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Looking ahead – global sandalwood production and markets in 2040, and implications for Pacific Island producers

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ABSTRACT

Sandalwood has distinct, high-value end uses that function to underpin its price and maintain demand in different market segments and regions. These uses and markets include essential oil from its heartwood as an ingredient (providing woody base notes and fixative properties) in fine perfumes, exclusive natural body-care products and new pharmaceuticals, especially for European and North American markets; in solid furniture, carvings, traditional medicines and religious uses in China, the Republic of Korea and Japan; for attars[1] funeral pyres and chewing tobaccos in India; and customary uses in the Middle East. The markets for sandalwood heartwood and oils from Pacific Island countries have been strong and have continually diversified since exports to China commenced over 200 years ago. The global sandalwood market remains buoyant, with 2019 wholesale prices of *Santalum album* oil ranging from USD 1750 kg^{-1} (unlicensed production through Dubai) to USD 2100 kg^{-1} for licensed production from India and USD 2000–2500 kg^{-1} as wholesale price for Australian *S. album* plantation oil. The wholesale price for *S. austrocaledonicum* oil is USD 1500–1750 kg^{-1}. The heartwood (air-dried) of *S. album* is mostly traded by growers for more than USD 100 kg^{-1}. The price for Fiji's *S. yasi* heartwood (partly to fully air-dried, 'village gate' price) for carving, furniture, and oil distillation has increased steadily to USD 50 kg^{-1} in 2019 while the price for grade 1 *S. austrocaledonicum* heartwood (partly to fully air-dried; 'on the beach' price) is USD 35 kg^{-1}. The global market for sandalwood products, sustainably sourced from a growing plantation resource in Australia, Asia and the Pacific Islands, is predicted to remain strong up to and beyond 2040. The high rate of increase in sandalwood prices in recent decades is unlikely to continue, however, due to both an expanding supply from increasingly better-managed plantations and the likelihood that, in the longer term, genetic improvement and the adoption of technological innovations will induce earlier and greater heartwood yields in planted sandalwood. Nevertheless, sandalwood prices will remain sufficiently high to make agroforestry cultivation a commercially attractive proposition for efficient Pacific Island sandalwood growers. This paper provides a prognosis for the production of and demand for sandalwood in 2040 for major sandalwood producer regions (Australia, India, Indonesia, Timor-Leste and the Pacific Island nations) and markets (China, Europe, Japan, the Republic of Korea, the Middle East, North America and the United Kingdom). These estimates of production and demand were made to inform prospective sandalwood growers, and especially smallholders in Pacific Island countries, on the likelihood that the current strong demand and prices will continue and the extent to which export/international markets will be affected by the large sandalwood plantations now being established in several countries.

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Introduction

From the beginning of the nineteenth century, European traders were exploiting the valuable sandalwood resources of the Pacific to supply the market for incense in the Buddhist, Confucian and other religious temples of China. By 1865, sandalwood supplies throughout the Pacific were commercially exhausted, and the boom era of trade had virtually come to an end (Shineberg 1967; Merlin & Fleetham 2013). Since then, the supply of sandalwood has fluctuated in Pacific Island nations; over the last decade, it has averaged about 270 tonnes of wood $year^{-1}$, equivalent to less than 10% of the volumes harvested in the early nineteenth century.

Few accessible mature sandalwood trees with reasonable quantities of the sought-after heartwood remain throughout the Pacific Islands (Doran, Thomson, Brophy 2005; Thomson 2013). In the last decade there has been a scramble to source the remaining wild sandalwood in Fiji, Tonga and Vanuatu, principally for oil distillation. This has sometimes led to unsanctioned and illegal activities such as theft of individual mature trees; the wasteful cutting of immature trees; and an associated undocumented trade, presumably at a low level, in sandalwood products. It is expected that, in the near future, sandalwood production in the Pacific Islands will be reduced, perhaps to only 100 air-dry tonnes heartwood (ADTH) $annum^{-1}$ from wild sources, dominated by the traditionally better-regulated supply of *Santalum austrocaledonicum* Vieill. in New Caledonia and Vanuatu. Soon after 2020, the supply of sandalwood from the South Pacific Islands will begin increasing as planted sandalwood stocks attain maturity, first in Vanuatu and then in Fiji and elsewhere.

Pacific Island sandalwood growers have been greatly assisted and encouraged by economic analyses of smallholder sandalwood production (Tacconi 1995; Thomson et al. 2011; Page et al. 2012). Nevertheless, although global sandalwood markets have been strong for centuries, prospective

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[1]Attars are fragrant essential oils used pure or as a base for perfume in South Asia and the Middle East.

smallholder sandalwood growers and others in the industry seek more information on whether the current strong demand and prices will continue and how export/international markets will be affected by the large sandalwood plantations now being established in northern Australia, India, Indonesia, the Pacific and reportedly other countries.

Santalum—the genus

Sandalwood has been highly esteemed in Asian cultures and religions for thousands of years, the traditional sandalwood sources being wild stands of East Indian sandalwood (*Santalum album* L.) in south India and eastern Indonesia. The most valuable portion is the heartwood found in the basal part of the trunk and larger woody roots. Sandalwood is produced by many species in the genus *Santalum*, which comprises about 17 described species and 14 varieties, and one extinct species (Harbaugh & Baldwin 2007; Harbaugh et al. 2010; Merlin & Fleetham 2013). *Santalum* is naturally distributed in parts of Australia, India, Indonesia, New Guinea, and several Pacific Island countries.

The main species of international commerce are:

- *Santalum album*—native to Indonesia, India, Sri Lanka (possibly naturalised) and Timor-Leste (and presumed naturalised in the Top End of northern Australia). This is the most highly regarded species in international commerce and is traded as both heartwood and oil (East Indian sandalwood oil International Organization for Standardization – ISO – 3518:2002). *Santalum album* is now mostly cut out in its native habitat (McWilliam 2005; Rimbawanto & Haryjanto 2007; Subasinghe et al. 2013; Padmanabha 2013a), and most of the future supply will come from plantations in northern Australia, India, Indonesia and other Asian countries (Thomson & Doran 2012; Coakley 2013; Thomson 2013; Anon 2014; Thomson et al. 2018).
- *Santalum spicatum* (R.Br.) A.DC. (West Australian sandalwood)—native to south-western Australia. One of the most traded sandalwoods, by volume, due to well controlled and sustainable harvesting. Australian sandalwood oil (ISO 22769:2009) is variable; has a relatively low percentage of the preferred santalols; can have high levels of E,E farnesol, a recognised allergen in cosmetics (Baldovini et al. 2011); and is used mainly in incense sticks (Statham 1990; Moniodis et al. 2013).
- *Santalum austrocaledonicum* (sandalwud)—native to New Caledonia and Vanuatu. The quality of oil varies with some populations, such as on Santo and Malekula in Vanuatu and many New Caledonian sources, having high-quality oils with similar oil profiles to East Indian sandalwood (Braun et al. 2005; Page et al. 2010; Butaud 2015).
- *Santalum yasi* Seem. (yasi or ahi)—native to Fiji, Niue and Tonga. This species usually produces excellent-quality heartwood and an exceptionally high-quality oil, typically with high levels of both α-santalols (34–40%) and β-santalols (29–31%) (Doran, Thomson, Brophy et al. 2005; Thomson 2006; Thomson, Bush et al. 2018).
- *Santalum paniculatum* Hook. & Arn. (ʻiliahi) and *Santalum ellipticum* Gaudich. (ʻiliahi alo'e)—native to Hawaii. The overall oil quality of these species is satisfactory, with some chemotypes being very good, with high proportions of α-santalols (up to 40%) and β-santalols (up to 16%) (Merlin et al. 2006; Braun et al. 2014).

Minor species that have been important at different periods in the history of sandalwood exploitation and trade include:

- *Santalum macgregorii* F.Muell. (PNG sandalwood)—native to Papua New Guinea (PNG). The heartwood generally has a poor-quality oil profile, with the exception of some trees in Western Province (Doran et al. 2007; Brophy et al. 2009); the Western Province subpopulation may turn out to be a different species and related to *Santalum lanceolatum* R.Br. on Cape York Peninsula, northern Queensland.
- *Santalum insulare* Bertero ex A.DC. (East Polynesian sandalwood)—native to French Polynesia and the Cook Islands. The overall oil quality is satisfactory, and some chemotypes are excellent (Braun et al. 2007; Butaud et al. 2018).
- *Santalum lanceolatum* (northern sandalwood)—native to northern Australia. The heartwood of this species generally produces an oil of inferior quality, with the exception of some trees on Cape York Peninsula, which may have oil profiles closer to East Indian sandalwood (Page et al. 2007; Lee et al. 2019).
- *Santalum leptocladum* Gand.—until recently considered to be a southerly subpopulation (latitudes above 20°S) of *S. lanceolatum* (Harbaugh 2007; Harbaugh & Baldwin 2007).
- *Osyris* spp.—an inferior type of sandalwood, with low levels of santalols (<10%) produced by several species in the related genus *Osyris*. The most utilised species for its sandalwood is *Osyris lanceolata* Hochst. & Steud, an extremely widespread species occurring over much of southern, eastern and northern Africa and also in southern Europe and in Asia, from China to India, and on Socotra, Yemen (Wilson 2018).

Santalum album and *S. yasi*, despite the large geographic disjunction in their distributions, are closely related species and are presumed to have arisen from a common ancestor in northern Australia about 3 million years ago (Harbaugh & Baldwin 2007). These two species freely hybridise when grown together in Fiji and Tonga (Thomson, Bush et al. 2018). Interestingly, the much more distantly related *S. album* and *S. austrocaledonicum* also hybridise readily, as has been observed by the author in Mangaia, the Cook Islands, and *S. austrocaledonicum* and *S. lanceolatum* also hybridise (Page et al. 2018).

Methods

This study involved a review of publicly available papers, reports, company prospectuses and other documents with information on the production of sandalwood from wild sources and plantations. This was supplemented by the direct knowledge of the author on the status of sandalwood in the South Pacific Islands and northern Australia, obtained through numerous field visits over the past 30 years and from meetings with industry stakeholders. The demand projections were made based largely on historical demand by different market segments in different countries, where this was known or able to be estimated. The increasing global population of middle-class consumers, many of whom will find sandalwood oil attractive, was taken into consideration,

as was the likelihood that the cultural significance of sandalwood will remain strong in China and India, and these and other traditional markets will likely grow.

Outlook for sandalwood production and markets in 2040

Australia

Production in 2040: One company, Quintis Ltd (formerly Tropical Forestry Services), a sandalwood producer and processor, has emerged as a globally dominant player in international sandalwood production and markets. Quintis has overcome major liquidity problems since being shorted[2] by Glaucous Investments in 2017–2018. The company was restructured and recapitalised in October 2018, is majority-owned by United States investment company BlackRock, and manages a vast *S. album* plantation resource comprising about 5.5 million trees on 12 564 ha in north-western Australia, the Top End of the Northern Territory, and Dalbeg, Queensland.

Quintis plantations are expected to have 420 surviving stems ha^{-1} at the final harvest at 14–16 years. The average yield is likely to be around 7–9 kg heartwood tree^{-1} (i.e. 2.94–-3.78 ADTH ha^{-1}), with content yielding 3.7% oil. It is estimated that 700 ha of *S. album* plantation will be harvested in 2040, producing 2058–2646 ADTH. If 95% of the Quintis harvest is distilled into oil (with the other 5% of heartwood supplied into the Asia art/furniture market), this would generate 72–93 tonnes of *S. album* oil for export, equating to approximately 30–40% of the current global demand for *S. album* oil. Santanol Group, now owned by Mercer International Inc., also has about 2500 ha of planted *S. album* in northern Australia, but the earlier plantings were of poor quality.

The two main Australian native sandalwood species, *S. spicatum* and *S. lanceolatum*, are expected to continue to be harvested in the wild at similar rates to the current harvest and supplemented by planted *S. spicatum*: there is 21 000 ha of planted *S. spicatum* in central-south Western Australia (Bush et al. 2018) but on a long rotation and with a rather low oil yield of about 1.5%.[3]

Demand in 2040: The local demand for sandalwood products in Australia will remain minor (as a proportion of global use). The main consumption will be through imported value-added products incorporating sandalwood oil, such as perfumes, body-care products and medicines.

Summary: In 2040, almost the entire (>98%) Australian sandalwood production will be destined for export. The product, export market and price will vary depending on species and other factors. In 2040, Quintis and Santanol plantations in northern Australia will produce approximately 100 tonnes of oil, equivalent to more than 30% of current world market demand for high-quality sandalwood oil. Given the market dominance of Australian plantation-grown East Indian sandalwood oil, it is possible that other producers/suppliers of high-value sandalwood oil will be price-takers if global supply exceeds demand. There is some risk of an oversupply of *S. spicatum* or Australian sandalwood oil in 2040 as the planted stands in Western Australia mature and are harvested.

Asia

China (including Taiwan Province of China)

Production in 2040: About 2000 ha of *S. album* plantations (<10 years old) have been developed in southern China, but heartwood has been slow to develop (Li 2003; Xiaojin et al. 2011). Some sandalwood plantations have been interplanted with *Dalbergia odorifera* T.C. Chen, which may cause future problems due to its heavy shading. Commencing in 2012, the Sandalwood Forest (Qingyuan) Co. Ltd in North West Guangdong has planted 200 000 sandalwood trees, with plans to establish a total of 6 million trees. The company is well organised and capitalised (http://www.3-dw.com/), but its plantations are expected to develop heartwood slowly and to be cut back to near ground level by annual frosts. It is estimated that, by 2040, about 70 ha will be harvested per year at 6 ADTH ha^{-1} (i.e. 420 ADTH) at 30 years of age (producing 8 tonnes of oil at 2% oil concentration).

Demand in 2040: The official annual import figure of 3100 tonnes of sandalwood logs and wood products (mostly air-dried heartwood) into China (in 2011) is an underestimate due to undocumented trade[4] in rare and expensive woods. China will remain a premium destination for carving logs and furniture—the most highly priced market segment for sandalwood logs. A conservative estimate of demand for solid sandalwood products in 2040 is 1000 ADTH year^{-1}. Sandalwood powder (*tan xiang*) is a vital ingredient in traditional Chinese medicine but, for much of the past decade, this ingredient has not been stocked by traditional pharmacies (*Zhong Yao Dian*) in China due to a lack of supply and high prices; nevertheless, the empty space on shelves with product name observed by the author in 2012 and 2014 indicates that practitioners are eager for sandalwood powder to again become available. China's growing middle and upper classes will demand at least 100 tonnes of oil annum^{-1} (equivalent to approx. 3000 ADTH) for local perfumes and body-care products. The value of current annual perfume sales in China of around USD 4 billion, which is growing at 15% annum^{-1} (https://bg.qianzhan.com/report/detail/300/180531-f3c5c52f.html), is expected to increase four-fold by 2040, and many – perhaps the majority – of these perfumes will include sandalwood oil in their formulations.

Summary: China will require at least an additional 5000 ADTH annum^{-1} of plantation *S. album* heartwood to meet new and unmet demand for oil, carving logs and solid wood furniture and powder for traditional medicines. The modest amount of heartwood to be derived from China's existing *S. album* plantations will mainly be used domestically for local handicrafts and incense products. China will continue

[2]Shorted—a short-seller makes a profit by borrowing shares, selling them on the market at a specific value, and then repurchasing the shares at a lower price. Glaucus is an activist short-seller that produced damaging reports on Quintis, its structure, customers/markets and forecasted future earnings, leading to a collapse in the share price and to trading halts.

[3]Production estimates are based on the author's interpretation of data in Australian sandalwood company prospectuses, several websites (https://sandalwood.org.au/; https://santanol.com/; https://quintis.com.au/; https://www.wasandalwood.com/wasp), and industry insider sources. It is anticipated that the future supply of plantation sandalwood from northern Australia will decline after 2040, commensurate with the reduced level of new plantings.

[4]The Harmonised System (HS) codes used in international trade for sandalwood are 1211.9050 for sandalwood chips and dust and 33012937 for sandalwood oil. Note: although Chinese (and Indian) customs data are generally considered reliable, they are suspect for sandalwood products given the unknown levels of undocumented trade.

to require and import substantial amounts of lower-grade sandalwood products for incense products (including from *S. album* spent charge and *S. spicatum* powder and pre-grind incense sticks).

India

Production in 2040: The annual official harvest of sandalwood (*S. album*) was 300–370 ADTH in 2008–2012 (Padmanabha 2013a), but the total production in 2011–2012 was estimated at 1250 ADTH, with 1000 ADTH associated with illegal harvesting (Coakley 2013). By 2040, the production of sandalwood from wild sources will substantially have been overtaken by that derived from planted *S. album*. In 2012, there was more than 1500 ha of *S. album* plantations in India (Padmanabha 2013b). There has been considerable private-sector interest in developing sandalwood plantations, including in more northern locations, such as Andhra Pradesh, Gujarat, Madhya Pradesh, Maharashtra and Rajasthan, where the species does not naturally occur and which are free from sandalwood spike disease (a mycoplasma organism). The area currently planted to sandalwood in India is estimated to have grown dramatically in the last five years to an estimated 30 000 ha in 2019, in both agroforestry configurations and plantations, with the majority of the plantings in Gujarat and Karnataka states through an initiative of Karnataka Soaps and Detergents Ltd. The Indian plantations of *S. album* are estimated to produce about 8 ADTH ha^{-1} on a 25–30-year rotation. It is considered that about 1000 ha of 25–30-year-old sandalwood plantation will be harvested per year in 2040, producing 8000 ADTH with an oil content of 2.5% oil, or 200 tonnes of oil. It is estimated that wild stands will produce 2000 ADTH with an oil content of 5% oil, or 100 tonnes of oil.

Demand in 2040: The local demand for sandalwood oil is estimated at a minimum of 250 tonnes in 2040. It is likely that local *S. album* plantation wood will mainly be used domestically for agarbatti,[5] funeral pyres (rather than oil production) and some oil, especially for soaps/attars.

Summary: India will likely be a net importer of sandalwood heartwood and/or oil in 2040, but it is difficult to predict the quantity due to uncertainties in the production, quality and maturation times of its recent plantations. These new plantations are mainly in non-traditional sandalwood-growing areas, and the impacts of sandalwood spike and other pests and diseases are unknown and growth rates/heartwood development rates uncertain.

Indonesia and Timor-Leste

Production in 2040: The main sandalwood (*S. album*) production areas are in eastern Indonesia in East Nusa Tenggara Province, including West Timor, Flores and Sumba (Rimbawanto & Masripatin 2005; Rimbawanto & Haryjanto 2007; Ora 2012), and Timor-Leste (Page et al. 2019), with wild populations also present in Gunung Sewu, central Java (Ratnaningrum et al. 2017). Indonesia has vast areas of land that are potentially suitable for sandalwood cultivation, but the most suitable lands are needed for short-term crops/food production. Current and projected future sandalwood production is limited due to previous unsupportive policy and legislation (Septiani & Setyawati 2013) and relatively long rotations that discourage planting by farmers in need of quick returns. Major replanting programs are in progress, such as an East Nusa Tenggara Government replanting program, with local nurseries distributing 500 000 sandalwood seedlings $year^{-1}$, equivalent to about 1000 ha of sandalwood plantation (Rimbawanto & Haryjanto 2019), and 50 ha $year^{-1}$ in Timor-Leste, with a national-government aspiration to plant 1 million sandalwood plants $year^{-1}$ (Ferreira et al. 2019). There is likely less than 5000 ha (equivalent) of planted *S. album* – mostly in low productivity agroforestry systems – currently in Indonesia and Timor-Leste. Estimated yield is 6 ADTH ha^{-1} at 30 years. It is estimated that 500 ha (equivalent) will be harvested in 2040 (at 30 years of age) with a yield of 3000 ADTH.

Demand in 2040: The traditional use of sandalwood in religious ceremonies will continue, especially among Balinese Hindus; a small amount of sandalwood oil may be distilled locally for use in perfumes and body-care products.

Summary: The local demand for sandalwood and its oil is expected to remain modest, such that Indonesia and Timor-Leste will likely export most of its production in unprocessed form—thus, about 2500–3500 ADTH of *S. album* is likely to be exported in 2040.

Other countries in Asia

Production in 2040: There are increasing areas of sandalwood (*S. album*) plantations in Malaysia, Sri Lanka, Thailand and Viet Nam. For example, 200 ha was planted in Sri Lanka in 2012, with Sadaharitha Plantations Ltd expanding its plantings by 75–100 ha $annum^{-1}$ (Subasinghe et al. 2013). In Thailand, about 250 ha was planted in 2018, with plans for the private sector to double this area. The yield is estimated at 8 ADTH ha^{-1} on a 25-year rotation. There will likely be only limited sandalwood production in 2040 – about 800 ADTH of heartwood – but production will increase thereafter.

Demand in 2040: Sandalwood is extremely important in East, Southeast and South Asian cultures and religions, with the first Buddha effigy reputedly carved out of sandalwood. It is mainly imported into East Asia in the form of powdered sandalwood, incense sticks and small logs for carving. Import data for Japan and the Republic of Korea are limited, but it is expected that current sandalwood demand will be maintained and increased for certain uses, such as perfumes and traditional medicines. It is difficult to predict future demand for sandalwood products in Southeast Asian countries, but it is likely that increased domestic demand (in perfumes, medicines, furniture and incense) will absorb increased domestic production.

Summary: In 2040, Japan and the Republic of Korea will continue to be large importers of sandalwood products. Increased demand for sandalwood products in other countries in Southeast and East Asia will mostly be met by increased sandalwood production from new plantations in Sri Lanka, Thailand and Viet Nam.

East Africa

Production in 2040: The main *Osyris* species used for its heartwood is *O. lanceolata*. Although *O. lanceolata* has a wide distribution, most of its utilisation for lower-grade sandalwood has been in East Africa, including Kenya, Somalia, Uganda and the United Republic of Tanzania, mainly in the last two decades (Mwang'ingo et al. 2010; Shyaula 2012;

[5]Agarbatti is a thin wooden stick covered in a substance that is burned to produce a pleasant incense smell.

Wilson 2018). It is predicted that wild-harvested *Osyris* will have been overharvested by 2040, such that there will be almost nil supply of this sandalwood substitute from wild sources and almost none from plantations due to its slow growth rate.

Demand in 2040: Currently, there is minimal demand for sandalwood products in African nations, but this is expected to change as African economies grow and because sandalwood is a desired consumer product – in body care and perfumes – among the upper and middle classes.

Summary: Osyris species are slow-growing shrubs that are not well suited to the commercial production of sandalwood, and the yield from planted sources will be limited in the medium to long term. Interest is reported in developing *S. album* plantations in Africa and the species would likely grow very well in several countries in East Africa if provided with appropriate hosting regimes. In 2040, East Africa and other African regions and countries (including Senegal and South Africa) will be low-level net importers of sandalwood products.

Europe and United Kingdom

Production in 2040: No sandalwood is grown in Europe, although sandalwood is cultivated commercially in the French territory of New Caledonia.

Demand in 2040: Europe and the United Kingdom will remain major markets for value-added sandalwood products such as perfumes, soaps and body-care products. Historically, 10–15 tonnes of oil have been imported annually into Europe, and these imports are predicted to grow as reliable and sustainable plantation sources are developed that can be used to develop new high-value products, especially French perfumes.

Summary: In the European Union and the United Kingdom in 2040, current demand for sandalwood ingredients and products will have increased for uses such as perfumes, aromatherapy and body-care products, with demand for high-quality sandalwood oil expected to have risen to 20–30 tonnes annum^{-1}.

Pacific Islands

The supply of sandalwood from the Pacific Islands has fluctuated considerably in the last 200 years, but in recent times it has averaged about 250 ADTH year^{-1} (Thomson 2013), equivalent to less than 10% of the sandalwood harvested per year in the early to mid-nineteenth century (Shineberg 1967; Merlin & Fleetham 2013).

Fiji and Tonga

Production in 2040: Recently, less than 100 ADTH annum^{-1} of *S. yasi* has been exported from Fiji and Tonga (Thomson et al. 2019). *Santalum yasi, S. album* and their hybrids are being planted on an increasing scale in Fiji, including through the Ministry of Forestry's Sandalwood Development Project (Bolatolu et al. 2019), and there has been greatly increased planting in Tonga in the last five years (Motuliki 2019). The estimated harvest of planted sandalwood in 2040 is 12 000 trees, with a total yield of 300 ADTH (with 3.5% of oil). The yield from natural stands of *S. yasi* in Fiji and Tonga in 2040 is estimated at 65 ADTH (with 5% oil).

Demand in 2040: In 2040, there will be limited local use and an insignificant domestic market, which will mainly comprise value-added sandalwood products such as perfumes, soaps and body-care products for expatriate communities and the carry-on export/tourist markets.

Summary: The estimated total production in Fiji and Tonga in 2040 will be in the range of 340–370 ADTH of sandalwood. Almost all this wood will be exported, mainly in an unprocessed form, likely to East Asia and the Middle East. As an increasingly large planted area is harvested in both countries, there will be more local value-adding, especially through the conversion of heartwood into essential oil.

New Caledonia

Production in 2040: The most recent inventories in New Caledonia on Maré and Isle of Pines have demonstrated the presence of reasonable quantities of sandalwood that could be harvested sustainably on the basis of an annual quota of heartwood (Brinkert 2003; Lemaresquier 2008). The replanting program for *S. austrocaledonicum* has historically been about 1–2 ha year^{-1} in Southern Province (Bourgine 2012). Limited plantings have been undertaken near Poya. The main sandalwood replanting has been in the Loyalty Islands: since 2010, seedlings have been planted at an annual rate of approximately 15 000 trees on Maré and Lifou. About 30 trees are planted for each sandalwood tree harvested, which is ten times more than the present regulated requirement. For the Loyalty Islands, there are plans for smallholders to replant 30 000 sandalwood seedlings per year: this replanting is to be undertaken in association with the distillery on Maré.

Demand in 2040: Metropolitan France has been a major market for sandalwood oil from New Caledonia for incorporation into value-added sandalwood products such as perfumes, soaps and body-care products. The supply of *S. austrocaledonicum* oil into Europe (>90% to France) from the Loyalty Islands has been increasing but was steady from 2016 to 2018 at 8.6–8.7 tonnes oil (with a declared value of USD 5.7 million or USD 650 kg^{-1}).

Summary: It is predicted that demand for high-quality sandalwood oil in France will grow to 15–20 tonnes by 2040, although this demand will be elastic depending on the availability and price of sandalwood oil. It is expected that sandalwood production from any increased plantings in New Caledonia will readily be absorbed by markets in France, including its Pacific territories, and elsewhere in Europe.

Papua New Guinea

Production in 2040: Harvesting of the native sandalwood species, *S. macgregorii*, commenced in the late 1800s (Kiapranis 2012). Since then, heartwood exports have fluctuating widely; the quantity was 73 ADTH in 2003 but there have been no recorded exports in recent years (Thomson 2013). The rather low-value heartwood of *S. macgregorii* has mainly been exported in an unprocessed form to East Asia. There has been only small-scale planting of sandalwood in PNG, mainly *S. macgregorii* in Central, East New Britain, Gulf and Morobe provinces. There is a need for more research and development on sandalwood in PNG, especially for the *Santalum* entity in Western Province, which has a more desirable chemotype than eastern provenances of *S. macgregorii* and which appears to be a different species and morphologically close to some populations of *S. lanceolatum* on Cape York Peninsula. The improvement and development of

these sandalwoods in Western Province and Cape York Peninsula has major potential to improve the livelihoods of people in those areas.

Demand in 2040: There are no recorded important local uses of sandalwood, and future demand in PNG will be low.

Summary: Production is likely to be negligible (<10 ADTH year^{-1}) in 2040 due to the past overharvesting of wild stands, coupled with limited replanting, slow growth, and frequent wildfire in its native habitats in Central and Gulf provinces.

Vanuatu

Production in 2040: The quantity of sandalwood (*S. austrocaledonicum*) heartwood harvested and exported from Vanuatu has been the most consistent of any Pacific Island country. This is due in large measure to assessment of the natural resource and effective regulation by the Department of Forests (Corrigan et al. 1999; Gillieson et al. 2008; Tate 2012). Exports have more than halved, however, from around 110–120 ADTH in 2003–2007 to less than 60 ADTH more recently, due to the decline in wild stocks (Thomson, Bush et al. 2018; Kalsakau 2019). Future sandalwood exports from Vanuatu will largely come from smallholder and commercial plantations (Page et al. 2012), where the sandalwood plantation area was about 1400 ha in 2014, with an annual planting rate of 20 000 seedlings of sandalwood. South Pacific Sandalwood Ltd (SPSL), based at the Summit Estate near Mele, is the major commercial plantation grower.

The annual sustainable resource in native stands is likely to be 50 ADTH, and smallholder growers are likely to produce 400 ADTH annum^{-1} by 2040. However, if SPSL, in collaboration with local landowners/partners, were to plant an additional 500 000 trees over the next five years, then the additional sandalwood heartwood production in 2040 from a 2020 planting of 100 000 trees (with survival of 95%) would be 95 000 × 20 kg tree^{-1} or 1900 ADTH.

Demand in 2040: There is limited local use of sandalwood and the domestic market is small, mainly for value-added sandalwood products such as perfumes, soaps and body-care products for expatriate communities and carry-on export/tourist markets.

Summary: Vanuatu's heartwood production could increase ten-fold by 2040 from historical levels to >2000 ADTH, mostly for export. There is a need to grow the international-market-preferred (i.e. santalol-rich) chemotypes of *S. austrocaledonicum* from Santo and Malekula, while differentiating *S. austrocaledonicum* oil from that of *S. album*.

Middle East

Production in 2040: Currently, no sandalwood is grown in the Middle East, and this is likely to remain the case due to unfavourable hot, arid climates.

Demand in 2040: During the late 1980s and early 1990s, when India and Indonesia were the main producers of *S. album* oil, the Middle East (including Oman and the United Arab Emirates) imported an average of 4 tonnes of oil annum^{-1} (Coppen 1995). It is expected that, by 2040, demand is likely to have more than trebled to 12–15 tonnes of oil annum^{-1}.

Summary: It is expected that demand for sandalwood oil and value-added products will remain strong in 2040. There will also be continuing demand in Saudi Arabia and the Gulf States for sticks of heartwood to be burnt at social evenings.

North America (United States and Canada)

Production in 2040: Hawaii is the sole supplier of *S. ellipticum* and *S. paniculatum* wood and oil to the world sandalwood market. Production and exports have been widely variable: sandalwood exports ranged between 250 and 600 ADTH annum^{-1} in 2010–2015, mainly of *S. paniculatum* to China, Dubai and Sri Lanka (Harbaugh 2007; Coakley 2013; Leopold 2015). The recent export phase of sandalwood from Hawaii appears to have almost ceased due to the dwindling availability of wild stands of trees of commercially exploitable size. Production in wild stands in Hawaii is expected to be limited in the future, possibly averaging up to 50–100 ADTH year^{-1} if currently protected/little-known stands are harvested sustainably. The costs of plantation establishment and maintenance, including for land and labour, are relatively high in Hawaii. Accordingly, there has been only modest commercial interest in sandalwood replanting, including recently by the United States essential oils company dōTerra.

Demand in 2040: The United States is a major market for value-added sandalwood oil products such as perfumes, soaps and body-care products. It will also likely continue to be a major market for sandalwood oil coming from Europe (mainly from France/New Caledonia) and Australia.

Summary: It is difficult to predict the amount of oil that large buyers, processors and users in the United States might require in 2040 and in the near future for incorporation into pharmaceuticals, body-care products and perfumes, but it is likely to be less than 15–20 tonnes year^{-1}.

Discussion

Replacement of wild harvest with plantation-grown sandalwood

An examination of the main traditional centres of sandalwood production indicates that heartwood harvested in wild stands is rapidly being displaced by heartwood from planted trees. This situation is exemplified in the Pacific Islands, where there are now very few remaining accessible mature sandalwood trees but where sandalwood plantings by smallholders are proliferating. With the high prices on offer over the last 2–3 decades, there has been a scramble to locate and harvest the last remaining wild sandalwood in Fiji, Tonga and Vanuatu. This has sometimes led to wasteful 'checking' and cutting of immature trees, sandalwood theft (mostly of individual mature trees), and an associated undocumented illegal trade in sandalwood products. In the future, sandalwood production from wild stands in the Pacific Islands will likely be at low levels, totalling ≤100 ADTH annum^{-1}; trade in wild sandalwood will be predominantly from the traditionally better-regulated supply of *S. austrocaledonicum* in New Caledonia and Vanuatu. The supply of sandalwood from the South Pacific Islands will gradually increase, however, as a result of (mainly) smallholder-planted sandalwood stocks attaining maturity, first in Vanuatu and then in Fiji and Tonga.

Global sandalwood market

It is difficult to quantify the size of the global market for sandalwood due to a lack of published and available trade data and also the scale of illegal trade (likely around 33% of the total market). The most reasonable estimate of the annual global sandalwood market in recent times is 6320 ADTH in 2011–2012 (Coakley 2013). It is clear, however, that global demand for

sandalwood remains strong and also that demand has considerably outstripped supply, especially for East Indian sandalwood, in the past two or three decades. Consequently, prices rose rapidly in the 2000s: the price of *S. album* sandalwood in India increased at a compounded rate of 15.1% between 1992 and 2014 (Anon 2014), and the wholesale price for high-quality East Indian sandalwood oil reached ≥USD 3000 kg^{-1} (for perfumes and new pharmaceutical uses in the United States)[6] in 2016 and early-to-mid 2017 before dropping back to around USD 2000–2500 kg^{-1}. The retail price for East Indian sandalwood oil derived from Australian plantations is also strong—for example AUD 1416 per 100 ml (Sydney Essential Oil Company 2020). The global sandalwood oil market in 2020 is estimated at USD 97 million (approx. 50 tonnes) (Global Sandalwood Oil Markets Report 2020, http://www.360marketupdates.com).

Sandalwood market outlook

The market outlook and prices for sandalwood heartwood and oil of high quality (i.e. with high levels of santalols and attaining the East Indian sandalwood ISO standard) are expected to remain strong for at least the next ten years. The global sandalwood oil market is predicted to double in value over the next five years, to USD 197 million by the end of 2026 (Global Sandalwood Oil Markets Report 2020, http://www.360marketupdates.com). The price elasticity for sandalwood products is rather high—that is, demand will increase substantially if the price of sandalwood falls due to latent high demand from uses such as in medicinal/body-care products. Counterbalancing this price elasticity is the low likelihood of a major, sudden and sustained drop in sandalwood price because the price is buffered and underpinned by product and regional market diversification—that is, diverse uses, including perfumes and attars, fragrant smoke, carving wood, medicinal and body-care products, in diverse regions with strong economies, such as China, Europe, India, the Middle East and North America. There are growing middle classes with high disposable incomes in China and India, nations with traditional cultural associations with sandalwood, which will maintain upward pressure on price even as supply increases or if individual products or markets face a downturn. Nevertheless, sandalwood is a luxury item, the price of and demand for which would inevitably decline to some extent in a major global economic downturn.

It is likely that a range of new uses will be developed and traditional uses will be re-established when more reliable and consistent supplies of high-quality sandalwood oil are generated through sustainably managed plantations. There is a substantial unmet demand to include sandalwood oil in high- and mid-range perfumes, body-care products, aromatherapy, traditional eastern medicines, new pharmaceutical products, and top-of-the-range solid furniture. Such uses and associated increased demand in China, India and other Asian economies will help underpin the price of better grades of sandalwood oil for the foreseeable future.

There is potential for an oversupply of plantation Australian sandalwood, which may result in a drop in the price for *S. album* and *S. spicatum* wood and oil when peak production is reached, but prices for Pacific Island sandalwoods will likely be less affected (Di Lallo 2019). In the future, species with inferior oil quality, such as *S. spicatum*, may struggle to maintain their market share, with lower grades of *S. album* products, including spent still charge, and possibly also lower grades of plantation *Aquilaria* agarwood, displacing *S. spicatum* in agarbatti.

Synthetic santalols are expensive to produce and in lesser demand in the perfume sector, and they are unlikely to be a major replacement for natural santalols (Brocke et al. 2008; Di Lallo 2019). Nevertheless, the biosynthesis of sandalwood oil (Diaz-Chavez et al. 2013) may become economic in the future. Other innovations may also affect sandalwood oil production, such as the production of larger amounts of higher-quality heartwood at a younger age through improved genetics and silviculture, including new heartwood stimulation technologies (Barbour et al. 2019).

Conclusions

A major shift is under way in almost all traditional areas of sandalwood production, such that planted trees will replace wild-harvested sandalwood resources. This is due to the commercial extinction of sandalwood in almost all its native occurrences (the main exceptions being *S. spicatum* in Western Australia and *S. austrocaledonicum* in New Caledonia due to better regulation and monitoring based on realistic sustainable yields). At the same time, and over the past 25 years, there has been a considerable research and development effort to determine and document best practices in the cultivation of sandalwoods (e.g. propagation, establishment, host species and pruning regimes). This has made sandalwood plantation development a commercially attractive and viable land use.

In the near future, if not already, planted sources of *S. album, S. austrocaledonicum* and *S. yasi* will overtake and supplant wild sandalwood resources of the same species, and this pattern will be repeated for *S. spicatum* in the next 10–15 years. Quintis, the major sandalwood grower globally, has high sandalwood production costs compared with those of smallholders in Fiji, Tonga and Vanuatu. Quintis's establishment costs were around USD 55 000 ha^{-1}, added to which are annual fees and rent of USD 4600 ha^{-1} over 15 years. Other production costs for northern Australian sandalwood plantations are also high compared with Pacific Island smallholder sandalwood growers, notably harvesting and processing fees of USD 11 000 ha^{-1}, which are likely more than double those for Pacific Island operations.

The quality of *S. album* oil produced in plantations in north-western Australia is lower than that for wild-harvested *S. album*: Quintis is now harvesting its trees at 15 years old, but harvesting would be better delayed by another 5–15 years to improve oil yield and quality. Due to the cost of maintaining these *S. album* plantations and investor contracts, Quintis cannot afford to keep them for 20–30 years. The planted sandalwood industry in northern Australia is expected to contract over the next few years: it is noted that there have been no new managed investment schemes

[6]Quintis 2016 Product Disclosure Statement: 'It (*S. album* oil) achieves a premium price of more than AUD 4,000 per kilogram in these export markets, compared to a figure of AUD 3,000 per kg in Indian markets'. Quintis had a contract to supply its *S. album* plantation oil to the United States firm Galderma but this lapsed in March 2017. In June 2017, the price was estimated by Mr Steve Zanin (independent agribusiness expert) to be about USD 3600 kg^{-1} and expected to fall much further (Australian Financial Review, 'Quintis discounts oil and timber, upending sandalwood market', V. Poljak 25 September 2017). On 30 June 2017, Quintis sold 2.85 tonnes of *S. album* oil to United States essential oils company Young Living at USD 3000 kg^{-1} (Quintis statement to shareholders/ASX).

(MISs) by Quintis since 2016, or indeed any other forestry MIS. Traditional landowners on Cape York Peninsula are expected to make new modest-scale plantings of native sandalwood in the next few years. A reduction in the area of sandalwood plantation in Australia, including no new plantings of *S. album*, will be advantageous for the stability of global sandalwood markets in the future.

The lower costs of Pacific smallholder sandalwood growers place them in a highly competitive market position – given the diversity of sandalwood products, end uses and markets – and there are opportunities to develop forward contracts. However, it is essential that sandalwood smallholder growers use the best genetic materials of native sandalwood species in their new (optimally designed and configured) agroforestry plantings. Genetic improvement needs to be based on a full understanding of *Santalum* taxonomy, and this applies especially to *S. macgregorii* (in Western Province) and *S. lanceolatum* (on Cape York Peninsula).

The Australian Centre for International Agricultural Research (ACIAR)'s Pacific and Australian Sandalwood Research projects (FST/2016/158, FST/2014/069 and earlier ACIAR sandalwood projects in Vanuatu) are providing vital outputs in terms of improved genetic stock of native species, advanced agroforestry systems and informed policy advice to Pacific Islands and Australian Government agencies. Indeed, they are essential if the planted sandalwood industry is to flourish and provide economic benefits to participating countries and smallholders, including Pacific peoples living on remote islands and First Nations peoples on Cape York Peninsula, who have few other viable cash-income-generating options. Pacific Island governments also need to improve the legislative regimes for and governance of their sandalwood industries to reduce theft and illegal trade to ensure that growers and owners are properly remunerated and to meet increased consumer need to demonstrate legality.

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