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Santalum ellipticum, S. freycinetianum, S. haleakalae, and *S. paniculatum* (Hawaiian sandalwood)

Santalaceae (sandalwood family)

ʻ*iliahialoʻe* (***S. ellipticum***)
ʻ*iliahi*, ʻ*aʻahi*, ʻ*aoa*, *lāʻau ʻala*, *wahie ʻala* (***S. freycinetianum*, *S. haleakalae*,** and ***S. paniculatum***)

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IN BRIEF

Distribution Hawaiian Islands, varies by species.

Size Small shrubs or trees, typically 5–10 m (16–33 ft) or larger at maturity.

Habitat Varies by species; typically xeric, subhumid, or humid tropics with a distinct dry season of 3–5 months.

Vegetation Open, drier forests and woodlands.

Soils All species require light to medium, well drained soils.

Growth rate Slow to moderate, 0.3–0.7 m/yr (1–2.3 ft/yr).

Main agroforestry uses Homegardens, mixed-species forestry.

Main uses Heartwood for crafts, essential oil extraction.

Yields Heartwood in 30+ years.

Intercropping Because sandalwood is parasitic and requires one or more host plants, intercropping is not only possible but necessary.

Invasive potential Sandalwood has a capacity for invasiveness in disturbed areas, but this is rarely considered a problem.

PHOTO: M. MERLIN

***Santalum freycinetianum* var. *lanaiense*, rare, nearly extinct. Photo taken near summit of Lānaʻihale, Lānaʻi in 1978.**

INTRODUCTION

Hawaiian sandalwood species are small trees that occur naturally in open, drier forest and woodland communities. They are typically multi-stemmed and somewhat bushy, attaining a height of 5–10 m (16–33 ft) or larger at maturity, and spreading to about the same width. Sandalwoods generally do not persist in moister, denser forest types due to their poor tolerance of high shade levels. The trees generally tolerate a broad range of soil conditions but show a preference for well drained neutral to slightly alkaline soils. They grow more quickly in fertile soils but are then at risk of being shaded out or overtopped by taller, faster growing trees on such sites.

In Hawai'i, there was a general belief in the early part of the 20th century that sandalwood had become extinct (St. John 1948). In fact, all four of the presently recognized species still exist. Three of these are not yet threatened with extinction or extirpation from any island where they are endemic. The fourth species, *S. haleakalae,* currently is a geographically and ecologically very restricted species. Its seeds and seedlings are quickly consumed by rats in its limited subalpine habitat on the upper slopes of East Maui's Haleakalā volcano. In addition, *S. freycinetianum* var. *lanaiense* on Lana'i Island is presently threatened by alien ungulate browsing and may become extinct in the near future if complete removal of the introduced hoofed animals is not sanctioned and carried out quickly. Although Hawaiian sandalwood species are still rare in most of their former ranges, natural, or perhaps artificial, regeneration could conceivably provide a very valuable natural resource that could be harvested on a sustainable basis.

Sandalwood trees are root-parasitic, which means they have special root extensions that capture water and nutrients from roots of certain other plants. The plants that donate nutrients to sandalwood are called hosts, and sandalwood does not grow well without them. Sandalwoods are also capable of root-suckering; this is most apparent after a tree is cut down, when clumps of suckers may regenerate in a circular pattern several meters away from the original stump.

Sandalwoods are well suited to interplanting, and due to their root-parasitic nature they need to be grown with other suitable host tree species. They may be interplanted with various other species, which could provide additional sources of revenue. Sandalwoods have a good regeneration potential and ability to colonize/invade nearby suitable sites. As long as some mature fruit-bearing trees are retained, birds will spread the fruit. Their invasive potential is seldom considered a drawback due to the exceptionally high value of their heartwood coupled with their small stature and susceptibility to being shaded out.

SANDALWOOD TERMS

Hemi-parasitic Describes a plant that photosynthesizes but derives water and some nutrients through attaching to roots of other species. Sandalwood is hemi-parasitic. In this text, the term "parasitic" is used in place of "hemi-parasitic."

Root-grafting This is where roots, usually of the same or related species, grow together, form functional unions, and exchange materials. Sandalwood roots can "graft" onto many different species, effectively joining whole plant communities through their root systems.

DISTRIBUTION

Native range

S. ellipticum

Endemic to Hawaiian islands, this species can be found as a sprawling to bushy shrub near the ocean shore. It is also occasionally found as a somewhat larger shrub to small tree in dry gulches, on slopes or ridges, and frequently in 'a'ā lava or rocky habitats. The species also grows in arid shrub land and forest, often persisting in areas invaded by non-native species up to elevations up to 560 m (1840 ft), and sometimes as high as 950 m (3120 ft) elevation on all of the main islands. It is now extinct on Kaho'olawe and Laysan, rare on Kaua'i, and on Hawai'i it is only known to exist in scattered areas, such as in the Kohala Mountains, Pu'uwa'awa'a in the North Kona District, and Pu'upāpapa and several other of the nearby cinder cones in the South Kohala District. It may also be found very rarely in the lower subalpine area between Mauna Kea and Mauna Loa (Wagner et al. 1999).

S. freycinetianum

Endemic to Hawaiian islands, this species can be found occasionally to commonly in moderately wet to very humid forests but also in dry forest on Lāna'i; it frequently occurs on slopes or ridges from as low as 250 m (820 ft) to as much as 950 m (3120 ft) on Kaua'i, O'ahu, Moloka'i, Lāna'i, and Maui (Wagner et al. 1999).

S. haleakalae

Endemic to Maui only, this species is restricted to scattered areas in the subalpine shrub land on dry slopes, especially in foggy areas at 1900–2700 m (6230–8860 ft) on Haleakalā (Wagner et al. 1999).

Santalum ellipticum **along Wai'anae coast, O'ahu.** PHOTO: M. MERLIN

***Santalum freycinetianum*, southern Wai'anae mountains, O'ahu.** PHOTO: M. MERLIN

***Santalum paniculatum*, Pu'uhuluhulu, island of Hawai'i.** PHOTO: M. MERLIN

***Santalum haleakalae*, subalpine region of East Maui.** PHOTO: M. MERLIN

S. paniculatum

Endemic to Hawai'i island only, this species is found in dry forest areas on lava substrates or on cinder cones up to higher elevations in more humid forest, or in secondary *Metrosideros* forest from about 450 m to 2550 m (1480–8360 ft) in elevation (Wagner et al. 1999).

Current distribution

Hawaiian species have primarily been planted inside of their natural range for economic or preservation purposes.

BOTANICAL DESCRIPTION

Preferred scientific names

Santalum ellipticum Gaud.
Santalum freycinetianum Gaud.
Santalum haleakalae Hillebr.
Santalum paniculatum Hook. & Arnott

Family

Santalaceae (sandalwood family)

Common names

Hawai'i

S. ellipticum: *'iliahialo'e*
S. freycinetianum, S. haleakalae, S. paniculatum: *'iliahi*, *'a'ahi, 'aoa, lā'au 'ala, wahie 'ala*

Other generic common names

sandalwood (English)
sándalo (Spanish)
bois de santal (French)

Size

S. ellipticum

A sprawling shrub to small tree, typically 1–5 m (3.3–16 ft) tall and 1–3 m (3.3–10 ft) in canopy diameter, maximally reaching 12 m (39 ft) tall and 5 m (16 ft) in canopy diameter, and bole diameter at breast height (dbh) of 30 cm (12 in). This species is extremely variable in vegetative and floral characters (Wagner et al. 1999, Little and Skolmen 1989).

S. freycinetianum

A small shrub to tree typically 1–9 m (3.3–30 ft) tall and 3–7 m (10–23 ft) in canopy diameter. The maximum tree dimension is 13 m (43 ft) tall and 10 m (33 ft) in canopy diameter, and bole diameter at breast height is 80 cm (31.5 in) (Wagner et al. 1999, Little and Skolmen 1989).

S. haleakalae

A small tree typically 2–4 m (6.6–13 ft) tall and 2–4 m (6.6–13.2 ft) canopy diameter. The maximum tree dimension is 4 m (13.2 ft) in height and canopy diameter. Maximum bole dbh is 20 cm (8 in) (Wagner et al. 1999, Little and Skolmen 1989).

S. paniculatum

A shrub or tree 3–10 m (10–33 ft) tall and 3–7 m (10–23 ft) canopy diameter. In some relatively protected situations, *S. paniculatum* will grow to heights of 15–20 m (49–66 ft). The maximum canopy diameter is 10 m (33 ft) with a bole diameter at breast height of 1 m (3.3 ft) (Wagner et al. 1999, Little and Skolmen 1989).

Flowering (Wagner et al. 1999)

Under good conditions plants begin flowering from an early age, typically about 3–4 years, but heavy flowering and fruiting may take 7–10 years. There is considerable variation in seasonality of flowering and fruiting. Trees flower and fruit throughout the year, usually with two peaks. Most species have a fruiting season throughout spring, summer, and fall.

S. ellipticum

The inflorescence is greenish in bud; after opening, the corolla remains greenish but is tinged with brown, orange, or salmon. Flowers are about as long as wide, produced in terminal, and more or less axillary, compound cymes. Pedicels are 0–1 mm (0–0.04 in) long, the floral tube is campanulate to conical, 4–7 mm (0.16–0.28 in) long, and the ovary is inferior. Flowers produce a sweet fragrance.

S. freycinetianum

Flowers are longer than wide, red to yellow in bud, and produced in terminal, more or less axillary, relatively open, compound cymes. Pedicels are normally 1–4 mm (0.04–0.16 in) long, with bracts that are rapidly deciduous. The floral tube is yellowish white to white but turns red as it ages; it is campanulate to cylindrical. The inner surface of the corolla, normally 8–17 mm (0.32–0.67 in) long, is pink to dark red. The ovary is partly inferior. Flowers produce a weak fragrance.

S. haleakalae

Flowers are longer than wide, reddish to cream-colored in bud, and produced in congested, terminal, compound cymes, very occasionally with a few extra axillary flower clusters. The pedicels are 2–4 mm (0.08–0.16 in) long. The bracts persist until flowering, and the campanulate to cylindrical floral tube is white, turning dark red as it ages. The

Santalum ellipticum. PHOTOS: M. MERLIN

Santalum haleakalae. PHOTO: M. MERLIN, INSET: J. B. FRIDAY

***Santalum freycinetianum* var. *lanaiense*.** PHOTOS: J. B. FRIDAY

Santalum paniculatum. PHOTOS: C. ELEVITCH

corolla is 8–17 mm (0.32–0.67 in) long; its outer surface is dark red and glaucous externally, turning to the same color on the inner surface after opening. The ovary is partly inferior. Flowers produce a weak fragrance.

S. paniculatum

Flowers are approximately as long as wide, greenish in bud, and produced in terminal and more or less axillary, compound cymes. The pedicels are about 1 mm long. The floral tube is campanulate to conical. The corolla is 4–8 mm (0.16–0.32 in) long and greenish but tinged with brown, orange, or salmon after opening. The ovary is inferior. Flowers produce a sweet fragrance.

Leaves (Wagner et al. 1999)

S. ellipticum

Leaves are 2.5–6.1 cm (1–2.4 in) long and 1.7–4 cm (0.67–1.6 in) wide, with petioles up to 15 mm (0.6 in) long. They are elliptic to orbicular, ovate, or obovate in shape and leathery to succulent. They have dull, grayish green, frequently glaucous upper and lower surfaces.

S. freycinetianum

Leaves are 4–9 cm (1.6–3.5 in) or occasionally longer and 1.3–7.5 cm (0.5–3 in) wide, with an acute to rounded apex. Petioles are 5–25 mm (0.2–1 in) long. The leaves are green,

Santalum ellipticum**.** PHOTO: J. B. FRIDAY

Santalum haleakalae**.** PHOTO: M. MERLIN

Santalum freycinetianum* var. *lanaiense**.** PHOTO: J. B. FRIDAY

Santalum paniculatum**.** PHOTO: C. ELEVITCH

occasionally a bit glaucous, more or less wilted in appearance, and tinged with purple when immature.

S. haleakalae

Leaves are 2.5-7.5 cm (1–3 in) long and 2–6 cm (0.8–2.4 in) wide with 2–7 mm (0.08–0.3 in) long petioles. Leaf shape is ovate, obovate, or orbicular, and the stiff to coriaceous surfaces are olive green, frequently tinged purple, and normally glaucous.

S. paniculatum

Leaves are 2.5–8 cm (1–3.1 in) long and 2–4.5 cm (0.8–1.8 in) wide with 2–15 mm (0.08–0.6 in) long petioles. Leaf shape is ovate, elliptic, or obovate, and the surfaces have glossy upper sides and dull, sometimes pale, lower sides. Both surfaces are often glaucous, and usually of different colors, occasionally yellowish orange to bluish or olive green.

Fruit (Wagner et al. 1999)

S. ellipticum

Mature fruits are purple to black drupes, often glaucous, 9–12 mm (0.4–0.5 in) long, with a distinctive apical receptacular ring.

S. freycinetianum

Mature fruits are reddish purple to almost black drupes at maturity, 8–24 mm (0.3–1 in) long, with a distinctive sub-apical receptacular ring.

S. haleakalae

Mature fruits are black or purplish black drupes 10–15 mm (0.4–0.6 in) long, with a distinctive sub-apical receptacular ring.

S. paniculatum

Mature fruits are purple to black drupes 10–12 mm (0.4–0.5 in) long, with a distinctive apical receptacular ring.

Seeds

The kernels consist of a hard, woody, smooth or slightly rough, light-colored endocarp enclosing a single seed. Data is lacking for seed size for the Hawaiian species.

Birds are the principal means of seed dispersal. However, in many habitats the fruits and seeds are attacked by rats (*Rattus exulans*, which were introduced by Polynesians before 1778, and more recently, *R. rattus*). In fact, rats have all but eliminated reproduction of the endangered Lana'i variety of *S. freycinetianum* in the wild by eating the fruits before they fall (Ziegler 2003).

Rooting habit

Sandalwoods have a widely spreading surface root system capable of grafting onto many other plant species and tapping water and mineral nutrients.

Look-a-like species

Look-a-likes include *S. album* (from India, Indonesia, and Australia), but it has been little planted in Hawai'i.

How to distinguish from similar species/look-a-likes

Fruits are very useful for distinguishing related tropical species. In *S. album,* the mature fruits are truncate-globular to ellipsoidal, have a raised calyx scar to about 5 mm (0.2 in) across forming an apical collar, and enclose a flat or slightly depressed disc with a small point.

GENETICS

Variability of species

All species exhibit considerable morphological variation, and numerous traditional varieties are recognized. In the past, taxonomists have divided the extremely variable species of *Santalum ellipticum* and *S. freycinetianum*. This resulted in the classification of as many as nine different native Hawaiian *Santalum* species. The four presently accepted Hawaiian species may be derived from two separate colonizing events. These are represented by two sections of the genus *Santalum*. *S. freycinetianum* and *S. haleakalae* are related to *S. album* and are all lumped into the section *Santalum*, characterized by red or red-tinged petals with flowers longer than wide that produce much nectar. *Santalum ellipticum* and *S. paniculatum* are the lone members of the endemic section *Hawaiiensia* Skottsb. They are typified by green petals that become yellowish brown, orange, or occasionally salmon, and the flowers are approximately as wide as long but produce little or no nectar. *Santalum ellipticum* and *S. paniculatum* probably evolved from other Polynesian species of *Santalum*. (Wagner et al. 1999).

***Santalum album* fruit.** PHOTO: L. THOMSON

Known varieties (Wagner et al. 1999)

S. ellipticum

This species is highly variable, both in vegetative and floral characters. As many as six taxa have been proposed for individuals belonging to *S. ellipticum*. However, there is no single or group of characters that provide a sound basis for an enhanced subdivision of this species. Research by Stemmermann (1980), based on leaf succulence, glaucous fruit, and shrubby habit, recognized a coastal type as var. *littorale*. However, all of the characters used to differentiate the variety can also be found in inland plants in *S. ellipticum*. Furthermore, the coastal form represents an extreme of the variation pattern. Essentially, this form represents an ecotype and probably does not warrant formal recognition.

S. freycinetianum

Three varieties with overlapping phenotypic forms have been recognized for this widespread species. These are *S. freycinetianum* var. *lanaiense* and var. *pyrularium*. These varieties are differentiated on the basis of leaf and floral tube form.

S. haleakalae

This geographically and ecologically restricted species appears quite closely related to *Santalum freycinetianum* var. *lanaiense* and is thus in need of additional research. Such investigation may show that the specific rank for *S. haleakalae* is unwarranted and it is best included under *S. freycinetianum*.

S. paniculatum

Although Fosberg (1962) included this species as a variety of *S. ellipticum*, more recent taxonomic research by Stemmermann (1980) indicates that, based on differences in leaf form and color, and shrub or tree habit, there are two significantly intergrading varieties of *S. paniculatum*; these are var. *paniculatum* and var. *pilgeri*.

ASSOCIATED PLANT SPECIES

S. ellipticum

This species has successfully developed into relatively large individuals when growing with endemic species such as *Wikstroemia sandwicensis* (ʻākia) and the Nihoa Island fan palm *Pritchardia remota* (loulu) in windward, lowland areas among other native species. In more xeric environments *S. ellipticum* has developed successfully in association with the endemic shrub *Chenopodium oahuense* (ʻāheahea), an introduced euphorb (*Chamaesyce hypericifolia*), and introduced grass species. Apparently *S. ellipticum*, if it does need a host plant, is flexible in the species it can parasitize for needed nutrients (Culliney and Koebele 1999).

S. freycinetianum

This species obtains some vital nutrients from other woody species such as koa (*Acacia koa*), an endemic forest tree which, when available, is reportedly the main host (Culliney and Koebele 1999).

S. haleakalae

Not identified, but most likely needs native species adapted to the subalpine habitat as hosts for its partial parasitism.

S. paniculatum

Not identified, but most likely needs to parasitize any of a number of native or exotic species that are adapted to the relatively wide range of habitats in which this species can grow.

ENVIRONMENTAL PREFERENCES AND TOLERANCES

Climate

Hawaiian species are variously adapted to a variety of ecological ranges (from sea level to the subalpine zone), at least as represented by the existing populations.

S. ellipticum

Adapted to arid habitats with typical summer drought in leeward lowland locations.

S. freycinetianum

Adapted to moderately wet to wet habitats.

S. haleakalae

Adapted to cool to cold, moderately wet to arid subalpine habitat of Haleakalā.

S. paniculatum

Adapted to moderate dry to wet habitats on Hawaiʻi only.

Elevation

S. ellipticum 0–560 (–950) m (0–1840 [–3120] ft)
S. freycinetianum (250–) 400–650 (–950) m ([820–] 1310–2130 [–3120] ft)
S. haleakalae (1800–) 1900–2700 m ([5900–] 6230–8860 ft)
S. paniculatum 450–2000 (–2550) m (1480–6560 [–8360] ft)

Mean annual rainfall

Direct rainfall data for Hawaiian species is lacking. General information on moisture regime is:

S. ellipticum Xeric lands.
S. freycinetianum Mesic to wet forest.
S. haleakalae Xeric subalpine.
S. paniculatum Xeric to wet forests.

Rainfall pattern

All species are found in climates with summer rains.

Dry season duration (consecutive months with <40 mm [1.6 in] rainfall)

Most localities experience a pronounced dry season of 2–5 months during the cooler months from January to May.

Mean annual temperature

Direct temperature data correlated to species is lacking.

Minimum temperature tolerated

For all species, the entire distribution is frost-free, with the exception of *S. haleakalae*.

Soils

S. ellipticum thrives in sandy soils, including those derived from raised limestone, but also does well in clay soils. Additional soil data for this and the other Hawaiian sandalwood species are lacking.

Soil texture

They prefer light and medium, well drained soils (sands, sandy loams, loams, and sandy clay loams).

Soil drainage

All species require freely draining soils.

Soil acidity

Acid to neutral soils (pH 4.0–7.4) are acceptable. They prefer neutral soils (pH 6.1–7.4).

Special soil tolerances

The species tolerate shallow and infertile soils.

Tolerances

Drought

They are able to survive a long dry season (up to 5–6 months) when attached parasitically to suitably drought-tolerant host plants.

Full sun

The plants can grow well in full sun when roots are attached parasitically to suitable host species; otherwise, plants growing in full sun can become yellow and even die.

Top: *Santalum ellipticum* is unique in its adaptation to coastal conditions, here in Makapu'u, O'ahu. PHOTO: M. MERLIN **Bottom: *Santalum ellipticum* growing in an upland area in Pu'uwa'awa'a, Hawai'i.** PHOTO: J. B. FRIDAY

Shade

They can survive with up to 60–70% shade, but growth will be very slow at higher shade levels. The optimum level of shade is up to about 25%, preferably as side shade. Side shade is provided by adjacent bushy, but not spreading plants that grow up to about the same height as sandalwood without overtopping them and casting overhead shade.

Fire

All species are sensitive to fire (and grazing) particularly in the first few years of growth.

Frost

All of the tropical sandalwood species are likely or known to be frost-sensitive, except perhaps *S. haleakalae*, which is adapted to the subalpine zone of Haleakalā.

Waterlogging

Prefer good drainage and will die or die back following any prolonged period (longer than 2 weeks) of waterlogging.

Salt spray

Plants growing in near-coastal situations may suffer severe scorching by salt-laden winds followed by total defoliation after cyclonic storms, but they usually recover fully. A coastal ecotype of *S. ellipticum* is an exception; it is adapted to growing near or along the coast, usually as a sprawling or small shrub.

Wind

Mature plants are typically of low stature and fairly resistant to strong winds associated with cyclonic storms. Younger specimens in open areas, especially if they have grown quickly and have a heavy canopy, may be blown over by strong winds or suffer breakage of stems and branches.

GROWTH AND DEVELOPMENT

Growth rate

After exhausting energy stored in the seed, seedlings may stop growing for a number of weeks during what may be termed a "waiting period." When necessary root contacts are established with other species, a rapid increase in growth of the plant begins. Frequently, the new growth in *S. ellipticum* and *S. paniculatum* manifests a distinct alteration of leaf color from an initial red or pink to a bluish green. Rapid addition of new foliage is a strong indication that the plant has established good water and nutrient uptake by its own roots in the soil and through its unions with roots of other plants. Development regimes and longevity records for Hawaiian sandalwood species are lacking.

Reaction to competition

Sandalwoods, especially as young plants, react poorly to competition from monocotyledons (such as grasses and coconuts). Being parasitic, they are best grown in close proximity to suitable host species.

Diseases and pests

Hawaiian sandalwood species generally appear to resist most insect attack, although weak infestations of whitefly or scale insects sometimes do occur. Insecticidal soap may be used to treat such pest infestations. Infrequently, a small gray weevil feeds on the young leaves, but usually not to a significantly damaging degree. Some insects such as cockroaches, sow bugs, crickets, and a variety of cutworms may nibble at ground-level stem parts. Slugs and snails may also feed on newly sprouted plants. To avoid lethal girdling of a seedling, a protective barrier such as a plastic container should be used to protect each newly planted seedling. This is laborious for new plantings of many seedlings but may preclude large losses (Culliney and Koebele 1999).

Abilities

Regenerate rapidly

Regeneration of wild sandalwood stands typically occurs very slowly following harvesting. This is due to the removal of most of the fruiting, larger specimens and, in at least some cases, the removal of other species whose roots the sandalwood plants parasitize.

Self-prune

In open situations, sandalwood plants often retain branches to near ground level. In shadier situations, especially where the shade is cast from overhead, plants exhibit reasonably strong self-pruning characteristics. Suitable shade regimes to keep plants growing straight and to avoid a bushy habit include either strong lateral shade with no overhead shade or a high canopy of intermediate shade.

Coppice

Plants frequently resprout from basal coppice, or by root suckering off lateral roots following removal of the stump and major roots. However, such coppice regrowth is likely to die out in heavily shaded situations.

Pollard

Plants can be pollarded, but this is not an appropriate regime for sandalwood because of the slow regrowth.

Other

Many species are capable of root suckering as long as not too much of the root system is removed during harvest.

Root shoots of *S. paniculatum* growing from exposed root. PHOTO: C. ELEVITCH

PROPAGATION

All species are readily propagated by seed in the nursery. Seedlings can also be collected from underneath selected heavy-fruit-bearing specimens and then transplanted to a new location. Vegetative cuttings taken from seedling material may be struck under mist. Cuttings from young plants strike much more readily than cuttings from old plants. Grafting and root-segment cuttings from mature specimens can be used to conserve selected individuals or bring them into breeding programs.

Since Hawaiian sandalwood plants rarely develop beyond the seedling stage in containers, they should be outplanted when they are youthful seedlings, before 6 months of age (Culliney and Koebele 1999).

Propagation by seed

Seed collection

It is recommended that mature fruits be collected while still attached to the tree, although recently fallen fruits may also be acceptable. Fruits that have attained maturity are full size and usually have begun to show slight color change, commonly a reddish tinge. For most species, flowering may occur year-round, with peak flowering in the late summer and fall. For all species, fruits mature about 4 months after flowering. Ripe fruits are reddish-purple to black. Seeds may be collected from the tree by hand, or collected from the ground, often with the pulp decayed or removed by birds.

Seed processing

The fleshy mesocarp needs to be removed from the fruits as soon as possible. Fruit that is hard to depulp by hand may be soaked for 1–2 days to soften the pulp prior to its removal. The depulped, cleaned seeds may then be disinfected (e.g., with diluted bleach) before being rinsed and air-dried in a well ventilated room, at a temperature below 25°C (77°F), out of direct sun, for up to 2–3 weeks. The number of viable seeds per unit weight varies considerably among species, provenances, and individual seedlots.

Seed storage

Many sandalwood species show intermediate storage behavior, with seed rapidly losing viability during storage. Seed storage behavior varies among species, and may even vary among seed sources. Seeds with high oil content, such as those of *Santalum*, are normally short-lived in storage.

It is usually preferable to sow sandalwood seeds as soon as possible after collection to reduce the risk of their losing viability during storage. If seeds must be stored, they should be placed in airtight containers in the refrigerator (2–4°C [36–39°F]) as soon as possible following surface drying. In general, ultra-dry storage (e.g., down to about 2% moisture) is recommended for this type of seed. Seeds of *S. freycinetianum* air-dried to 8% moisture have retained good viability for several years when stored at 5°C (41°F).

Germination rates vary from 10% to 50%, depending on seed lot and germination method. Germination of up to 90% can be achieved with fresh and healthy seed and proper germination technique.

Pre-planting treatments

Scarification treatment has been shown to produce quick germination of viable seeds of *S. ellipticum* and *S. freycinetianum.* Before treating, seeds should be removed from the ripe fruit, cleaned by hand, and air-dried for about a week. After this, a small part of the seed coat at the apex of the seed should be removed so that the embryo becomes visible but is not damaged. This can be done using nail clippers, forceps, or medium sandpaper. Soaking the seeds in a growth hormone solution can greatly improve results. One recommended method is to soak the seeds in diluted (0.05%) gibberellic acid (a plant hormone) for 5 days, changing the solution daily. After 5 days, the seeds are removed from the growth hormone solution and dusted with a 1:1 mixture of powdered sulfur and captan to prevent fungus infection.

Growing area

Seeds are germinated under cover in a greenhouse or other protective structure. The germination area should be protected from rats, birds, and other predators that will eat seeds or young seedlings. As seedlings grow, they are moved to progressively higher light levels, e.g., 50% shade in the early months, then 25% shade. Two months of hardening under full sun is recommended prior to field planting.

Germination

Seeds are germinated in trays of vermiculite, preferably with a translucent cover to keep humidity high and protect from pests such as rats and birds. The mixture should be kept slightly moist but not wet in order to avoid rotting of seeds and damping off. The optimum temperature for germination is between 28°C and 31°C (82–88°F). When pretreated as described above, *S. ellipticum* and *S. paniculatum* begin to germinate after approximately a week and continue germinating over a 2–3 week period. Without the hormone and scarification pretreatments, germination takes much longer (Culliney and Koebele 1999). The seed's thick wall will develop a crack as the root emerges. The seedlings can then be placed in individual containers in a mixture consisting of equal parts of fine cinder (not black sand) and vermiculite. The success rate of germination following the above treatment can be greater than 90%, even for seeds more than 6 months old (Culliney and Koebele 1999).

At the two- or four-leaf stage a host plant can be planted together with the seedling (see host table).

S. paniculatum **germinants sprouting in pure vermiculite.** PHOTO: C. ELEVITCH

Media

The potting mixture used should be well drained with reasonable water-holding capacity, such as equal parts of fine cinder (not black sand) and vermiculite.

Time to outplanting

Seedlings are ready for outplanting after about 6 months when height is about 20–25 cm (8–10 in).

Guidelines for outplanting

Sandalwoods need to be either planted out among established long-term host plants, or else together with intermediate hosts (relatively short-lived woody perennials) while longer term hosts are established (see Suitable Hosts box).

Survival rates are high (>80%) for large, healthy seedlings planted at the onset of the rainy season and kept well weeded in the first 2 years. Survival and growth will be low for plants established in shady forest situations or grassy, sunny situations.

Santalum ellipticum and *Santalum freycinetianum* should be placed in the ground within 2–6 months of germinating, because they will hardly ever grow beyond this stage in pots. The seedlings can be planted directly into the ground from their vermiculite sprouting trays after establishment in a 1:1 fine cinder:vermiculite mixture. The planting hole should have enough space so as to not cramp the root structure of the seedling (Culliney and Koebele 1999).

SUITABLE HOSTS

Koa (*Acacia koa*), koaiʻa (*Acacia koaia*), aʻaliʻi (*Dodonea viscosa*), and koʻokoʻolau (*Bidens* spp.) are thought to be good native Hawaiian host plants. Exotics such as amaranth (*Amaranthus* sp.), strawberry (*Fragaria* sp.) and beggar's tick (non-native *Bidens* spp.) are reputed to be good short-term hosts. Other exotics that are used outside Hawaiʻi as long term hosts (but not recommended in Hawaiʻi unless already present on site) include *Calliandra* spp., *Casuarina* spp., and *Pinus caribaea*.

Propagation using wildlings

The following technique is useful for promoting germination of wildlings, which can then be transplanted and grown on in the nursery before field planting in a suitable location.

- Select sandalwood trees that are fruiting or are known to fruit heavily.
- Clean undergrowth from beneath the canopy of the selected sandalwood trees.
- Loosen the soil in the cleared area by shallow digging or cultivating only the top 5 cm (2 in) of the soil.
- Wildlings begin to germinate in the cultivated area about 1–2 months after soil disturbance.
- If possible, water the cultivated area during dry periods or after some seedlings are observed.
- Keep the cultivated area weeded.

DISADVANTAGES

The main drawbacks of planting sandalwood are

- lack of seed and planting materials
- relatively complex silviculture and need to be grown with suitable host plant species
- susceptibility to root and butt rot fungi and rapid death of plants when grown in higher rainfall zones
- risk of theft of trees when nearing maturity.

Potential for invasiveness

Sandalwood species generally have a capacity for invasiveness in disturbed, more open plant communities. This is not considered a problem because of their very high value, their small stature, and the fact that they do not appear to modify such communities in any substantial way. Due to being classified as a parasitic plant, importation of viable *Santalum* seed into the U.S. (including Hawai‘i) is prohibited by federal law.

Host to crop pests/pathogens

Not known to be an important host to any crop pests and diseases.

Other disadvantages or design considerations

Security is an issue with sandalwood. Trees should be planted in well protected areas in which opportunities for theft are minimized, such as in homegardens, isolated areas, and well fenced, closely guarded locations.

Sandalwoods are root parasites, with the potential to "root graft" and link whole plant communities. They are therefore at particular risk of infection from pathogenic fungi, such as *Phellinus noxius,* that can also spread from tree to tree through root grafts. For this same reason, herbicide sprayed on healthy plants can be transferred to sandalwood through root grafts.

Threats to survival

A wide range of contemporary dangers threaten the survival of native sandalwood species in Hawai‘i.

- In addition to the rapacious early historic harvesting, recent logging on Hawai‘i has occurred within perhaps the only remaining groves of large and numerous sandalwood trees.
- Fires, fueled by alien underbrush such as fountain grass (*Pennisetum setaceum*), also threaten remaining sandalwood trees.
- Conversion of forests lands to agricultural crops has been a major threat to sandalwood at lower elevations since humans arrived. This threat continues to this day as population pressure leads to clearing additional land for agricultural uses.
- Cattle, goats, and deer all readily eat sandalwood foliage. Cattle and horses trample the shallow root systems. The impact of these mammalian herbivores must be curtailed to safeguard remaining trees and protect new plantings.
- Rats and mice voraciously consume sandalwood seeds. On Lāna‘i and at Haleakalā, these rodents have virtually eliminated natural reproduction.
- Aggressive alien vines such as banana poka (*Passiflora mollissima*) and German ivy (*Delairea odorata*) climb over native vegetation and shut out sunlight. Because sandalwood is a light-demanding species, these aliens pose a threat to it.
- Off-road vehicles impact native Hawaiian coastal plants. Such activity has severely damaged native plants at Ka‘ena Point, O‘ahu, including *S. ellipticum*.

AGROFORESTRY/ ENVIRONMENTAL/ INTERPLANTING PRACTICES

Alley cropping

Sandalwoods are suitable for inclusion in alley cropping systems, especially where the other alley species include good hosts, e.g., *Calliandra* spp.

Homegardens

The trees are very suitable for planting in homegardens, which have the advantages of mixture of host species, intermediate/variable light levels, and high security.

Improved fallows

Could be included in improved fallows of nitrogen-fixing trees, with a fallow rotation of 20 or more years to ensure that sandalwoods attain commercial maturity.

Windbreaks

Sandalwoods are suitable for inclusion in windbreaks, especially where the main windbreak species include good hosts, e.g., *Casuarina* spp.

Woodlot

Sandalwoods are suitable for inclusion in woodlots, especially when planted along sun-exposed edges and in combination with compatible species, e.g., *Acacia koa*.

Native animal/bird food

The fruits of sandalwood are consumed by various bird species.

Host plant trellising

There is minor potential to trellis slow-growing vines that would not interfere with full sun reaching the canopy, such as *maile* (*Alyxia oliviformis*).

Bee forage

When in flower, the trees are attended my many pollinators, including honeybees.

Coastal protection

S. ellipticum provides a small amount of coastal protection, as it can grow near (within a few meters) the sea.

A BRIEF HISTORY OF HAWAIIAN SANDALWOOD EXPLOITATION

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 Hawai'i 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 islands, a feat never previously accomplished. During this period, the commercial value of Hawaiian sandalwood as an export item became known to various foreign traders and native chiefs.

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 Hawai'i. 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).

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 Hawai'i in these frenetic years of Hawaiian sandalwood exploitation. Kamehameha accumulated large amounts of luxury goods.

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). Judd (1926) 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. 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).

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) 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 their 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."

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 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, 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), 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.

Source: Merlin and VanRavenswaay 1990

***Alyxia stellata*, a traditional vine used in leis, climbing on *Santalum yasi* in a homegarden in Tonga.** PHOTO: C. ELEVITCH

Ornamental

All species are quite attractive, especially when in flower, and suitable for homegardens.

USES AND PRODUCTS

Wood from sandalwood was traditionally used in the Pacific islands for carvings, cultural uses, medicine, and burnt as an insect repellent; it is rarely used nowadays because of its scarcity and cash value. Heartwood from sandalwood trees yields an aromatic oil. The oil was traditionally used to a limited extent to scent coconut oil (for application to the hair and body) and cultural artifacts such as tapa. Today, the oil is widely valued and has been the basis of a lucrative and exploitative trade for hundreds of years.

In the Hawaiian Islands, during the late 18th and early 19th centuries, the aromatic lower trunks and rootstock of native *Santalum* species were harvested in great quantity and shipped to China, where they were used to make incense, fine furniture, and other desirable products. The extensive and often exploitative sandalwood trade in Hawaiʻi was an early economic activity that adversely affected both the natural environment and the human population. Indeed, this activity represented an early shift from subsistence to commercial economy in Hawaiʻi that was to have far-reaching and long-lasting effects in the islands.

Fruit/Nut

The seed kernels are said to be edible (and some say tasty), although the scarcity of seeds and their high value for propagation makes their use as food somewhat inappropriate.

Medicinal

Traditionally, the fragrant heartwood (*ʻlaʻau ʻala*) of sandalwood trees (collectively known as *ʻiliahi*), was used in medicines. A shampoo made from a leaf infusion was used for curing dandruff and eliminating head lice. A drink made from finely ground powdered heartwood, mixed with other plants, followed by laxative was used in curing diseases of both male and female sex organs (Krauss 1993).

Fuelwood

In Hawaiʻi, *Santalum* spp. were sometimes used for firewood (Wagner 1986); however, as sandalwood, at least *S. freycinetianum*, did not make useful charcoal, residents in Hawaiʻi during the early 20th century cut and burned it as a mosquito repellent (St. John 1947).

Craft wood/tools

The highest value sandalwood is used for carving religious statues and objects, handicrafts, art, and decorative furniture. Larger basal pieces and roots are preferred for carving. In Hawaiʻi, sandalwood was sometimes used to make musical instruments such as the musical bow (*ʻūkēkē*) (Buck 1964, Krauss 1993).

Canoe/boat/raft making

Sandalwood trees in Hawaiʻi were used in some parts of traditional canoe construction. For example, *hoe* (paddles) were fashioned from sandalwood.

Cosmetic/soap/perfume

The oil from the heartwood, extracted by steam distillation or by solvent, is used for cosmetics, scenting of soaps, perfumery, aromatherapy, and medicinal purposes. In Hawaiʻi, the heartwood was pounded into a fine powder, and this, or fine chips, was pounded into new tapa (paper mulberry) cloth. The heartwood powder was also used to scent coconut oil and used to make a waterproof, perfumed tapa (Krauss 1993, Kepler 1985).

Ceremonial/religious importance

A mixture of heartwood and sapwood is powdered and made into incense or joss sticks which are used in eastern religious ceremonies. Sawdust, wood shavings from carv-

Sandalwood sculptures Bangalore, India. PHOTO: M. MERLIN

ing, or wood residue after oil distillation may be used.

URBAN AND COMMUNITY FORESTRY

This much-revered native plant can have a place in many urban environments, but it requires proper care and protection. Being a parasite, sandalwood must be grown in the company of other plants. This makes Hawaiian sandalwood a perfect component in a group planting of native Hawaiian plants, although it will form root associations with many exotic species as well. Cultivating sandalwood is relatively new, and there is quite a bit that is not yet known about horticultural practices. It does require special care (no herbicide, no nearby foot or vehicle traffic, etc.), which may mean significant alterations in regular landscaping practices. Even the best and most experienced tree growers often have trouble establishing sandalwood trees. However, once established, sandalwood trees tend to be tough, tenacious plants. Sandalwood is a "must-have" species for native plant landscapes.

Before planting sandalwood, a plan should be made sure it has the company of other plants that will act as hosts throughout its lifetime. When planting short-lived hosts such as a'ali'i, a long-term host such as koa should also be planted nearby well before the short-term host dies. It is best to think of sandalwood as a member of a plant community, rather than a lone specimen.

Size in an urban environment

Some Hawaiian sandalwoods can reach 5–10 m (16–33 ft) at maturity, but it typically takes trees many decades to reach their mature size. The canopy diameter is approximately half the height of the tree. Because of the slow rate of growth and relatively small size of the tree, growing too large is often not an issue.

Size for each species:

S. ellipticum A sprawling shrub to small tree, typically 1–5 m (3.3–16 ft) tall.

S. freycinetianum A small shrub to tree, typically 1–9 m (3.3–30 ft) tall.

S. haleakalae A small tree, typically 2–4 m (6.6–13.2 ft) tall.

S. paniculatum A shrub or tree 3–10 m (10–33 ft) tall.

Rate of growth in a landscape

Under optimum conditions, the growth rate can be 0.7 m/yr (2.5 ft/yr) in height, although it is usually slower. As with most trees, the rate of growth decreases as the tree gets older.

Root system

Sandalwood's extensive network of roots links with roots of other species that serve as a source of moisture and nutrients. Because sandalwood roots are intimately linked with the surrounding plant community, the health of sandalwood trees is tied to the health of neighboring plants. The trees also have an extensive surface root system and can produce suckers where the roots are damaged or when the main stem is cut down, injured, or stressed.

Products commonly used in a Pacific island household

The wood was traditionally used by Hawaiians in crafts, for its scent, and in medicine. The seed kernels are edible (and some say tasty), a food that can be taken advantage of when seeds are abundant. The flower clusters and young leaves of some species are used in leis (McDonald and Weissich 2003). Perhaps the greatest value of growing sandalwood in the landscape is an intangible one: the satisfaction of nurturing this esteemed cultural tree.

Light requirements

As young seedlings, or trees that have not yet formed strong root associations with host plants, moderate shade may be beneficial until strong root associations are formed with other plants. Healthy sandalwood plants that have formed root associations with other plants grow best in full sun. Trees can grow with moderate side shade or moderately filtered light.

Water/soil requirements

Specific soil requirements are unknown for Hawaiian sandalwoods. Most other *Santalum* species require well drained soils but tolerate shallow or infertile soils. Some Hawaiian sandalwoods grow in ʻaʻā lava together with species such as lama, aʻaʻliʻi, māmaki, ʻōhiʻa, māmane, ʻūlei, and ʻalaheʻe.

Life span

Longevity data for sandalwood are lacking. Given ideal conditions, it is expected to grow for many decades.

Varieties favored for use in homegardens or public areas

There are no varieties specifically selected for urban environments. It is strongly recommended that seed be used whose natural origin is as close as possible to the planting area and environment. See "Native range" above for information about the natural distribution of the various species.

Seasonality of leaf flush, flowering, fruiting

Growth of leaves, flowers, and fruits varies between species, individual plants, and environments. Plants typically grow throughout the year. Usually there are two peaks of flowering and fruiting, although in some areas flowering and fruiting is strongly seasonal, and in others they are nearly continuous.

Exceptional ornamental values

The flowers and berries are attractive, and the flowers are mildly scented. The newly flushing leaves of *S. freycinetianum* and *S. haleakalae* are tinged with purple before turning green.

Use as living fence, hedge or visual/noise barrier

Sandalwood trees are too slow growing and sensitive to environmental factors to be practical for these uses.

Bees and other pollinators frequent the abundant flowers. *S. paniculatum*, Kealakekua, Hawaiʻi. PHOTO: C. ELEVITCH

Maintenance requirements

Because sandalwood trees rely on root connections with nearby plants, herbicide used to control weeds is easily transferred through the root systems to the sandalwood trees. Therefore, weeds within a radius of the tree equal to about twice its height should be cut by hand or machine. As with most native Hawaiian plants, avoid any herbicide drift from nearby applications that can adhere to the tree leaves even in minute quantities.

Surrounding host species may require pruning, especially if they grow much faster than sandalwood (e.g., aʻaʻliʻi, māmaki, etc.) in order to allow adequate light to penetrate.

For low-fertility soils, fertilizing with a handful (up to 100 g [4 oz]) of slow-release NPK fertilizer per tree may help when trees show signs of yellowing or slow growth. Use of rapidly available, soluble commercial fertilizers is not well studied for sandalwood. Another option is to spread a 3 cm (1.2 in) layer of weed-seed-free compost around the tree, and cover it with 5–10 cm (2–4 in) of weed-free woody mulch such as chipped tree limbs. This mulch slowly adds nutrients and organic matter to the soil, protects the tree's surface roots, and helps conserve soil moisture. Be sure to keep the mulch 10 cm (4 in) away from the trunk of the tree to avoid rotting the bark and girdling the tree.

Special considerations regarding leaf, branch, and fruit drop

None.

Nuisance issues

None.

Hazards

None.

Common pest problems

As with all plants, supporting plant health is the best way to prevent pest and disease problems. The Hawaiian sandalwoods are tough trees once established and are little affected by insects. Whitefly or scale can be treated with insecticidal soap. Certain insects such as cockroaches, sowbugs, crickets, and cutworms may nibble at ground-level stem parts. Slugs and snails may also feed on newly sprouted plants. To avoid lethal girdling of a seedling, a protective barrier such as a plastic container can be used to protect newly planted seedlings (Culliney and Koebele 1999).

COMMERCIAL PRODUCTS

The primary commercial products from sandalwood are the heartwood and the essential oil distilled from the heartwood.

The heartwood from Pacific sandalwood species is mainly exported to Asia. For example, most *S. yasi* from Tonga is exported to East Asian countries, particularly China via Hong Kong, Taiwan, and Japan, but some is also supplied to the U.S. The main markets for sandalwood oil are Europe and the U.S. In the latter part of the 20th century *Santalum paniculatum* wood was also exported from western Hualālai (Kona District, Hawai'i) to Asia.

One of the advantages of growing sandalwoods is their ability to produce a high-value, non-perishable product (heartwood) that can provide cash income even when grown on a small scale. They may also be grown in environmentally sensitive areas, such as water catchment and biodiversity conservation areas, where extraction of a few small trees can cause minimum disturbance while providing good economic returns.

Spacing for commercial production

The spacing for commercial production varies considerably depending on type of planting. The final crop is likely to be around 100 mature sandalwood trees per hectare (40 trees/ac) due to need to include host tree/shrub species (at a rate of 2–4 per sandalwood trees depending on host species). Due to the high value and demand for even a single mature tree, there is effectively no minimum area or number of trees required for commercial production.

Management objectives

The main management objective should be to establish and manage a good mixture of host plant species which are necessary for sandalwood and provide suitable light and shelter. Host tree species may need to be pruned or progressively thinned to maintain good levels of sunlight to maturing sandalwood plants. For soils of lower fertility, periodic fertilizing with 100 g (4 oz) NPK fertilizer per tree, when tree growth slows, will promote more rapid growth. Weed growth, especially of long, flammable grasses, needs to be well controlled in early years. Weeds should be manually removed to avoid the risk of herbicide drift and/or translocation through weeds to sandalwood plants.

Design considerations

Greater accessibility of sandalwood plantations increases the risk of theft.

Advantages and disadvantages of growing in polycultures

A diverse mixture of host species is preferred so as to

- enable sandalwood trees to optimally obtain their mineral nutrition and water needs
- reduce pest and disease risks associated with reliance on just one or two main hosts.

Estimated yields

No data available.

On-farm processing

Whole trees including major roots are harvested. The main on-farm processing is careful removal of the sapwood, using a sharp knife. Wood pieces that are kept in dry conditions for several months may exhibit small increases in oil content and improvement in quality, but this is off-set by a lower weight and hence a lower return to the grower.

Markets

The world production and consumption of sandalwood oil is on the order of several hundred tons per year. India, with 90% of the world's production, is the major sandalwood producer. It is also the largest user of sandalwood oil. Exports from India of *S. album* oil during a 6 year period 1987/88–1992/93 averaged 40.5 metric tons (mt) (44.6 t), with the main importers of this oil being France and the U.S. Indonesian exports of *S. album* oil during 1987 to 1992 averaged 15 mt/yr (16.5 t/yr) and went mainly to the U.S., which is the single largest market outside India. International demand for *S. album* oil exceeds supply, and prices continue to rise. Annual global sandalwood heartwood production is estimated to be approximately 5100 mt (5610 t); however, production has declined markedly over the past 20–30 years. Apart from India, with its own production capability, China, Taiwan, Singapore, Korea, and Japan, with no natural resources of sandalwood, are the main markets.

PUBLIC ASSISTANCE AND AGROFORESTRY EXTENSION

Extension offices for agroforestry and forestry in the Pacific: http://www.traditionaltree.org/extension.html

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Species Profiles for Pacific Island Agroforestry (www.traditionaltree.org)

Santalum ellipticum, S. freycinetianum, S. haleakalae, and *S. paniculatum* (Hawaiian sandalwood)

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