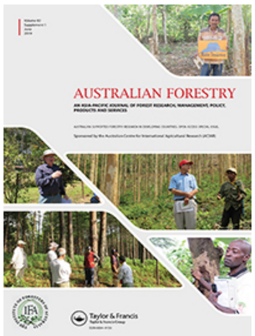

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ARTICLE

Domestication of northern sandalwood (*Santalum lanceolatum*, Santalaceae) for Indigenous forestry on the Cape York Peninsula

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ABSTRACT

Over recent decades there has been considerable private investment in developing a sandalwood (*Santalum* spp.) industry due to the high international demand for products derived from its heartwood. While *Santalum album* (Indian sandalwood) has been the primary species used in these investments, other species may also have potential for commercialisation. In Cape York Peninsula (CYP), where *Santalum lanceolatum* occurs naturally, there are limited options for industry development, but research has shown that sandalwood products may provide an opportunity. The potential to incorporate sandalwood into existing Indigenous land management plans and further extend this into commercial plantings provides the opportunity to utilise an endemic tree species for economic development. This paper summarises participatory research with two Indigenous communities in the CYP to evaluate and improve conservation and development outcomes through sandalwood domestication.

The project has been implemented through a series of community consultations with the aim of reaching a consensus on how a sandalwood industry could develop and facilitating community involvement in the technical aspects of domestication and forest development. Differences in the progress achieved in the communities are significant and depend on the cultural and municipal structures and relationships within the communities.

The participatory approach in the northern part of the CYP has resulted in the establishment of important *S. lanceolatum* genetic resources that will be used to underpin the development of an industry: (1) sandalwood demonstration plantings (Bamaga and Lockhart River); (2) clonal seed orchard (Bamaga); (3) conservation enrichment plantings (Bamaga) and (4) two progeny trials (Bamaga). The survival of *S. lanceolatum* from the northern CYP has been good in both the progeny trials and the grafted seed orchards; however, sandalwood from other sources (other sandalwood species including *S. album, Santalum austrocaledonicum* and *Santalum leptocladum* and non-local provenances of *S. lanceolatum*) have performed poorly in the northern CYP. This paper outlines the history of sandalwood exploitation in CYP, which has led to the need for interventions to improve its conservation, as well as efforts to domesticate sandalwood so that the Traditional Owners of the northern CYP can benefit from this species.

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Introduction

There are 16 extant species of *Santalum* L. Santalaceae (sandalwood) occurring throughout India, South-East Asia, Australia and the Pacific Islands (Harbaugh 2007; Harbaugh et al. 2010). Around 1910, a sandalwood species, *Santalum fernandezianum* F. Philippi, became extinct due to over-exploitation of trees in the Juan Fernandez Islands of Chile (Stuessy et al. 1997). Many sandalwood species are economically and culturally important in their country of origin due to the aromatic oil in their heartwood (Applegate et al. 1990a; Harbaugh et al. 2010). Currently, sandalwood timber is ground to produce incense (joss) sticks, used in carvings and the heartwood oil is extracted via distillation for use in cosmetics, aromatherapy and pharmaceuticals (Brennan & Merlin 1993; Clark 2006; Jirovetz et al. 2006).

Sandalwoods are facultative hemi-parasites (root grafting via haustoria to host species to access water and nutrients, but they are capable of photosynthesis) and vary from shrubs (e.g. *Santalum spicatum* R. Br. in West Australia) to medium size trees (e.g. *Santalum album* L. in India and *Santalum paniculatum* Hook. & Arn. in Hawaii) (Applegate et al. 1990a; Applegate & McKinnell 1993). The northern sandalwood (*Santalum lanceolatum* R. Br. *sensu stricto*) (also known as Queensland sandalwood, plum bush or plumwood) is one of seven native sandalwood species that occur in Australia. This species is generally distributed north of the 20°S latitude; however, there are intergrades with *Santalum leptocladum* Gand. south of this, in Western Australia and the Northern Territory (Harbaugh 2007). Other sandalwood species native to Australia include *Santalum acuminatum* R. Br., *S. album* (which also occurs in Timor Leste and India), *Santalum murrayanum* T. Mitch, *Santalum obtusifolium* R. Br. and *S. spicatum* (Applegate & McKinnell 1993; Harbaugh & Baldwin 2007). All the Australian *Santalum* species are thought to be diploids (2n = 10); except *S. leptocladum* which displays two ploidy levels—diploid (2n = 10) and tetraploid (2n = 20) (Harbaugh 2008).

Sanatalum lanceolatum is described as a tall shrub or small tree up to 7 m with an air-dried wood density of 930–950 kg m^{-3} (Applegate et al. 1990b). It is generally considered to produce low quantities of heartwood oil, less than

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5% air-dried weight (Jones & Smith 1929, 1931; Weiss 1997). The oil comprises low levels of the preferred α- and β-santalol oils (0.6–2.6% and 2.0–4.3%, respectively) relative to the less preferred Z-lanceol (20–90%) (Doran et al. 2005). In contrast, *S. album* heartwood is reported to contain 6–7% heartwood oil with high levels of α- and β-santalol (42.3% and 16.1%, respectively) and low levels of Z-lanceol (1.8%; Doran et al. 2005). The international standard for sandalwood oil derived from *S. album* (the benchmark species for sandalwood oil) requires α- and β-santalol exceeding 41% and 16%, respectively (ISO 3818:2002). Hence, *S. lanceolatum* is regarded as a species with low quality heartwood and oil, relative to that from India and many of the Pacific Island sandalwoods.

Traditional uses of sandalwood in Australia

Sandalwood has a range of uses in Traditional Owner cultures, many of them are ceremonial or associated with religious practices. In Australia, the fruit of *S. lanceolatum, S. leptocladum* and *S. acuminatum* were eaten by the Aborigines of the central and western parts of the continent (Maiden 1889; O'Connell et al. 1983; Latz 1995) and the roots of *S. murrayanum* were also used as food (Maiden 1889). Traditional Owner and Gudang/Yadhaykenu Group Elder Meun 'Uncle Shorty' Lifu (pers. comm. 2012) commented that the logs and leaves of *S. lanceolatum* were thrown on the fire to ward off mosquitoes when camping in the bush. *Sanatalum acuminatum* is documented as one of the species that Indigenous people used as rubbing sticks to obtain fire (Maiden 1889). An infusion of *S. lanceolatum* bark and leaves was used as a purgative (Latz 1995) and a poultice made from the roots was traditionally used to treat rheumatism (Bush Food Shop, Web Resource 2018). An infusion of the inner bark of *S. spicatum* was reported to have been used as a cough medicine and extracts from the inside of the nut (the kernel) has been rubbed on the body to treat stiffness and colds (Bush Food Shop, Web Resource 2018). *Santalum lanceolatum* wood was also used to help attract new spouses in some Indigenous communities in northern Australia (Sansom 1980).

Commercial harvesting of wild Sanatalum lanceolatum *in Queensland*

Commercial harvesting of northern sandalwood commenced in CYP in the mid-1860s (Applegate et al. 1990b), shortly after the Australian industry commenced in Western Australia in 1844 (Statham 1990). Indigenous people on CYP were involved in the commercial harvest of the trees, working for the sandalwood-getters (Wharton 2009), gathering the sandalwood logs, debarking them and bringing them to the sandalwood-getters campsite prior to it being loaded onto horseback and shipped out via Lockhart River (Lloyd Bay), Somerset, Old Weipa Mission, Aurukun, Mapoon and Port Stewart. Unfortunately, due to unsustainable harvesting practices of the wild resource on CYP the industry collapsed around 1930 and retreated to the gulf country north of Hughenden (Applegate et al. 1990b; Wharton 2009). Overexploitation, scarcity of resources, the Sino-Japanese war (1937–1945) and legislative changes resulted in the wild northern sandalwood harvesting industry in Queensland effectively ceasing around 1940 (Holzworth unpubl. 2005). The Queensland sandalwood industry was revived following the repeal of the Queensland Sandalwood Act in 1982 with controlled harvests south of the Gulf of Carpentaria (between Normanton and Mitchell River) (Statham 1987; Applegate & McKinnell 1993). Most of this resource is exported to Taiwan where it is powdered and turned into incense sticks (Bristow et al. 2000). However, on CYP the harvest of wild sandalwood has not recommenced, as the species is regionally scarce, with a limited number of harvestable size trees (over 10 cm diameter at breast height) observed during extensive surveys (Bragg pers. comm. 2010; unreferenced).

Current wild harvest of northern sandalwood from south of the Gulf of Carpentaria between 2013 and 2016 ranged from 160 to 364 tonnes (State of Queensland 2016); prices for this are unknown. However, prices for *S. spicatum* in 2012 were AU$14 000 per tonne for good-quality, uncleaned logs (AgriFutures Australia 2017). The price received for northern sandalwood would be lower than that reported for *S. spicatum* due to the lower oil yield and poorer oil quality of the material around the southern Gulf. In 2011–2012, the gross production value of the Australian sandalwood industry was estimated to be AU$14.7 000 000 (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee 2013), hence it is a small but valuable industry.

The need for sandalwood conservation

A recurring theme over the last 40 years has been the need to conserve the *Santalum* species, including *S. lanceolatum*, that have been over-harvested for their oil-rich heartwood (Applegate et al. 1990a; Applegate & McKinnell 1993; Clark 2006; Teixeira Da Silva et al. 2016). Three *Santalum* species are listed as threatened by the International Union for the Conservation of Nature (IUCN) and one species listed as extinct (Teixeira Da Silva et al. 2016). On CYP, the remnant populations of *S. lanceolatum* are not recovering and there is little natural regeneration, despite the species being reported as a prolific seed producer (Applegate et al. 1990b). These authors considered the lack of recruitment was influenced by soil moisture availability limiting growth and poor survival of the seedlings, pressure from animal grazing and continued illegal harvesting.

Page and Leakey (2007) noted that of 177 *S. lanceolatum* trees surveyed across the CYP, 72% had flower buds and 27% had open flowers; however, only 1% had mature fruit, despite sampling of sites at different times of the year. They also found that most recruitment was by root suckering following fire. Tamla et al. (2012) recently observed that the *S. lanceolatum* from the CYP was fairly self-incompatible, with only 20% of trees setting fruit following self-pollination. They also found much higher seed production in cross-pollinations, using pollen of an unrelated *S. lanceolatum* trees, compared to self-pollination, using pollen from the same tree, with 9.0% and 1.0% of these pollinations producing seed, respectively. The low seed set in the control pollinated experiments was consistent with a low mature fruit production being observed in the field by Page and Leakey (2007). This observation may indicate that many of the small isolated clumps of sandalwoods trees on CYP are closely related, resulting in low production of mature fruit due to inbreeding. Also, this may explain the low levels of seed-based northern sandalwood regeneration on CYP.

Page et al. (2007) found that 3.4% of the *S. lanceolatum* trees sampled across seven CYP populations, comprising 20–29 trees sampled per population, had oil quality profiles that met the international standard oil for *S. album* (ISO 3518:2002). Overall, the heartwood oil yield across these seven populations averaged 2.5% ranging from 0.1% to 8.2%. This is a much wider range than previously reported: 2.5–4%. They also identified a population in the northern CYP trees producing high quality heartwood oils with elevated levels of the preferred α- and β-santalol oils. Twenty-four percent of these trees had heartwood oil profiles that met the international standard for *S. album*. The overall mean oil at this site was 25.6% and 9.7% for α- and β-santalol, respectively. The trees in the six other populations they sampled generally had low levels of α- and β-santalol and higher levels of cis-nuciferol and cis-β-curcumen-12-ol. Their study revealed a significant opportunity for the development of this species as a commercially viable tree crop. Further work was required to sample more sites and increase the number of high-quality trees included in a domestication program.

The aim of this research was to determine how the unique and higher-quality nature of CYP sandalwood could provide the basis for an intensively managed sandalwood estate and/or extensive enrichment plantings with the participation of Traditional Owners. This paper outlines the two-pronged approach to achieving this aim, which includes: (1) community engagement and capacity building through practical/participatory involvement in the research and (2) capturing and establishing the genetic resources and demonstration plantings to support conservation and commercial development.

Engagement and capacity building

Indigenous community development opportunities presented by the domestication of northern sandalwood

There has been no opportunity to commercialise northern sandalwood on CYP, as the species has not recovered from the over-harvesting of the wild trees that occurred over 80 years ago. However, northern sandalwood offers the prospect for developing a sustainable industry for Indigenous communities on CYP for several reasons:

- The high oil content and high quality (α- and β-santalol) content of some populations of the species should result in high value products (Page et al. 2007)
- The species occurs across a wide range of environments presenting the opportunity to build broadly based adaptable genetic resources that are needed to underpin the development of the species
- The species is adapted to the environments found in the region unlike *S. album* that has died out in the various tests it has been trialled in across CYP (anecdotal observations)
- Serious declines in the population of other *Santalum* species, e.g. *S. album* in India due to unsustainable harvesting practices, including illegal harvesting and little regeneration of the species there (Howes et al. 2004; AgriFutures Australia 2017; IUCN 2017)
- Increasing demand for sandalwood timber and oil, particularly from *S. spicatum* and *S. album*, as consumer preferences switch to natural products over synthetic substances (Clark 2006; AgriFutures Australia 2017)
- There currently are limited employment opportunities for Indigenous people of CYP (e.g. tourism, working for councils, Indigenous Rangers and Community Develop Program (CDP)). However, many Indigenous people of CYP want to develop business opportunities on their land with meaningful jobs, for themselves and their children
- A niche sandalwood industry based around Indigenous communities could provide an agribusiness that suits the needs of Indigenous communities, including the requirement of having an industry that allows for a flexible labour system (e.g. part-time, seasonal and full-time employment as required) (Annandale 2009) and suits their cultural, community and environmental needs (Shepherd 2009; Loxton et al. 2012).

Community engagement for conservation and domestication of sandalwood

Sandalwood conservation and domestication work were undertaken in two areas of the CYP: the Northern Peninsula Area (NPA) located north of the Jardine River and the Lockhart River Community located on the eastern coast of CYP near Lloyd Bay. The domestication of the northern sandalwood builds on six years of continual project work on CYP that can be broken down into three interlinked components:

(1) Connecting with the Traditional Owners and achieving consensus
(2) Joint learning, training and capacity building
(3) Conservation and domestication of northern sandalwood.

Each of these components is outlined below.

Connecting with the Traditional Owners and achieving consensus for work on their land

Conducting any work to develop the genetic resources of *S. lanceolatum* naturally required informed consent of the Traditional Owners of those resources. This aspect of the project was the most challenging component of the project. Identifying and contacting the appropriate Traditional Owners in the communities where the work was to be undertaken was demanding because of changes in project staff and membership of local councils and land trusts. These bilateral changes in people eroded prior knowledge and goodwill, both of which needed to be re-established to progress the community engagement. Another issue with getting informed consent was, local perceptions that the sandalwood trees were of immediate commercial value, hence it was suggested that large fees would be required to capture the seed or scions (tip cuttings) from these trees. Further discussions centred on the current and potential value of the resources and the need for their conservation and development to achieve the prospective commercial outcomes. It was proposed that initial collection of seed and scions from trees in the NPA would help to conserve the locally endangered species and provide the basis for further investigations for their commercial development.

Following a series of direct consultations with Traditional Owners, we gained informed verbal and written consent from them, including the Apudthama Land Trust and the Ipima Ikaya Aboriginal Corporation RNTBC (the Prescribed Body Corporate (PBC)), who hold native title on most of the land in the NPA. The consent was to undertake research and develop the locally available *S. lanceolatum* that was present within their custodial lands. This was achieved through a consistent and iterative approach to stakeholder consultation, including open discussions with the Land Trusts; Northern Peninsula Area Regional Council (NPARC); Traditional Owners and Elders; high school staff and students and interested community members.

Joint learning, training and capacity building

Capacity building has been an ongoing and two-way process from the commencement of the project, beginning with the establishment of demonstration plantings at Bamaga Farm (Fig. 1) in the NPARC and at Lockhart River Community Farm. Training workshops were conducted prior to the establishment of these demonstration plantings with the following points discussed:

- Indigenous use and knowledge of sandalwood
- The previous over-harvest of wild sandalwood from the region leading to CYP sandalwood being locally rare with little regeneration
- How sandalwood grows (e.g. being a hemi-parasite)
- Uses of sandalwood (carving, incense sticks, perfumes and cosmetics)
- Need to conserve the species in the wild
- Potential for the communities to benefit from development of a niche sandalwood industry including:
  - sandalwood plantation development
  - planting the species back into the wild (conservation and enrichment plantings)
  - ecotourism (blending traditional and commercial use of sandalwood on CYP) and
  - ultimately harvesting, processing and using the timber after 15–25 years.

These messages have been reiterated during each visit to the NPARC community (three or four times a year) with the project team now known as the 'sandalwood people' by community members. Engaging with the elder Traditional Owners to discuss customary knowledge related to sandalwood (e.g. medicinal uses), has led to discussion of the ethnobotany of other local plants. This has helped the project team understand sandalwood within the context of indigenous plant use (joint-learning), and further built rapport with community elders.

Joint learning, training and capacity building has been central to the establishment of the various sandalwood plantings undertaken by the project. The project took a collaborative approach across all facets of trial establishment including site selection, layout, establishment, management and measurement of the trials. This collaborative approach was considered an essential part of developing sustainable resources and a genuine way for all stakeholders to determine the interest and commitment of others. This method can potentially result in imperfect trial establishment, but was considered to offer much greater potential for community engagement, ownership and long-term sustainability, as key community members became local champions for sandalwood conservation and domestication. The follow-up by the project team following some failures (e.g. the Bamaga Farm demonstration planting had poor survival) has been one of the most important aspects of building community trust for the project. The practical collaboration has seen a 'rolling engagement', which has resulted in a higher general awareness of the project among the wider community.

Establishment of the sandalwood clonal seed orchard, back 'on country' enhanced the engagement with the community. For many Indigenous people in Australia, 'country' or 'land' 'relates to all aspects of their existence—spiritual, physical culture, language, law, family and self-identity. Rather than owning land, the people belong to a piece of land (Queensland Studies Authority 2008). Following the planting of the clonal seed orchard, stakeholders from the Land Trust and PBC have directly contacted us to discuss sandalwood and the potential of this species to be developed as an agribusiness and its ability to be planted back on country.

Sandalwood demonstration plantings

The establishment of demonstration plantings in the two communities on CYP was of great importance as it

(a) (b)

Figure 1. (a) Farm staff, CDP workers and project staff planting the demonstration trial at the Bamaga Farm July 2012. (b) John Huth and Traditional Owner and Elder, Meun 'Uncle Shorty' Lifu at the sandalwood workshop at Bamaga Farm

generated initial interest within the communities around the potential of the sandalwood. Taxa planted at the Bamaga Farm demonstration planting consisted of: three *S. lanceolatum* provenances from the southern part of the species distribution in Queensland Hughenden, Cooktown and Archer Point (south of Cooktown) and one source each of *S. album* and *Santalum austrocaledonicum* Vieillard. These were established with the host species *Acacia simsii* A. Cunn. ex Benth as the intermediate-term host and *Millettia pinnata* L. Panigrahi (syn. *Pongamia pinnata*; a legume being developed for biofuel production) as the long-term host. The trial was not irrigated and unfortunately the sandalwood in this planting was not adapted to the environments in the northern CYP. This led to extremely poor survival of the sandalwood and relatively good survival of the *Pongamia* (over 90%). Hence *Pongamia* has been adopted by the project, as the preferred long-term host, while testing of other host species continues.

Taxa established at the Lockhart River Community Farm were three provenances of *S. lanceolatum* Davies Creek, Walkamin and Delta Downs and a *S. album* source. The best of the *S. lanceolatum* trees had reached 2.5 m tall by age 1.5 years with flowers and immature fruit when last inspected. The Lockhart River trial was unfortunately damaged by fire about this time. This fire, constant political change in the Lockhart River and lack of engagement by some of the Traditional Owners in the community for the conservation and development of sandalwood on their country resulted in project work ceasing there, as we could not make sufficient progress within the timelines of the project. It is hoped that following the success of the work in the NPA that we will be able to re-engage with the community at Lockhart River in the future.

Establishing the demonstration plantings, planting the species on country in the wild (enrichment plantings) and other plantings discussed in the next section, required training and capacity building within the communities. The Indigenous people in the NPA and Lockhart River had limited experience with agricultural production systems and many of them had not planted a tree prior to this activity. Joint learning from establishing the demonstration plantings included: understanding the need for weed control and training CDP workers on the correct use of brush-cutters near the sandalwood seedlings to avoid ringbarking, the need to develop robust tree guards to protect the trees and the need to apply insecticides shortly after planting to protect the young sandalwood seedlings from generalist insect species (i.e. grasshoppers).

Another aspect of capacity building in the communities, in addition to those detailed in the previous section, was via the conservation and domestication of the species. The main thrust of this work was to develop a genetic base of the local *S. lanceolatum*, as the current scarcity of the species in the wild and the lack of seed-based regeneration meant the communities had no opportunity to benefit from the species. Initially, we aimed to capture the species from the wild via seed collections from the remnant wild stands with additional grafting of the known high oil content trees that had desirable α- and β-santalol profiles. Despite significant effort during the first three years of the project, only nine ripe seeds were collected from the wild, producing only a single seedling. This experience contrasted previous reports that state the species was a prolific seed producer

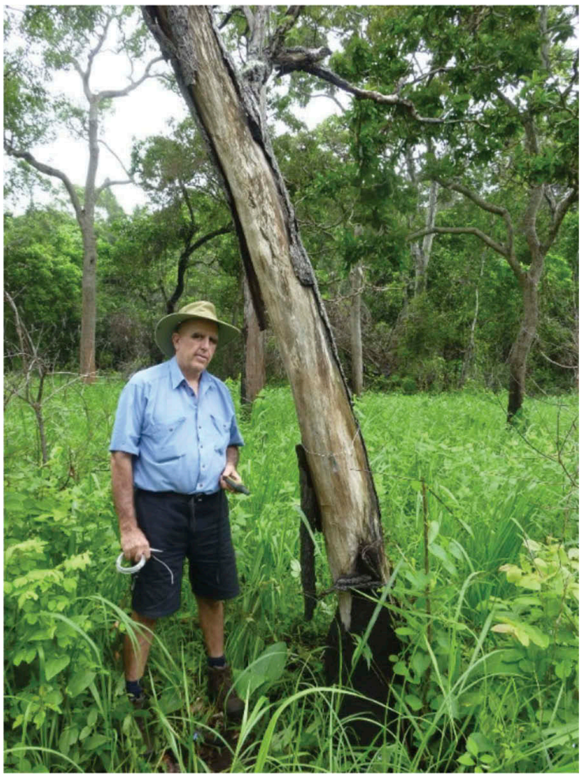

Figure 2. John Huth standing beside a high oil content and high α- and β-santalol profile *Santalum lanceolatum* tree that has been killed by fire

(Applegate et al. 1990a; Applegate & McKinnell 1993; Bristow et al. 2000; Page & Leakey 2007). During our field trips, little seedling-based regeneration was observed with most regeneration appearing to be via root suckers following fire or erosion damage, which fits with observations by Applegate et al. (1990b) and Page et al. (2007). We also observed that the species was in significant decline in the wild with 19% of the previously identified trees in the region being killed by wild fires between 2011 and 2016 (Fig. 2). Many of these trees have not been captured in any collecting program and hence these genotypes are lost for future breeding work. Details of the conservation and domestication work are expanded on in the next section.

Conservation and domestication of Cape York Peninsula sandalwood

Wild sandalwood trees on Cape York Peninsula and associated vegetation

Many of the remaining sexually mature sandalwood trees on CYP occur in small isolated groups of 1–20 trees of varying size with many thought to be root coppice following fire (Applegate et al. 1990b; Page et al. 2007). Many of these trees are taller and have larger stem diameters than that documented for the species, which is generally regarded as tall shrub up to 7–8 m tall (Applegate et al. 1990b; Applegate & McKinnell 1993). We have identified trees up to 17 m in height and diameters at breast height of over 25 cm.

Page et al. (2007) documents that most common species associated with northern sandalwood on the CYP are: *Acacia auriculiformis* A.Cunn. ex Benth., *Acacia polystachya* A.Cunn. ex Benth., *Acacia cambagei* R.T.Baker and *Acacia farnesiana* (L.) Wight ex Arn.; however, in the populations we are dealing with in the northern part of the CYP, the most common associated species (and potential hosts) are: *Melaleuca quinquinervia* (Cav.) S.T.Blake, *Alphitonia excels* (Fenzl) Benth., *Grevillea glauca* Banks & Sol. ex Knight, *Grevillea parallela* Knight, *Pandanus solmslaubachii* F.Muell., *Eucalyptus tetrodonta* F.Muell, *Corymbia nesophila* (Blakely) K. D.Hill & L.A.S.Johnson, *Petalostigma pubescens* Domin and occasionally *A. auriculiformis*. Of note during the current project we observed that northern sandalwood often occurred near basalt intrusions, which has likely influenced the tree species that it is associated with.

Variation in morphology and anatomy

Given the disjunct distribution of *S. lanceolatum* on CYP and the likely high level of inbreeding in the species, a study of morphology was undertaken to determine any associations with high quality forms, which could be used to inform future sampling regimes.

Morphological assessments undertaken during current and previous projects reveal, that populations with high oil qualities may be discriminated from most other *S. lanceolatum* populations. This is important for identifying new candidate sites for the selection of high-quality individuals for infusion into the domestication program. Characters such as tree form, leaf orientation, leaf colour, leaf thickness and leaf surface anatomy can be used to differentiate *S. lanceolatum* populations. While any of these characters alone may not be particularly diagnostic, when combined they offer a practical means to discriminate between the higher and lower quality *S. lanceolatum* populations on CYP. The higher quality populations have trees with branches that are typically less pendulous and leaves with a more horizontal orientation when compared with the lower quality trees. On sites where sandalwood is of low quality, the leaf colour does not vary between the upper and lower surfaces. Trees from high oil quality sites have a notable colour difference with a dark glossy green upper leaf surface and the whitish matt green lower leaf surface and these trees are typically less glaucous than low oil quality trees. Trees from high oil quality populations also produce a greater proportion of leaves with pronounced undulate margins (≥ 85% of leaves are undulate) compared to typical *S. lanceolatum* populations (≥ 35%). The two quantitative characters used to confirm the unique high oil form of *S. lanceolatum* are leaf thickness and stomatal density. Leaves were found to be significantly thinner ($P < 0.05$) in high oil quality populations (0.26–0.28 mm) compared with the typical *S. lanceolatum* populations (0.33–0.7 mm). Leaf stomata density was an unequivocal determinant character of these high oil quality populations with a complete absence of stomata on the upper side of the leaf, whereas all other *S. lanceolatum* populations were found to have stomata occurring on both sides of the leaves at an upper to lower ratio of 0.5:1 to 1:1.

Capturing the wild trees and establishing clonal seed orchards

As seed-based capture of the wild trees was not practical due to the low seed set, capturing the trees from the wild through grafting subsequently became the focus of the project for the conservation and domestication of the species. Preliminary grafting experimentation was undertaken to evaluate the following factors: (1) best season to collect scion material for grafting: mid-wet season, start of the dry season or mid-dry season; (2) type of scion material to collect: semi-lignified versus lignified scion (Fig. 3) and (3) impact of species of rootstock on grafting success: *S. album* or *S. lanceolatum*. Based on our studies, top-cleft grafting using semi-lignified scion material with active axillary buds, collected during the middle of the wet season using *S. lanceolatum* rootstock (74% success relative to 44% success when grafted onto *S. album* rootstock) resulted in greater grafting success that any other method evaluated. Once a successful graft union has been achieved, we have found very little graft incompatibly no matter what rootstock was used.

This method of sandalwood grafting facilitated capture of 20 wild *S. lanceolatum* trees from the NPA including nine trees with superior oil profiles, as well as 11 other trees that have not yet been characterised for their oil profiles. Selection of these later trees was made to ensure a broad genetic base of the species from the region had been

(a) (b)

Figure 3. (a) Typical semi-lignified *Sanatalum lanceolatum* scion material tested with active axillary buds and (b) fully lignified scion material without active axillary buds

captured and conserved. Enough grafts from 16 of these trees have been captured to establish a grafted clonal seed orchard back on country at the Northern Peninsula Area State College with the help of staff and Senior Campus students, who have included learning about the species in their classroom activities.

Seed production from the grafted Sanatalum lanceolatum *trees*

Flowering of the grafted *S. lanceolatum* trees began in the nursery, approximately six months after the scions had been successfully grafted. The grafted trees have continued to produce flowers regularly and abundantly since they have been planted out in the clonal seed orchard. As expected for a small flowered species like *S. lanceolatum*, insects including domestic European bees, flies, wasps, ants and butterflies appear to be the main pollinators. These pollinations have resulted in excellent seed production compared to that observed in natural stands and produced enough seed to plant over 20 ha of sandalwood plantations.

Planting sandalwood progeny back on country

Viability of seed of *S. lanceolatum* from the clonal seed orchards was good (81.5%) with an average of 35% of the seed producing 'plantable' seedlings at age six months. Bulked family seedlots comprising seed from multiple ramets of a single clone had viabilities ranging from 0% to 90%, when approximately 100 seed per family sown. Seed germination reported in the literature for the related species *S. album* was 67% at ten months (Hirano 1990) and 45–65% (Ramalakshmi & Rangaswamy 1997). Unfortunately, no indication of numbers of plantable seedlings from their study of *S. album* were documented.

During February 2017, sufficient seedlings were available to establish two sandalwood progeny trials in the NPA. Soils at both progeny trials are described as ferruginous laterites (Briggs & Philip 1995). Both trials were established as randomised complete block designs of single tree plots using 4–6 replicates. The size of these trials was limited by suitable land availability at the time. These progeny trials also served as further demonstration plantings of the species for the community. High school staff and students and CDP workers assisted with these plantings. The larger trial near the Northern Peninsula Area State College is being irrigated periodically as needed with town water whereas the trial at the Bamaga Farm is not irrigated. While the progeny trials are too young to provide any statistical comparison, they have excellent survival and the best *S. lanceolatum* family had reached 1.06 m height at eight months of age (family height range 0.55–1.0 6 m).

Enrichment plantings

Two small enrichment plantings have been undertaken with the Traditional Owners, on country, to test whether this may be a viable option to establish the species back into the wild. These trees were planted with the help of Traditional Owners and Elders on sites they selected. They are watering the seedlings and keeping project staff informed of their progress. Similar enrichment plantings in Vanuatu using *S. austrocaledonicum* had basal diameter growth rates of 1.1 cm y^{-1} (Page et al. 2012). Monitoring the growth of the enrichment plantings on the CYP is planned. In addition, we have distributed over 80 sandalwood seedlings to interested Indigenous people from the community to be planted around homes and parks in the NPARC.

Discussion and conclusions

Comparison with a similar sandalwood domestication program in the Pacific

Participatory domestication of sandalwood conducted in Cape York reflects a similar and successful approach implemented in Vanuatu. This included surveys of wild populations of sandalwood and identification of candidate trees producing heartwood oils of high quality (Page et al. 2010b). These were captured as the basis for an improved seed source available for small scale woodlots (Page et al. 2008). Engagement with landowners in Vanuatu followed an iterative and practical approach to build relationships over time and demonstrate the unique silvicultural aspects of sandalwood production, particularly related to its host requirements (Page et al. 2016). In Vanuatu, sandalwood plantings are typically established by individual family units as small agroforestry woodlots where trees are planted among or adjacent to other garden and cash crops (Page et al. 2010a). On CYP, the sandalwood seed orchards and demonstration plantings have been established on country with help from public/community institutions (e.g. the local high school, land trust, prescribed body corporate and regional council) with the aim of providing the community with the greatest exposure to the concepts and methods for its production and commercialisation. Development of a sandalwood industry in the CYP will be with these public/community institutions as land is a community asset and not owned or managed by individuals.

The future of Cape York Peninsula sandalwood

Based on the success of capturing the species from the wild, establishing demonstration plantings and progeny trials and the associated engagement with the Traditional Owners of the germplasm, the future for *S. lanceolatum* on CYP looks promising. We now have Traditional Owners actively seeking opportunities to develop the species with potential investors as an agribusiness that will lead to regional employment and business opportunities in the region. There are many research questions and development requirements that still need to be addressed:

- Investigate population diversity within the remnant stands
- Study the recruitment in these remnant stands
- Broaden the genetic base by capturing additional trees as grafted clones
- Test additional trees for oil quality
- Evaluate the growth rates, oil yields at different ages, age of heartwood formation, bole length and economics of *S. lanceolatum* plantations and enrichment plantings
- Study potential pest and disease issues
- Evaluate additional sandalwood host species that may improve the economics of *S. lanceolatum* plantations (e.g. other crop species)
- Investigate the potential of dryland versus irrigated *S. lanceolatum* plantations

- Study the management requirements of *S. lanceolatum* plantations
- Test the fruit and seed for food nutritive values, potential and opportunities
- Test planting the species on additional sites.

The project team will work on these issues as funding becomes available and continue to learn while developing this species with the Indigenous people of CYP.

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