78
Cassia siamea	64	28	27	55	73	47	68	115	120
Bahunia biloba	49	15	16	31	102	79	103	181	125
Tectona grandis	50	14	16	30	105	140	160	300	110
Azadirachta indica	39	22	20	40	61	20	30	50	100
Adenanthera pavonina	38	9	11	20	86	70	95	165	53
Moringa pterigosperma	35	10	9	19	103	60	45	105	62
Anogeissus latifolia	32	10	8	18	108	70	110	180	49
Pterocarpus santalinus	30	9	8	17	30	8	18	26	28
Tamarindus indica	31	8	7	15	58	30	27	57	31
Pterocarpus marsupium	30	7	8	15	67	17	30	47	28
Eucalyptus hybrid	30	9	8	17	130	59	80	139	37
Syzygium cumini	30	8	7	15	100	38	56	94	21
Phyllanthus emblica	30	8	6	14	122	57	49	106	18
Ailanthus' malabaricum	28	10	9	18	89	54	54	108	20
Madhuca indica	28	8	8	16	90	90	80	170	60
Swietenia mahogany	28	8	6	14	140	170	80	250	48
Artocarpus integrifolia	26	8	6	14	75	45	40	85	36
Leucena leucocephala	28	6	5	11	140	159	116	276	18
Cassia fistula	28	7	8	15	30	13	28	41	18
Acacia auriculiformis	28	8	6	14	154	69	58	127	17
Mundelea suberosa	27	7	6	13	73	32	27	59	28
Albizzia lebbek	28	9	7	16	65	25	37	62	52
Control	27	6	4	10					8

Table 2—*Photosynthetic activity of sandal seedlings grown with different hosts*

Species	Photosynthetic rate mg/cm^2/s	Chlorophyll			Stomatal frequency per mm^2
		a	b	Total	
Casuarina equisetifolia	4.15	41.42	32.84	73.76	7.4
Melia dubia	4.53	51.35	25.27	76.82	7.3
Acacia nilotica	5.2	30.62	23.83	54.45	7.6
Wrightia tinctoria	3.6	27.52	20.89	48.41	7.6
Pongamia pinnata	*2.3*	49.67	36.69	86.36	5.7
Terminalia arjuna	2.83	27.23	22.88	50.11	8
Dalbergia sisso	2.12	33.09	34.60	67.69	6.8
Cassia *siamia*	1.76	25.63	41.41	67.04	7.5
Azadirachta indica	1.32	20.74	18.81	39.55	5.7
Acacia indica	1.5	21.99	14.99	36.97	4.7
Albizzia lebbek	1.7	15.55	14.37	29.92	5.5
Artocarpus integrifolia	0.77	6.71	8.53	15.24	5.6
Control	0.83	10.67	16.49	27.16	5.3

failure of pure plantations in the past. Sandalwood establishes haustorial connections with the host plants and depends on them for its requirement of nitrogen, phosphorous, and potassium. It can obtain other nutrients on its own. Seedlings can survive without a host for 3 years but thereafter they tend to die. In a natural population 2 percent of seedlings do not produce haustoria, and they fail to survive on their own beyond 3 years of age.

Pot culture experiments have indicated the efficacy of secondary hosts for sandal. Average stem, root, and total biomass (dry weight at 85 degrees C for 24 hours) of host and sandalwood plants, and the average heights are given in *table 1*. *Table 2* gives photosynthetic rate, chlorophyll content, and stomatal frequency of the first 12 most suitable host plants. In our studies, we found that *Cajanus cajan* acted as the best primary host. A primary host must have a life cycle of 1 or 2 years so that it does not compete with the sandalwood plant.

USE OF SANDALWOOD AND OIL

Heartwood of the sandalwood tree is the most valuable part. It yields fragrant sandalwood oil. In India sandalwood and its oil were among the first items traded, along with spices and silk, to Middle Eastern and other countries. The wood is used for burning in certain rituals by Hindus, Buddhists, and others. The wood paste and oil are used as coolants. The wood paste is also used as an ointment to dissipate heat and as a beauty aid. There are excellent descriptions by Kalidasa of this use of sandalwood in his *Sanskrit* epics (300 B.C.).

Sandalwood oil is mainly used in the perfume industry. The oil is an excellent base and fixative for other high grade perfumes. Most top grade perfumes have sandalwood oil as their base. In itself it is an excellent, mild, long-lasting, and sweet perfume, yet the industry finds that it can blend very well with other perfumes and does not impart its fragrance when used as a base. It can also fix the better perfumes, which are volatile, for longer hours. Several chemicals have been tried in this role, yet sandalwood oil has retained its place of pride. From perfumery to joss sticks, there are several hundred products that use sandalwood oil. It is also used in the soap industry.

Sandalwood oil has antipyretic, antiseptic, antiscabietic, and diuretic properties. It is also effective in the treatment of bronchitis, cystitis, dysuria, and diseases of the urinary tract. The oil has an important place in the indigenous system of medicine. It is considered a cure against migraine.

Sandalwood is used for carving and other artifacts. The sapwood and sometimes the mixed woods are used for manufacturing joss sticks. From the exhausted sandalwood powder, an entirely new essential oil has been produced by the process of hydrolysis.

TRADE

As mentioned earlier, trade in sandalwood dates back to the dawn of trading by India. Realizing its value, the Sultan of Mysore declared it a royal tree during 1792. It continues to retain that place even today, although individuals are entitled to receive 75 percent of its value as a bonus for growing and protecting the trees. Due to its high value and steeply rising demand both in internal and external markets, sandalwood prices have skyrocketed, as can be seen from the price per ton:

Year	*Rs/Ton*[1]
1900	365.00
1933	1,000.00
1965	6,000.00
1970	10,000.00
1980	31,000.00
1987	78,000.00
1990	160,000.00

[1]US$ = Rs 17

The rise in prices was partly due to decrease in supplies. During the 1930's through 1950's, the country's production was roughly 4000 tons of heartwood per year; now it is only around 2000 tons.

On an average, 60 kg of oil is obtained for every ton of wood. Quite a sizable proportion of the wood produced is used for distillation of oil which is exported outside the country for use in the perfume industry.

HEARTWOOD FORMATION AND OIL CONTENT

Heartwood formation in sandal trees generally starts around 10-13 years of age, but what triggers this process has not been very well understood. Certain factors, generally relating to stress, such as gravelly dry soil, insolation, and range of elevation (500-700 m), seem to provide the right environment for the formation of heartwood, irrespective of the size of the stem after 10 years of age. The occurrence of heartwood varies. Most of the root portion after a certain age is heartwood; however, in the stem it is highly variable from place to place. It can range from 90 percent of the stem wood to a negligible amount, or be absent. The value of heartwood is due to its oil content, and the superiority of the oil is due to the percentage of santalol.

(i) In a tree the oil content is highest in the root, next highest in the stem at ground level, and gradually tapers off towards the tip of the stem.

(ii) Similarly, there is a gradient in oil content from the core to the periphery of the heartwood in a stem.

Depending upon their age, trees can be called young or mature, although this is an empirical classification and holds good only for a particular population. The oil content and its composition may differ at the same age:

(i) Young trees (height less than 10 m, girth less than 50 cm, and heartwood diameter 0.5-2 cm) have heartwood with 0.2-2 percent oil content, which has 85 percent santalol, 5 percent acetate, and 5 percent santalenes.

(ii) Mature trees (height 15-20 m, girth 0.5-1 m, and heartwood diameter 10-20 cm) have heartwood with oil content of 2-6.2 percent, which has over 90 percent santalol, 3-5 percent acetate, and 3 percent santalenes.

The heartwood of sandalwood is yellowish to dark brown. This again is an indicator of oil content. Yellowish heartwood has 3-4 percent oil and 90 percent santalol; light brown heartwood contains 3-6 percent oil and 90-94 percent santalol. Brown and dark brown wood has only 2-5 percent oil and 85-90 percent santalol. Hence, lighter heartwood is better and superior.

Using oil as the main criterion, elite trees were selected based on rate of growth, and heartwood and oil content for future propagation through seed and tissue culture. The work has been on going. Several clonal orchards have been established for production of seed.

ECOLOGY AND FLORISTICS

Sandal is primarily a tree of dry deciduous forests. It is prone to fire damage. It generally avoids hill slopes and grassy banks that are prone to annual fires; however, when these areas are protected from fire, sandalwood appears again. Similarly, under moist deciduous conditions when a site becomes more mesic, sandalwood recedes to drier portions. Its main associates in the top canopy are these: *Terminalia tomentosa, T. chebula, Anogiessus latifolia, Sapindus trifoliatus, Diospyros melanoxylon, Albizzia lebbek, A. odoratissima, A. amara, Chloroxylon swietenia, Feronia elephantum, Limonia acidissima, Zizyphus xylopyrus, Grewia tilaefolia, Bridelia retusa, Ixora parviflora, Pterocarpus marsupium, Dendrocalamus strictus, Bauhinia racemosa, Acacia sundra* and others. The undergrowth consists of *Carissa carandus, Dodonea viscosa, Randia dumetorum, Cassia fistula, C. auriculata, Lantana camara, Zizyphus oenoplea, Flacourtia montana* and others.

Sandalwood regenerates naturally under the protection of thorny bushes, along streams (some seeds that float in water germinate faster), and under trees where birds generally roost. Dispersal of seeds and spread of the species effectively takes place through birds, provided the area is free from recurrent fire and browsing animals.

Initially, seedlings need shade for survival, and in the sapling stage they need diffused light for proper growth. However, once the trees are nearly 4 meters high, they can grow under full overhead light. Plants growing under full exposure have yellowish leaves while those under lateral shade have dark green leaves.

Up to 50 sandalwood stems are generally found per hectare, which could be roughly 2 percent of the composition in a forest. Higher populations are found under certain favorable and protected conditions for regeneration.

REGENERATION FROM SEED

Seed from known superior populations is desirable. Sandalwood flowers and fruits twice a year, i.e., in September/October and in March/April. The seeds of both the seasons perform alike.

Sandal fruits are collected fresh from the tree, soaked in water, and rubbed to remove the soft pulp. The wet seeds are dried under shade, then the dry seeds are stored in polyethylene bags or gunny bags. About 6000 seeds weigh 1 kilogram.

Fresh seeds usually have a dormancy period of 2 months. The seed takes 4 to 12 weeks to germinate after the dormancy period. Eighty percent of the seeds are viable up to 9 months. The germination rate is about 80 percent under laboratory conditions and 60 percent under field conditions. Germination can be hastened by cracking the hard seed coat. Soaking seeds in 0.05 percent gibberellic acid overnight before sowing, ensures uniform germination.

Nursery Techniques

Two types of seed beds are used to raise sandalwood seedlings: sunken and raised beds. Both beds perform equally well under different climatic conditions.

Both seed beds are formed with only sand and red earth in a3:1 ration and are thoroughly mixed with nematicides (Ekalux or Thimet at 500 g per bed of 10 m by 1 m). The seeds are soaked in 0.02 percent Agallol (organo mercuric compound) solution for half an hour to remove surface contamination. Then the seed is spread uniformly over the bed. About 1 cm of of sand is spread over the seed. Around 2.5 kg of seed is used for one bed. The bed is covered with straw which should be removed when the leaves start appearing on the seedlings.

The seed beds are sprayed with (1) the fungicide Dithane Z-78 (0.25 percent) once in 15 days to avoid fungus attack, and (2) 0.02 percent Ekalux solution once a month to avoid nematode damage. Sandalwood seedlings suffer from a virulent disease caused by a combined fungal and nematode infection. The initial symptom is wilting of leaves followed by sudden chlorosis and root decay. On account of this disease the mortality rate is very high, but this can be controlled by the application of nematicide and fungicide (Ekalux and Dithane) as mentioned above.

When the seedlings have 5 to 6 leaves, they are transplanted to the polyethylene bags along with the seed of the primary host *Cajanus cajan*. The seedlings are carefully removed from the bed with all the roots intact and then carried in a container with fungicide soluition [sic] (Agallol 0.1 percent). Roots should not be allowed to dry.

Shade can be provided for a week immediately after the transplanting. Watering should be done daily, but excess moisture is to be avoided. Host plants are pruned frequently, so that they do not overgrow the sandal and hamper its growth. Poly bags should contain a soil mixture in the ratio 2:1:1 (sand:red earth:farmyard manure). Poly bags 30 by 14 cm are best. To avoid nematode damage, Ekalux at the rate of 2 g/poly bag or 200 g for 1 m^3 of poly bag mixture should be thoroughly mixed in before filling the bags.

A plantable seedling of about 30 cm height can be raised in 6-8 months. A well-branched seedling with brown stem is ideal.

At the time of planting in the field a perennial host, if given, increases the growth of sandal. Sandal has over 300 host plants; some of the good hosts are *Casuarina equisitifolia, Acacia nilotica, Pongamia binnata, Melia dubia, Wrightia tinctoria,* and *Cassia siamea.* It is ideal to plant sandal in 50 cm^3 pits, 3 by 3 m apart in alternate rows with host plants.

Plantation Techniques

Sandal has been successfully regenerated by the following techniques:

(i) Dibbling seeds into bushes
(ii) Dibbling seeds in pits or mounds
(iii) Planting container-raised seedlings.

Dibbling of Seed Into Bushes

This planting method is adopted in open scrub jungles with lots of bushes. The seeds are sown during monsoon. An instrument can be made using a bamboo pole of4 to 6 cm internal diameter and 1.5 m long to sow the seeds. The septa at the nodes are removed and one end of the pole is sharpened, or a hollow metal piece is attached to rake the soil. The pole is introduced at the base of the bush and through the hole four to five seeds are transferred to the base of the bush. Fairly good success has been achieved by this method.

Dibbling of Seeds in Pits or Mounds

The usual trench mound technique adopted for afforestation for other species of trees has also been adopted for sandal, but here a perennial host plant is also grown along with sandal either on the mound or by the side of the pit.

Planting Container-Raised Seedlings in Nurseries

The area required for this purpose is completely clear felled. Pits of 50 cm^3 are dug out at a spacing of 3 m. Healthy sandal seedlings, preferably above 30 cm in height, are planted in the pits. Miscellaneous secondary host plants are planted in the alternate rows. This method has proved successful in many areas. *Figure 2* gives a diagramatic sequence of nursery to planting stages of sandal.

After Care

Working the soil to a radius of 50 cm once in 6 months is recommended. The host plant tends to overgrow sandalwood and may be pruned, so that sandal gets maximum sunlight. Adequate protection against fire and grazing is necessary.

GROWTH AND YIELD

Though sandal is considered to be a slow-growing tree under forest conditions (1 cm girth/year), it can grow at a rate of 5 cm of girth or more per year under favorable soil and moisture conditions. The heartwood formation in sandal starts around 10-13 years of age. So far the growth data is available only in respect to natural forests, mainly from Javadis in Tamil Nadu and the Dharwad area of Karnataka. *Table 3* gives an idea of its growth.

Assuming about 250 trees are growing well, they can put on an annual increment of 1 kg per year per tree, thus giving an overall increment of 250 kg of heartwood per year. The returns can be increased by adopting intensive practices.

CURRENT PROBLEMS WITH THE RESOURCE

Sandalwood as an important species has been losing ground in India, mainly due to four factors: (i) recurrent annual ground fires in its zone of occurrence; (ii) browsing and lopping of trees for fodder; (iii) "spike" (little leaf) disease in a part of its zone of distribution where maximum temperatures do not go beyond 38 degrees C; and (iv) smuggling of sandalwood for clandestine trade.

The first two factors generally have prevented occurrence of natural regeneration and the establishment of artificial regeneration.

The spike disease causes mortality across all age groups to the extent of 1 to 1.5 percent. Sandalwood spike now is considered to be caused by a mycoplasma-like organism, which is transmitted from one live plant to another through sap-sucking insects.

Table 3—*Growth of sandal in natural forests, mainly from Javadis in Tamil Nadu and the Dharwad area of Karnataka*

Age (years)	GBH (cm)	Heartwood (kg)	Sapwood (kg)
10	10	1	5
20	22	4	25
30	33	10	60
40	44	20	100
50	55	30	135

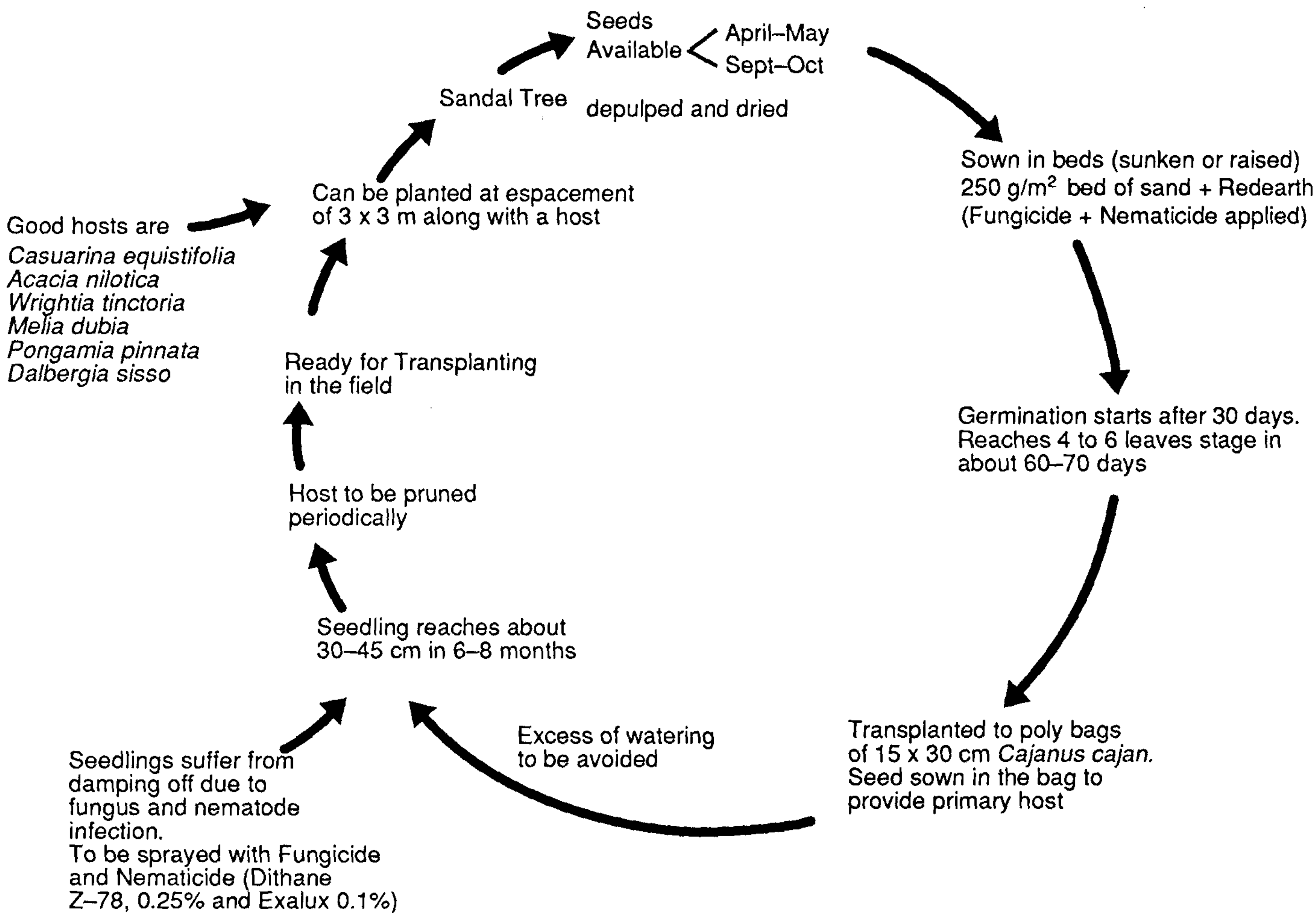


Figure 2—Cultivation of sandalwood from seeds.

Remission in symptoms was obtained by drip application of tetracycline to the stem. However, curative measures have not been found so far. Spike disease has been found to appear and disappear in a cyclic fashion from certain infected areas. Some tracts are free from it, but it seems to be spreading. Even in the zone where it occurs, all trees are not affected. However, at the same time, in the process of screening by innoculation we have not found resistant trees so far.

Smuggling of sandalwood has been causing grave concern. The government of India is about to bring in a uniform law for the entire country on use and transport of sandalwood.

REFERENCE

Ananthpadmanabhe, H. S.; Nagveni, H. C.; Rai, S. N. 1988. Influence of host plants on growth of sandal. My Forest 26 (2): 156-160.

Growing Sandalwood in Nepal—Potential Silvicultural Methods and Research Priorities[1]

Peter E. Neil[2]

Abstract: Interest in sandalwood has increased recently in Nepal as a result of a royal directive to plant it in the Eastern Development Region. The most suitable seed sources, seed acquisition, nursery techniques, direct sowing and plantation establishment methods are discussed here on the basis of results from elsewhere. Suggestions are made as to what research is most needed to assist with successful establishment of sandalwood in Nepal. The silvicultural methods discussed could well be of use to other countries that are interested in introducing and establishing sandalwood plantations.

This paper is related to one that was recently published in *Banko Janakari,* a forestry journal in Nepal (Neil 1990). It summarizes knowledge on the propagation and silviculture of sandalwood so that it can be successfully established in the kingdom. It also summarizes research results from elsewhere so that any new research will not repeat completed work or continue to investigate methods that have already been proved unsuccessful. The need for research into the establishment of sandalwood in Nepal has arisen because of the interest that His Majesty the King has shown in the species, which has led to a royal directive to plant it in the Eastern Development Region.

The methods discussed and recommended for adoption in Nepal may well prove useful for other countries that wish to establish sandalwood plantations. This could apply particularly to countries that are interested in introducing the species, or that would like to plant their indigenous sandalwood species but are unsure of how to go about it.

SANDALWOOD

The genus *Santalum* belongs to the family Santalaceae, which comprises herbs, shrubs, and small trees. It has long been a source of sandalwood, a fragrant wood prized for its use in producing ornaments, cabinets, and chests; incense for religious rites; and oil for perfume and medicines. *Santalum album* is the best known commercial species. It is found in southern India (but may have originally been introduced from Java, Indonesia), especially in Karnataka, Kerala, and Tamil Nadu, and also in Sri Lanka and other parts of south-eastern Asia (Brandis 1978). Various descriptions of it occur in Hindu mythology. Powdered wood in the form of a paste, with added pigments, is used in caste distinguishing marks (Drury 1985).

Other species are found in the Pacific region and Australia. The natural resource of Pacific sandalwood species has been heavily exploited since the early 19th century (Shineberg 1967), and on some islands, the resource has been practically exhausted (Nor 1982, Neil 1986, Barrance 1989). Some confusion exists over the taxonomy of these species due to variations in appearance and habit. For example, *S. insulare* from French Polynesia and *S. marchionense* from the Marquesas may be varieties of the same species (Neil 1986).

Sandalwood is generally considered a slow-growing tree in natural forest conditions, although it varies considerably, and in favorable conditions its annual girth increment can be 5 or 6 centimeters. In plantations it usually grows faster; in Vanuatu *S. austrocaledonicum* was 3 meters tall with a d.b.h. of 4 centimeters at *3* years (Neil 1986), and similar growth has been recorded for *S. album* (Barrett 1988).

Santalum species are capable of developing haustoria and are usually partially parasitic on the roots of other plants. *S. album* is said to be an obligate parasite and must therefore be associated with suitable hosts if it is to survive (Sinha 1961, Mathur 1961). However, there have been suggestions that some sandalwood species, including *S. album,* are not necessarily obligate parasites. Nagaveni and Srimathi (1985a) report the occurrence of haustoria-less *S. album,* although the majority of sandalwood plants produce haustoria when still in the seedling stage. Likewise, *S. austrocaledonicum is* sometimes found in apparent isolation with no potential host plants present (Barrau 1960). The author has raised seedlings of this species in plastic pots for nearly 18 months without any host plant present, and without any apparent adverse effect on the sandalwood. Research results from New Caledonia, on the other hand, suggest that *S. austrocaledonicum* seedlings are able to survive for only a short time without a host; otherwise, they soon turn chlorotic and die (Douheret 1981).

Evidence shows that sandalwood obtains nitrogen, phosphorous, and basic amino acids from its hosts, and calcium and potassium from the soil (Iyengar 1960, Sen-Sarma 1975, Struthers and others 1986, Angadi and others 1988). In concurrence with this, it is interesting to note that many of the species parasitized by sandalwood are nitrogen-fixing.

Sandalwood's aromatic oil, which is contained in the heartwood, is only produced when the tree reaches a certain maturity. Some trees develop heartwood between 4 and 6 years of age, others when they are between 15 and 20 years old, and others never develop it at all. Depending on genetic and environmental factors, trees are in their prime as heartwood producers between *30* and 80 years of age. The color varies from yellow through light brown to a deep chestnut. Light brown wood contains the most oil.

S. album in India is commonly attacked by "spike disease" caused by a mycoplasma-like organism. There is a very large literature on this subject (Mathur 1979), but apparently spike disease is not present in sandalwood outside India (Ramaswamy 1956).

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawaii.

[2]Plantation Silviculturist, Nepal-United Kingdom Forestry Research Project, Kathmandu, Nepal.

SANDALWOOD IN NEPAL

The typical Nepali name for sandalwood is "shrikhand," although the Hindi name, "chandan," is also used. In Sanskrit it is called "malayaja." It is much used in both Hindu and Buddhist religious rites. For example, it is occasionally burnt on the funeral pyre of Hindus and is often a traditional offering at religious worship. Newars offer sandalwood during the Navaratri festival during Desain. Sandal paste is offered to Jupiter in the "puja" to the nine planets.

Majupuria and Joshi (1988) report that it grows in Gorkha district, but add that it has been imported into the country. It is not indigenous to Nepal, although four other genera from the family Santalaceae are represented (Hara and others 1982). Some trials with *S. album* have been carried out by the Royal Botanical Garden and Royal Palace Garden, but these have been with very limited quantities of seed (Anon., 1987). A few trees still survive in the terai from these trials, suggesting that it might be possible to grow sandalwood commercially at low altitudes in Nepal. His Majesty's directive to plant it in the East of the country has prompted new efforts to establish plantations. However, the most suitable techniques for establishing plantations are not yet known. A summary of research findings from other countries is given below. These results should be used as the basis for new research to be carried out in Nepal and potentially in other countries interested in planting sandalwood. Time should not be wasted in testing methods that have already failed; instead, new work should build on proven and successful methods.

SEED ACQUISITION

Since sandalwood is not indigenous to Nepal, seed will have to be imported. Conflicting reports concerning the germinative capacity and quality of *S. album* seed exist (Sinha 1961, Bagchi and Kulkarni 1985, Ananthapadmanabha and others 1988). High quality seed is important, i.e., seed that has been collected at the right time and been properly stored. Trees can produce fertile seed from 3 or 4 years of age, but as they get older, they produce more seed, and a larger proportion of it is fertile. For maximum viability, fruit must be picked from the tree or collected from the ground when fresh, completely depulped by washing in water, dried in the shade, and stored in a dry place.

Traditionally it has been thought that the harder or harsher sites produce sandalwood with a much higher oil content in the heartwood than sandalwood planted on more fertile sites (Troup 1921). However, results from the Sandal Research Centre, Bangalore, India, suggest that genetic factors are more important than edaphic factors. If *S. album* seed from India is to be used, it would be desirable to obtain seedlots from stands that have been selected as seed production areas, such as those in Kerala, Tamil Nadu, and Karnataka. The Sandal Research Centre has already surveyed and assessed sandalwood characteristics for both quality and quantity as a gene resource for breeding and conservation. "Plus-trees" have been selected on the basis of fast growth, maximum heartwood volume and fragrance, straight boles, resistance to pests and diseases, and flowering and fruiting ability (Barrett 1988).

The Forestry Research Division has obtained a seedlot of the Western Australian *S. spicatum,* and proposes to raise it for testing in the terai. This species is of interest since it will tolerate much more and conditions than *S. album* and may be more cold tolerant; there are often mild frosts (-2°C) in the desert where it grows naturally. It may therefore be more suited to Nepal than *S. album. S. spicatum,* however, has a relatively low oil content.

SEED PRETREATMENT

Santalum album seed has a minimum dormancy of 50 to 60 days, and untreated seed does not normally germinate for another 30 days or so (Ananthapadmanabha and others 1988). For 80 percent germination, about 7 months may be required (Barrett 1988). To speed up the germination, various pretreatments have been tested. The most successful appear to be some form of scarification (removing or nicking the seed coat) or soaking in gibberellic acid (Nagaveni and Srimathi 1980, 1981, 1985b; Mahdi 1986; Nagaveni and others 1989). Similar pretreatments are recommended for S. *spicatum* (Fox 1989, CALM undated). Results from New Caledonia have shown that scarification followed by soaking in water is the best pretreatment for *S. austrocaledonicum,* and that optimum temperatures for germination are between 28°C and 30°C. Manual techniques of nicking the seed coat and soaking in water are thought most suitable for propagation in Nepal.

NURSERY TECHNIQUES

Much research has been carried out into how best to propagate sandalwood. Techniques have been developed and undergone revision as understanding of its parasitic nature has increased.

In general, vegetative propagation methods have not been successful (Uniyal and others 1985).

Seed propagation techniques that are most suitable for nurseries in Nepal are those developed by the Sandal Research Centre at Bangalore. In these, sandalwood is raised in open beds, either sunken or raised, according to the climate. Barrett (1988) reports on techniques that require a greenhouse or shade house during the germination and subsequent potting out, but it would seem that these are less suited to Nepal.

Great attention should be given to treating seed, seedlings, and potting soils with fungicides and nematicides (Sandal Research Centre 1983, Sivaramakrishnan and others 1984). Germination is normally carried out in sand, sand and soil mixes, or vermiculite. Research in New Caledonia suggests that vermiculite is the best medium. Seedlings should be shaded 50 percent and protected from extremes of temperature, frost, and wind. They should not be over- or under-watered.

Sandalwood seedlings should be grown in pots with a suitable host. At present, a project funded by the Australian Centre for International Agricultural Research (ACIAR) is investigating a method of raising sandalwood seedlings in a dual-host system. This system involves a short-lived "primary" host in the nursery stage and for the first few months after planting in the field. Later a longer-lived "secondary" host is planted near the sandalwood to support it. For *S. album,* good results have been obtained in Timor, Indonesia, with *Sesbania grandiflora, Breynia cerrua,* or a local species of *Amaranthus* as the primary host (F. McKinnell, Project Leader, ACIAR Sandalwood Project, pers. comm.). Other primary hosts can include tomato, *Merdicago, Calitropis, Capsicum,* or any small legume such as *Cajanus* or acacias. Various grasses, herbs, and bushes make good intermediate hosts. Good secondary hosts include *Albizia* spp., acacias and other large legumes. Padmanabha and others (1988) suggest that *Casuarina equisetifolia, Melia dubia* [azedarach?] and *Acacia nilotica* are the best secondary hosts for S. album, although the following are also known hosts: *Acacia catechu, Bauhinia biloba, Cassia siamea, Dalbergia sissoo, Pongamia pinnata, Terminalia alba, T. arjuna* and *Wrightia tinctoria.* In New Caledonia *S. austrocaledonicum* is being very successfully raised using a small shrub, *Alternanthera* sp. as a primary host and *Paraserianthes falcataria [Albizia falcataria]* as the secondary host, although *Acacia spirorbis* is apparently sandalwood's most common natural host in New Caledonia and Vanuatu (Neil 1986, 1989).

Nepal could easily adopt this dual-host approach, as some of the potential hosts for each stage are already successfully grown in the country.

DIRECT SOWING

Direct sowing has been successfully practiced in a number of places (Dayal 1986). The seed needs to be treated with some form of poison to discourage predators. Seedlings will not survive the hot weather if they are not well established when the dry season begins or if they cannot be irrigated. Broadcasting does not generally give good results (Sinha 1961). Dibbling is the most successful and widely used technique (Troup 1921, Fox 1989). Pretreated seed is dibbled into the ground in areas that already have potential hosts either naturally present or artificially established. Some have suggested that for *S. spicatum,* direct sowing appears to produce plants of greater vigor than nursery-raised seedlings (CALM undated).

It would be interesting to test this technique in Nepal in areas where *Acacia catechu,* a recognized host for *S. album* in India (Sinha 1961), occurs naturally. The *A. catechu* would not only act as the host, but would provide shade and protection from browsing because of its thorns. Having said that, it is more likely that Nepal will adopt methods that utilize nursery-raised seedlings to establish stands of sandalwood.

PLANTATION ESTABLISHMENT

S. album will grow under a wide range of conditions. It will tolerate an annual rainfall from 500 to 3000 mm, temperatures from near zero to 40°C once it is established, altitudes up to 1800 m, depending on how cold it is, and various soil types from sandy to poor, rocky soils. Most often it grows on red ferruginous clay soils (Troup 1921).

Despite this potential to grow in a wide range of conditions, plantation sites should be carefully chosen. Annual rainfall ideally should be 600 to 1600 mm, and temperatures an annual minimum of about 10°C and maximum of about 35°C. There should be plenty of sun, although seedlings should be protected against excessive drought or heat. Altitudes of 700 to 1200 m are most suitable. Waterlogged soils should be avoided, while rich, fairly moist, fertile, iron-rich clay soils give best growth.

Many types of sites will likely exist in a given locality, but sandalwood will do best if planted in cultivated soils with host plants already established to provide shade (Mathur 1961, Streets 1962, Neil 1986, Fox 1989). Young sandalwood do not tolerate drought and should be planted into pits at the start of the rainy season. Sandalwood seedlings are occasionally planted in the same pit as their host; otherwise hosts are planted in alternate or adjacent pits. Trials have shown that hosts should be not farther than 2.2 m from the sandalwood, otherwise growth is very significantly affected (Ananthapadmanabha and others 1984). Hosts should be pruned if they overgrow the sandalwood, and weeding around both plants is necessary to maintain good growth.

Since sandalwood is very palatable to animals, it should be protected from browsing by fencing or surrounding it with thorny branches. It is also sensitive to fire, and appropriate precautions should be taken to protect it from this hazard.

CONCLUSIONS

Since sandalwood has previously been successfully established in Nepal, albeit only on a very limited basis, there appears to be potential for planting it here. On the basis of the methods described above, the following procedures for establishing sandalwood plantations should be followed until more reliable techniques are proven. These procedures could be just as easily applied to other countries interested in artificially establishing their indigenous or imported sandalwood.

- Use only a reputable source of high quality seed (e.g., genetically selected *S. album* seed from seed production areas in south India).
- Pretreat all seed by scarification, followed by soaking.
- Germinate the seed in beds of a 1:3 sand to soil mixture that has been treated with nematicides and fungicides. If available, vermiculite or a similar medium would be preferable.
- Move the sandalwood seedlings into large plastic pots (13 x 30 cm) at the four-leaf stage. A primary host such as *Sesbania* spp., *Cajanus cajan, Acacia* spp., tomato, *or Capsicum* spp. should be transplanted into the pots. Keep the seedlings under 50 percent shade and protect them from extremes of weather. Fertilizer should not be needed if a good potting mixture is used.
- Plant out seedlings at the start of the monsoon. The ideal planting site would be at an elevation of 700 to 1200 m, with annual minimum and maximum temperatures of 10°C and 35° respectively, and an annual rainfall of 600 to 1600 mm. Soils should be fairly moist, fertile, iron-rich clays. A secondary host should be present before planting, or introduced at the same time as planting the sandalwood. The site should be fenced to reduce the possibility of grazing damage. Precautions should be taken against fire.

• Seedlings should be well weeded, although some side shade should be maintained. Large host trees may require lopping to avoid overshading.

The priority areas for research should be:

• Selection of the most suitable primary and secondary hosts for sandalwood in Nepal—preferably indigenous species.

• Testing of various species of sandalwood that seem appropriate to conditions here (e.g., *S. album, S. spicatum).*

• Direct sowing of degraded forest areas that still retain potential host species, and that can be protected from grazing.

REFERENCES

Ananthapadmanabha, H.S.; Rangaswamy, C.R.; Sarma, C.R.; Nagaveni, H.C.; Jain, S.H.; Venkatesan, K.R.; Krishanappa, H.P. 1984. Host requirements of sandal *(Santalum album* L.). Indian Forester 110 (3).

Ananthapadmanabha, H.S.; Nagaveni, H.C.; Rai, S.N. 1988. Dormancy principles in sandalwood seeds *(Santalum album)* Linn. Myforest 24(l):22-24.

Angadi, V.G.; Kamala, B.S.; Rai, S.N. 1988. Effect of deficiency of trace elements on leaf area, chlorophyll level, and photosynthetic efficiency in tree seedlings. Myforest 24(2): 124-128.

Anon. 1987. Sandalwood in Nepal. Banko Janakari 1(1): 27-28 (Miscellanea). Bagchi, S.K.; Kulkami, H.D. 1985. Germination of open pollinated seeds and

survival of seedlings from the selected trees of *Santalum album.* Myforest 21(3):221-224.

Barrance, A.J. 1989. Controlled development of sandalwood in Vanuatu—a mid-term review of the five year moratorium on sandalwood cutting. Vanuata Forest Service, June 1989.

Barrau, J. 1960. Plantes utiles des î1es du Pacifique—Le Santal. Bulletin des études Pacifiques. July.

Barrett, D.R. 1988. *Santalum album* (Indian Sandalwood) literature survey. Mulga Research Centre, Western Australia.

Brandis, D. 1978. Indian trees. International Book Distributors, Dehra Dun.

CALM. [undated]. Germination technique for *Santalum spicatum.* Conservation and Land Management Department internal file note, Western Australia

Dayal, R. M. 1986. An assessment of propagation of sandal, *Santalum album,* by bush sowing techniques. Journal of Tropical Forestry 2(1): 44-46.

Douheret, J. 1981. Le santal en Nouvelle Calédonie. Nature Calédonienne, November.

Drury, C.H. 1985. The useful plants of India. International Book Distributors, Dehra Dun, (2nd edition).

Fox, J.E.D. 1989. Sandalwood for remnant bush areas. Land Management Society Newsletter. (Winter)6-7.

Hara, H.; Chater, A.O.; Williams, L.H.J. 1982. An enumeration of the flowering plants of Nepal. Vol. III. Trustees of the British Museum (Natural History), London.

Iyengar, A.V.V. 1960. The relation of soil nutrients to the incidence of spike disease in sandalwood *(Santalum album* Linn.). Indian Forester 86(4):220-230.

Mahdi, A. 1986. The biology of *Santalum album* seed with special reference on its germination characteristics. BIOTROP Technical Bulletin 1(1): 1-9.

Majupuria, T.C.; Joshi, J.P. 1988. Religious and useful plants of India and Nepal. Craftsman Press, Bangkok.

Mathur, C.M. 1961. Artificial regeneration of *Santalum album* in Rajasthan. Indian Forester 87(1).

Mathur, N.K. 1979. An annotated bibliography of spike disease of sandal *(Santalum album* Linn.) Forestry Research Institute, Dehra Dun.

Nagaveni, H.C.; Srimathi, R.A. 1980. Studies on the germination of sandal *(Santalum album* Linn.)—Chemical stimulant for germination. Indian Forester 106(11): 792-799.

Nagaveni, H.C.; Srimathi, R.A. 1981. Studies on the germination of sandal *(Santalum album* Linn.)—Pretreatment of sandal seeds. Indian Forester, 107(6).

Nagaveni, H.C.; Srimathi, R.A. 1985a. A note on haustoria-less sandal plants. Indian Forester 111(3): 161.

Nagaveni, H.C.; Srimathi, R.A. 1985b. Germination capacity of floating and sinking sandal seeds. Indian Forester 111(8): 615-618.

Nagaveni, H.C.; Ananthapadmanabha, H.S.; Rai, S.N.1989. Effect of different chemicals on germination of sandal seeds *(Santalum album* Linn.). Myforest 25(4): 311-313.

Neil, P.E. 1986. Sandalwood in Vanuatu. Forest Research Report 5/86, Vanuatu Forest Service, Vanuatu.

Neil, P.E. 1989. Notes on Vanuatu's indigenous acacia species. Nitrogen Fixing Tree Research Reports 7:62-64.

Neil, P.E. 1990. Possible techniques for raising and planting sandalwood in Nepal. Ranko Janakari (2(3): 223-228.

Nor, Salleh Mohd. 1982. Fiji resource information and management practices for forest industries development. FO:RASI78/010, Working Paper No.11, FAO, Kuala Lumpur.

Padmanabha, H.S.A.; Nagaveni, H.C.; Rai, S.N. 1988. Influence of host plants on growth of sandal. Myforest 24(2): 154-160.

Ramaswamy, N.M. 1956. Sandal spike—a plant virus disease. Indian Forester 82(2): 70-73.

Sandal Research Centre. 1983. Note on the techniques of raising sandal seedlings by adopting effective control measures against sandal seedling disease. Myforest 19(3):131-132.

Sen-Sanda, P.K. 1975. Spike disease of sandal—a yellows type disease. In: Pests and diseases of fast-growing hardwoods. 2nd FAO/IUFRO World Technical Conference on Forest Diseases and Insects, New Delhi, India. FOR:FAO/IUFRO/DI/75/16, Rome, Italy.

Sinha, R.L. 1961. Sandalwood in Bundelkhand Forest Division, Uttar Pradesh. Indian Forester 87(10): 590-597.

Sivaramakrishnan, V.R.; Ananthapadmanabha, H.S.; Ramanujam, B.; Subramani, M.; Nayar, R. 1984. Control of seedling disease of sandal *(Santalum album* Linn.) Journal of the Indian Academy of Wood Sciences 15(2): 60-64.

Shineberg, D. 1967. They came for sandalwood. Melbourne University Press.

Streets, R.J. 1962. Exotic forest trees in the British Commonwealth. Clarendon Press, Oxford.

Struthers, R.; Lamong, B.B.; Fox, J.E.D.; Wejesuriya, S.R.; Crossland, T. 1986. Mineral nutrition of sandalwood *(Santalum spicatum).* Journal of Experimental Biology 37(182): 1274-1284.

Troup, R.S. 1921. The silviculture of Indian trees. Vol. III. Clarendon Press, Oxford.

Uniyal, D.P.; Thapliyal, RC.; Rawat, M.S. 1985. Vegetative propagation of sandal by root cuttings. Indian Forester 111(3).

The Status of Sandalwood *(S. macgregorii)* in Papua New Guinea[1]

John H. Paul[1]

Abstract: *Santalum macgregorii* grows between 100 and 1500 m and is not evenly distributed throughout the country. It grows only around the central province where savannahs are found. Most of this original *S. macgregorii* stand was harvested during 1890-1910 and again in 1933. The government of Papua New Guinea does not have a stand of sandalwood. Any remains of *S. macgregorii* are owned and harvested by the landowners. Landowners then sell the graded logs to agents in Port Moresby, who in turn sell them to buyers in Hong Kong, Singapore, Taiwan, and Japan. Studies including phenology, silviculture, and growth of S. *macgregorii* are yet to be established.

Papua New Guinea lies in the southwestern part of the Pacific Ocean and covers a land area of 461,700 square kilometers between latitude 0° and 12°S and longitude 141° and 156°E. The country consists of the eastern half of the Island of New Guinea; the Trobriand, Woodlark, d'Entrecasteaux and Loursiade groups of Islands; the Bismarck Archipelago with New Britain, New Ireland, Manus; and the Buka and the Bougainville Islands of the Solomons.

The central part of Papua New Guinea is a massive mountain chain with peaks exceeding 4500 m (Mount Wilhelm 4508 m) that form a natural east-west barrier. The mountain chain is made up of a series of ranges divided by large fertile valleys at altitudes between 500 and 1800 m. High rainfall is responsible for the existence of many rivers, which are navigable only in their lower parts. Exceptions, however, are the Sepik River in the north and the Fly River in the southwest, both with extensive swamps. Southwestern Papua New Guinea is a flat land covered with dry evergreen forest (Department of Forestry 1986). It is here that Zieck (1970) and others reported stands of *Santalum macgregorii,* the Papua New Guinea species, in savannah areas.

THE SANDALWOOD INDUSTRY IN PAPUA NEW GUINEA

The general timber industry in Papua New Guinea has the potential to become one of the mainstays of the country's economy, as a provider of employment for an increasing number of people, as a major foreign exchange earner, and as a significant source of revenue for the government. Developments in the industry over the past 30-40 years have been marked. Export of forest products has expanded from a value of A$257,000 in 1951-52 to K82,069,900 in 1984 *(table 1).* This value is approximately 10 percent of the total national export earnings (Department of Forestry 1986).

Sandalwood is classified as a minor part of the forest products industry. The resource conditions of sandalwood are very poor, and, according to some reports, the sandalwood of Papua New Guinea was nearly cut out in 1975. They go on to say that sandalwood in Papua New Guinea should be given special care by the Forestry Department and local landowners. This care can be in the form of tending and protecting still available "root suckers" against grassland savannah fires. The law protecting the stand of sandalwood in Papua New Guinea was this (Smith 1927): "It shall be unlawful for any person to cut any sandalwood tree the trunk of which at the height of 1 foot (about 30 cm) from the surface of the ground measures less in circumference than 18 inches (46 cm). A licence may be issued to any person who wishes to cut sandalwood, or collect or buy it from natives. The licence shall remain in force for six or twelve months, and may be renewed. The fee payable shall be at the rate of £2 per year."

After an expedition in southwestern Papua New Guinea, Zieck (1970) reported that survival of many younger and older *Santalum* trees in the area was due to low population density, nearly no roads, no cattle grazing, and slight fire intensity for gardening or hunting purposes. Moreover, most of the *S. macgregorii* stands are surrounded by semi-deciduous thickets, which usually lack fire-susceptible grass. Howcroft (1990), in his working paper of the Review of Information on Papua New Guinea Sandalwood, stated that little information is available on Zieck's work on the Papua New Guinea sandalwood and that research is necessary.

EXPORT OF SANDALWOOD

Papua New Guinea's timber industry is rated as the third major revenue earner for the government, after mineral and agricultural commodities such as coffee, copra, cocoa, and palm oil. As can be seen in *table 1,* most of the timber revenue is earned through export of logs through major markets in Japan, South Korea, Australia, and New Zealand. Exported sandalwood is weighed in kilograms and not measured in cubic meters. According to statistics compiled by the Marketing Branch of the

Table 1—*Forest products exported from Papua New Guinea, 1984*

Commodity	Quantity		Value		Percentage	
	1984	(1983)	1984	(1983)	Value of Total	
	thou. cubic meters		thou. Kina[1]			
Logs	1283.9	(1019.2)	70272.8	(44055.7)	85.6	(79.3)
Woodchips	[2]102.5	[2](99.9)	6137.8	(5922.5)	7.5	(10.6)
Sawn Timber	17.8	(20.1)	3322.1	(3161.2)	4.1	(5.7)
Plywood	5.1	(5.5)	2317.2	(2464.2)	2.8	(4.4)
Sandalwood	—	(0.1)	16.3	(45.6)	—	(0.1)
Veneer Flitches	—	(—)	—	(31.7)	—	(0.1)
Chopsticks	—	(0.1)	3.7	(17.0)	—	
Total	1306.8	(1045.0)	82069.9	(55697.9)	100.0	(100.0)

[1]Kina = US$1.01 or AUS$1.4671 (1985).
[2]Thousand bone dry units. 1 bdu = 1.546 m^3

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai'i.

[2]Assistant Tree Breeder, Papua New Guinea Forest Research Institute, Lae, Papua New Guinea.

Table 2—*Forest products exported from Papua New Guinea, 1987*

Product	Actual							Anticipated	
	1982	1983	1984	1985	1986	1987	1988	1989	1990
	Thousand cubic meters								
Logs Sawn	1063	1019	1283	1158	1314	1442	1507	1550	2050
Timber	21	20	18	15	7	4	10	40	50
Plywood	6	6	5	1	.2	.02	3	10	10
Woodchips	148	100	103	82	61	66	80	100	100
Total	1238	1145	1409	1256	1382	1512	1600	1700	2200
Value	53	56	82	67	77	113	126	136	176

Notes: Value is million kina at free on board price. Log exports will stabilize at around 2,000,000 m^3/yr. On-shore processing will increase significantly.

Department of Forestry, 100 kg of sandalwood were produced in 1983, bringing in K45600. In 1984 the revenue earned was K16300. The data in *table 2* are also from the Marketing Branch, but sandalwood was not included for 1987 exports (Department of Forestry 1987).

From 1891 until 1980, a total of about 9,000 tonnes of sandalwood were exported. Zieck (1970) reported that sandalwood harvesting for export in later years (1962-1964) came more from inland areas. Otherwise easily accessible stands were cut down between 1890 and 1910, and probably again in 1933.

Howcroft (1990) in his working paper reported that a total of 8,150 tonnes of sandalwood were sent to Singapore and China from Port Moresby before 1971. As estimated by Zieck, a cut of 180,000 trees would have been required to supply this amount.

Overseas Markets

The markets for sandalwood from Papua New Guinea are in Hong Kong, Singapore, Taiwan, and Japan, through intermediate merchants or entrepreneurs in Port Moresby. Through approval of the National Investment and Development Authority (NIDA), there is no restriction on the quantity of sandalwood exported. *Table 3* contains the statistics on the quantity of sandalwood exported and the amount sold for the period 1891-1976 (Zieck 1970).

Preparing Sandalwood for Export

After sandalwood is felled it is cut into logs of about 1 meter (3-4 ft) for de-sapping. The felled log must have a heartwood diameter of 18 cm (7 inches), as cutting trees of smaller diameter is prohibited. Logs are then air dried to attain a moisture content of about 18 percent. The logs are then graded and classified into five groups: roots and stumps, crooked thin pieces (e.g., good branches), logs with holes, straight small logs, and big logs (25-37 cm; 10-15 inches) with no holes.

Export Prices

In 1978 the price for *S. macgregorii* per tonne was K400-K1000, while the same quantity of Indian sandalwood *(S. album)* was sold at A$2000-5000. In 1980 Indian sandalwood was valued at £2000 per tonne ($6000/tonne). Indian sandalwood contains 95 percent santalol, while that of Papua New Guinea contains 45 percent santalol and perhaps has a value of about a third or a quarter of the mentioned amount.

Local use of sandalwood is possible with the availability of forestry distillation equipment that can extract 3-5 percent of the santalol oil. The quality of the oil would be low, but it can be used in the local perfume industry, for example, as in manufacturing soap. With the addition of chemicals the quality can be improved, but chemicals are rather costly.

PROBLEMS RELATED TO THE SANDALWOOD STAND IN PAPUA NEW GUINEA

The problems related to the *S. macgregorii* stand in Papua New Guinea are numerous. I will describe two of them. According to Zieck (1970, p. 2), the stand is not continuous for two reasons: "... the grassy open savannah areas are more sensitive to fire. Large tracts of semi deciduous thickest vegetation enclose many islands of open savannah forest where more sandalwood stands may be expected after more detailed investigations. And, that the light loving sandalwood seemed to avoid the thickest. In some way this could be one of the causes of the discontinued distribution."

Howcroft (1990) reported that Zieck raised sandalwood seedlings in the Brown River (west of Port Moresby), using host plant seedlings in the same pots. He successfully used guava *(Psidium guava)* as a host plant for *S. album* at Brown River but later lost the sandalwood when the guava died. Howcroft also reported that several Eucalyptus species were identified by Zieck as hosts for the local sandalwood, but there is no information to substantiate this claim.

The value of Papua New Guinea sandalwood *(S. macgregorii)* is low in comparison with Indian sandalwood *(S. album)*. Therefore any artificial propagation should be with Indian stock or seed.

Table 3—*Sandalwood exports from Papua (Zieck 1970)*

Year	Value	Quantity (tonnes)	Value Per Tonne	Year	Value	Quantity (tonnes)	Value Per Tonne
1891-92	£290	42.98	£6.75	1921-22	£609	19.30	£31.55
1892-93	7183	913.49	7.86	1922-23	282	11.17	25.24
1893-94	1896	326.14	5.81	1923-24	585	18.28	32.00
1894-95	2568	384.86	6.67	1924-25	666	15.24	43.70
1895-96	4035	533.21	7.56	1925-26	250	5.08	49.02
1896-97	2323	305.06	7.61	1926-27	240	6.09	39.40
1897-98	2940	309.27	9.50	1927-28	424	21.33	19.87
1898-99	2290	312.11	7.34	1928-29	225	3.05	73.77
1899-1900	8698	737.66	11.79	1929-30	2779	99.06	28.05
1900-01	2957	208.46	14.18	1930-31	716	28.45	25.51
1901-02	8353	642.26	13.00[1]	1931-32	2,523	93.21	27.07
1902-03	4494	361.84	12.41	1932-33	536	25.65	20.89
1903-04	8382	599.94	13.97	1933-34	2699	105.15	25.66
1904-05	7873	489.10	16.10	1934-35	5,548	174.50	31.79
1905-06	2522	213.75	11.80	1935-36	268	8.38	31.98
1906-07	3932	276.29	14.23	1936-37	85	7.11	11.95
1907-08	6346	427.73	15.00[1]				
1908-09	2701	204.50	13.20				
1909-10	4628	308.52	15.00[1]				
1910-11	190	15.54	12.20	1962-63[2]	4934	30.73	160.53
1911-12	259	173.26	15.00[1]	1963-64	13,493	78.99	170.82
1912-13	74	5.00	15.00[1]	1964-65	3528	18.99	185.78
1913-14	85	5.66	15.00[1]				
1914-15	1363	54.52	25.00[1]	1972-73[2]	$800	3.13	$256.00
1915-16	1416	52.83	26.80	1973-74	638	1.45	440.00
1916-17	633	25.40	24.52	1974-75			
1917-18	252	10.05	25.87	1975-76	K157,367	208.279	K755.00
1918-19	704	22.14	31.79				
1919-20	2071	31.09	66.60				
1920-21	222	4.06	54.62				

	Period 1891-92 to 1913-14 j (23 years)	Period 2 1914-15 to 1936-37 (23 years)	Period 3 1962-63 to 1964-65 (3 years)
Value p.a.)	£85,019 (£3,696 p.a.)	£25,096 (£1,091 p.a.)	£21,955 (£7,318
Quantity	7640.6t (332.2 t.p.a.)	841.14t (36.6 t.p.a.)	128.71t (42.95 p.a.)
Value/ Tonne	£11.6	£33.60	£172.4

Total for 51 years: $265,578 ($5207.4 p.a.); 8615.1 tonnes (168.9 t.p.a.)

[1]Here statistics only mention values, so quantities were determined by an estimated value per tonne.

[2]No exports from 1937-38 to 1961-62 and from 1965-66 to 1971-72.

Sandalwood grows on the driest part of Papua New Guinea, on savannah forest and on grassland. Tending the parasite seedling is critical until it can withstand all but very hot grass fires. This need applies whether the seedling is naturally or artificially propagated. A young sandalwood stand is sensitive to fire; thus it is necessary to protect it from the yearly fire that is customary in its natural habitat—if it is to succeed.

A second problem of sandalwood in Papua New Guinea is that the government owns none of the sandalwood forest. Any remainder of the original stand is owned by a traditional landowner.

RECOMMENDATIONS

As mentioned earlier, sandalwood in Papua New Guinea is classified with minor forest products, together with others like rattan. Despite the value of sandalwood *(table 1),* to date neither the Forestry Department nor any other organization has shown interest in developing the sandalwood industry. This lack of interest could be due to both economic factors and to the density of the sandalwood stand in Papua New Guinea.

Howcroft (1990), who cited several publications relating to sandalwood in Papua New Guinea and who was once nominated by a former Director of Forestry, A. Yauieb, to carry out the work left by Zieck, reported that further research on Papua New Guinea sandalwood is necessary. He came up with the following recommendations before any future work is proposed and implemented:

(a) Research should be carried out to see whether any further information is available from J. Zieck's work on *Santalum.*

(b) Any available herbarium material from Papua New Guinea sandalwood should be inspected to collect information on distribution, flowering, and fruit production.

(c) Further collections should be studied by the Botany Branch for distribution records.

(d) Host plant compatibility trials should be conducted with local and introduced *Santalum* species.

(e) Fire control management trials should be implemented with native sandalwood, and growth data collected.

CONCLUSIONS

There may be undiscovered sandalwood stands in Papua New Guinea. The only person who studied Papua New Guinea sandalwood was J. Zieck, but he did not complete his work.

Intensive studies including phenology, growth, and general silvicultural techniques for Papua New Guinea sandalwood are yet to be established.

ACKNOWLEDGMENTS

I thank the East-West Center and others for funding my trip to Hawai‘i for the symposium, the Papua New Guinea Forest Research Institute for allowing me the time to attend the symposium, and N. S. H. Howcroft for his comments and review of this paper.

REFERENCES

Department of Forestry. 1986. Forest research in Papua New Guinea. Port Moresby.

Department of Forestry. 1987. Annual Report. Port Moresby, Papua New Guinea.

Howcroft, N.S.H. 1990. A review of information on Papua New Guinea sandalwood. Department of Forestry, Lae.

Smith, S.M.B.E. 1927. Handbook of the Territory of Papua. Port Moresby.

Zieck, J. 1970. Minor forest products: sandalwood (and rattan) in Rigo Sub District. Department of Forestry, Port Moresby.

Status of Sandalwood Resources in Vanuatu[1]

Leonard Bule **Godfrey Daruhi**[2]

Abstract: On eight islands of Vanuatu archipelago, sandalwood stands have been heavily exploited since the late 1800's. Because of the over-exploitation, which worried the Vanuatu Government, a moratorium was imposed in early 1987. The status of the valuable wood and the beginnings of research into one of the country's potential commodities are reviewed.

Sandalwood is one of the most common commodities in Vanuatu and has been valued by people who own the trees as a direct sources of cash. This valuable commodity has been extensively cut throughout the country from the early 1800's until 1987, when a 5-year moratorium was imposed to ban the exploitation of this valuable resource in the country. It is believed that sandalwood has been completely depleted from one island (Aneityum) as a result of the big rush to exploit the resource between the 1800's and the early 1900's.

This paper details the Department of Forestry's views on the future use and development of sandalwood resources in Vanuatu after the current running moratorium, January 1,1987 to January 1, 1991. It uses the earlier reports by Neil (1986) and Barrance (1989a).

STATUS OF SANDALWOOD IN VANUATU

Sandalwood occurs on eight islands: Espiritu Santo (the west side of the Cumberland Peninsula), Malakula (Dixon Reef), Efate, Erromango, Tanna, Aniwa, Futuna, and possibly Aneityum *(fig.1)*. It is believed, however, that this valuable resource has been depleted on Aneityum as a result of over-exploitation during the last century. A moratorium on the cutting of sandalwood for 5 years is currently being imposed.

In early 1987 the Vanuatu Government sent a formal request to the Australian Government to fund a national Forest Resource Inventory Survey, with an emphasis on investigating Vanuatu's sandalwood resources. Subsequently, Vanuatu Government approached the Centre Technique Forestier Tropical (CTFT)—a division of the International Center of Agriculture Research for Development (ICARD)—for assistance. CTFT has done a lot of work on the biology and silviculture of the sandalwood. Initial contact with Vanuatu has been established, with ICARD's official resident representative there requesting a Fact-Finding Mission by ICARD to the country. C'I FI or ICARD could also offer research and development support. It is our hope that after this Fact Finding Mission, coordinated research and development programs will be established in Vanuatu with ICARD's participation.

A Smallholder Sandalwood Extension planting program is being proposed but would not eventuate until the department is fully equipped with the expertise the implement the program successfully. Demonstration plots will be established prior to this extension program on islands where sandalwood occurs.

The objective here is to attract landowners' interests and acquire the necessary techniques before developing the program on a smallholder scale. An extension policy has yet to be decided on by the Department of Forestry, which may extend the current moratorium on cutting of sandalwood for another 5 years after January 1, 1991.

The possibility of establishing a Market Unit in the near future within the department is our consideration. The objective is to identify, monitor, and advise on potential markets in the country and overseas for all forest products expected from existing and proposed Industrial Forest Plantations and any developed Smallholder Forestry Ventures. Recommended prices for sandalwood would be publicized by the Unit to protect the producers from unscrupulous purchasers.

TRADE AND HISTORY OF SANDALWOOD EXPLOITATION

Sandalwood produces a scented and oily heartwood much prized for its valuable aromatic oil, which is used in perfumery and medicines. In China, it was and still is used in connection with various religious observances. It was the high prices available in the eastern ports at the beginning of the 19 century that sent swarms of adventurers in search of the wood and started the "Sandalwood Trade."

The first Pacific Islanders to feel the effect of scramble for sandalwood were the Fijians. To all intents, their sandalwood had been cut out by 1816 (Shineberg 1967). The Marquesas were stripped of their sandalwood at around the same time, and Hawaii was exploited between 1811 and 1828.

Erromango was the first island in Vanuatu to have its sandalwood exploited for trade to China after missionary Peter Dillon visited the island in 1825. None of the islanders in this area made use of their sandalwood except for some of the people on Tanna, who used it as fuelwood. Thus, no special value was placed on the wood. Exploitation of stands on the Isle of Pines, Loyalty Islands, and New Caledonia (mainland) started in the 1840s.

By the early 1850's sandalwood was gradually becoming more and more difficult to find in Vanuatu. Aneityum had been completely stripped; the forests of Efate had been greatly depleted; only Erromango still had large amounts of wood, but it was not easy to obtain (MacClancy 1981). However, in 1853, sandalwood forests were discovered on Espiritu Santo and for the next decade, exploitation continued. By 1865, the sandalwood trade had practically ceased (Shineberg 1967). The wood was still taken in small quantities in the late 1860's and later as supplementary cargo.

Sandalwood must have occurred in prolific amounts in some of these Melanesian countries to have survived unremitting

[1]Presented at the Symposium on Sandalwood in the Pacific, April 9-11, 1990, Honolulu, Hawai'i.

[2]Director, and Head of Research and Technical Support Section, Vanuatu Forestry Department, Port Vila, Efate, Vanuatu.

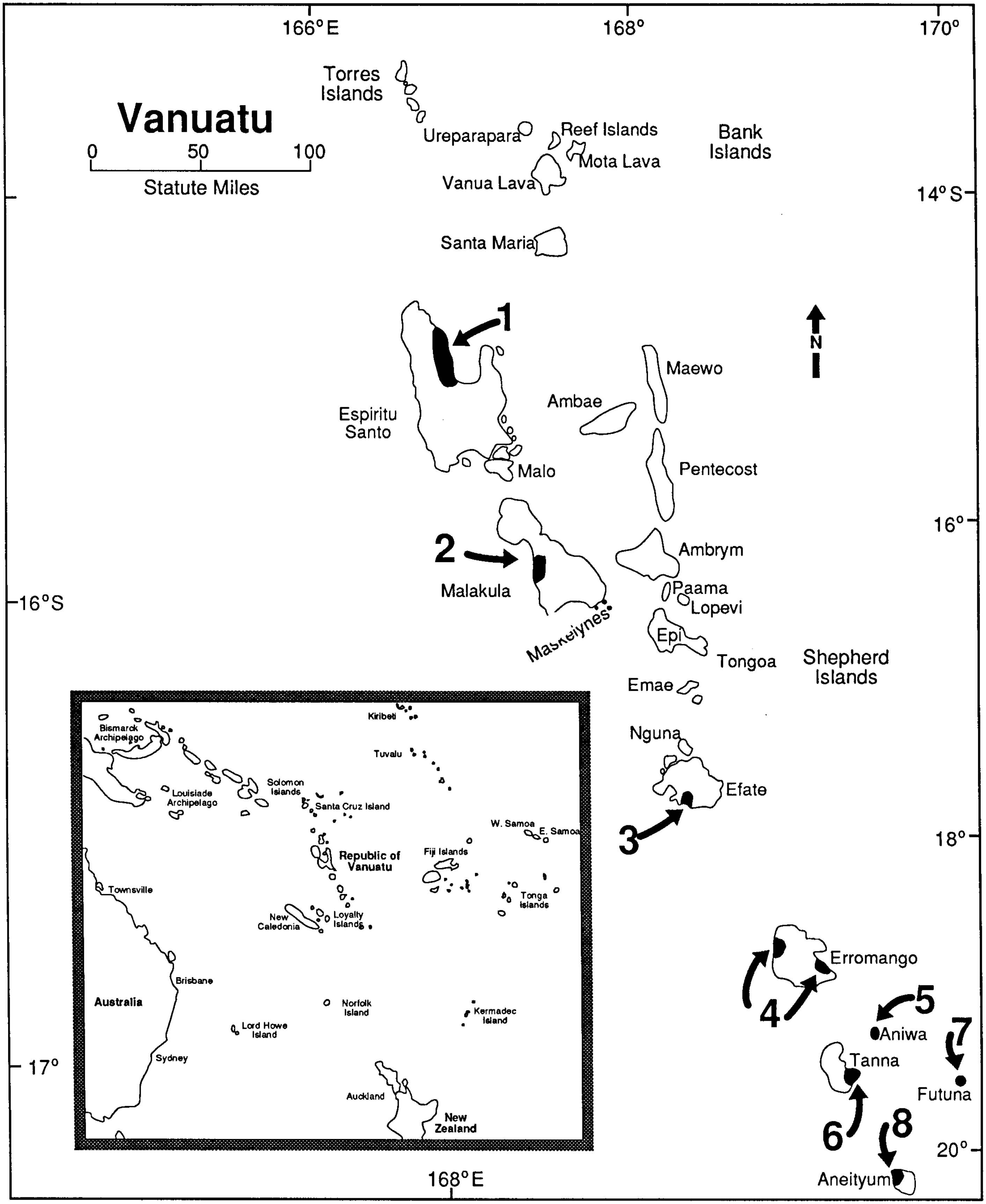


Figure 1—The island republic of Vanuatu.

exploitation for over 30 years, as there were apparently no attempts at conservation or replanting. In particular, Erromango must have been extremely rich since despite being one of the first islands in Vanuatu to be exploited, and being continuously visited during the whole period, it was still yielding wood in 1865. In addition, the sandalwood from Erromango was reputed to be of superior quality than that cut elsewhere (Neil 1986).

Exploitation of sandalwood continued in Vanuatu until the first of January 1987, when the government imposed the current moratorium on cutting of sandalwood following Neil's proposals (1986) *(table 1).*

Table 1—*Statistical information for 1977-1987*

Year	SANTO		VILLA		TOTAL	
	Metric Tonnes	Thousand[1] Vatu	Metric Tonnes	Thousand Vatu	Metric Tonnes	Thousand Vatu
1977	4	170	35	1,740	39	1,910
1978	—	—	40	3,400	40	3,400
1979	—	—	47	2,960	47	2,960
1980	—	—	61	3,440	61	3,440
1981	—	—	11	80	11	80
1982	—	—	44	3,141	44	3,141
1983	—	1,834	35	2,656	60	4,292
1984	—	493	44	3,118	52	3,612
1985	—	—	58	4,247	58	4,247
1986	73	13,748	37	2,582	110	16,330
1987	32	8,688	172	14,932	204	23,620
Totals	142	24,933	584	42,296	726	67,032

Source: National Planning and Statistics Office, Vila, Vanuatu. Government f Vanuatu.

[1] About 120 atu = U.S. $1.

PROBLEMS WITH SEED SUPPLY

The Department of Forestry has proven through research that the Vanuatu species of sandalwood—*Santalum austro-caledonicum*—is especially suitable for planting. The main problem is seed supply; it is difficult to ensure a consistent supply of viable seed from different mother trees because they tend to be very variable. Seeds also need careful handling to prevent them from deteriorating. Trees have started producing well again since the devastation of Cyclone Uma in 1987.

CURRENT INTEREST

Thus far three foreign companies have proposed to manufacture sandalwood products within the country for export markets, primarily Taiwan and China. All three proposals were rejected for various reasons.

CURRENT RESEARCH

As previously mentioned, the Ministry of Agriculture, Forestry and Fisheries, issued a 5-year moratorium on sandalwood cutting and exporting in January 1987 with the following objectives:

(a) to protect the remaining resources;

(b) to allow time for an inventory of total production, from which sustainable annual cut yields could be calculated;

(c) to allow the Research Section to investigate the ecology of the species, with the goal of enhancing field production;

(d) to allow the Research Section to establish an extension program.

So far the Research Section has established two trials to investigate the most efficient means of growing sandalwood.

Trial No. 1

The first trial, established in 1987 under the direction of P.E. Neil, the Forest Research Officer, was designed to gain basic information on sandalwood growth rates and performance at the Ipota plantation site on Erromango. The trial was of simple random design with 3 m by 3 m spacing, with growth rates being measured annually. The seedlings were raised from seed from neighboring Aniwa, a small, low lying island southeast of Erromango.

The site was typical of the Ipota area, being covered with secondary bush, of which the dominant species were a grass species, burao *(Hibiscus tiliaceus),* navenu (*Macaranga* spp.), and small patches of melek tree *(Antiaris toxicaria).* The soils are of moderately humic, unsaturated ferrallitic, red-brown type and are rich in clay minerals. The site relief is undulating, being on a moderately dissected plateau ranging from 150-200 m elevation, and on the wetter (avg. 1200 mm) side of the island.

On analyzing the measurement data to date in October 1989, the 22-month-old trial then had mean heights of 1.91 m and a basal diameter of 10.40 cm. Adrian Barrance, a former forestry research officer from the United Kingdom, suggested in his assessment of the trial (Barrance 1989b) that sandalwood in Vanuatu appears to grow very well without association with a host plant. This view is apparently contrary to results found in other countries where host plants are regarded as essential to good production (Barrance 1989b).

However, since the question of the relationship between sandalwood and its host(s) remained unresolved by the first trial, Barrance suggested that a second trial be established to investigate the matter further.

Trial No. 2

The second trial was established to compare establishment success and initial growth rates with the most promising primary host(s) currently known to us, *Alternanthera sessilis,* against fertilized and untreated controls.

Seed stock was taken from Ipota, Erromango. The trial, of nursery scale type with seedlings growing in bags on Cyclone mesh wire beds in plots of 150, includes the following treatments:

(a) seedlings with primary "host" *A. sessilis,*

(b) seedlings with NPK fertilizer, and,

(c) seedlings without treatments as a control.

The trial was established at the Vila Tagabe Nursery in January 1990, and height increments are measured and general performance is observed weekly. It is too early in the trial to draw any conclusions; the first initial assessment is planned for June 1990, when the trial will be 6 months old.

Extension

The program and extension materials have been kept simple, both to make them easier for the islanders to understand and to allow our Forest Rangers to gradually build their experience in this field. The following outlines the extension steps taken to date:

(a) Leader farmer demonstration plots. Demonstration plots with seedlings have been established and free technical advice is being provided on the land of a number of leader farmers on Aneityum and Erromango, the main sandalwood-growing islands in the group. It was considered important to establish these plots on private land to ensure full and visible participation by landowners to encourage others to follow suit. Any revenues arising out of these plots will go to the landowners, but it is intended that there will be a charge for future materials and/or technical advice—the ultimate aim being to make this project self-sustaining.

(b) Extension. In addition to the leader farmer demonstration plots, Forest Rangers are also visiting other smallholders, discussing the project, and distributing an explanatory leaflet on the subject. This leaflet, written in simple terms in Bislama (Vanuatu pidgin), the national language, contains a step-by-step sandalwood growing guide from seed collection and treatments to establishment and crop care methods *(appendix)*.

FURTHER WORK NEEDED

The following sections outline further research and extension requirements for promotion of the project:

Extension

(a) Publicity. Further publicity by radio, either by a specific program or as part of existing Agriculture Extension programming, would be useful. The Research Section is looking into this.

(b) Expansion of Demonstration Plots. More leader farmer demonstration plots, especially in areas distant from Forestry Stations, are planned to extend the project to a greater number of people.

(c) People with forestry expertise are needed for extension efforts.

Research

Establishment of international provenance trials is planned.

REFERENCES

Barrance, A. 1989a (June). Controlled development of sandalwood in Vanuatu (A Mid-Term Review of the Five-Year Moratorium on Sandalwood Cutting). Research report on file, Forestry Department, Port Vila, Vanuatu.

Barrance, A. 1989b (November). Research Trials: Results of trials up to 1989. Research report on file, Forestry Department, Port Vila, Vanuatu.

MacClary, J. 1981. To kill a bird with two stones. Publication No. 1: Vanuatu Cultural Center.

Neil, P.E. 1986. Sandalwood of Vanuatu. Report 5/86, Research Report on file, Forestry Department, Port Vila, Vanuatu.

Shineberg, D. 1967. They came for sandalwood. Melbourne University Press.

APPENDIX

FORESTRY DEPARTMENT - VANUATU GOVERNMENT

PLANT SANDALWOOD ON YOUR LAND !

Lots of people have considered cuttig sandalwood growing on their land in order to earn money. In some parts of Vanuatu, sandalwood is in short supply or has been completely exploited. For this reason, the Government has imposed a 5 year ban on sandalwood cutting which is from 1978 to 1992. During this period, an inventory will be conducted and research carried out. This will be a good time for sandalwood planting - don't wait until your sandalwood has disappeared !

1. Collecting Seeds

Sandalwood seeds ripen twice a year: sometimes in May and at about October - November. Collect only ripe seeds which are bluish in colour and are soft. Seed collection from trees or have just fallen are good. Old seeds which are on the ground are not suitable for planting.

2. Washing Seeds

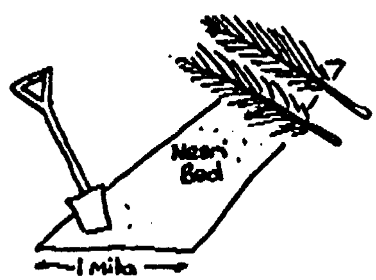
The seeds should be washed directly after collection to remove the flesh: the flesh should not be left to rot on the seeds. The seeds should be sowed directly after washing. If this is not possible, they should be stored in a dry, cool and well ventilated area
Plastic bags should not be used as they cause mouldiness to the seeds.

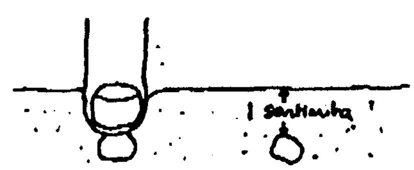
3. Establishing a Nursery

An area behind 'the house should be appropriate where the soil is easy to work with and accessible to water. The bed should be dug about 1cm wide. Work the soil until you have a fine tilth then smooth off the bed and water it.

4. Sowing in the Nursery

To sow, push the seeds into the bed one at a time, using your index finger to a depth of about 1cm, that is about to the top of your finger nail. Bury them lightly. Coconut fronds can be used for shade.



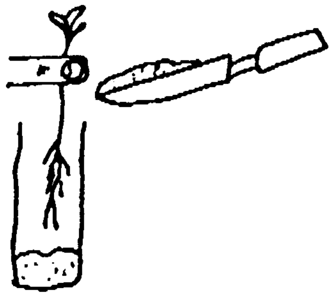


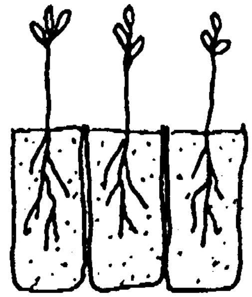
5. Containerising

Dig up some dark soil, but don't dig too deep to use red or solid material. Work the soil to a fine tilth removing roots, stones and hard lumps of soil. Pile the soil in the nursery. Get some small plastic bags which are about 15-20cm long and 5cm in diameter.

6. Transplanting

When the seeds germinate, dig them up and transplant them into the plastic bags. The, transplanted seedling should have some soil attach to the roots. Holding the seedling in the plastic bag, start filling the soil When filling make sure the roots are vertical for good support and anchorage. If potting is done first then planting, the roots may easily be damaged or anchorage would be poor. After transplanting, the seedlings may be watered and may be put under coconut frond shade.



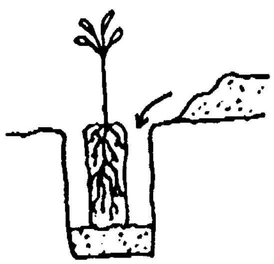


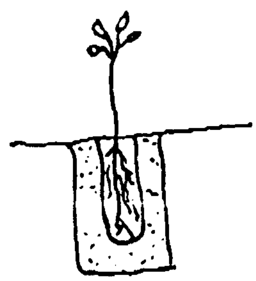
7. Land Preparation

Select somewhere where the bush should not be too dense. The area should not be totally cleared because sandalwood grows well in proximity with other trees, such as amoung Acacias.
If there is cattle morning around, the area should be fenced off.
When the trees are ready for planting, the area should be marked out and use a spacing of 3 x 3m. At each location (only), the site should be slightly cleared.

8. Planting

Allow the trees to grow to about 20-25cm in height, which by then they should be ready for planting. Hardening-off should be done 1 or 2 weeks before planting, but if scorching is seen, shading should be placed back. At each location marked for planting, a hole should be dug to about 30-40cm deep and 20cm across. The plastic bag must be removed before planting. Put some soil back into the hole in order that the seedling root collar is level to the surrounding ground. Fill the hole up and press with your hand to ensure that the seedling is firm.





GPO 788-746/39280