AN OUTLINE OF THE

SANDALWOOD INDUSTRY, 1974

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SUMMARY

We briefly review the existing sandalwood resource, the history of the utilisation of sandalwood, describe the growth, demonstrate how to grow the crop and make recommendations. Recruitment of sandalwood is essential to sustain the productivity of the sandalwood industry. This means that the rates of growth of the regeneration from the seed and of the immature sandalwood subsequently into the required commercial size must equal not less than the rate of cropping. By taking account of sound findings of research work since the 1920's, our recommendations are made for these purposes. Regions of lowest rainfall under 225 mm do not meet these requirements. In regions of over 300 mm annual rainfall agricultural land has been converted to more intensive use.

Seven million hectares, between 225 and 300 mm annual rainfall, is the area classified as commercially feasible sandalwood country. This carries a total resource of some 11 million sandalwood trees, ca 50-175 mm diameter. The time available for replacement of this resource, with a yearly harvest of 1200 tonnes of sandalwood and with ingrowth to 127 mm commercial diameter is about 40 years. An equivalent resource may be located in the harsh conditions of the remote areas but any reliance on this is scarcely feasible for the trade. Supply at all times is difficult.

The period required to grow the commercial tree from seed is 70-90 years and then only in the best sites of the existing resource. Seventeen million sandalwood are required to sustain the present industry. Replacement therefore requires 200 000 sandalwood to become established annually in the absence of grazing. Overall therefore an area of 100 000 hectares of suitable sites is required for replacement to sustain the sandalwood industry. Possibly one quarter of these quantities would be required for irrigated plantations. A long term research project in the presence of grazing in this region is recommended. Reserves have been established at Kalgoorlie and others are needed.

Sandalwood (Santalum spicatum R.Br.) DC is a small stoutly branched shrub or tree, up to a height of 3-5 metres with a diameter to 200 millimetres, although larger trees have been exploited. At one time it extended throughout the agricultural and arid lands of Western Australia on sites where suitable hosts, mainly Acacia species of the Eucalyptus and Acacia woodlands. It occurred on well drained, mainly valley soils where from north of Carnarvon then southerly on the drier fringe of the main forest zone it continued to the Nullabor Plain and into South Australia.

The sapwood is pale yellow, the truewood usually dark brown, and it is the truewood and roots which contain the valuable strongly aromatic Santalols. The common name is derived from the aromatic Arabian sandalwood, while the botanical name spicatum arises from the tight spike arrangement of the flower buds.

The genus Santalum has three other species widely distributed in Australia but which lack the aromatic fragrance, although S. lanceolatum does contain oil. Quandong, S. acuminatum (R.Br.) DC has a deeply pitted nut and an edible kernel. Plumbush, S. lanceolatum (R.Br.) has an ovoid plum-like fruit, and is mainly found in the north west. Bitter

Quandong, S. murrayanum (L.T. Mitch.), C.A. Gardn. has a finely pitted nut inside a bitter outer coat and occurs mainly in South Australia.

The fruit of S. spicatum has a round almost smooth nut inside an outer brown coat, and an edible kernel.

Note: Taxonomy of these species varies widely and S. spicatum is synonymous with Eucarya spicata (R.Br.), Spr. et Summ, Fusanus spicatus (R.Br.) and Santalum cygnorum DC.

The Chinese have a long history of using sandalwood in ornaments, fine art and ceremonies. The common joss-stick is a slip of bamboo 1 mm x 300 to 600 mm long, two thirds of which is smeared with sandalwood flour by a simple dipping technique in water and gumwood flour or with sandalwood paste. When dry the sticks are used by lighting the tip and blowing out the flame, leaving the stick to smoulder and give off smoke and incense.

Harvesting

Sandalwood is usually not sawn or chopped down as are most wood products. It is pulled out of the ground because the root, butt, stem and branches are all valuable products. Originally the pieces were adzed to remove bark and sapwood but currently only the bark is removed prior to shipment of the wood to Spearwood (near Fremantle, W.A.), where the material is processed before export:

Trimming the logs and other pieces into sawn lengths of 1.3 metres or less;

Grading of logs, butts, roots with the first grade pieces 1.3 metres length having the sapwood shaved off each end by a milled wheel;

Crushing the chips, shavings and sawdust through a small hammer mill;

Separating the wood flour and foreign matter with air blowers and magnets;

Sieving the wood flour and re-treating the coarse fragments until all will pass through the sieve.

Packing the marketable grades into one tonne pallets as follows:

No.1 Grade: truewood, 1.3 metre lengths, cleaned of sapwood;

No.2 Grade: total wood, 1.3 metres;

No.3 Grade: dead pieces of total wood, comprising grey coloured and weathered wood as harvested;

No.4 Grade: small pieces of truewood, butts and roots in bales;

No.5 Grade: standard grade of sandalwood flour in bags.

The products are then exported by sea to Chinese buyers in Taiwan, Hong Kong, Singapore, Malaya and Burma.

Distribution

Sandalwood has a scattered and broad distribution among the host plants of Acacia sp. and other endemic species, but is restricted mainly to soils in bottomlands and gentle slopes of the main inland drainage system. The distribution map, Map 2, shows present occurrence while an approximate boundary of the resource prior to 19th century exploitation is shown on Map 1. The palaeo-drainage system* provides a basis for mapping the broad distribution of sandalwood. It is usually present in ecotypes of the ephemeral Murchison and Gascoyne Rivers and main drainage into the inland salt lakes, and is usually absent from the continental watershed and ridges of the Western Australian Shield.

Rainfall patterns influence soils and plant associations, and therefore help determine the distribution of sandalwood.

There is an overall zone of 81 million hectares, including an initial 64 million hectares of sandalwood, which forms three rainfall zones:

Rainfall 200 mm	20 230 000 hectares
Rainfall 200-300 mm per annum	28 295 000 hectares
Rainfall 300 mm plus per annum	15 598 000 hectares

Farm development and remoteness reduces the area of exploitable sandalwood:

Areas allocated to land development	14 000 000 hectares
Areas remote for exploitation	11 000 000 hectares
Residual area of available sandalwood	39 123 000 hectares
	64 123 000 hectares

The residual area of 39 million hectares has been grouped as eight geographic units which are plotted in detail on the distribution map, and summarised in Table 1, and which are based on departmental information.

TABLE 1 SANDALWOOD DISTRIBUTION (Attached)

Within these units there are an estimated 7 million hectares of fair quality sandalwood, while much of the other 32 million hectares could become commercial in the long term.

Little is known about sandalwood in the systems north of latitude 25° South.

*Beard 1973

Sandalwood occurrence is irregular and ecosystem boundaries are generally diffuse. Further field observation is expected to modify the map information.

Development of the Industry

The sandalwood trade in Western Australia was one of the first industrial activities of the young Swan River Colony and a small shipment of 4 tonnes was exported to China in 1845. The South Australian industry began much later.

Sandalwood was originally produced from resources in various Asian countries, notably Indonesia, from the Spice Islands in the second century A.D., and from Timor to Calicut about 1850, being imported into India and China. Disease and exploitation decreased supplies in China and India and the wood was being obtained from these diminishing resources of the Pacific Islands at the time of European settlement in Western Australia.

The Asian demand was long established and so it was not difficult for Western Australia to become the major supplier by the end of the nineteenth century.

Knowledge of Western Australia's hinterland and its productive capacity was very limited, grants of land being made on relatively blank maps and subsequently located on the ground by surveyor/explorers. Initial sales in 1845 had shown that Australian sandalwood was acceptable to the Chinese and its exploitation helped the pioneers to settle in the southern interior between Perth and Albany. Many of the towns which still exist in the wheat growing areas owed their origin to sandalwood operators.

By the 1860's sandalwood trade made up 15 percent of total export earnings of the State with prices of $14.00 a tonne being obtained by 1862. The Treasury received $2.50 per license and $2.00 to $3.00 per tonne as export duty.

In 1868 there were 3 048 tonnes exported, earning $104,180 compared with timber exports worth $2 552. The port at Bunbury alone exported 20 000 tonnes during the early days. A hundred years later, (1968) 1 422 kg of sandalwood oil and 859 tonnes of wood brought an export income of $505 821 - 500 percent increase. This oil was distilled by Plaimar from wood imported from Indonesian Timor.

Production from the Goldfields did not begin until 1894 when the eastern railway was extended to Southern Cross and then in 1900 to Kalgoorlie. A further 4 000 kilometres of new line was built between 1904 and 1919 in the south west and land along the railway was surveyed for settlement.

Operational control was by a simple license system until Royalties were introduced under the Land Act in 1908.*

The population increased almost six times during the period of expansion caused by the gold rush, from 49 782 in 1891 to 282 114 in 1911.** Successive Governments encouraged settlers to take up holdings free of charge and with other

* Hutchins 1916; Robertson 1954; Underwood 1958

** W.A. Year Book 1973

incentives under the Homestead Act and the Land Act, provided that they contributed with physical improvements. The ready cash from sandalwood assisted farmers, pastoralists and gold miners during periods of low production and when markets for agricultural products were depressed.

Uncontrolled competitive marketing operated for a hundred years until the introduction of the Sandalwood Act in 1929. Exploitation was destructive and virtually uncontrolled during this period when a quantity three times as large as the residual sandalwood resource was removed. The amount destroyed by clearing for agriculture will never be known, and even with recent farm development there has been considerable loss of sandalwood in areas adjoining pastoral leases.

It was shown in 1908 that dead sandalwood was acceptable to the trade but at a lower price, and a proportion of deadwood has been used ever since. Modern clearing by bulldozer and chain is followed by removal of sandalwood wherever possible since it will otherwise be burned.

Demand for sandalwood was subject to violent fluctuations caused by agents who manipulated the market for their own purposes. Hong Kong agents achieved a margin of 30% between import to Hong Kong and export to the Chinese mainland.

At one stage, China had four years supply of sandalwood on hand as a result of local agents over-buying, producers over-cutting and stockpiling. Conditions encouraged extreme fluctuating demand, uncertain employment and increased hardship for sandalwood procurement.***

The legislation of 1929 enabled agreement between the sandalwood industry and government, represented by the Sandalwood Merchants Association and the Sandalwood Export Committee. The industry was stabilised and provided with continuous employment and trade.

The only significant sandalwood remaining is located in the eastern and north eastern goldfields and the Murchison district. There are small sources previously pulled, which were either too small or too inaccessible for horse and dray operations. Slow growth of the small sized trees also limits recruitment into commercial size material.

Legislation

The acts and regulations which control production of sandalwood from Crown and other land are contained in:

Forest Act 1918-1974 and Regulations;

Sandalwood Act No.27 of 1928;

Land Act, 1933-1967.

The Sandalwood Act states "This Act may be cited as the Sandalwood Act, 1929-34 and shall be read as and with the Forests Act, 1918, hereinafter referred to as the principal Act".

*** Bolton 1972, McMahon 1972

Within the principal act, pertinent clauses are 32 (1) which relates to issue of permits and licenses for forest produce, and clause 39 (2) extends licensing to pastoral and other leases.

The Land Act 1933-67 provides in its Pastoral Lease, that issue is subject to the provisions of the Forests Act 1918-1974. The legislation sets size limits for sandalwood removal such that "no living sandalwood tree of less than 400 mm in circumference measured over the bark at 150 mm from the ground level or the log of which when cleaned of sapwood is less than 250 mm in circumference measured at a point equivalent to 150 mm above ground level shall be cut or pulled under this order."

The Sandalwood Act also allows for limits and restrictions on the quantity of sandalwood which may be pulled or removed from Crown land and alienated land. This limit, at present set at 1 200 tonnes a year is reviewed annually by the Sandalwood Export Committee consisting of Forests Department and Australian Sandalwood Company Limited representatives and chaired by the Conservator of Forests. The harvesting controls preserve immature trees, avoid damage and stabilise supplies of sandalwood.

Orders and licenses are co-ordinated by the Australian Sandalwood Company and the Conservator of Forests. By agreement with the company, the Government receives a proportion of net returns as well as royalty on the wood. The legislation enables continuity of production, employment and trade at an optimum price.

However, there are some problems from a conservation viewpoint. Under normal grazing practice effective regeneration of sandalwood cannot occur. For this reason 47 000 hectares of sandalwood have been reserved at Kalgoorlie and further reserves are being investigated.

The existing reserves are shown on Map 3 and are made up as follows:

Reserve 19211	Calooli	3 121
Reserve 19212	Yellari	6 326
Reserve 19214	Lakeside	3 707
Reserve 19825	Bullock Holes	13 313
State Forest 8	Karramindie	781
Reserve land between Kalgoorlie and Widgiemooltha		20 000
		47 248 hectares

Other general provisions of the Forests Act and the Land Act are of importance. Forests Act Regulation 91 precludes production within 400 metres of any well, watering trough, river, homestead or shearing shed, on any reserve, common, pastoral lease or other Crown land. The Land Act provides for a stocking rate on pastoral leases or 75 sheep or 15 cattle for each 1 000 hectares of the area leased, subject to various provisions controlled by the Pastoral Board. However, the pattern of stock movement near watering points tends to intensify their impact on these areas, such that regeneration will not occur, unless the lease conditions are reviewed.

The ability of a department or other body to maintain or improve reserves of this kind is usually limited by

the availability of funds. In the case of sandalwood areas which need regenerating, the funds for rabbit-proof fencing have never been available in the past, and any fencing proposals continue to depend on available finance.

The present level of production is 1 200 tonnes per year from eight major and eight part-time operators.

Contemporary Production

The production of sandalwood is hard work in lonely situations and attracts only hardy people who are oriented to living in the bush (Fig.1).

Most teams comprise two men who could expect to collect and clean one tonne each day.

The tree is usually pulled out of the ground with a chain attached to a vehicle, hence the name "sandalwood puller". The crown is lopped at 35-40 mm diameter under the bark, all solid roots are taken and the bark is removed with a small axe. If the bark is tight, the whole piece is soaked in water for a short time.

When 4 to 7 tonnes of wood has been trimmed and cleaned, it is transported to the nearest rail head for a distance of 60 to 400 kilometres. There is a transport subsidy for haulage beyond 80 kilometres, and the wood is railed to the Australian Sandalwood Company at Spearwood. The material is prepared for export and payment is made to the puller as soon as consigned weight has been checked. Three classes of sandalwood are prepared by the puller.

- Cleaned Wood: bark and sapwood are removed sufficient to reveal the dark-coloured heartwood in patches all along the stem. Cleaning is done by hand adze or a small motorised planing machine.

- Barked Wood: bark is removed, but not sapwood.

- Pieces: dead stems with dirt knocked off but with no other preparation.

NOTE: Root material has only the bark removed yet may fit into all categories.

Preliminary work studies of different production and preparation methods have been made but no conclusive results were obtained.

Earnings vary between licenses but production of 40 to 50 tonnes per man year gives a reasonable income. Those who produce less than this usually have supplementary income from other jobs.

In the decade from 1962 to 1973 a total of 90 individuals have held licenses, of which there were seventeen current at June 1974. The eight principal operators account for 86 percent of the annual yield.

All production is in remote areas which are recorded as the Kalgoorlie Centre, 70 percent, and the Paynes Find

Centre, 30 percent of production. There are 74 pastoral leases where sandalwood production occurs, and which have produced approximately half of the 10 000 tonnes produced in the last ten years. Fifteen of these stations contribute three quarters of the station yield.

Quality of Production

Dry pieces from pastoral leases	11.6%
Dry pieces from Crown land	2.0%
Green wood	86.4%
	100.00

Sandalwood Oil

Although the medicinal importance of sandalwood oil has been reduced by modern antibiotics, the oil is still of value for cosmetics, soaps and perfumes.

The British Pharmacopoeia describes it as -

> "a colourless or pale yellow oily liquid with a characteristic odour and unpleasant taste, containing not less than 90% W/W of free alcohols. Mass per millilitre is 0.964 to 0.974 grams, soluble 1 in 3 to 6 of 70% alcohol. Store in a cool place in air-tight containers, protect from light".

The oil has a specific gravity of 0.975, a refractive index of 1.507 and an optical rotation of -8p to -3o. East Indian oil has an optical rotation of -15o to -19o, has more odour and is more bitter.

Anomalous properties of Australian sandalwood oil have been explained by the content of farnesol, an acyclic primary alcohol. The trees from low rainfall areas produce a higher quality oil*, and this factor, together with availability of large tracts of land in the eastern Goldfields has generated interest in growing sandalwood on inland sites.

Commercial extraction of the oil was developed by H.V. Marr of Plaimar Ltd., the finely ground wood being digested with volatile solvents and oil extracted from the resultant liquor by vacuum distillation.

The commercial yield to Australian standard K174 varies from 2.4 to 2.9 percent for shavings, ground or hogged roots, and butts.

In practice the equivalent of 21 kilograms per tonne of wood is used for royalty calculations. Dead pieces produce an average of 10.45 kilomgrams per tonne.

When available, the oil of Santalum lanceolatum has been blended with the more aromatic S. acuminatum oil, prior to export, and up to June 1950 oil sales had exceeded the value of Santalum wood by $1 195 460.

Assessment of the Resource, 1974

In recent years most sandalwood production has come from two distinct regions, viz. Kalgoorlie and Paynes Find.

The pulling has been from both north and south of Kalgoorlie town, and west and south of Paynes Find. Odometer and compass traverses followed mapped tracks and roads for 304 kilometres of the Kalgoorlie and 191 kilometres of the Paynes Find regions as on map 3 and map 4.

Sandalwood trees were recorded by 25 millimetre diameter classes for a distance of 20 metres on either side of the traverse, but non-typical sections of main road were not recorded.

Three classes were recognised:

0-50 mm	:	small, immature, retained
51-125 mm	:	medium, immature, retained
126 mm plus	:	currently merchantable

(NOTE: Area assessed = length of traverse in miles x 6.47=ha).

The limitations of sampling the broadly distributed sandalwood are appreciated, but it is believed that this assessment is a reasonable representation of pastoral leases from which present supplies are drawn, and data is summarised in Table 2.

TABLE 2 ASSESSMENT SUMMARY (Attached)

Stocking rates of small sized sandalwood for site classification were preferred to those of mature trees, since the latter are affected by the irregular cutting history.

Three site quality types were recognised by the assessment. Paynes Find and south-east Kalgoorlie were considered of low quality, while north and south Kalgoorlie were mainly good quality with smaller areas of fair quality.

SANDALWOOD RESEARCH

Regeneration of sandalwood is rarely found outside Timber Reserves and a few stock and rabbit-proof enclosures. The authors have knowledge of two areas of natural regeneration - the Bullock Holes reserve, and a holding paddock near Gindalbie Station shearing shed.

Host or "nurse" plants are primarily Gratystilis subspinescens, but include Kochia pyramidata, Rhagodia sp., Atriplex sp., and Enchylaena tomentosa (Figures 2 and 3).

Further research of sandalwood regeneration is required, and the Australian Sandalwood Company which contributed $1 500 in 1973 and in 1974 has helped to initiate this work.

The literature contains only two reports of natural sandalwood regeneration over an 80 year period.*

Artificial Regeneration

From 1895 to 1930 more than 1 000 hectares of land were sown with sandalwood seed (nuts) and a few hundred hectares were fenced against grazing stock and rabbits.

*Richardson, C.G. Annual Reports 1899, 1910.

Sowing Methods for Kalgoorlie Region, 1921-31

After recording soil and drainage characteristics of the site, the nuts were usually sown without pre-treatment, but some tests were done with pre-treatment by cracking the seed coat and soaking overnight in water.

In rabbit infested areas, sowings were protected with galvanised iron tubes and 330 x 150 millimetre wire netting guards. The sowing method involved loosening of the soil with a small hoe at intervals of three metres. Two seeds were planted in each spot to a depth of 20 to 50 mm and the soil firmed around them.

Above average rainfall in 1925 facilitated commencement of sowing on February 1926 and completion at the end of April. Later sowings were made each month for several years both on flats and on ridges. The sowing rate was between 1 500 and 2 000 seeds per hectare with an overall range from 1.7 to 7.5 kilograms per hectare. In areas which were deficient in host plants, seeds of Acacia graffiana and Cassia eremophila were sown either before or at the time of sandalwood sowing.

Sowing Methods for Narrogin District, 1918-1956

In 1921 sowings by the same method were made on a gently sloping ridge of light grey brown granitic sandy loam carrying jam, Acacia acuminata and York gum, Eucalyptus loxophleba in the Bendering Reserve. The reserve (No. 25081) is situated north-west of Kondinin.

A wider range of soil types was sown at Dryandra, near Narrogin, in 1931 and 1956, including light and heavy sandy loams and clays associated with Eucalyptus loxophleba, E. wandoo, E. salmonophloia, poison bushes, Gastrolobium sp., and Oxylobium sp., jam and Acacia microbotrya. Thirty kilograms of seed, previously dipped in red lead was sown 600 mm from host plants in autumn 1956. This contrasted with experiments in 1918 at Pikaring Hill reserve where a broombush heathflat Casuarina campestris on light gravelly sandy clay was treated by ploughing-in seeds and scrub.

Results of Artificial Regeneration

Germination: Best results were obtained with fresh, treated seed, and viability beyond two years has not been recorded.

Germination rates were invariably low, and good germination occurred only following one or two years of good rainfall.

This was shown by drought following the planting of 89 hectares in 1922. The first germination occurred after rain in June 1923. Similar effects were noted in March 1927 for the sowings of 1925 and 1926 in the Narrogin district.

A season with opening rain in autumn and following winter rain invariably produced good results if sowing was done in late summer or autumn. Germination was 100 per cent for February, 1925, 11 per cent for March on ridges and for April sowing in flats was 50 per cent.

Soils: Light soils gave poor results in dry seasons while clays gave poor results in wet seasons due to washaways of disturbed soil. Lower slopes of good soil gave the best overall result.

Grass and shrub growth on light and medium soils was observed to protect and sometimes to provide temporary host tissue for the sandalwood until it was able to parasitise a more permanent host. In many instances however, rabbits browsed the seedlings in late summer when they were the only available greenery. Few plants germinating in 1931 survived rabbit damage, and browsing by other animals severely affected both sandalwood and hosts, especially close to watering points.

Hosts: Although sandalwood showed a preference for Acacia hosts, over 50 host species were listed by Gardner*, and another author, Herbert*, found parasitic attachments along the full length (30 metres maximum) of sandalwood lateral roots and found the connecting haustoria in roots of jam, York gum, Dodonaea lobulata, and Eremophila sp.

Insects: Insect attack on regeneration was noted in June 1930 when new shoots and leaves were destroyed by the larvae of a native Chrysomelid beetle. The attack appeared to be periodic and was thought to be due to failure of natural predators. It may also have been the cause of dry-sides and dead-tops of older trees. Other diseased sandalwood were heavily infected with insect scale.

Despite heavy losses due to some of the factors already mentioned, officers at Kalgoorlie have located some of the surviving plants. notably those sown between 1925 and 1930 in Karramindie State Forest No.8. The sandalwood remaining in this 780 hectare reserve are the sole source of growth data in the Goldfields some fifty years since planting. Other specimens which survived the wildfires of 1970 are located 120 kilometres south west of Kalgoorlie on a sandy site in Scahill Reserve 19621 (Figure 4).

Growth Rate of Sandalwood

Sandalwood grows slowly and personal observations by long term workers with the species have revealed no reliable indication of growth rate.

Estimation of growth therefore depends entirely upon accurate records of seeding, germination and location of trees in experimental plots.

Between 1925 and 1930 good sites of 530 hectares were sown at Karramindie and 91 hectares of poor sandy flats at Scahill. The Karramindie sites were flat or gently sloping with heavy loam soils, and ridges were not planted at either site.

Established trees at Karramindie vary from 2 to 4 metres in height and from 10 to 105 mm diameter at 150 mm above the ground. (Figure 5).

* Gardner, C.A. 1925, Forests Dep. Ann. Report.

* Herbert, 1925.

The age range of the trees cannot be precisely determined and the smaller trees could be either slowly grown originals or natural regeneration from other plot trees. Because of this, data were extracted only for trees which could be positively identified by survey and tree numbers.

A total of 22 trees were measured at Karramindie and 26 at Scahill plots. While it is appreciated that this is meagre data on which to base long term predictions of growth, it is nevertheless the only "solid" data presently available.

Further refinement of growth calculations will require an expansion of this study.

TABLE 3 - PLOT DATA (Attached)

All of the 48 trees were measured to record total height, height to various diameter limits, and bark thickness.

Individual trees were grouped into 1.5 metre height classes and data were summarised for measurements at 44 and 49 years of age, representing the period over which establishment occurred. Measurements were adjusted to one age of 44 years and a mean sample tree was chosen to represent each height class, for the Karramindie plots only.

Sample trees were measured by the sectional method to derive volume and increment of truewood, sapwood and bark.

TABLES 4 & 5 - PLOTS KARRAMINDIE, SCAHILL (Attached)

Volume was calculated from the formula*:

$V = 0.0785 \times d2 \times L$ when V = volume in cubic metres $\times 10^3$
D = mid-diameter in cm
L = length in metres

Sandalwood mass was determined from the mass-volume ratio of 880 kg/m^3 established by studies of wood density one month after cutting.

The sample trees from Karramindie and the height/diameter relationships of all plots were used to derive information on growth rate, production of timber and age at which sandalwood will reach commercial size.

For the largest sample tree, 1.15 kilograms of truewood was produced in 44 years in sizes which require 870 trees per tonne of wood, and which have about 40% bark. Sapwood made up 30% of truewood volume and had a constant thickness of 22 millimetres.

Comparable trees in the largest group have 2.5 kilograms of total wood and 1.3 kilograms of truewood : equivalent to 400 and 770 trees per tonne.

Analysis of Production

Twenty two trees were pulled, weighed and prepared for sale. The component roots, stems, branches, twigs and leaves were weighed and measured.

* Forestry and Timber Bureau, Canberra, 1973.

As a separate study, three 50 kilogram parcels were weighed monthly to assess moisture losses. The true wood sample was weighed regularly for three years, the total wood samples for two years and one year respectively. Weight recording commenced at time of collection viz: September for the first two samples and November for the others. Volume of the four straightest pieces was used to calculate air dry density for each parcel.

Data were recorded through the drying test, as percentage of initial mass, actual cumulative moisture loss and moisture loss for the first month. The latter figure was used as a base figure for the moist season and an average base figure for the summer season.

Mass and volume statistics for this trial were analysed by simple linear regression to clarify the relations between the various components - roots, butt logs, stem sections, branch wood, twigs and foliage etc. The details of regression and predictions from the regression are shown in Tables 6 and 7.

TABLES 6 & 7, LINEAR REGRESSIONS
WHOLE TREE FIBRE & FOLIAGE (Attached)

A tree of commercial size will weigh about 40-45 kilograms total with a usable 30 kg made up as follows:

foliage (fodder) and twigs (-10 mm diameter)	11 kg
roots	2 to 3
butt logs	4 to 5
stem	10 to 11
	30 kg

+ bark 6 kg; branch sapwood 4 kg; branch truewood 2 kg (approx.)

Analysis of samples also gave proportions of bark, total wood, and truewood in commercial parts of larger trees (127 mm d.o.b.) in growing stock (less than 127 mm d.o.b.) and in advanced regeneration.

Bark comprises 30 per cent of basal area in all ages and 34 per cent by volume in older trees.

Truewood is 70 per cent of basal area and of volume of the procured wood in trees greater than 127 mm d.o.b.

For trees below commercial size either as small old trees or as regrowth in the diameter ranges 55 mm to 127 mm over bark, the following regressions apply:

Small, old trees: Y (Volume ratio)
= -0.1132a + 0.0075 bx n10, r 0.6, SE 13 p.c.

Y1 (b.a. ratio) =
= 0.3719 z + 0.0039 bx n12, r 0.6, SE 5 p.c.

Y2 (healthy trees)
= 0.13227a + 0.0061 bx n6, r 0.74, SE 8 p.c.

and for advanced regrowth,

Y (b.a. ratio) = 0.3475 - 0.0082 bx n9, r 0.87, SE 18 p.c.

From these formulae were calculated proportions of truewood in particular diameter classes.

51	millimetre	do.ob.	contains	7	per cent	truewood in total u.b. volume	
76	"	"	"	28	"	"	"
102	"	"	"	49	"	"	"
127	"	"	"	69	"	"	"

Rates of Growth

At Narrogin on good sites carrying jam and wandoo and with 500 mm rainfall the 1956 trials in forest blocks Lol Gray and Stokes should reach commercial size in 23 to 30 years, and in adjacent land affected by rabbits, the 1931 trials will take 50 years.

On poorer jam and wandoo ecotypes the 1956 trials in blocks South, Peters and Franks need 30 to 38 years while the scattered regeneration in Smith block will need 50 years to reach rotation size (Figure 7).

Lower rainfall sites, 335 to 385 mm with lowland jam forest and ploughed broombush flats indicated from the 1918 to 1921 experiments that 45 to 50 years will produce commercial sandalwood (Figure 8). Unploughed broombush tests and in upland jam at Bendering (near Kondinin) in 1918 to 1921 require 90 to 130 years growth (Figure 6).

At Kalgoorlie, with a rainfall of 250 mm on the red brown calcareous clay loams in wattles Acacia graffiana and A. microbotrya and salmon gums Eucalyptus salmonophloia, growth records showed that 70 to 90 years are needed to produce usable sandalwood.

TABLE 8 - FORECAST OF GROWTH (Attached)

Drying Studies and Stem Numbers per Tonne

As would be expected, drying is most rapid in the first summer after sandalwood is pulled and mass losses can be as great as 8.5 per cent of truewood, or 14 to 17 per cent of total wood. Losses in following seasons are at the level of 1 or 2 per cent. Trials were established in late spring and loss of moisture (hence of mass) during the first month was 1.4 per cent of truewood and 5 per cent of total wood.

The mean of pooled data after the first month gave losses in truewood mass greater than 7 per cent with seasonal extremes of plus or minus 1 per cent for truewood.

By the end of the first month wood density was 880 kilograms per cubic metre (± 50 kg) and there was no real difference between total wood and truewood. Further drying reduced density to 810 kilograms per cubic metre with a seasonal variation for truewood of 822 to 804, and for total wood of 818 to 790 kilograms per cubic metre.

From an assessment viewpoint the number of stems per tonne is an important statistic and the following relationships have been determined for material air-dried for one month ($y = 3.77 - 0.305\ bx$ (ins); $r = -0.9875$):

Diameter in millimetres	25.4	50.8	76.2	102	127	152
Stems per tonne	2917	1446	716	355	176	87

These figures include sapwood but exclude roots and butts (S.E. = 10 p.c.). Retention of a sound root stock for a coppice rotation is one alternative for regeneration of the species, but if roots and butts are also harvested the relationship of tonnes to stems becomes ($y = 3.32 - 0.011\ bx$ (mm); $r = -0.969$):

Diameter in millimetres	25.4	50.8	76.2	102	127	152
Stems per tonne	1063	546	280	144	74	38

In practice pulled material requires about half as many trees per tonne as removal of stems only.

The proportions of sapwood and truewood vary inversely with overall tree size, as do most tree species. The break-even point on trees grown from seed is the tree of 102 mm diameter over bark.

RESOURCE ASSESSMENT

The survey of residual sandalwood resources in Western Australia was intended to provide a first approximation of what is available. It has limits but is the best information presently available and even though sampling errors are magnified in the aggregate resource statements, these can be periodically reviewed and modified while sandalwood continues its slow growth into the 21st century.

A direct estimate of the resource using stem distribution and conversion to stem numbers per tonne has been adopted. A range of minimum commercial diameters at 102, 114 and 127 millimetres has been examined to predict the potential yield and the time available for research and replacement.

Indirect methods have been used to appraise the complex interaction of factors in the sandalwood ecotypes.

For either method data are limited by the known distribution of the species and by the restricted scale of field and research operations.

Broad site quality classes between districts have been defined by the continental drainage system and annual rainfall. Within districts quality has been related to topography and presence or absence of sandalwood. Above 224 mm rainfall, three site classes have been defined and the sites considered potentially productive comprise some seven million hectares in the localities of Perenjori, Ningham, Lake Seabrook, Gindalbie and Menzies.

Assessment lines were established in 225 and 250 millimetres rainfall zones and the Kalgoorlie research plots of about 240 millimetres. Both sets of data were therefore pooled and applied to three site classes. Growth of trees through various size classes was recorded for each site class.

Class 1. Represented by the best third of sample trees at Karramindie.

Class 2. The remainder of Karramindie and the best half of Scahill plots.

Class 3. The remainder of Scahill.

Allowance was made by approximate methods for loss of growth due to grazing on pastoral leases, at the rate of 20 years, 30 years and 40 years respectively for the 3 classes. However, since there were no measurements of this loss these approximations were omitted from the direct appraisal.

Mortality of sandalwood is reflected in the proportion of dead pieces in samples of prepared wood, and comprises about 13 per cent of the total. Predictions do not include other potential sandalwood supplies in low density or remote areas at present, but may be considered in future revisions of the estimate.

TABLE 9 - ELEVEN YEARS OF PRODUCTION (Attached)

Inventory data expressed on the basis of million hectare units can be derived from Table 10.

TABLE 10 - RESOURCES PER MILLION HECTARES (Attached)

Pooling these data for the seven million hectares of potentially productive classes gives an estimated total resource of:

11 million stems
22400 tonnes of stem mass
9170 tonnes of commercial product

As previously mentioned the 1974 rate of production has been established at 1 200 tonnes per year, which would provide 3 to 8 years of supply at present standards.

Three alternative strategies for commercial diameter limits of 102, 114 or 127 mm, have been analysed. Use of higher limits reduces available material but improves the long term potential, while the converse is true at lower commercial limits. Consequently, the number of years available for research and replacement of size classes is correspondingly increased if larger sizes are used.

These alternatives are of the following order in the use of existing resources -

25-35 years to a commercial limit of 102 mm
33-39 years to a commercial limit of 114 mm
45-50 years to a commercial limit of 127 mm

If the present output will last 3 to 8 years and it takes 25 to 50 years to replace it within the 7 million hectares then other sources must be used in order to maintain a viable industry.

Production of sandalwood by "pulling" doubles the immediate return of wood but precludes any regrowth from coppice and causes soil disturbance in which seed should be planted (Fig. 9). In India, so much was thought of the tree, as soon as one was cut down another was planted.* A long term research programme also should consider the alternative of cutting the tree at or near ground level, thereby reducing yield but encouraging coppice growth if grazing animals are excluded.

*Hutchins, 1916

Collection of sandalwood from pastoral leases, such as the 418 tonnes in 11 years at Gindalbie, is equivalent to 3 kilograms of commercial fibre per hectare per annum. The twigs and leaves produced by this method amount to 1.55 and 0.45 kilograms per hectare per annum. It has been estimated ** for the Wiluna-Meekatharra area that in dry periods on stony ground the natural fodder yield can be as low as 16 to 17 kilograms per hectare; and that over-grazing can bring about the replacement of valuable perennial grasses by less useful species.

The growth of grass in good seasons creates a dangerous fire hazard as was shown in early summer of 1974. Sandalwood is a fire tender species and there is a need for prevention and suppression of wildfires to preserve sandalwood sources.

Research Plots, 1974 Series

A new series of plots were designed in 1974 to examine the management of sandalwood regeneration in the inland mulga and eucalypt woodlands.

Trials included non-grazing and deferred grazing in the Kalgoorlie area for regeneration from seed and from stump coppice over a range of seasonal conditions.

Research working plans relate to direct seeding, pelletised seeding, seeding of nurse plants with deferred grazing, and sandalwood coppice. The experimental design will test five factors -

F1 - protection of the seed and plants, by rabbit proof fence for four plots and four unfenced controls.

F2 - the natural and artificial seed supply with untreated seed on the surface and treated seed below the soil surface.

F3 - seed bed preparation, cultivation and weed control,
- special fenced plot of 16 hosts and 100 seeds per host.

F4 - methods of sowing seed on soil and below soil at depth equal to seed size. Two units each of 25 seeds in alternate lines.

F5 - a simulation of natural wet seasons with watered and unwatered treatments. Irrigated test lines at 25 litres per square metre per month. (More frequent schedules when feasible need testing).

Seed Pre-treatment

Following germination tests in the laboratory the seed with cracked coat and mercuric dust pesticide gave 84% germinants when soaked 24 hours and 80% when not soaked. Sound hard seed coat soaked 30 hours = 35%.

Other tests with seed coat removed, with seed in peat carrier, with and without soaking, and pesticide dusting, with and without organic manure pellets are being made.

** Wilcox, D.G. 1970

Plot Establishment

Five plots 20 metres by 80 metres, fenced and unfenced were established in February, 1974 half were cultivated in April/May and the plots were sown with soaked whole seed during the first week of May. In 3 plots (1, 3 and 5) a further series of treatments for seeds (cracked and whole; soaked and not soaked) and sown, with and without peat, were commenced in 3 plots (Nos. 1, 3 and 5) in May 1975.

Plot 1 Jeedamya Station, 145 km north north west from Kalgoorlie in arid open mulga woodland on red-brown sandy loam over concretionary limestone (calcrete).

Plot 2. Gindalbie Station, 70 km north north east from Kalgoorlie in a wide valley of salmon gum and mulga on red earths (figures 10, 11).

Plot 3. Bullock Holes sandalwood reserve, 40 km north west of Kalgoorlie in a well-defined valley with fine alluvial silt and gravel overlying red-brown clay and with a woodland of Eucalypt and sheoak.

Plot 4. Calooli sandalwood reserve, 12 km south west of Coolgardie on a Eucalypt and acacia ridge of red-brown calcareous loam (figures 12, 13).

Plot 5. was established on a sandy site, in the Kalgoorlie arboretum, where the whole plot could be fenced and periodically watered.

During 1974 there were 236 mm rain to May 9th and a further 84 mm to August 22nd, 30 mm in September and 49 mm October-December. The radial lines of hosts were irrigated on June 17 and August 9 at the rate of 25 litres per square metre. Flooding occurred with a further 210 mm into April, followed by a normal 113 mm into July 1975.

RESULTS

The following differences for germination between sites were shown in October 1974 -

Calooli 34%; Bullock Holes 10%; Gindalbie 7% and Jeedamya 5%.

One germinant has been recorded at Kalgoorlie.
Survivals in July were 9% and 1%, only at Calooli and Bullock Holes.

Fresh germination of the 1974 sowings showed in July 1975 - Gindalbie 28%; Calooli 11%; Jeedamya 8% and none at Bullock Holes.

Unploughed, spot sown seed produced highest germination of all - 54% and 40% at Gindalbie for the fenced and unfenced treatments. The ploughed treatments were 15 and 2 per cent respectively.

From the 1975 sowings, the cracked seeds, soaked overnight and sown with and without peat, produced highest germination of 28% in August at Bullock Holes. Whole seeds soaked overnight were next highest with 13 per cent.

At Jeedamya, neat 20 mm holes were dug above 90 per cent of the standard dusted seeds. Field mice were prevalent and germination continued - cracked seed was 7 and 3 per cent only for soaked and not soaked treatments; whole seed was 6 and 11 per cent for corresponding treatments.

FUTURE STUDY OBJECTIVES

This paper provides some of the information required to develop a programme for the long term management and conservation of sandalwood in Western Australia.

The present distribution and stocking of the species has been broadly defined together with an interpretation of the likely outcome of several cropping strategies.

Further information is needed concerning growth rates, achieving effective regeneration and recovery from drought, grazing or fire. This information can be obtained by extending investigation of the productive activity, by additional assessment and by maintenance of all research plots now existing.

RECOMMENDATIONS

Sandalwood Seed:

Information regarding flowering and seed availability should be recorded and large supplies of seed collected for storage and viability studies in Perth.

Regeneration:

The 1974 seeding trials should be maintained and supplemented with further sowings in Kalgoorlie arboretum and on pastoral properties. Seed should be sown with a variety of host plants including:

Cratystylis subspinescens
Acacia tetragonaphylla
Cassia eremophila
Kochia pyramidata
Enchylaena tomentosa

After the next year of above average rainfall, seeding trials should be done in the following summer and autumn with watered and unwatered plots at Kalgoorlie arboretum.

Studies of grazing effects should be done in liaison with the Department of Agriculture.

Protection and Management

The broad objectives of management are to maintain a productive sandalwood operation consistent with growth of the resource.

Existing reserves are not presently adequate as a source of supply nor are they well stocked with regeneration.

Ground and aerial survey should be used to locate areas of good quality sandalwood and where possible new reserves should be created.

The availability of sufficient finance to protect and to regenerate reserves should be a matter of high priority.

Protection should aim at control of browsing animals, and protection from fire is necessary by liaison with settlers of adjoining land and through emergency services.

ACKNOWLEDGEMENTS

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Figure 1 Sandalwood operators Alan and Graham Pinner removing bark from green sandalwood at Monaghan Wells 1974.

Figure 2 Natural regeneration of Santalum species and of nurse plants mainly Cratystylis subspinescens (10 June 1974), Gindalbie holding paddock for sheep.

Immature plants decrease in size (or age, Figure 3) down creek from the parent seed source in background.

Figure 3 Close view of Santalum seedling and nurse plants, ca 3 chains down creek from the parent seed source.

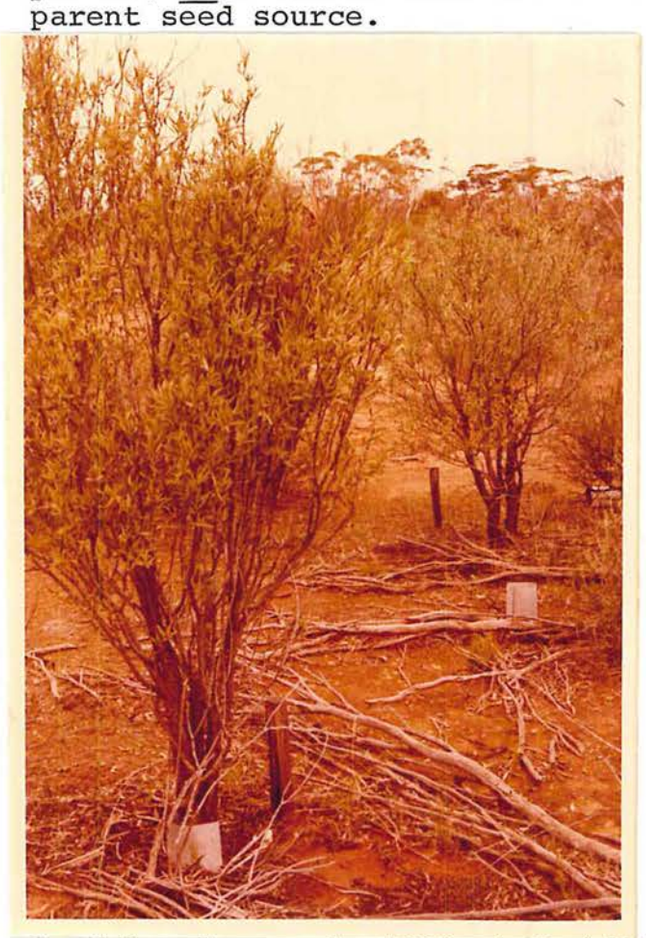


Figure 4 Sandalwood sown in 1930 at Scahill, plot 1, at 44 years, 1974.

No. 437 diameter 81 mm, height 2.0 m.
No. 438 diameters 50 and 51 mm, height 1.6 m.

Figure 5 Artificial regeneration of sandalwood at 49 years from seed sown in 1925 in 60 hectares of Karramindie; height range 2-4 m, diameter range 50-105 mm, 1914 in Acacia bush and Eucalyptus salmonophloia woodland (W.Brennan).

Figure 6 Sandalwood drought deaths at 50 years of age on granitic ridge with healthy jam (Acacia acuminata), which survived the 1969-71 drought. Bendering Reserve, seed sown in 1921. (Photo 1974).

Figure 7 Scattered sandalwood regeneration to 2 m height, downslope 1-2 chains from residual seed trees under Casuarina hueglii-Eucalyptus wandoo. Smith Block, parent seed sown in 1931. (Photo 1974)

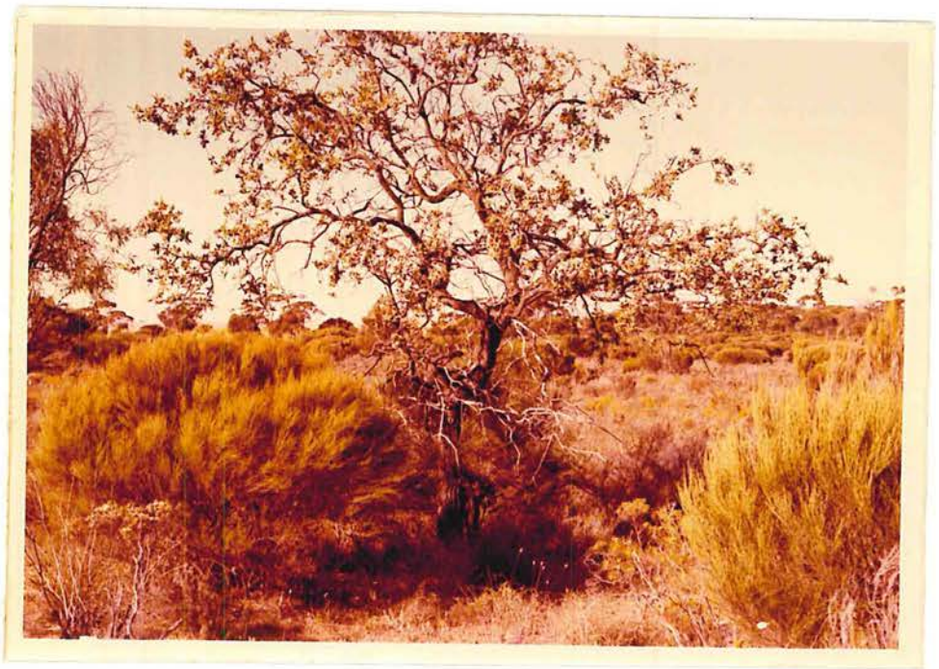


Figure 8 Overmature sandalwood at 56 years of age from natural seed (M. Milesi W.A.F.D. 1925), ploughed into gravelly sandy clay flat of Pikaring Reserve ca 1918. November 1974 diameter 150 mm, height ca 3 m, dry patches on stems; incipient rot in centre of butt of largest sample tree 178 mm d.o.b., 152 mm totalwood and 133 mm truewood.

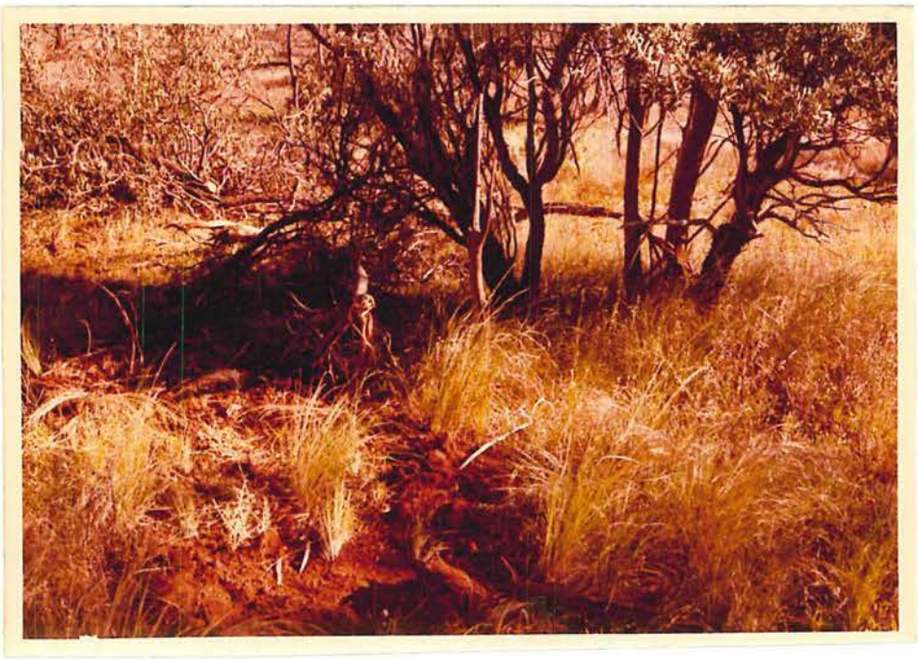


Figure 9 Utilisation of sandalwood with crown left in background, disturbance of soil in pulling the removed tree. Immature trees are retained. Edjudina Station, 1974.

Figure 10 Gindalbie sandalwood and host plants:
Treatments May 1974;
fenced and not fenced;
rotary hoed and not rotary hoed;
seeded by natural seed supply and by hand.

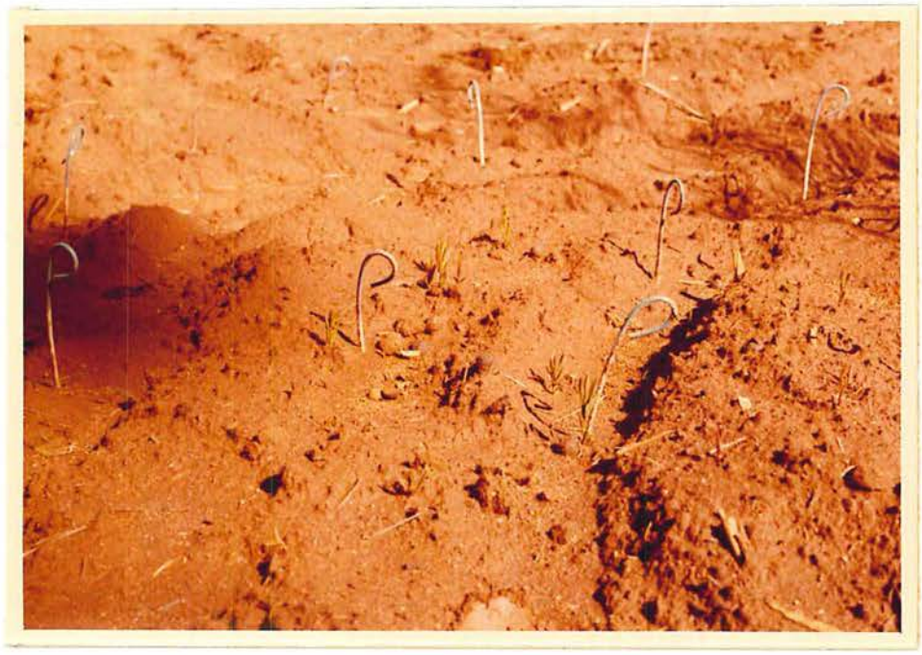


Figure 11 Close view of germinants in July 1974. Cultivated natural seed supply. (N. Caporn).

Figure 12 Calooli sandalwood and host plants.

Treatments May 1974;
fenced and not fenced;
rotary hoed and not rotary hoed;
seeded by natural seed supply and seeded by hand.

Figure 13 Close view of germinants in July 1974, seed sown and not rotary hoed. (N. Caporn)

TABLE 1

SANDALWOOD DISTRIBUTION, PAST CUTTING AND POTENTIAL FOR FURTHER PRODUCTION

Map 2 Reference	Locality	Level of past production	Potential for further production	Area in Hectares x 10^6
1	Wheatbelt	Total	Nil	14 030
2.1	Perenjori	Medium	High	1 568
2.2	Ningham	Heavy	High	2 262
3.2	Lake Seabrook	Light	Moderate	1 972
4.2	Gindalbie	Light	High	1 277
8	Norseman	Light	Low	4 203
9	Shark Bay	Light	Low	4 740
4.3	Menzies	Medium	High	1 057
3.4	Lake Barlee	Light	Moderate	2 812
4.4	Wiluna	Medium	Moderate	9 972
5	Murchison	Medium	Moderate	8 340
6	Carnegie	Light	High	4 740
7	Plumridge Lake	Heavy	High	1 395
10	Desert Lakes	Medium	Low	5 755
				39 598

TABLE 2 - SUMMARY OF ASSESSMENT 1974

Description	Line No.	Quality	AREA ASSESSED IN HECTARES Sandlwd	Other	Total	SANDALWOOD STOCKING PER HECTARE BY 25 mm DIAMETER CLASSES 0-25mm	26-50	51-75	76-100	101-125	126-150	Total	GROUPED DIAM - CLASSES 0-125mm	125mm+
KALGOORLIE														
Lefroy	1	Good	20	45	65	.02	.34	3.0	1.34	.11		4.81	4.70	.11
Kambalda	2	"	55	26	81	.01	.46	2.40	1.21	.10	.04	4.22	4.08	.14
Karramindie	3	"	64	28	92	.27	1.76	1.59	.55	.14	.05	4.36	4.17	.19
Mt. Vetters	4	Medium	100	100	200	.02	.26	1.59	.71	.12	.02	2.72	2.58	.14
Mendelyarri	5	"	78	122	200	.01	.01	2.00	.96	.45	.12	3.55	2.98	.57
Morapoi	6	Poor	43	54	97			.84	.21	.01	.01	1.07	1.05	.02
Gindalbie	7	"	123	67	190	.12	.82	.84	.28	.02	.02	2.09	2.05	.04
Lakewood	8	"	157	133	290		.15	1.02	.37	.07	.04	1.65	1.54	.11
			640	575	1215									
PAYNES FIND														
Maroubra	9	Poor	162	162	324	.003	.04	.30	.20	.020	.020	.61	.56	.05
Thundelarra	10	"	114	151	265		.03	.18	.08	.003	.003	.30	.29	.01
Karana	11	"	65	116	181		.03	.17	.13	.080	.030	.44	.37	.07
			341	429	770									
			981	1004	1985									
POOLED DATA														
Lines	1,2,3	Good	139	99	238	.10	.85	2.33	1.03	.12	.03	4.46	4.31	.15
Lines	4,5	Medium	178	222	400	.01	.13	1.80	.84	.29	.07	2.78	2.78	.36
Lines	6,7,8	Poor	323	254	577	.04	.32	.90	.29	.03	.02	1.60	1.55	.05
Lines	9,10, 11	Poor	341	429	770		.04	.23	.14	.03	.01	.45	.41	.04
			981	1004	1985									

TABLE 3 - SANDALWOOD PLOTS, KARRAMINDIE AND SCAHILL

PLOT NO.	YEAR SOWN	HEIGHT					DIAMETER						BARK
		Total Height (metres)		Increase	to 38mm truewood	to 55mm overbark	At 75mm above ground		Increase	At 150mm		Overbark	Twice Thickness
		1940	1974	34 yrs			1940	1974	34 yrs	ob	ub	38mm truewood	at 300 mm
arramindie													
lot 1	1930	1.50	3.80	2.30	0.62m	1.12	16	107	91	100	78	72mm	22
		1.25	3.60	2.35			13	107	94				
(6 trees)		1.25	3.65	2.40			19	70	51				
		.97	4.10	3.13			13	107	94				
		.84	3.20	2.36			6	80	74				
		1.07	3.78	2.71	0.66m	1.31	10	105	95	102	81		21
	Mean	1.15	3.68	2.53			13	96	83				21
	M.A.I.			0.074					2.44				
	Sample Tree				0.45	0.92		91		90	69	87	21
arramindie													
lot E	1925	1.50 to	2.95			0.55	24	70	46	65	47		18
12 trees)	Mean	1.50	2.50	1.00		0.66	24	70	46	70	54		14
	M.A.I.			0.030					1.35				
		1941					1941						
cahill	1930	1.08	1.93	0.85			18	57	39	56	38		16
14 trees)	M.A.I.			0.025					1.18				10
12 trees)		.91	1.23	0.32			15	38	23	37	22		11
	M.A.I.			0.010					0.70				

TABLE 4

ANALYSIS OF KARRAMINDIE SAMPLE TREES OF 44-49 YEARS

Sandalwood Sample Trees		Wood & Bark	Bark	Total Wood	Truewood	Sapwood
Largest Sample						
Diameters (mm) at 75 mm from ground		104	25	79		
" (mm) at 150mm (and at 300 mm)		98	(20)	78	56	22
Diameter at 650 mm for truewood to 40 mm	3.86	78	18	60	40	20
Volume for above (m^3 x 10-3)		4.2		2.5	1.3	1.2
Percent by volume (%)		100		60	30	30
Diameter at 1250 mm for stem to 55 mm		55	16	39	18	21
Volume for above (m^3 x 10-3)		6.2		2.8	1.5	1.3
Percent by volume (%)		100		45	25	20
Weight of stem for wood density (kg)				2.5	1.3	
Number of stems per tonne				400	770	
Large Class Mean Sample						
Diameters (mm) at 75 mm from ground		91	21	70		
" (mm) at 150 mm (and at 300 mm)	3.54	90	(21)	69	46	23
Diameter at 450 mm fork for truewood to 40 mm		83	18	65	43	22
Volume for above (m^3 x 10-3)		2.7		1.6	0.7	0.9
Percent by volume (%)		100		60	25	35
Diameters at 920 mm for stem to 55 mm		55	16	39	16	23
Volume for above (m^3 x 10-3)		4.5		2.2	0.8	1.4
Percent by volume (%)		100		50	20	30
Weight of stem for wood density (kg)				1.9	0.7	
Number of stems per tonne				525		
Small Class Mean Sample						
Diameters (mm) at 75 mm from ground		71	18	53		
" (mm) at 150 mm (and at 300 mm)		70	(16)	54	33	21
Diameter at 660 mm for stem to 55 mm	2.76	55	15	40	18	22
Volume for above (m^3 x 10-3)		2.2		1.3	0.4	0.9
Percent by volume (%)		100		60	20	40
Weight of stem for wood density (kg) at 880 kg/m^3 + 50 in June				1.1	0.35	
				910		

Volume (m^3 x 10-3 = 0.0785 x D^2 (cm) x L (m) Comm. Aus. F.T. Bur. (1973)

TABLE 5

GROWTH RATES (Santalum spicatum) AT KARRAMINDIE AND SCAHILL

Research plots	Karramindie 1.	Karramindie 2.	Scahill	
Numbered trees (1974)	10	12	26	
Height classes at age 44 (m)	3.0 + m	1.5-2.99 m	1.5-2.99m	0-1.49m
Height mean, 1974 (m)	3.68	2.50	1.93	1.23
Number of trees, 44 by plot class	6	12	14	12
Diameter at 75 mm at 10 years	13			
" " " " 11 years			18	15
" " " " 15 years		24		
" " " " 44 years	96		57	38
" " " " 49 years		70		
Annual increment in 34 years (mm)	A=2.44	B= 1.35	C= 1.18	D= 0.7
Age to attain 400 mm girth (o.b.)	56	91	102	170

TABLE 6

LINEAR REGRESSIONS OF COMPONENTS OF SANDALWOOD TREES

Kalgoorlie and Morawa

15 trees under commercial diameter 127 mm.

y (feature) = a + bx (diam) $\bar{x}$ = 85.7mm. SD 18.3

Mean features (Kg)	$\bar{y}$	S.D.	a	b	r
(1) Total weight	15.8	7.2	-7.728	0.2750	0.70
(5) Twigs (-10mm), leaves	4.93	2.15	-2.922	0.0917	0.78

22 trees (N) includes 7 over commercial diameter 127mm, (55mm - 180mm)

y (feature) = a + bx (diam) $\bar{x}$ = 106mm SD 36mm.

Mean features (Kg)	$\bar{y}$	S.D.	a	b	r
(1.1) total weight	28.5	20.8	-29.32	0.5441	0.94
(2) Sound roots (n=13=60%N)	3.0	1.7	- 1.35	0.0370	0.82
(3) Commercial logs	10.2	7.4	-10.53	0.1952	0.95
(3.1) Butt log section	3.6	2.1	- 0.91	0.0428	0.74*
(3.2) Stem log sections	7.0	7.2	-12.01	0.1790	0.90
(4) Total branchwood	8.4	5.7	- 6.11	0.1366	0.87
(5.1) Twigs (-10mm), leaves	8.3	5.7	- 6.10	0.1360	0.87

*Broken butts (40%)

Diameters overbark at 150 mm above ground level.

TABLE 7

WHOLE TREE FIBRE AND FOLIAGE PRODUCTION OF SANDALWOOD PER SIZE CLASS

Diameter Class Mean	Total Weight (1)	(1.1)	Commercial Fibre (kg) Roots (2)	Butt (3.1)	Logs (3.2)	Branches (4)	Twigs & Leaves (5)	(5.1)	Total Leaves Oven Dry	Area	Crown Width	Total Height
(mm)	(kg)	(kg)				(kg)	(kg)	(kg)	(kg)	(m^2)	(m)	(m)
51	6.2		0.5	1.3	-	2.7	1.74		0.325	1.04	1.0	2.15
			(0.3)	Total	1.6							
76	12.7		1.5	2.35	1.6	4.3	4.2		0.776	2.50	1.5	2.4
			(0.9)	Total	4.85							
102		26.0	2.4	3.4	6.2	7.8		7.72	1.73	4.63	2.0	2.6
			(1.45)	Total	11.05							
127		39.8	3.35	4.5	10.7	11.2		11.17	2.50	6.70	2.5	2.8
			(2.0	Total	17.2							
152		53.6	4.3	5.6	15.3	14.7		14.63	3.27	8.78	3.0	3.05
			(2.6)	Total	23.5							
									Samples of 100		Linear Regressions	
									(g)	(cm^2)	-0.0101a	1.690a
	without roots		(60% sound)		(without bark)		fresh leaves proportion 0.49, SD 0.11		9.51	255	0.0199b	0.009b
									SD 3.4	SD 84	r0.85	r0.67
			fresh weight (with sapwood)									
							SE 0.04		SE 0.7	SE 18	$\bar{y}$1.85	$\bar{y}$2.65

Moisture content = 121%

TABLE 8

FORECAST OF SANDALWOOD GROWTH

Minimum diameter limits (mm)	102	114	127
Allocation of 11 046 000 sandalwood in 7 million hectares			
(i) Immediately available, over above limits:			
Stem numbers (n. millions)	2.11	0.78	0.49
Weight (tonnes)	22 400	13 160	9 170
(a) Number of years at 1200 t/y (years) pulled or	19	11	8
(b) Number of years at 1200 t/y (years) coppiced	8	5	3
(ii) Balance available for growth and coppice:			
Stem numbers (n, millions)	8.93	10.26	10.56
Annual growth to merchantable size (stems)	0.421	0.302	0.211
(by removal at 1200 t/y)			
Number of years for above (years)	21	34	50
(iii) Less 13½% for mortality (years)	4	6	8
(dead pieces)			
(iv) Total years available for replacement:			
(a) Pulled (i), coppiced (ii), less (iii) (years) or	35	39	50
(b) Coppiced only (i plus ii), less (iii) (years)	25	33	45
(No allowance for grazing)			

TABLE 9

SANDALWOOD PRODUCED OVER 11 YEARS FROM 1963

(for main localities collected over 110 tonnes in 11 years)

Locality		Land Tenure				Total
Station (Region P = Paynes Find K = Kalgoorlie)		Pastoral Lease		Vacant Crown Land		Weight Collected
		Pieces (t)	Logs (t)	Pieces (t)	Logs (t)	(tonnes)
Bimbijy	P	17	141			158
Coonana	K	51	222			273
Cowarna	K	63	64			
Cundeelee	K			120	892	1012
Diemals	K	-	250			250
Edjudina	K	102	186			288
Gindalbie	K	216	418			634
Hampton Hill	K	111	-			111
Kookynie	K	33	127			160
Maroubra	P	-	828			828
Menangina	K	56	64			120
Mt. Gibson	P	-	213			213
Paynes Find	P	-	152			152
Pingin	P	108	411			519
Pingin (NE)	P			41	315	356
Plumridge	K			-	1549	1549
Wannara	P	10	415			425
Yindi	K	142	10			152
Other leased		283	1460			1743
Other unoccupied				55	1252	1307
Bullock Holes Reserve				11	-	11
Total		1192	4961	227	4008	10388
Percent		11	48	2	39	100

TABLE 10

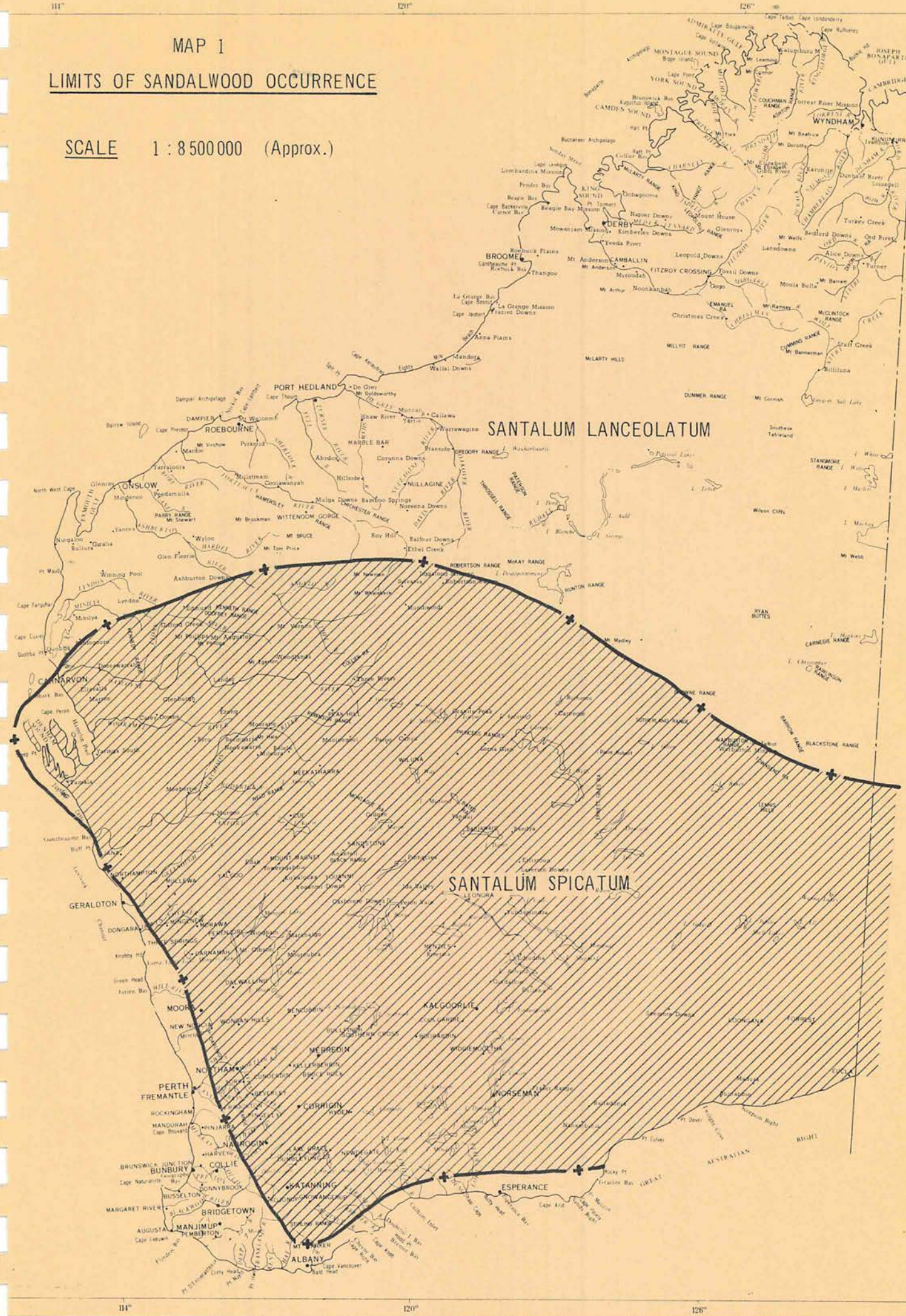
RESOURCES PER MILLION HECTARES

Per million hectares	Kalgoorlie	Paynes Find
Number of trees	2.7×10^6	0.453×10^6
Total Weight	5340 tonnes	1060 tonnes
Commercial Weight (>127 mm diam.)	880 tonnes	240 tonnes

MAP 1

LIMITS OF SANDALWOOD OCCURRENCE

SCALE 1 : 8 500 000 (Approx.)



MAP 2

DISTRIBUTION OF SANDALWOOD

RF 1 : 3168 000

—175— ISOHYETS (m.m.)

MORAPOI
abt 53 916 ha
14·5·74
JEEDAMYA
abt 198 126 ha.
MENDLEYARRI
abt 87 164 ha
MENANGINA
abt 117 032 ha
YERILLA
abt 100 580 ha
REDCLIFFE
14·6·74
GOONGARRIE
abt 100 686 ha
14·5·74
MT VETTERS
abt 147 074 ha.
GINDALBIE
abt 132 784 ha.
14·5·74
13·6·74
15·5·74
15·5·74
EDJUDINA
abt 330 920 ha.

MAP 3

KALGOORLIE ASSESSMENT LINES
AND
SANDALWOOD RESERVES

SCALE 1:500 000

LEGEND

KALGOORLIE GROUP

1.	SANDALWOOD RESERVE 19211, CALOOLI	3121 ha
2.	SANDALWOOD RESERVE 19212, YELLARI	6326 ha
3.	SANDALWOOD RESERVE 19214, LAKESIDE	3707 ha
4.	SANDALWOOD RESERVE 19825, BULLOCK HOLES	13313 ha
5.	STATE FOREST No. 8, KARRAMINDIE	781 ha
6.	SCAHILL RESERVE (PART OF V.C.L.)	~~26250 ha~~
7.	~~VACANT~~ CROWN LANDS	268250 ha
	TOTAL	~~47248 ha~~ 299748 ha

ASSESSMENT LINES

GOOD QUALITY SANDALWOOD
MEDIUM QUALITY SANDALWOOD
POOR QUALITY SANDALWOOD

TYPICAL STATION AREAS

EDJUDINA	330 920 ha	MENDLEYARRI	87 164 ha
GINDALBIE	132 784 ha	MORAPOI	53 916 ha
GOONGARRIE	100 686 ha	MT. VETTERS	147 074 ha
MENANGINA	117 032 ha	YERILLA	100 580 ha
			1 070 156 ha

1470 C

MAP 4

PAYNES FIND ASSESSMENT LINES

SCALE 1:500 000

LEGEND

SITE CLASS POOR QUALITY ●●●●●●

BUNNAWARRA
BADJA
BURNERBINMAH
NALBARRA
WYDGEE
NARNDEE
LEMBYE
THUNDELARRA
LOCHADA
WARRIEDAR
OUDABUNNA
PULLAGAROO
KARARA
NINGHAN
MARANALGO
PINDABUNNA
WANARRA
WHITEWELLS
MT GIBSON
MOORE LAKE
PAYNES FIND
MOUROUBRA
BIMBIJY
GOONABURNA HILLS
WERLHAMBY LAKE
MONGERS LAKE
BLUE HILL RANGE
VERMIN FENCE
GREAT NORTHERN HIGHWAY