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.

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

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

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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

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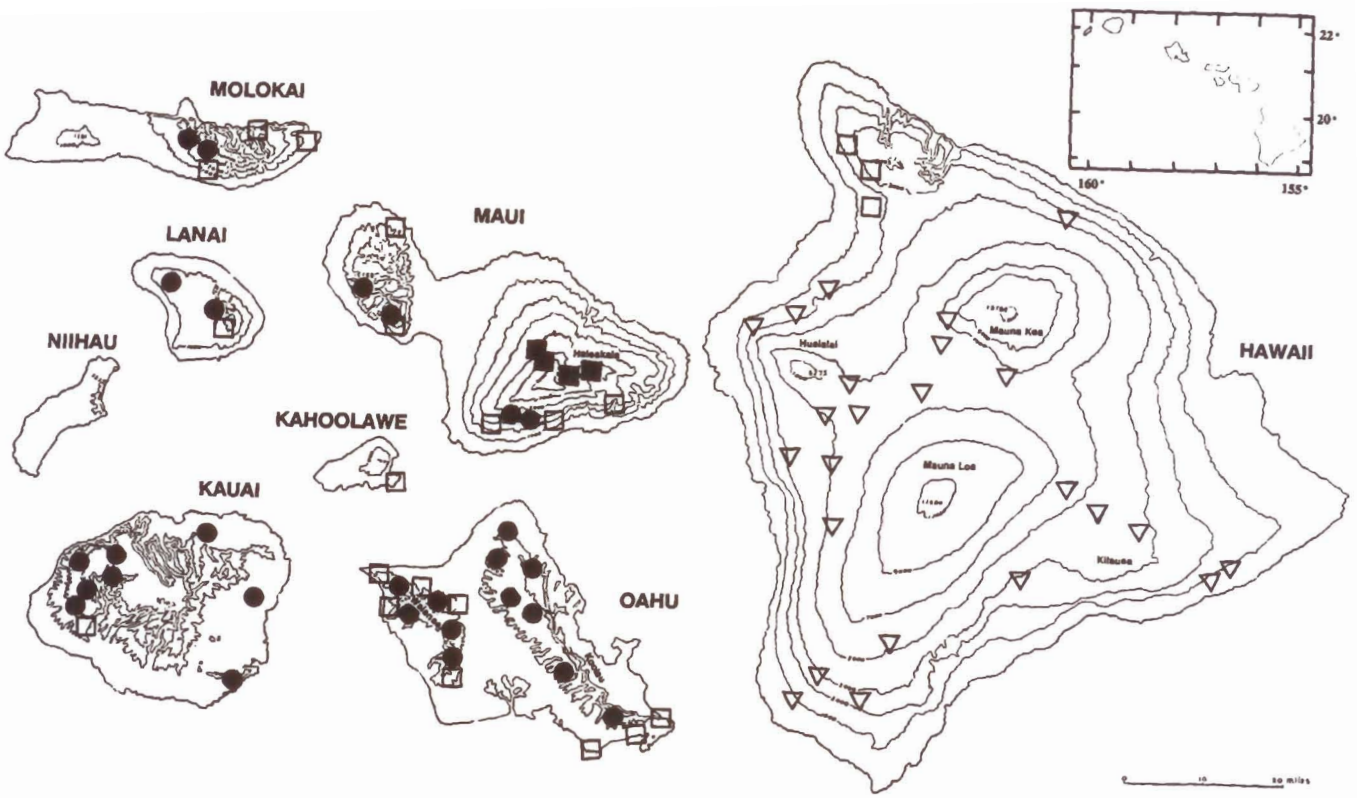

Figure 1—Generalized distribution of Hawaiian sandalwoods.

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 Moloka'i, Lana'i, 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 'alala, 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 Hawai'i 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 O'ahu, 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 Ko'olau 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 O'ahu 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 Lana'i 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 Kaho'olawe. This species, however, is still found on many other Hawaiian islands.

MANAGEMENT NEEDS IN HAWAI'I

In Hawaii, extensive stands of sandalwood are only known from the island of Hawai'i. 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 Akiapola'au, 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.

Hawai'i 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.

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Status and Cultivation of Sandalwood in India[1]

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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.

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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/cm²/s	Chlorophyll a	Chlorophyll b	Chlorophyll Total	Stomatal frequency per mm²
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

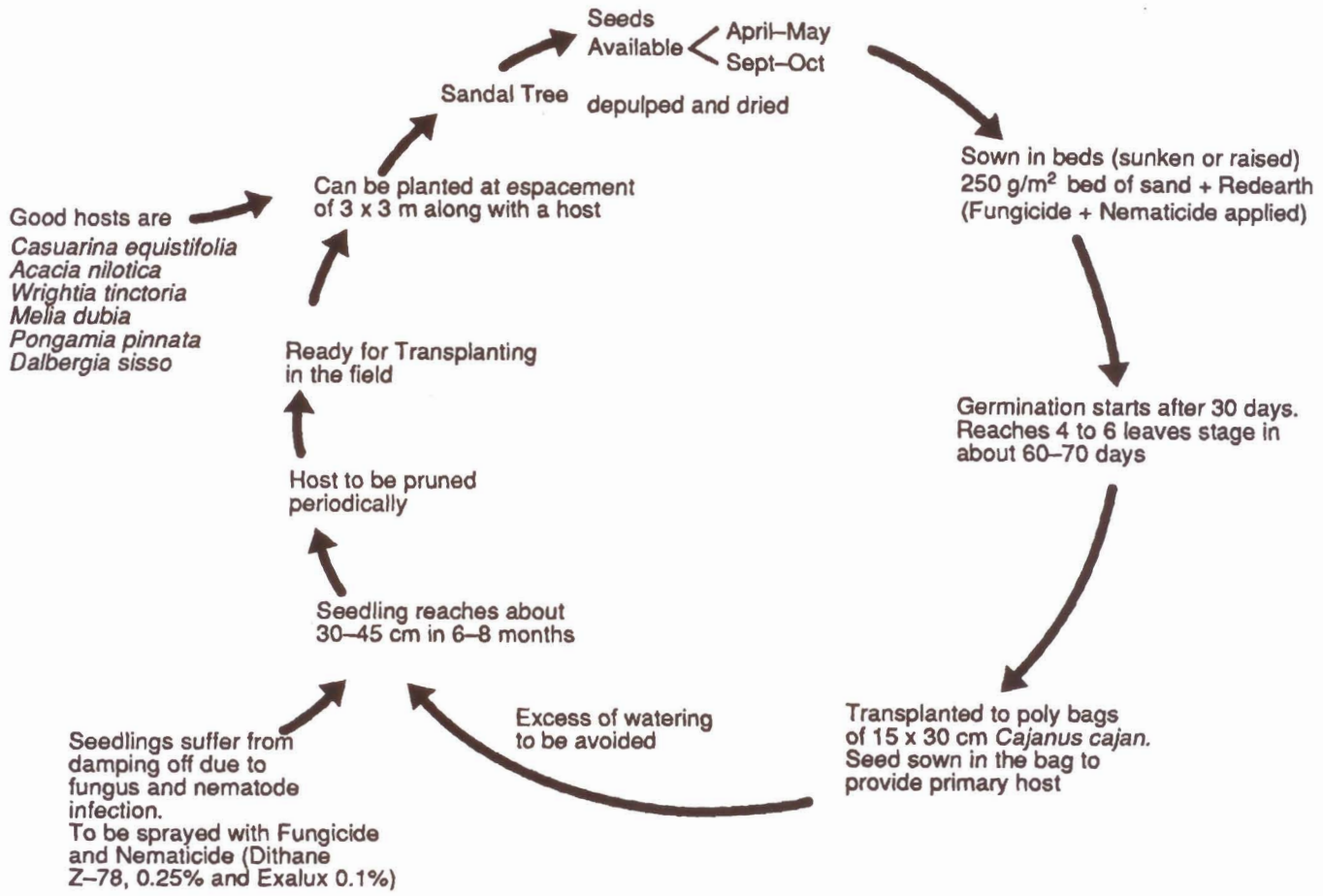

Figure 2—Cultivation of sandalwood from seeds.

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.

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Growing Sandalwood in Nepal—Potential Silvicultural Methods and Research Priorities[1]

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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).

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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.

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