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Direct seeding Acacias of different form and function as hosts for Sandalwood (*Santalum spicatum*)

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SUMMARY

It has long been recognised that *Acacia* species are the premier hosts upon which to establish the parasitic Sandalwood (*Santalum spicatum*). Most plantations established to date in the wheatbelt have Jam wattle (*Acacia acuminata*) at 830 per hectare as the main or sole host species of *Acacia*. Whilst it is apparent that *A. acuminata* is one of the ideal principal hosts and should form a significant part of the host mix, the inclusion of other species should also be considered as they can complement the role played by Jam. Inclusion of multiple host species can benefit Sandalwood plantations by: reducing the parasitic load on individual hosts and host groups, thus maximising the potential for long-term survival; providing additional seasonal sources of water and nutrition; providing shade to Sandalwood seedlings and full sun to mature trees; protecting seedlings against pests and diseases; reducing the weed burden; sustaining host vigour; and increasing nature conservation value. By direct seeding a biodiverse host mix it is possible to establish a large number and range of *Acacia* species (and other genera) as potential hosts. The use of direct seeding for host establishment is discussed.

INTRODUCTION

The sale of Western Australian Sandalwood (*Santalum spicatum*) harvested from remnant vegetation generates revenue of $12 million for the State of Western Australia (Anon. 2000). Sandalwood once grew throughout the wheatbelt of Western Australia but this resource has been exhausted due to over-exploitation and clearing for agriculture (Loneragan 1990). There has been increasing interest from the farming community and other investors in the development of a plantation *Santalum spicatum* industry in the wheatbelt.

Extensive trials have shown that parasitic *Santalum* species show improved growth and vigour when cultivated with leguminous hosts (Radomiljac and McComb 1998; Brand *et al.* 2000; Loveys *et al.* 2001). It has long been recognised that *Acacia* species are the premier hosts upon which to establish Sandalwood. Most host plantations established to date in the wheatbelt have concentrated on planting seedlings of Jam wattle (*Acacia acuminata*) at 830 per hectare as the sole species of *Acacia* (Brand *et al.* 1999, 2000; Brand and Jones 2001). This paper investigates why species other than Jam should be included in Sandalwood plantations. Direct seeding of acacias is discussed, as are the benefits of using direct seeding for host establishment.

A DIVERSITY OF HOST SPECIES BENEFIT SANDALWOOD

A large research effort has been spent on determining which species, grown as a sole host for Sandalwood, gives best growth (e.g. Brand *et al.* 2000). Such research has improved our understanding, but basing plantations on one host species planted at low densities ignores the research that has shown that Australian woody root hemiparasites of the Santalaceae, Olacaceae and Loranthaceae all naturally parasitise numerous species from a range of genera and families (Herbert 1925; Fineran and Hocking 1983; Pate *et al.* 1990). Both Herbert (1925) and Loneragan (1990) reported *Acacia*, *Allocasuarina*, *Templetonia*, *Dodonaea*, *Eremophila* and *Eucalyptus* as hosts of *S. spicatum*. Whilst it is apparent that *A. acuminata* is one of the ideal principal hosts of wheatbelt Sandalwood and should form a significant part of the host mix, the inclusion of other species should also be considered as they can complement the role played by Jam.

Justification for the inclusion of other species into the host mix is provided through the following factors:

Reduced stress

In most plantations established to date the parasitic load is imposed on one or two individual hosts of the same species. In some cases, five to ten years after establishment the parasitic load on hosts has caused host decline or death, resulting in a decline or death of Sandalwood (Brand *et al.* 1999). When sown among numerous host plants of diverse species, Sandalwood parasitises a number of individual hosts, even at one or two years of age (Table 1). This reduces the parasitic load applied to individual hosts and host groups, maximising the potential for long-term survival of sandalwood plantations.

TABLE 1
Maximum extent of host root parasitism of along a rip line (north and south) of four Sandalwood seedlings 17 months old. Sandalwood diameter was measured at the soil surface. The presence or absence of functional haustoria on excavated host roots at various distances from the sandalwood was used to determine the extent of parasitism.

	DIAMETER OF STEM (MM)	HEIGHT (M)	EXTENT OF PARASITISM FROM PLANT (M)		NUMBER OF ADDITIONAL HOSTS ACCESSIBLE TO PLANT
			NORTH	SOUTH	
			NORTH	SOUTH	
Sandalwood 1	19	0.9	0.9	1.5	21
Sandalwood 2	5.3	0.4	0.4	1	9
Sandalwood 3	11.8	0.2	0.8	0.9	6
Sandalwood 4	13.9	1.3	1.2	1.2	7

Additional seasonal sources of water and nutrition

Although shallow-rooted annual and perennial hosts may not be good sole hosts and are unable to supply water to and support Sandalwood during the dry summer period (see study on the root hemiparasite *Olax phyllanthi* by Pate *et al.* 1990), they are parasitised during autumn, winter and spring and would be important nutrient and water sources during this period. The authors have observed that shallow-rooted perennial acacias such as *A. pulchella* and *A. lasiocarpa* and even annual weeds such as *Erodium* sp. *Brassica* spp., *Arctotheca calendula* and *Trifolium* spp. are extensively parasitised by Sandalwood grown in host plantations. These hosts provide Sandalwood with additional seasonal sources of water and nutrition. Acacias and other hosts with deep root systems (e.g. some *Hakea* and *Eucalyptus* species) are able to access moisture stored at depth and thus can be important sources of water for attached Sandalwood. Non-leguminous deep-rooted host may not be ideal sole hosts for Sandalwood but in a mixed species host plantation would provide attached Sandalwood with a much-needed additional water source.

Plants differ in their ability to extract and utilise nutrients from their surroundings. For example, proteoid roots of *Hakea* and other Proteaceae assist with phosphorous uptake from soils that have low phosphorous content (Bowen 1981). The authors have often observed functional *S. spicatum* haustoria on roots of *Hakea* and *Dryandra*, yet these species are not often included in host plantings. These species could provide the parasite with an important additional source of phosphorous. A similar nutritional benefit argument would exist for the inclusion of species which form mycorrhizal associations.

Access to sunlight

Santalum seedlings can benefit from partial shading (Barrett and Fox 1994), whereas wild mature trees are not often shaded. The use of low thorny or laterally spreading *Acacia* species in plantations initially shades Sandalwood seedlings but allows access by the hemiparasite to full sunlight when it grows beyond canopy (Fig. 1).

Figure 1. Complementary growth form: Acacia redolens *and an emergent* Santalum spicatum.

Protection from pests and diseases

Pests and diseases (i.e. galls, mistletoes, and viruses in or on *Acacia*) can kill host trees and, when a sole host species is grown, the consequences of a pest or disease outbreak can be severe. An outbreak of a pest or disease will have less impact in a mixed host plantation because a single ailment is unlikely to affect all host species.

Plants accumulate a range of chemical compounds that protect them from herbivores. Loveys *et al.* (2001) demonstrated that a defence compound was transferred from host plants to parasitic plants in the Santalaceae, where it offered protection from herbivores. It is possible that such transfers also occur between principal or other hosts and Sandalwood. Thus, establishing Sandalwood with a diverse mix of host plant may increase the chance of such transfers occurring.

Sandalwood shoots are palatable to most herbivores. Host plants that have spines (e.g. *A. pulchella*, *A. lasiocarpa*) or form dense, low, laterally spreading bushes (e.g. *A. redolens* and *A. consobrina*) provide protection to young Sandalwood trees until they are above grazing height.

Reduced weed burden

Annual and perennial grass weeds compete with hosts for resources and can pose a fire hazard. Sandalwood is killed by fire (Loneragan 1990) and the industry requires that all harvested wood to be free of charcoal. The authors have observed that the inclusion of low, laterally spreading *Acacia* bushes (e.g. *A. redolens* and *A. consobrina*) significantly reduces weed growth (Fig. 2).

Figure 2. Suppression of grasses by Acacia consobrina.

Sustained host vigour

It is also important to include long- and short-lived acacias in the host mix. Fast-growing hosts (e.g. *Acacia saligna* and *A. pulchella*) offer protection to young Sandalwood seedlings, initial vigour and an immediate host resource, but longer-lived, slower-growing hosts such as *Acacia acuminata* and *A. redolens* are required to sustain Sandalwood growth in the long term.

Enhanced nature conservation

From field excavations the authors have found that *Santalum spicatum* naturally parasitises a wide range of native plants, from small perennial herbs to large deep-rooted trees. It makes good commercial and biological sense to attempt to simulate at least some of this diversity in host plantations. Direct seeding with a wide range of species can be designed to confer great structural and species diversity in the plantation (Fig. 3). The randomness, density and diversity resulting from direct seeding will provide a natural vigour and resilience

Figure 3. Direct seeded hedgerows such as this (composed of 6 Acacia *species and a selection of other species) can protect and camouflage Sandalwood seedlings. The system also provides suitable habitat for a number of animals. Inset: a burrow of the Bush Rat* (Rattus fuscipes) *and discarded Sandalwood nuts.*

potentially lacking in a more traditional forestry layout. Dense, species-rich host plantations will not necessarily look like plantations and may be strategically placed to form viable habitat corridors, or to buffer existing remnants. If the species mix is diverse enough, after natural competition has occurred, each soil type will be adequately vegetated. Usefulness to native animals is increased with density of planting which can provide protective cover (especially thorny species) for foraging and nesting (habitat) for smaller animals, which will not be favoured by widely spaced host monocultures. Many leguminous genera such as *Gastrolobium*, *Acacia* and *Daviesia* provide seed that is consumed by a variety of birds and insects.

The commercial aspect of Sandalwood plantations means that some establishment will be on good agricultural land that would not normally be available for nature conservation. It is the authors' experience that landholders are more likely to consider creation of habitat or corridors if there is the long-term prospect of some commercial gain through production of Sandalwood.

DIRECT SEEDING ACACIAS AS HOSTS FOR SANDALWOOD

Acacias are relatively large-seeded, and direct seeding is cheap and usually very successful if adequate site preparation is carried out. Seedling densities of over 5,000 per hectare are readily achieved from seeding rates of 0.5 kg per hectare. As seed costs about $300 per kg, direct seeding carried out by landowners can be a very cheap way of establishing hosts. Other costs apart from seed may be hire of machinery (e.g. Chatsfield tree planter with seed box) and weed control. Sandalwood will eventually kill some hosts and in plantations with a low host to Sandalwood ratio, host death will adversely influence Sandalwood growth and survival (Brand *et al.* 1999). High host densities achieved with direct seeding (*Acacia* and other genera) result in a high host-to-Sandalwood ratio and thus the death of some hosts would have little influence on Sandalwood survival and vigour. Indeed the higher number of hosts per hectare will maximise host resource available to Sandalwood.

Direct-seeded hosts may form dense hedgerows of many vertical stems. In this formation, sandalwood is also forced to grow taller and the authors have observed reduced herbivore damage to young sandalwood seedlings growing amongst the host stems. This was particularly evident at a site adjacent to Stirling Range National Park where there was intense grazing pressure from kangaroos, rabbits and also sheep, which breached outer fencing several occasions. The hedgerows of *Acacia acuminata* at this site appeared to offer physical protection and/or camouflage to the sandalwood saplings that were growing up as part of the hedgerows.

Hedgerows of hosts and emergent sandalwood established at Narrogin suffered damage from parrots but the damage to the sandalwood was observed to be minimal. At this site many hosts were damaged but because there were very high numbers of hosts (>1500 host/ha) the impact on the plantation as a whole was minimal. Furthermore, host species with thorns (*Davesia* sp. and *Acacia lasiocapa*) were not damaged.

The proportions of species in direct seeding mixes must be selected carefully. High concentrations of cheap seed of fast-growing species such as *A. saligna* can swamp other slower growing, long-lived hosts, dry the soil out too much for Sandalwood seed germination, and shade young Sandalwood. In the south west, it is recommended that about half the seed mix by weight comprise *A. acuminata*, and that *A saligna* be no more than 30 gm per hectare.

TABLE 2
Species and genera suitable for inclusion in host mixes

SOME OF MANY SUITABLE ACACIA HOST SPECIES	OTHER NITROGEN -FIXING HOST GENERA	OTHER USEFUL GENERA
Acacia acuminata	*Allocasuarina* (sheoak)	*Hakea*
Acacia saligna	*Bossiaea*	*Dryandra*
Acacia pulchella	*Brachysema*	*Dodonaea*
Acacia cyclops	*Chorizema*	*Eremophila*
Acacia redolens	*Daviesia*	*Myoporum*
Acacia glaucoptera	*Jacksonia*	
Acacia rostellifera	*Kennedia*	
Acacia microbotrya	*Nemcia*	
Acacia dictyoneura	*Senna*	
Acacia consobrina	*Mirbelia*	
Acacia lasiocalyx	*Gastrolobium*	
Acacia lasiocarpa	*Templetonia*	

SANDALWOOD GROWTH IN DIRECT-SEEDED BIODIVERSE HOST PLANTATIONS

From a purely commercial viewpoint, growth (wood biomass), oil quantity and quality determine the financial returns from plantation Sandalwood. At Kwobrup, Brand *et al.* (2000) reported a mean annual growth rate (i.e. stem diameter increase at 150 mm above soil surface) of 8.6 mm per annum for sandalwood grown on *Acacia acuminata* as the sole host (625 hosts/ha). The mean was calculated from measurements made on the tallest Sandalwood sapling at each planting spot and there were up to four saplings per spot. At Narrogin, where plantation sandalwood is grown among many direct seeded hosts of diverse species, the authors have measured a mean annual increase in stem diameter (at 150 mm above the soil surface) of 6.5 mm (± S.E. 0.3, 50 randomly selected two-year-old Sandalwood saplings were measured). This result suggests that plantations composed of numerous hosts of diverse species can support Sandalwood growth rates that are similar to plantations consisting of a single host species planted at a low density.

CONCLUSION

Commercial plantations of Sandalwood (*Santalum spicatum*) may be achieved through direct seeding biodiverse host mixes. This technique is not only cheaper than conventional forestry techniques but provides many other benefits to the young Sandalwood, ensures long term growth and can make a beneficial contribution to nature conservation.

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