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EDITOR'S NOTE

In this issue of the SRN, Nagaveni and Vijayalakshmi investigate Santalum album performance with different host species in both the nursery and in the field, near Bangalore, India. Suitable host species are always a key for a successful sandalwood plantation. Also within India, Jain, Angadi, Shankaranarayana and Ravikumar examine the relationship between oil percentage and tree girth in three provenances of S. album. Heartwood volume and oil percentage set the price of all sandalwood species, so it is important to understand the relationships between tree size and oil percentage.

In Western Australia, Marie Murphy describes the relationship between woylies (Bettongia pencillata) and Santalum spicatum seed dispersal. Many small mammals, like the woylie are now absent from inland Western Australia, where much of the remaining stands of S. spicatum occur. Currently, recruitment of S. spicatum in these regions is very poor, partly due to grazing and poor seed dispersal. Studying the relationships between the woylie and S. spicatum may help show how S. spicatum seed dispersal occurred before the disappearance of these small mammals.

Jon Brand

Growth performance of sandal (*Santalum album* L.) with different host species

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Abstract

Santalum album L (Sandal plant) is a partial root parasite on several host plants. It shows a preference to certain host species and grows well. In the present study, Pongamia pinnata and Casuarina equisetifolia supported the sandal plants, yielding robust growth, where as some hosts like Artocarpus integrifolia, Acacia auriculiformis and Swietenia mahogany hindered the growth of sandal. Understanding the dynamics of parasitism may help in raising successful multi species plantations of sandal along with other valuable timber species.

Introduction

Sandal (*Santalum album* L.) has gained importance world over for its scented heartwood and essential oil, which is used in perfume, medicine, incense material, carving and other handicrafts of curious interest.

Sandal is a hemi-parasite and was first reported by Scott in 1871. Barber (1906 &1907), has observed that absence of root hairs and presence of actively absorbing haustoria in the rhizosphere of sandal plants; this hemi-parasitic nature made them to believe that sandal plants depend on hosts for certain nutrients.

Sandal can be a parasite on over 300 species of plants found in nature from grasses to other sandal. But, Sandal shows different growth patterns with different host species. Lack of understanding of the complex host -parasite interaction has been the cause for the failure of sandal plantations in the past. Limited studies conducted earlier in pot culture experiments on the influence of hosts on sandal have shown that certain hosts have promoted better growth (Parthasarathi *et. al.*, 1974, Venkata Rao, 1938 and Ananthapadmanabha. *et. al.*, 1988). In these pot culture studies, plants had restricted rhizosphere, inadequate for the proper growth of both sandal and the host plants. It is likely that some of the same hosts may behave differently in the field condition because of wider root zone. The information on growth performance of sandal plants with different host species in the field condition is not adequate. Hence, this study was undertaken to understand comparative growth performance in both pot and field conditions.

Materials and Methods

Studies were conducted under the world bank project during the year 1998-99. Experiments were established in both the nursery and in the field.

Nursery experiment

Studies were conducted under nursery conditions in earthen pots, 40 cm x 30 cm (holding 8-10 kg of soil). The potting mixture consisted of sand, soil and farm-yard manure in the ratio of 2:1:1. Based on earlier studies, nine tree species were selected as poor, medium and good hosts (Ananthapadmanabha, *et. al* 1988 and Parthasarathi, *et al*. 1974) for the experiment. Seedlings of each host species and sandal plants of known seed origin were raised separately in nursery beds.

Subsequently, uniform sandal seedlings were maintained in poly-bags along with the primary host *Cajanus cajan*. After 6 months in the polybag, each sandal seedling and it's primary host were transferred to a pot, with one selected host species. One week after planting, the primary host was trimmed at the base. One set of plants without a host served as the control. The following were the different host plant treatments:

1. *Wrightia tinctoria*
2. *Casuarina equisetifolia*
3. *Pongamia pinnata*
4. *Tectona grandis*
5. *Azardirachta indica*
6. *Eucalyptus camaldulensis*
7. *Acacia auriculiformis*
8. *Artocarpus integrifolia*
9. *Swietenia mahogany*
10. Control (without host)

The experiment was laid out as a random block design with four blocks and five replications in each block.

Field experiment:
The field experiment was conducted in Gottipura, a field station of IWST, 40 km from Bangalore. This was a parallel experiment established in the field with the same host species as for the pot culture experiment.

The sandal plants were transferred to the field along with their selected host species. There were four sandal plants in each block along with host in the same pit and also three host plants planted in quincunx pattern. It was observed that quincunx pattern of host helps the sandal to parasitise at a later stage and grow without over shading each other (Ananthapadmanabha, *et. al*., 1984). Subsequently, the host in the same pit can be removed. Three replications were kept for each treatment (hosts) and the seedlings were planted in a completely randomized design of row planting with alternate hosts, at a ratio of 4:3, with 3 m between sandal and host, and 6 m between two sandal plants. Each block was 6 m long, including trenches in the middle of the block. Total area of the experiment was 5130 m^2. The land was plain without any undulation or slope. The soil work was done periodically and weeded regularly. Experiments were closely monitored for a year in both the pot and the field. Soil working, watering and weeding were done regularly in both experiments. In the pot experiment, hosts were periodically pruned. Mortality of the sandal plants were noted and infilling was carried out for the first month. Plant height was recorded at monthly intervals for 12 months. Different growth parameters, like survival percentage, collar diameter, fresh and dry weight of shoot and root by oven dry method (for pot studies only), chlorophyll content (Sadasivam and Manickam, 1991), leaf area by using the instrument CI-203(leaf area meter) and nitrate reductase activity (Sadasivam and Manickam, 1991) were recorded after 12 months. Seedling quality index was calculated with the following formula (Dickson. *et. al*., 1960) for the pot culture plants.

"biomass in sandal plants with *Pongamia* and *Casuarina* as host were discernibly higher..."

$$\text{Seedling quality index} = \frac{\text{Total dry wt}}{\text{Ht/collar diam.} + \text{Shoot dry wt./Root dry wt.}}$$

Statistical analysis:
The data was analysed statistically and the significance of the difference between the treatment means was tested at 5 % of the probability using 'F' and 't' test.

Results and Discussion

Tables 1 and 2 show the results of the experiments after 12 months. Analysis of all the parameters presented in the Tables shows that the results are significant at the 5% level.

The height and collar diameter measurements revealed that sandal plants with *Pongamia* were significantly superior, followed by *Casuarina, Wrightia, Tectona, Azadirachta*, and *Eucalyptus*. Plant height and collar diameter in sandal plants with *Pongamia* and *Casuarina* increased by

Table 1. Parameters of Sandal plants with different hosts in pots.

Host treatments	Height (cm)	Collar diam. (mm)	Total biomass	Chlorophyll a	Chlorophyll b	Chlorophyll Total	Nitrate reductase activity	Seedling quality index
Pongamia pinnata	57.94d	5.64d	30.12d	1.21h	0.46g	1.66h	0.24d	0.2952d
Casuarina equisetifolia	44.78c	4.15c	21.13c	0.87g	0.37f	1.24g	0.27d	0.1962c
Wrightia tinctoria	37.16c	3.79c	7.48b	0.44d	0.24d	0.67d	0.2d	0.0808b
Tectona grandis	33.37b	3.17b	1.28a	0.62f	0.29e	0.9f	0.12c	0.0117a
Azardirachta indica	33.81b	3.14b	2.14a	0.5e	0.28e	0.78e	0.13c	0.0196a
Eucalyptus camaldulensis	32b	3.8c	3.46a	0.27b	0.19c	0.46c	0.06b	0.0335a
Acacia auriculiformis	18.42a	1.97a	0.89a	0.23b	0.15b	0.38b	0.04a	0.0058a
Atrocarpus integrefolia	19.81a	1.7a	0.76a	0.14a	0.16b	0.31a	0.02a	0.0022a
Swietenia mahogany	20.6a	1.95a	0.76a	0.23b	0.16b	0.39b	0.02a	0.0069a
Control(no host)	22.43a	2.19a	0.78a	0.23b	0.14a	0.37b	0.06b	0.0079a

Note: In each column values followed by a common letter indicate they were on par with at P= 0.05.

Table 2. Parameters of Sandal plants with different hosts in the field.

Host treatments	Height (cm)	Collar diam. (mm)	Total biomass	Chlorophyll a	Chlorophyll b	Chlorophyll Total	Nitrate reductase activity	Seedling quality index
Pongamia pinnata	187d	29.29c	1.03f	0.28d	1.31g	0.2c	187d	29.29c
Casuarina equisetifolia	183d	25.08c	1.45h	0.38f	1.82i	0.22c	183d	25.08c
Wrightia tinctoria	156c	25.04c	0.88d	0.3e	1.18f	0.19c	156c	25.04c
Tectona grandis	148c	20.88b	0.86d	0.22c	1.08e	0.12b	148c	20.88b
Azardirachta indica	163d	25.52c	1.08g	0.37f	1.44h	0.13b	163d	25.52c
Eucalyptus camaldulensis	136c	20.59b	0.63b	0.15a	0.78a	0.12b	136c	20.59b
Acacia auriculiformis	114b	12.39a	0.89e	0.19b	1.08e	0.02a	114b	12.39a
Atrocarpus integrefolia	125b	19.67b	0.82c	0.14a	0.96c	0.02a	125b	19.67b
Swietenia mahogany	80a	13.86a	0.6b	0.21c	0.81b	0.02a	80a	13.86a
Control(no host)	110b	18.86b	0.86d	0.14a	0.99d	0.02a	110b	18.86b

Note: In each column values followed by a common letter indicate they were on par with at P= 0.05.

about 200-260 % over the control, and other poor hosts such as *Acacia, Artocarpus and Swietenia.* Those sandal plants in association with *Wrightia, Azadiracta* and *Eucalyptus* as host showed height and collar diameter increases of around 150 % (medium hosts).

The results of the total biomass in pot culture experiment supported the height data; biomass in sandal plants with *Pongamia* and *Casuarina* as host were discernibly higher and the increase was 3000-3500 % compared to the control. Whereas near *Wrightia, Tectona, Azardirachta* and *Eucalyptus* sandal biomass increase was 200-600 % compared to the control and poor hosts such as *Acacia, Artocarpus* and *Swietenia.*

Data obtained on chlorophyll content were also significant when compared to the control and support the other growth parameters. Although the order of performance is the same as in other growth parameters, each treatment falls under a different group.

Seedling quality index of sandal plants with *Pongamia* and *Casuarina* as the host was very significant when compared to sandal plants without a host (control). The increase in growth is more than 2000 %, and it is a clear indicator of the growth performance and order of ranking.

Sandal plants associated with *Pongamia* and *Casuarina* did not show any mortality; where as the medium hosts like *Wrightia, Tectona, Azadiracta* and *Eucalyptus,* had mortality rates of up to 10 %. Mortality rate of sandal plants was very high (up to 60 %) in the control, and near *Acacia, Artocarpus* and *Swietenia.* Mortality rate in sandal plants was a little less in the field experiment compared to that of the pot experiment, though the trend remained the same as in the case of pot culture experiment. This may be due to the unrestricted rhizosphere zone in field conditions.

The result of nitrate reductase activity of sandal plants was quite significant and shows that the activity is directly proportional to the growth parameters of the plants. Nitrate reductase activity in sandal plants with good hosts was more than 1000 % compared to poor hosts and the control. Poorly grown sandal plants showed low nitrate reductase activity. This activity may be taken as an index for the growth and biomass performance. Based on these studies and performance of growth parameters of sandal plants, hosts can be classified into three distinct groups; viz, good, medium and poor. These results support the findings of Ananthapadmanabha *et al.* (1988), who classified three groups of hosts based on different physiological activity with sandal. Pokhriyal *et al*., (1993) recorded that the major sources of nitrogen available in the soil is nitrate and that it has to be reduced before assimilation in the metabolic processes and this nitrate reductase activity has direct effect on biomass production.
Leaf area was more in sandal plants that were growing with *Pongamia* and *Casuarina* compared to the other hosts in the pot culture. Whereas in the field, leaf area was more in sandal plants that were grown with *Pongamia* and *Casuarina*. Sandal leaf area near *Tectona, Azardiracta, Eucalyptus* was also good, but the results were inconclusive.

The present study showed that there are some variations in growth and other parameters between different host treatments. But in both the pot and field experiments, *Pongamia* and *Casuarina* as hosts supported maximum growth and biomass, whereas association of sandal plants with *Wrightia, Tectona, Azardiracta* and *Eucalyptus* as hosts resulted in moderate growth performance. *Acacia, Artocarpus* and *Swietenia* as hosts did not support good growth of the sandal plants. It was observed that the poor hosts hindered the growth of sandal plants to some extent when compared to that of the control. This may be due to the fast growth of the hosts and over shadowing of the sandal plants by a thick canopy, which might have slowed growth.

The Field study showed that the medium hosts also supported good growth for sandal compared to the pot experiment, though the order of performance remains the same as that of the pot experiment. This may be due to the wide root zone where negative stress of interaction between the host and the parasite may be reduced, unlike in potted plants with a narrow root zone. The results of this field experiment emphasis the need for further studies to understand the process of heartwood formation with different hosts. *Santalum album* planted with multiple hosts in the field has shown to be successful in plantations in Kununurra, Western Australia (Radomiljac *et. al*., 1998) and similar information can be obtained from continuing this field experiment. Further work in this direction will help in establishing a farm forestry system or multi-species plantation of sandal along with other valuable timber species.

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Relationship between Girth and percentage of oil in trees of sandal (*Santalum album* L.) provenances

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Abstract

In three provenance areas of sandal viz. Bangalore, Thangli (Karnataka) and Maryoor (Kerala), studies have been made in respect of GBH and oil. It was observed that percentage of oil remains nearly constant at 4 % after 80 cm girth and that rise in oil percentage beyond 80 cm girth was found to be just marginal.

Introduction

The Sandal tree is mainly exploited for its heartwood which yields the renowned East Indian Sandalwood oil - rated very high for its sweet, fragrant, persistent, spicy, warm, woody note, tenacious aroma and fixative property. Sandal heartwood is currently priced at R.12 lakhs per ton and its oil Rs. 22,000 per kg.

Karnataka and Tamil Nadu occupy nearly 90 % of the total area of Sandal (*Santalum album* L) of 9000 sq. km in India. The rest is distributed in other States like Andhra Pradesh, Kerala, Madhya Pradesh, Orissa, Maharashtra, Rajasthan, Uttar Pradesh, Bihar and Manipur.

At present, India produces 1000 tons of heartwood and 40 tons of oil per annum. For many years till now, amongst the export of various essential oils - sandalwood oil alone contributes for nearly 25 % of the earned revenue.

A study on the girth and oil content in sandal trees growing in different areas and the influence of girth increment on oil yield has been reported earlier (Venkatesan, 1980). The present study reports on the relationship between girth and percentage of oil in three provenances viz. Bangalore, Thangli and Marayoor.

Materials and Methods

Nine sandal-bearing areas were identified as potential provenances in India on the basis of population density, phenotypic character, latitude, longitude and eco-climate. Jain *et.al.* (1998) found that the age/ girth of sandal trees influences the content of oil in the heartwood. Heartwood from young trees (around 10 years of age, height < 10 m, girth < 50 cms) contain 0.2 to 2 % of oil and that from the mature trees (30 to 50 years of age, height 20 m, girth 100 cms) contain 2.8 to 6.2 % of oil.

In the present study, an attempt was made to find out any relationships between girth and oil content within sandal provenance areas. Oil content in the standing tree was determined using UV-spectroscopic method (Shankarnarayana *et.al*, 1997) from core samples taken at breast height, using an increment borer (BH). In each provenance, 20 sandal trees of girth class ranging from 40 to 100 cm were chosen at random for core samples. Girth class range, the average percentage of oil in respect of 4 to 6 trees have been evaluated for the three provenance areas viz, Bangalore, Thangli (Karnataka) and Marayoor (Kerala) and the results are presented in graphs 1,2 and 3 respectively (Figure 1).

Results and Discussion

From Figure 1, it is evident that in three provenance areas (out of nine in India) of sandal viz Bangalore, Thangli (Karnataka) and Marayoor (Kerala) that the percentage of oil was nearly the same at 4 % from GBH 80 cms and onwards. Rises in oil percentage beyond 80 cm girth were found to be just marginal.

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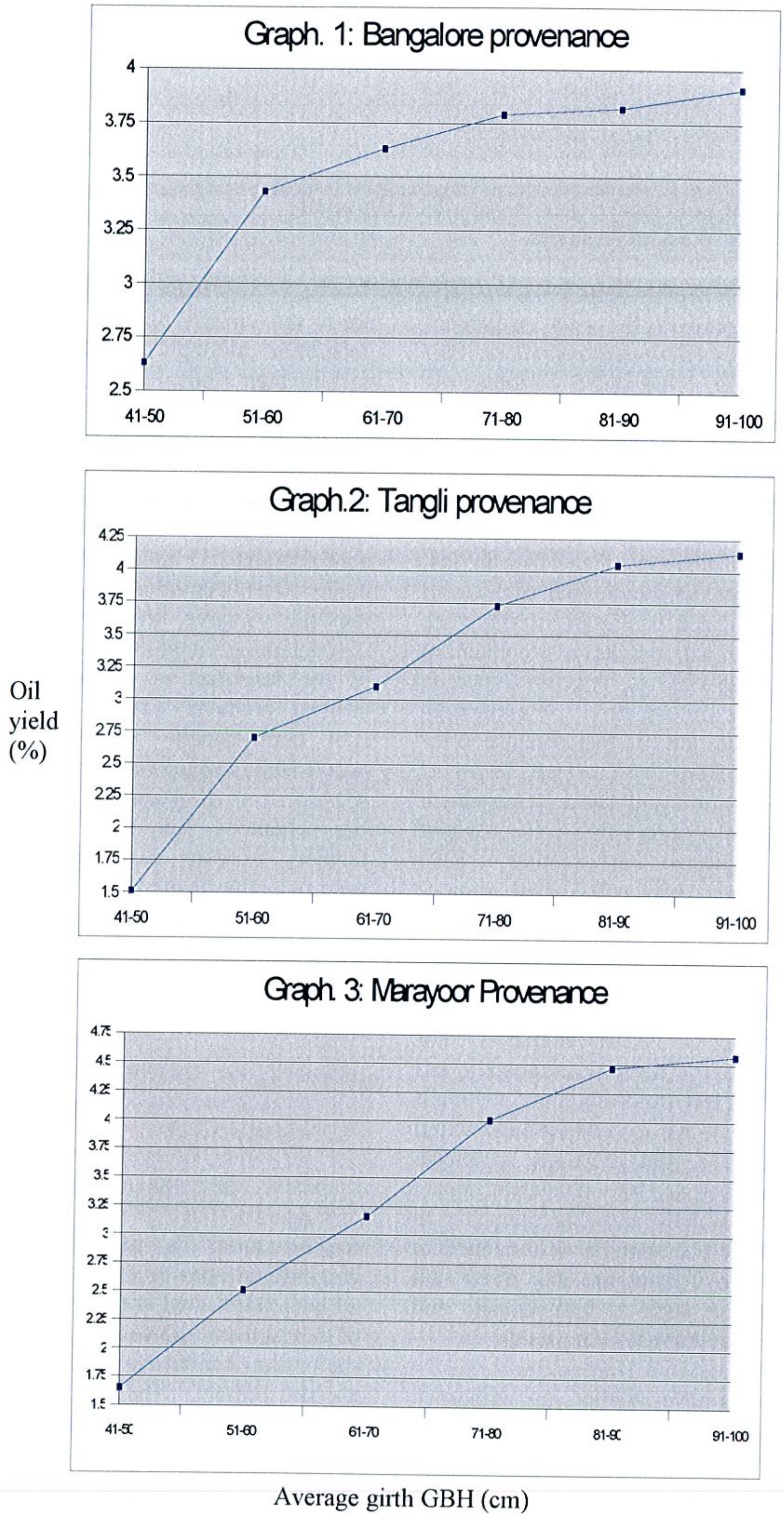

Figure1. Average girth and percentage yield of oil in different provenances.

Hopping Into A Bright Future- The Woylie Sandalwood Story

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At the time of European settlement the woylie (*Bettongia pencillata,* Figure 1) or brush-tailed bettong was extremely common and occurred in large numbers across the southern third of the continent. Indeed, accounts from the 1880s reported woylies "swarming" over large areas of the landscape. Tragically, in just 100 years the woylie had declined to the point that it existed in only three small remnant patches of woodland in the south-west of Western Australia and was on the brink of extinction. The good news is that recent conservation efforts by the Department of Conservation and Land Management has seen a remarkable come back of the woylie, so much so that in 1996 the woylie was reclassified to non-threatened. Since the recovery of the woylie, it has become possible to study their ecology in some detail and it has been shown that woylies are important ecosystem 'engineers". For example, the woylie can create in excess of 100 small diggings per night as they forage for underground fungi, or truffles, and a variety of bulbs. These diggings have a positive impact on the soil by allowing rainwater to infiltrate the normally water repellent soil. Woylie diggings also affect soil properties such as bulk density and the behaviour of soil nutrients.

Woylies have another very important role in the ecosystem, which has been largely over looked until recently. They are very efficient seed dispersers. For the past 30 years, anecdotal evidence suggested that woylies disperse and cache seeds from a variety of plants including *Gastrolobium* species, quandong (*Santalum acuminata*) and Western Australian sandalwood (*S. spicatum*); however, this behaviour was not examined in any detail until recently. In a study carried out in Dryandra Woodland it was shown for the first time how important woylies are to the ecology of sandalwood regeneration through dispersing and caching their seeds.

Sandalwood has been harvested for many years in both Western Australia and South Australia and is a profitable industry yielding export earnings of approximately 11 million dollars annually. The heartwood and roots contain the valuable, strongly aromatic oil containing santalols, which is used in the manufacture of sandalwood scented products. Sandalwood is a root hemi-parasite and commonly grows with nitrogen fixing plants such as *Acacia* or *Allocasurina.* The tree has pendulous fruit, with red-brown leathery exocarp encasing a large seed; it is the nature of this seed that hints at the intriguing relationship that has evolved between sandalwood and the woylie.

"After a few moments the woylie picked up the seed in its fore paws, put the seed in its mouth and left the area at some speed."

In recent years, natural regeneration of sandalwood has been poor. Habitat fragmentation, its parasitic nature, grazing and poor seed dispersal have all been implicated in these poor rates of recruitment; however, this is not the case in habitats in which woylies are still present. The woylie sandalwood story began in a sandalwood stand just outside the main block of Dryandra Woodland where it was noted that many new sandalwood recruits were springing up across the road from the main plantation. This fascinating development sparked the interest of sandalwood managers and so, in collaboration with scientists from the Forest Products Commission of Western Australia, the investigation into how the recruits got there began.

Throughout this sandalwood site there was extensive regeneration of all age classes of sandalwood, and the young plants are spreading up hill away from the parent trees. Clearly some animal was removing the seeds from where they fell under the adult trees and dispersing them in all directions. In striking contrast, sandalwood stands in Wickepin, 54 km east of Dryandra showed no regeneration at all and there were literally hundreds of seeds lying beneath the parent, the vast majority of which will perish. Trapping sessions were conducted at the Wickepin site to determine if there were any woylies, but it was completely devoid of native mammals. These findings pretty much confirmed the theory that woylies were a significant dispersal agent for sandalwood. The question was… how do we prove it?

We decided to set up bait stations at the Dryandra village where woylie numbers were relatively high. To enable us to determine the fate of the sandalwood seed once it was removed by the woylie, cotton bobbins were used; the end of the thread was glued to the seed and the bobbin was staked into the ground. This allowed the thread to unwind freely if the seed was removed. We then sat and waited. Sure enough, after a short while a woylie appeared at our bait station to investigate the seeds. After a few moments the woylie picked up the seed in its fore paws, put the seed in its mouth and left the area at some speed. The cotton thread unwound rapidly as the woylie hopped away with its prize. A few moments later the cotton stopped unwinding and the woylie returned to the bait station and repeated the procedure.

The trail left by the cotton was clearly visible and was easy to follow around, under and through vegetation. Finally, the trail stopped and disappeared into a small hole in the ground. There at the bottom was the sandalwood seed, pressed hard into the soil. Surprisingly, the cache was not covered by soil in the majority of cases, but after a couple of days the caches were almost completely covered with leaf litter that had fallen into the cache. The distance of the caches from the bait station ranged from 8 m to 81 m and occurred in a scatter hoarded pattern (one seed per cache). So for the first time ever it was shown that woylies do disperse and cache sandalwood seeds and as a result, woylies have an important role to play in the regeneration of at least one woodland plant species. The study was also the first of its kind to link directly the conservation of a mammal to the regeneration and management of an important plant species.

The implications of these findings for conservation of biodiversity are clear. The discovery of the link between the woylie and sandalwood provides an "icon" for the many functional relationships that exist in our landscapes. Over the millennia, many plants and animals have co-evolved, forming close and intimate relationships. The woylie sandalwood story is one example of such a relationship and is a prime example of how biodiverse ecosystems can function; indeed, the woylie sandalwood story can give us a "functional icon" to drive the conservation of plant and animal biodiversity as a whole. For the first time we have the opportunity to demonstrate to all Australians the relationships, complexity and beauty of the ecology of Australia and hopefully, we can change our current view of degraded systems to one of high functional biodiversity.

This article has also been published in Western Wildlife 7 (3), July 2003, Department of Conservation and Land Management, Western Australia.

Figure 1. A woylie (*Bettongia pencillata*) carrying a sandalwood (*Santalum spicatum*) seed in its fore paws, at Karakamia sanctuary, Western Australia (Photo: R. Armistead).

Genetic study for Santalum

The Forest Products Commission of Western Australia is supporting a Doctorate grant application to the Australian Research Council to investigate "Indian Sandalwood: genetic and oil diversity, and biochemistry of the Australian germplasm collection". This is a request for partners who can provide material from their local populations, whether they are *Santalum album* or one of the other 15 *Santalum* species. In return, a phylogenetic analysis of the *Santalum* species will be distributed to all partners, which will provide information on the relationships between species and resolution of the taxa within the genus. This information is of vital importance to the world-wide genetic conservation of the genus and *S. album* species. It also will place the Australian germplasm collection in context.

The project is supported by the expertise of Assoc. Prof. Julie Plummer (Plant Biology, University of Western Australia) who is a plant physiologist with expertise in breeding and selection, including plants for essential oil production; Prof. Emilio Ghisalberti (Chemistry, UWA) who has an international reputation as a chemist of secondary products in Australian plants; Dr. Margaret Byrne (Department of Conservation and Land Management) is a molecular geneticist with considerable expertise in the application of genetic markers to tree breeding and Dr Liz Barbour (FPC) who is the scientist responsible for developing elite sandalwood germplasm for the Forest Products Commission.

If you can supply the material or would like further information, please contact:
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If you would like to contribute an article to the SRN or wish to be included on the SRN mailing list, please send details to the Editor stating: your name, title, position, organisation, postal address, telephone, fax and email address.

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