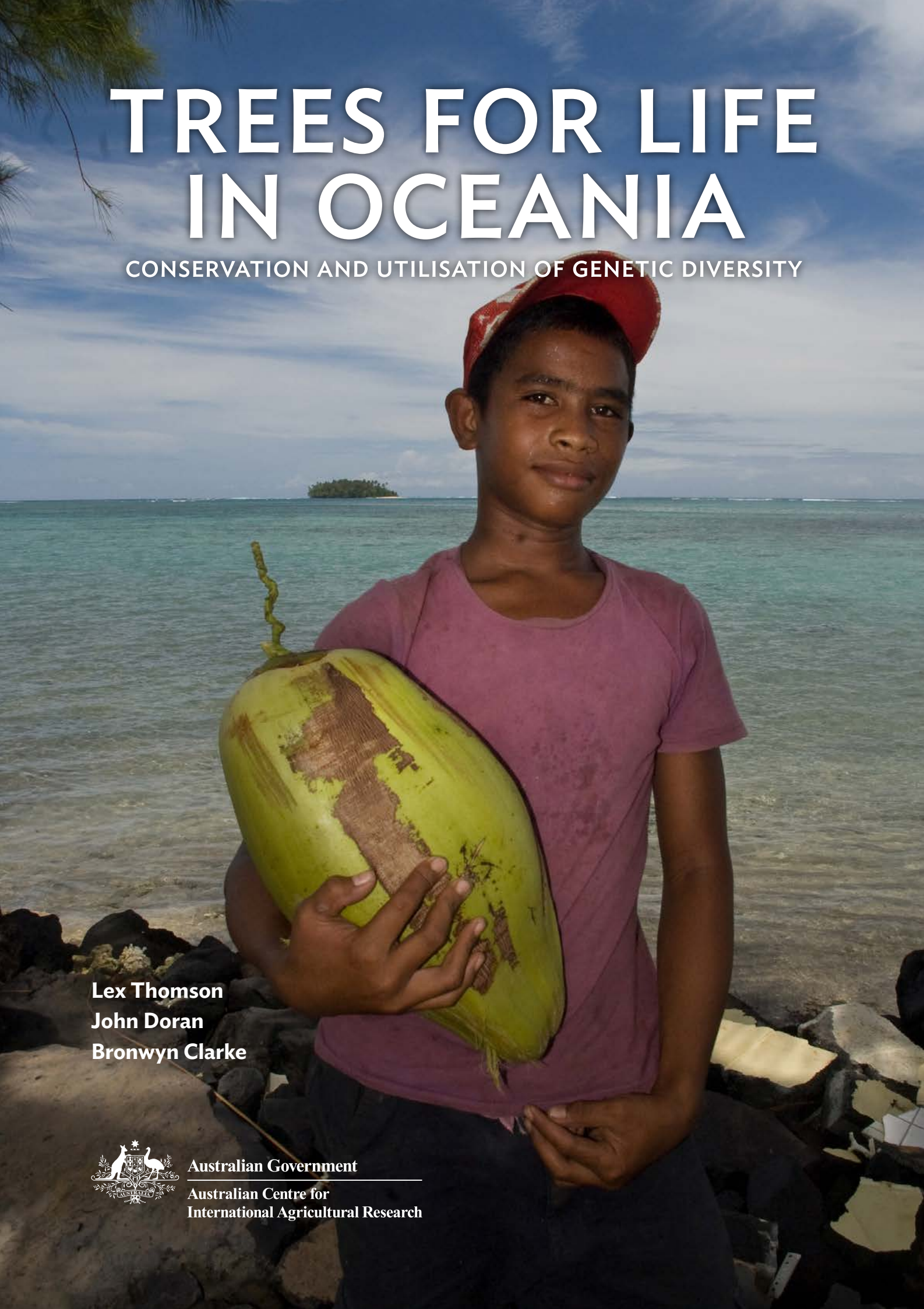


TREES FOR LIFE IN OCEANIA

CONSERVATION AND UTILISATION OF GENETIC DIVERSITY

Lex Thomson
John Doran
Bronwyn Clarke

Australian Government
Australian Centre for International Agricultural Research

Santalum austrocaledonicum

Family: Santalaceae
Botanical name: *Santalum austrocaledonicum* Vieillard. In *Ann. Sci. Nat., Bot.*, sér. 4, 16: 61 (1862).

The specific epithet refers to the location of the type specimen from New Caledonia. Four varieties are recognised: var. *austrocaledonicum*, var. *pilosulum,* var. *minutum* and var. *glabrum*.
Common names: Coral Sea sandalwood, sandalwood, Loyalty Islands sandalwood (var. *glabrum*) (English); *sandalwud* (Vanuatu); *bois de santal*, *santal* (French)

Summary of attributes and why diversity matters

Santalum austrocaledonicum is native to the island archipelagos of New Caledonia and Vanuatu where it grows as a small, root-parasitic shrub or tree, typically with a short, crooked bole and spreading crown. It produces a highly valuable heartwood and essential oil. The species is mainly harvested from the wild and has been an important source of income for poor rural peoples for centuries. Most native populations are greatly depleted and major replanting efforts are now underway.

In Vanuatu, continuous variation is found in the commercially important santalol content of its heartwood essential oil, ranging from trees with very low (1%) to very high (47%) oil concentrations. Trees with high proportions of heartwood and rich in oil with high santalol concentrations are being used for seed supply and for breeding to develop high-quality forms for smallholder plantings in Vanuatu. In New Caledonia, the essential oil varies mainly between individuals, and the different harvesting areas present similar-quality oils. Harvesting is regulated and new results have permitted the delineation of conservation zones that take into account genetics and both chemical and morphological variation.

Above: Buds and flowers (Photo: L. Thomson)

Description

Habit small hemiparasitic shrub or tree, 5–12 m tall with ≤30–50 cm dbh; crown round, bushy, with many individuals forking at a low level; often with crooked

Top right: Fruit at different stages of ripeness (Photo: L. Thomson)

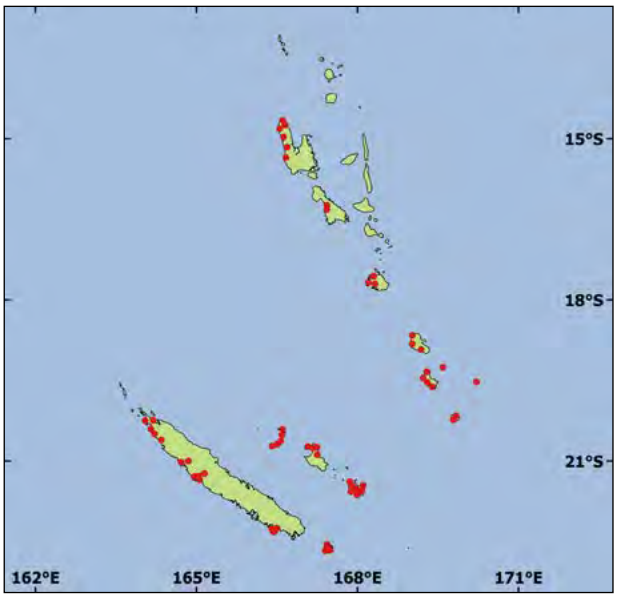
Bottom right: Planted tree growing in village; Erromango, Vanuatu (Photo: T. Page)

bole in open situations and straight bole in denser forest situations. ***Bark*** greyish, rough, longitudinally fissured. ***Leaves*** opposite, usually in 1 plane, decussate on erect new growth, simple, entire, glabrous, dark green/shiny above, dull light green/glaucous below; initially long and thin in seedlings and young plants, becoming narrowly elliptic or ovate, lanceolate or obovate, 4–6 × 1.5–2.5 cm, tapering equally to the base and blunt tip, as they mature; there is wide variation in foliage characteristics between trees and populations. ***Inflorescences*** terminal and axillary panicles of bisexual flowers. ***Flowers*** small (±5 mm across), tepals 4 or rarely 5, remaining greenish-white to cream through to maturity; yellow disc lobes alternate with tepals and anthers; long unicellular hairs occur at base of each filament and extend to anther; pollen shed via longitudinal slits in anther; stigma typically 3-lobed (rarely 2- or 4-lobed), fused into a single style. ***Fruit*** subglobular or ellipsoid, single-seeded drupe, green and firm, ripening red, turning purplish-black and thinly fleshy when mature; longitudinal ridges 4, square calyx scar at the apex; size can vary between populations. ***Seed*** kernel woody, enclosing light-coloured endocarp and single seed.

Like many of the sandalwood species, *S. austrocaledonicum* trees can flower at an early age, from about age 3 years onwards. Fruit take about 3 months to reach maturity and fruiting is generally abundant on each tree.

Distribution

Santalum austrocaledonicum occurs naturally in the island archipelagos of New Caledonia and Vanuatu in the south-western Pacific. In Vanuatu, it mainly occurs on the islands of Aneityum, Aniwa, Efate, Erromango (north-western, western and south-western areas), Espiritu Santo (western coast), Futuna, Malekula and Tanna. In New Caledonia, the distributions of the four varieties are distinct. Var. *austrocaledonicum* is common on Isle of Pines, and less common on Grand Terre, the main island. Var. *pilosulum* is restricted to near Noumea and surrounding area at low elevations on Grand Terre. Var. *minutum* is restricted to the north-west of Grand Terre. Var. *glabrum* is common in the Loyalty Islands.



Santalum austrocaledonicum has not been planted commercially outside its natural range. Experimental plantings have been established at: Kununurra in northern Western Australia and Atherton Tableland in northern Queensland (Australia); Nukurua, south-eastern Viti Levu, and Ovalau (Fiji); Rarotonga and Mitiaro (Cook Islands); and ʻEua (Tonga).

This species prefers warm to hot, lowland, subhumid or wet/dry tropical climates with a mean annual, mainly summer, rainfall of 800–2,500 mm and a short to lengthy (0–5 months) dry season in the cooler months. Altitudinal range is 5–800 m asl. Tropical cyclones are a feature of the entire distribution range, occurring mainly during the hot wet season from December to April. The species prefers well-drained acidic to alkaline soils and does not grow well on waterlogged soils and strongly acidic, clayey soils.

Uses

Carvings, incense production and sandalwood oil are the three major wood uses of *S. austrocaledonicum* and they are highly valued for their therapeutic and religious significance. The species was exploited heavily over about three decades in the mid-1800s and has been utilised periodically since then. Projected rotation lengths for plantations of this species range between 20 and 40 years reflecting a moderately fast rate of growth under suitable conditions.

Wood—the heartwood is close-grained, very finely and evenly textured, hard, durable and renowned as a carving material. It has a specific gravity of 0.92 and weighs 897–1,137 kg/m^3. Timber seasons well when dried slowly. The wood can be worked to a smooth finish and takes on a satin-like polish. The heartwood has been used for many centuries for carvings, prayer poles and other religious artefacts, valuable handicrafts, fuel for funeral pyres, coffins and joss sticks.

Non-wood—pure distilled sandalwood oil products have demonstrated anti-inflammatory and antimicrobial properties. The oil has been used topically to treat fungal and bacterial skin infections and inflammation related to sunburn and joint and muscle pain. Inhalation of the oil fragrance has a mild sedative effect and contributes to relieving anxiety, sleep disorders and promoting relaxation and a feeling of wellbeing. Sandalwood oil has been used as a coolant, astringent, antipyretic and aphrodisiac. It is also used to treat migraines, erysipelas (skin bacterial infections), gonorrhoea and cystitis.

Above left: Commercial *S. austrocaledonicum* plantation, Summit Estate; near Mele, Efate, Vanuatu (Photo: L. Thomson)

Above right: Loading logs of *S. austrocaledonicum*; Ponkil Bay, Erromango, Vanuatu (Photo: T. Page)

Left: Boiler for distillation of essential oil, with Phila Raharivelomanana; Maré Island, Loyalty Islands, New Caledonia (Photo: L. Thomson)

Sandalwood oil is used widely in the cosmetic, fragrance and soap industries. It has a highly sought-after fragrance, particularly those oils rich in santalols which give the oil with its distinctive aroma. The oil is also of considerable value for its exceptional binding qualities for other fragrant components that may be added to create a characteristic bouquet for a branded perfume.

In terms of volume consumed, its use in the perfumery industry currently outweighs its use in medicinal and natural therapies. It is produced commercially by steam distillation with an average commercial yield of 3–5%. However, individual tree yields can vary between 0.1% and 8.0%. This variation in oil content is attributed to tree age and position of heartwood within the tree and is also expected to be partly influenced by genetic and environmental factors.

Diversity and its importance

The quantity of heartwood in its timber, concentration of oil in the heartwood and the levels of α- and β-santalol in the distilled oil determine the market value of *S. austrocaledonicum*.

There is significant tree-to-tree variation in percentage heartwood—in Vanuatu, it was reported to vary from 1% to 73% with a mean of 27%. Similarly, heartwood santalol content in Vanuatu varied from 1% to 47% with a mean of 20%. Populations on the northern islands of Espiritu Santo and Malekula had a higher frequency of trees with elevated levels of santalols. Total oil yield also varied between trees with a range of 0.1–8.0%. No geographical pattern was identified for trees with high oil yields.

Deployment of improved germplasm has progressed in Vanuatu with the establishment of elite grafted seed orchards on several islands (Efate, Espiritu Santo and Malekula). These orchards consist of a genetically diverse range of trees with an average of 33% α-santalol. Seed produced from these orchards will be used to improve the sandalwood plantation resource in Vanuatu for both livelihood and conservation benefits.

In New Caledonia, the santalol content of *S. austrocaledonicum* heartwoods did not vary as much as in Vanuatu. The mean percentage of α-santalol in the concrete was 39.4% with a standard deviation (σ) of 11.2, and 16.4% for β-santalol with σ of 5.23. However, the E-lanceol content, a molecule characteristic of New Caledonian sandalwood, varied considerably between individuals (mean = 13.7%, σ = 16.6). The majority of the variation was between individuals within populations (81% of the total variance of the molecules) rather than between populations (19% of the total variance), so it is challenging to delineate candidate provenances for domestication.

Above: Variation in juvenile leaf morphology in school planting of *S. austrocaledonicum*; Onerua, Mangaia, Cook Islands (Photo: L. Thomson)

Left: Variation in heartwood colour of *S. austrocaledonicum* in Vanuatu (Photo: L. Thomson)

Throughout New Caledonia, *S. austrocaledonicum* exhibits a high level of morphological variation, particularly in juvenile leaf morphology and seed characteristics. Field experimental designs have shown that this variation is partially under genetic control. This could result from adaptation to local ecological conditions, especially for rainfall, which varies markedly between the western coast of Grande Terre and the Loyalty Islands.

Genetic diversity in New Caledonia

Due to the geographical isolation of islands across the New Caledonian archipelago, gene flow between islands is reduced and populations have been evolving separately: this is leading to significant genetic differentiation as assessed by molecular genetic markers. The populations of Grande Terre were found to be different to each other, reflecting the impact of anthropogenic fragmentation which has led to the isolation of small remnant populations. Genetic diversity within each population was also variable between islands and noticeably lower on the island of Maré (Loyalty Islands) where *S. austrocaledonicum* appears to reproduce mainly through self-fertilisation and by root suckering. This could be due to a lack of pollinators in this particular island, or resprouting due to numerous bushfires.

Genetic diversity in Vanuatu

The genetic diversity of *S. austrocaledonicum* across the islands of Vanuatu was generally higher than that observed in the islands of New Caledonia. In Vanuatu, population differentiation due to genetic structure was lowest among the three southern islands, Erromango, Tanna and Aniwa. The small island of Aniwa exhibited the lowest genetic diversity, not unexpectedly given the small population size and its possible anthropogenic introduction. Small clusters of genetically related trees, full siblings, were observed on Espiritu Santo and Malekula which may be the result of localised inbreeding or due to the planting by people of seed from a single source tree. Some level of inbreeding in *S. austrocaledonicum* is likely given the general presence of self-compatibility in the genus.

Conservation of genetic resources (including threats and needs)

Intense exploitation of the sandalwood resource in Vanuatu and New Caledonia occurred from the 1820s to the 1860s until the industry became unprofitable. The resource has since recovered but is only a small fraction of its original size. High levels of interrelatedness of trees on some islands in Vanuatu may be a genetic bottleneck caused by harvesting in the 1800s.

The sandalwood industry in Vanuatu is based primarily on harvesting of wild trees of *S. austrocaledonicum* and the Department of Forests has developed a conservation strategy for the species. An inventory in 2008 found a low aggregated density (0.4 trees/ha) in known *S. austrocaledonicum* regions. In the mid-2000s, the mean annual harvest was >100 tonnes, which exceeded the then

80-tonne sustainable limit. The current annual quota is 60 tonnes, although harvesting rates in the mid-2010s were between 30 and 40 tonnes. While much of the wild resource has been commercially exhausted, smallholder plantings now represent a modest commercial supply.

In New Caledonia, the current quota is 29.2 tonnes/year, and *S. austrocaledonicum* can only be harvested in the Loyalty Islands. The genetic, chemical and morphological data recently obtained supplemented this measure by enabling the delineation of conservation zones (evolutionarily significant units) where seed transfer has to be regulated.

In Vanuatu and New Caledonia, *S. austrocaledonicum* is currently grown in small plantings or managed in natural stands. It grows at moderate rates and can produce substantial quantities of the valuable heartwood on a rotation of 25–40 years. This species has good commercial potential; in particular, to generate cash revenue for rural communities in remote areas. There is increasing interest among villagers, other small-scale entrepreneurs and government agencies to expand the scale of planting in both countries.

Santalum austrocaledonicum can freely hybridise with other species, including *S. album* and *S. lanceolatum*. This opens the potential for introgression of desirable traits between species and/or development of vigorous hybrids. While the productivity benefits of hybrids are evident, consideration must be given to potential incompatibility or other deleterious factors that could manifest in later generations. Production of hybrids may also have unpredictable consequences in terms of potential disruption of a species' genetic integrity; for example, *S. album* introduced to Vanuatu was much less resilient to high wind speeds associated with cyclones than *S. austrocaledonicum*. It is unclear what effect uncontrolled hybridisation between these two species would have on the wind firmness, or other traits of natural *S. austrocaledonicum*. There is concern that introduction of other varieties of *S. austrocaledonicum* into the Loyalty Islands may eventually lead to loss of the distinctive Loyalty variety (var. *glabrum*) through hybridisation and subsequent introgression. Market acceptance of, and demand for, products derived from hybrid sandalwood is also yet to be defined and may jeopardise the development of a niche market and brand for pure *S. austrocaledonicum* oil. Sandalwood is a culturally significant product with a long history of trade and consumers are sensitive to quality differences between species.

Authors: Tony Page, Lorraine Bottin, Jean-Marc Bouvet and Hanington Tate